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HIGH-RESOLUTION MG/CA RATIOS IN A CORALLINE RED ALGA AS A PROXY FOR BERING SEA TEMPERATURE VARIATIONS FROM 1902 TO 1967

STEFFEN HETZINGER,[1]* JOCHEN HALFAR,[1] ANDREAS KRONZ,[2] ROBERT S. STENECK,[3] WALTER ADEY,[4] PHILLIP A. LEBEDNIK,[5] and BERND R. SCHÖNE[6]

[1]*Department of Chemical and Physical Sciences, University of Toronto, Mississauga, Ontario, Canada;* [2]*Geowissenschaftliches Zentrum, University of Göttingen, Germany;* [3]*Darling Marine Center, University of Maine, Walpole, Maine, USA;* [4]*Department of Botany, Smithsonian Institution, Washington, D.C., USA;* [5]*LFR Inc., Ecosystems Services Group, Emeryville, California, USA;* [6]*Department of Applied and Analytical Paleontology, Institute of Geosciences, University of Mainz, Mainz, Germany*
e-mail: steffen.hetzinger@utoronto.ca

ABSTRACT

We present the first continuous, high-resolution record of Mg/Ca variations within an encrusting coralline red alga, *Clathromorphum nereostratum*, from Amchitka Island, Aleutian Islands. Mg/Ca ratios of individual growth increments were analyzed by measuring a single-point, electron-microprobe transect, yielding a resolution of ~15 samples/year and a 65-year record (1902–1967) of variations. Results show that Mg/Ca ratios in the high-Mg calcite algal framework display pronounced annual cyclicity and archive late spring–late fall sea-surface temperatures (SST) corresponding to the main season of algal growth. Mg/Ca values correlate well to local SST, as well as to an air temperature record from the same region. High spatial correlation to large-scale SST variability in the subarctic North Pacific is observed, with patterns of strongest correlation following the direction of major oceanographic features that play a key role in the exchange of water masses between the North Pacific and the Bering Sea. Our data correlate well with a shorter Mg/Ca record from a second site, corroborating the ability of the alga to reliably record regional environmental signals. In addition, Mg/Ca ratios relate well to a 29-year $\delta^{18}O$ time series measured on the same sample, providing additional support for the use of Mg in coralline red algae as a paleotemperature proxy that, unlike algal-$\delta^{18}O$, is not influenced by salinity fluctuations. Moreover, electron microprobe–based analysis enables higher sampling resolution and faster analysis, thus providing a promising approach for future studies of longer *C. nereostratum* records and applications to other coralline species.

INTRODUCTION

Natural proxy archives provide indirect information on past climatic conditions and can help complement and significantly extend climate data in space and time (Jones et al., 2001). In boreal and temperate regions, the majority of seasonal and year-to-year climate reconstructions are almost exclusively based on terrestrial proxies, predominantly tree rings (Jacoby et al., 2004), ice cores (Moore et al., 2003), and varved lake sediments (Overpeck et al., 1997), although these data do not directly reflect marine environmental conditions. Coralline red algae constitute an ideal biogenic marine climate archive owing to their common occurrence in mid- to high-latitude oceans, their longevity, and their incremental growth pattern. Unlike long-lived bivalve mollusks, which are commonly used to develop paleoenvironmental proxy records from extratropical marine settings (Schöne et al., 2005), coralline red algae do not suffer from the drawback of an ontogenetic growth trend (Halfar et al., 2007) that is known to complicate the analysis of some other recorded climate signals, in particular the reconstruction of low-frequency signals.

Several studies have discussed the potential of coralline algae as recorders of past environmental conditions and climate variability (Adey, 1965; Chave and Wheeler, 1965; Moberly, 1968; Frantz et al., 2000; Halfar et al., 2000). The presence of paleoclimate records in corallines has been examined recently for rhodoliths (a nodular unattached growth form) using oxygen isotopes and Mg data as indicators for paleotemperature (Halfar et al., 2000; Kamenos et al., 2008), and $\delta^{18}O$ in encrusting growth forms (Halfar et al., 2007, 2008). The encrusting forms have great potential as archives of past climate variations, because they produce spatially fixed growth increments in a high-Mg–calcite framework (i.e., calcite deposited in association with the cell walls), grow from the subtidal zone to >100 m water depth, and can show extreme longevity (Adey and Macintyre, 1973; Frantz et al., 2005). Live specimens of *Clathromorphum nereostratum* collected from the North Pacific Ocean and exhibiting continuous growth can reach ages of up to 850 years (Halfar et al., 2007), making this species one of the longest-lived marine organisms on record. *Clathromorphum* is further characterized by annual formation of conceptacles (cavities accommodating the reproductive structures) that can be used as markers for individual annual growth increments, which have been shown to accurately record climate information in their calcite (Adey, 1970; Halfar et al., 2007, 2008). *Clathromorphum nereostratum* has been described from the central and western North Pacific and Bering Sea region (Lebednik, 1977) and displays average vertical accretion rates of ~350 μm/year (Halfar et al., 2007).

Mg/Ca ratios have previously been shown to record temperature variations in different marine organisms, such as foraminifer shells (Lea et al., 1999) and corals (Mitsuguchi et al., 1996). The substitution of magnesium in calcite is endothermic and, hence, is favored at higher temperatures, providing the basis for magnesium paleothermometry (Lea, 2003). Thus far, however, the use of Mg as a temperature proxy in encrusting coralline algae has not been fully evaluated.

Here we present the first continuous, high-resolution record of Mg/Ca variability within an encrusting coralline red alga, *C. nereostratum*, from Amchitka Island, Bering Sea, in the Aleutians. By first conducting an intersite comparison using another *C. nereostratum*-derived Mg/Ca record from a distant second Aleutian site, we assess the robustness of the algal-recorded environmental signal in specimens from the same region. We then compare the 65-year Mg/Ca record to sea-surface temperature data and a 29-year $\delta^{18}O$ record from the same specimen in order to test the use of high-resolution algal Mg/Ca ratios as a recorder of past temperature variability.

DATA AND METHODS

Study Site and Sampling

The Aleutian Island arc extends >2000 km from the Alaskan Peninsula in North America westward to the Commander Islands off the Kamchatka Peninsula in eastern Asia (Fig. 1). The long, narrow chain of

* Corresponding author.

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