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Relationship between calcification and strontium uptake in the zooxanthellate coral *Acropora* sp.

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operates under an agreement
between the International Atomic
Energy Agency and the Government
of the Principality of Monaco"

INTRODUCTION

Strontium (Sr^{2+}) is a relatively common constituent of seawater and one of the most abundant trace elements (8 mg l^{-1} or 91 mM). It is chemically similar to calcium (Ca^{2+}) and is generally considered to substitute for calcium ions in the aragonite lattice of biogenic carbonate.
Strontium thermometry has been suggested to be a powerful tool for reconstructing seawater surface temperature. In corals, it has been shown an inverse relationship between seawater temperature and skeletal Sr/Ca ratios.

However, it has also been suggested that Sr/Ca ratios vary with calcification (vital effect), which in turn is dependent on light and temperature.
The aim of this study was therefore to improve our knowledge on the uptake of Sr^{2+} as a function of light and temperature in the scleractinian coral *Acropora* sp. using a radioactive isotope of Sr as a tracer. We sought to look at the relationship between calcification and strontium uptake.
For this puspose, two experiments were set up in which corals nubbins were cultured under 3 light levels (for the first experiment), and under 3 temperatures (for the second experiment).

MATERIALS AND METHODS

Experimental set up

Experiment were performed in the laboratory using the branching zooxanthellate scleractinian corals, *Acropora* sp. "Nubbins" were obtained by cutting terminal portions of branches from a single parent colony and then suspended with a nylon mesh in aquaria. After 2 weeks of healing, tissue entirely recovered the exposed skeleton and coral fragments were ready to be used for experiments.
In the first set of experiment, 27 nubbins were distributed in 3 tanks (30 l), and cultivated under 3 light levels: 100 (low light, LL), 200 (medium light, ML), and 400 µmol m^{-2} s^{-1} (high light, HL) for 4 weeks. The temperature was kept constant and equal to 27°C.
In the second set of experiment, 15 nubbins were distributed in 3 tanks and cultivated at 20, 25 and 29°C. The light was kept constant (400 µmol m^{-2} s^{-1}).

Calcification rate

Corals nubbins were weighted once a week during the two experiments according to the buoyant weight technique, using a Mettler AT 261 balance.

Experimental set-up

filters used for reduce the light intensity

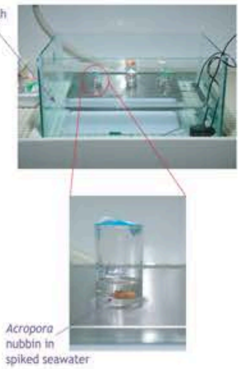
Acropora nubbins

Radioactive measurements

* For the "light experiment", 5 nubbins from each light level were incubated during 4 h in beakers containing 50 ml of seawater spiked with microliter quantities of the radiotracer ^{85}Sr (carrier-free, obtained from LEA, $T_{1/2}$ = 64.85 days) to reach an activity of 7.052KBq l^{-1}. Temperature was kept constant to 27°C by incubating beakers into a waterbath. The light level was equal to the one set up in the culture condition (100, 200, and 400 µmol m^{-2} s^{-1}).

* For the "temperature experiment", 5 nubbins from each temperature were incubated for 24 h in beakers containing 50 ml of seawater spiked with the radiotracer ^{85}Sr. The light was kept constant to 400 µmol m^{-2} s^{-1}.

At the end of the incubation, colonies were rinsed with normal seawater, blotted dry on absorbent paper to eliminate any adhering radioactive medium, then incubated 30 minutes in beakers containing 50 ml of seawater (efflux). This step is necessary to get rid off the labeled seawater contained in the coelenteric cavity of the corals (and therefore radioactivity not incorporated into the tissue or the skeleton).
The ^{85}Sr bioaccumulation into the tissue and the skeleton was determined by gamma counting, using a well-type NaI detector.



RESULTS

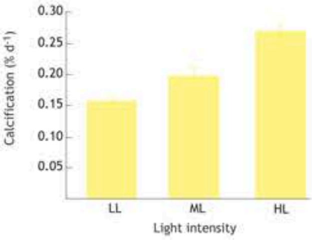
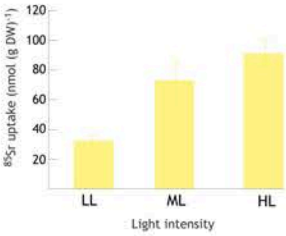


Fig 1.
The rates of calcification increased with light (0.16, 0.20 and 0.27 % d^{-1} respectively under LL, ML, and HL conditions).



The strontium was mainly incorporated into the skeleton (less than 1% was found in the tissue).

Fig 3.
Incorporation of strontium into coral skeleton increased with light and were equal to 32.4 ± 3.0, 72.9 ± 13.5 and 91.2 ± 9.0 nmol (g dry weight)$^{-1}$ d^{-1}, respectively for corals cultured under LL, ML and HL.

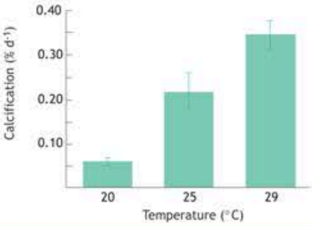


Fig 2.
The rates of calcification also increased with temperature from 0.06 % d^{-1} (at 20°C) to 0.35 % d^{-1} (at 29°C).

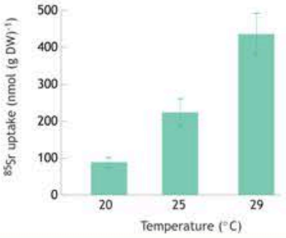


Fig 4.
Rates of strontium incorporation into coral skeleton also increased with temperature, and were equal to 89 ± 14, 224 ± 38 and 436 ± 58 nmol (g dry weight)$^{-1}$ d^{-1}, respectively for corals cultured at 20, 25 and 29°C.

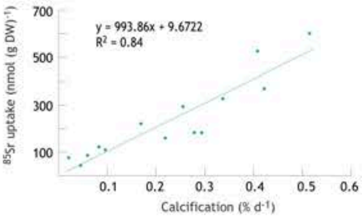


Fig 5.
The relationship between strontium incorporation into coral skeleton and the calcification rates was statistically significant (*P*<0.001).

DISCUSSION

Since more than 20 years now, the Sr/Ca ratio of coral skeleton has been widely used to determine the temperature of the ancient seas (Swart, 1981; Aharon, 1991). It is therefore important to fully understand the processes involved in coral calcification, in order to have a better interpretation of the Sr/Ca data collected. Up to now, studies on calcification has mainly focused on the incorporation of calcium into the skeleton (Chalker 1976, Tambutté et al. 1996), or on global calcification. It has been shown that calcium is actively transported to the sites of calcification and that the coral itself regulates this incorporation (Tambutté et al. 1996). It has also been shown that calcification depends on several factors, and among them, light (Barnes & Chalker, 1990; Gattuso et al., 1999) and temperature (Clausen & Roth, 1975; Kajiwara et al., 1995; Howe & Marshall, 2002). Few studies have however investigated the incorporation of strontium into corals' skeleton. Except the work of Ip & Krishnaveni (1991), most of the studies have suggested that the incorporation of strontium is *via* an active process (reviewed in Ferrier-Pagès et al. 2002), as for calcium. We have therefore tested in this work if the incorporation of strontium was also dependent on light and temperature.

We found a strong effect of the "light-past history" and the "temperature-past history" of the corals on Sr^{2+} uptake. However, this effect is "indirect". By changing either the light or the temperature, we indeed changed the rates of calcification, which in turn, has affected the Sr^{2+} uptake rates (figures 3 and 4).

These results suggest that there is a strong vital effect on the incorporation of strontium in corals skeleton that should be taken into account during paleoclimatology studies. They are in agreement with previous studies, which have found that extension rate has an important control on skeletal Sr/Ca uptake (Weber, 1973; Oomori et al., 1982; de Villier et al., 1995). These conclusions are also in agreement with the findings of Cohen et al. (2001). They demonstrated, using a ion microprobe, that the Sr/Ca ratio in the symbiotic coral *Porites lutea* was more related to calcification rates than directly to seawater temperature. They showed that the Sr/Ca content of the day-time skeleton was always lower than the adjacent night-time skeleton.

The following experiments will have to investigate, under laboratory conditions, the long-term effect of light and temperature on the Sr/Ca ratio, since the incorporations of calcium and strontium might vary in parallel or not with light and temperature.

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