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Magnesium and strontium compositions of recent symbiont-bearing benthic foraminifera

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Abstract

Minor and trace elements in foraminiferal carbonates are potential paleo-proxies of climate, nutrient and seawater composition. There are very few reports of trace element composition of symbiont-bearing, larger foraminifera that are known to be important constituents of shallow-marine, modern and ancient carbonates. In this paper we examine the range of variation in Mg and Sr content of Recent species of these foraminifera from a lagoon of Lakshadweep Atoll (Indian Ocean) and Akajima Islands, Japan. Two hyaline species, *Amphistegina lessonii* and *Neorotalia calcar*,and two porcellaneous species, *Amphisorus hemprichii* and *Marginopora vertebralis* were collected live from Lakshadweep islands. Mg/Ca in these foraminifera is of an order of magnitude higher than the values reported for planktonic and symbiont-free benthic foraminifera. The Sr/Ca values are, however, comparable with the reported values in other foraminiferal taxa and they are found to vary within a narrow range. Electron-probe micro-analysis of three symbiont-bearing benthic species indicates spatial heterogeneity of high orders in Mg/Ca composition in all the species. The annual variation in temperature and pH of the lagoon water cannot explain the observed amplitude of the compositional variation. The photosynthesis and respiration of the symbionts and host foraminifera are possibly the major cause of compositional heterogeneity in individual tests, as has also been recently postulated for symbiont-bearing planktonic foraminiferal species. It highlights the need to isolate biological factors and necessitates species-specific paleotemperature scale in paleoclimatic analysis. We also analyzed δ^{18}O, δ^{13}C, Ca, Mg and Sr in carefully dissected chambers of a reef-dwelling, porcellaneous benthic foraminifer, *Marginopora kudakajimaensis*, collected live in four seasons. A moderate positive correlation is observed between Mg/Ca and temperature. However, large inter- and intra-test variation in Mg limits the precision of Mg/Ca as palaeotemperature proxy. The Sr/Ca of the test calcite is unrelated to temperature of the sea water. The δ^{13}C of *M. kudakajimaensis* does not correlate with δ^{18}O, Mg/Ca or Sr/Ca.

Keywords: Trace elements; Foraminifera; Symbiosis; Palaeotemperature; Stable isotopes; Biogenic carbonates

1. Introduction

Studies on magnesium and strontium composition of the foraminiferal test have gained importance in recent years because of their potential as paleotemperature proxies. There are conflicting views, however, on the relationship between magnesium content and the growth temperature. Positive relationships between the two have been reported in modern foraminifera by Savin and Douglas (1973), Bender et al. (1975), Izuka (1988), Nürnberg (1995), Rathburn and De Deckker (1997)

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and Rosenthal et al. (1997) among others. Based on culture studies of *Globigerinoides sacculifer* by Nürnberg et al. (1996) and of *Globigerina bulloides* and *Orbulina universa* by Lea et al. (1999), these researchers concluded that temperature is the primary control on Mg/Ca of foraminiferal carbonates. In contrast, Krinsley (1960) did not find any correlation between temperature and magnesium content of planktonic foraminiferal tests from the Atlantic. Similarly, Delaney et al. (1985) found no direct relationship between temperature and Mg/Ca or Sr/Ca in cultured specimens of *G. sacculifer* and *O. universa*. Eggins et al. (2003) used laser ablation ICP-MS to examine variation in magnesium composition across single specimens of selected planktonic foraminiferal species and found it to be consistent with change in seawater temperatures during habitat migration by the species. Mean ocean Sr/Ca, temperature, salinity and pH variation in the ambient water may be factors that explain the variation in foraminiferal Sr/Ca (Lea et al., 1999; Martin et al., 1999). A combination of proxies (Mg/Ca and δ^{18}O) can be used to constrain palaeotemperature when there are multiple-factor effects. This approach is used to filter the ice effect from δ^{18}O values by using Mg/Ca of the same foraminiferal carbonates (Elderfield and Ganssen, 2000; Nürnberg, 2000).

Mg/Ca analysis requires a systematic cleaning procedure (Martin and Lea, 2002; Barker et al., 2003). Diagenetic alteration of fossil foraminiferal tests can alter their geochemistry. To overcome these problems, electron microprobe (Nürnberg, 1995; Brown and Elderfield, 1996), ion microprobe (Allison and Austin, 2003) and laser ablation-inductively coupled plasma-mass spectrometry (Eggins et al., 2003, 2004; Hathorne et al., 2003; Reichart et al., 2003) have been used in recent times. These techniques not only elude the rigorous cleaning procedure and enable avoidance of diagenetically altered parts, but also permit analysis of elements at high spatial resolution in a very small sample.

Most observations on minor and trace element composition of foraminiferal carbonates have been limited to planktonic and smaller benthic foraminifera. The symbiont-bearing benthic foraminifera, commonly categorized as larger foraminifera, are important components of coral reef communities. Their fossils are found abundantly in tropical carbonates of certain geological epochs. In spite of their potential as an environmental proxy, the minor and trace element composition of larger foraminiferal species is not well known. Langer and Gehring (1994) analyzed manganese content of five species of larger foraminifera from Papua New Guinea and found that it ranges between 25 and 530 ppm. Toler et al. (2001) compared Mg/Ca of normal and stressed populations of *Amphistegina gibbosa* and did not find any difference between the two. Though data on larger foraminiferal species are few, the reported values for Mg and Sr in these species (Carpenter and Lohmann, 1992; Langer and Gehring, 1994; Toler et al., 2001) are found to be consistently higher than those in planktonic or smaller benthic foraminifera.

In this study we assess the reliability of Mg and Sr in larger foraminifera tests as a proxy of ambient water temperature. We examine (i) inter-species variation in the Mg and Sr content of co-existing species, (ii) Mg heterogeneity in single tests, (iii) relationships between sea-water temperature and Mg/Ca and Sr/Ca in seasonally collected species and (iv) inter relationships between Mg/Ca, Sr/Ca, δ^{18}O and δ^{13}C.

2. Materials and methods

2.1. Sample collection

Live specimens of foraminifera for the present study were collected from the lagoons of Kavaratti (10°35′N, 72°30′E), Amini (11°07′N, 72°44′E) islands of Lakshadweep archipelago, India (Fig. 1A), and from the reef flat at Akajima (26°3′52″N, 127°5′30″E), Japan (Fig. 1B). The samples at all three sites were collected from a water depth of ~2 m. The samples from Lakshadweep were collected in January 2002, June 2002 and November 2002. The average sea-surface temperature during the collection periods varied from 28 to 30 °C and the annual variation is 27.5 °C to 31.5 °C (Chakroborty and Ramesh, 1997). The live foraminifera, identified by the color of their symbionts, were picked under stereozoom binocular microscope. Two hyaline species, *Amphistegina lessonii* and *Neorotalia calcar*, and two porcellaneous species, *Amphisorus hemprichii* and *Marginopora vertebralis*, were separated for analysis. Specimens of another porcellaneous species, *Marginopora kudakajimaensis*, from Akajima were collected in September 2003 (28.7 °C), November 2003 (25.2 °C), January 2004 (22 °C) and March 2004 (21.2 °C). The sea-surface temperature varies seasonally from 21 to 29 °C.

Marginopora and *Amphisorus* belong to the subfamily *Soritinae* and they keep zooxanthellae as symbiotic microalgae (Lee and Anderson, 1991). *Marginopora* and *Amphisorus* settle freely on macrophytes and coral rubbles on the reef flat of Akajima Island (Saraswati, 2002). Population dynamics of *M. kudakajimaensis* indicate asexual reproduction twice a year and the spring cohort life span extends up to one year while the winter cohort is up to six months (Fujita et al., 2000).