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Isotopic signatures ($\delta^{18}O$ and $\delta^{13}C$) of bivalve shells from cold seeps and hydrothermal vents☆

Signature isotopique ($\delta^{18}O$ et $\delta^{13}C$) de coquilles de bivalves de suintements froids et de sources hydrothermales

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Abstract

The oxygen and carbon isotopic compositions of 108 modern shells of various bivalve species collected from cold seeps and hydrothermal vents were investigated in order to evaluate whether these parameters can provide information on environmental geochemical variability as well as on bivalve species and on the type of symbiotic bacteria present in their gills. The results show that the carbonate of bivalve shells from hydrothermal vents is characterized by abnormal positive $\delta^{13}C$ values due to kinetic isotope effects, whereas the carbonate of bivalve shells from cold seeps exhibits positive as well as negative $\delta^{13}C$ values suggesting that oxidized methane emitted by the seeping fluids may be incorporated in the shell. Comparison of the $\delta^{18}O$ and $\delta^{13}C$ values of bivalve shells hosting different chemosymbiotic bacteria suggests that each type of symbiosis is associated with a specific environment and bivalve species, indicating that there is a strong physiological/metabolic control on the incorporation of stable isotopes during the biomineralization process.

Keywords: Oxygen; Carbon; Stable isotopes; Bivalve shells; Cold seeps; Hydrothermal vents

Résumé

Les compositions isotopiques de l'oxygène et du carbone de 108 coquilles de bivalves vivants d'espèces variées, prélevées au niveau de sites de suintements froids et au niveau de sources hydrothermales, ont été analysées dans le but d'évaluer si ces paramètres pouvaient fournir des informations sur la variabilité géochimique de l'environnement ainsi que sur l'espèce de bivalve et le type de bactéries symbiotiques présent sur leurs branchies. Cette étude montre que le carbonate des coquilles de bivalves provenant des sources hydrothermales est caractérisé par des valeurs de $\delta^{13}C$ anormalement positives dues à des effets cinétiques, tandis que le carbonate des coquilles de bivalves provenant des sites de suintements froids montre aussi bien des valeurs de $\delta^{13}C$ positives que négatives ce qui suggère que le méthane oxydé issu des fluides qui sont émis au niveau du fond marin peut être incorporé dans la coquille. La comparaison des analyses de $\delta^{18}O$ et de $\delta^{13}C$ de coquilles de bivalves portant des bactéries chimiosymbiotiques différentes permet de suggérer que chaque type de symbiose est associé à un environnement et à une espèce de bivalve spécifique, ce qui indique un fort contrôle physiologique/métabolique sur l'incorporation des isotopes stables au cours du processus de biominéralisation.

Mots clés : Isotopes stables ; Oxygène ; Carbone ; Coquilles de bivalves ; Suintements froids ; Sources hydrothermales

1. Introduction

Bivalves are prominent members of the benthic communities that inhabit cold seeps and hydrothermal vents. They live close to venting fluids and their survival is based on symbiosis with chemosynthetic bacteria (Distel and Felbeck, 1987;

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Fiala-Médioni, 1984; Fiala-Médioni and Felbeck, 1990). Bivalve shells are precipitated from marine bottom waters, the temperature and geochemistry of which may be locally and strongly modified by the seeping fluids. The carbonate composition of bivalve shell is thus able to register modification of the deep sea parameters such as the isotopic characteristics of their surrounding environment (Killingley and Berger, 1979; Schöne and Giere, 2005).

The present study investigates the oxygen and carbon isotopic compositions ($\delta^{18}O$, $\delta^{13}C$) of a total of 108 modern specimens of bivalve shells, collected using submersibles at various cold seeps and hydrothermal vents in the Atlantic Ocean, the Pacific Ocean and the Mediterranean Sea (Fig. 1). The oxygen isotopic composition of a carbonate shell is mainly controlled by the ambient temperature and $\delta^{18}O$ composition of the seawater in which precipitation takes place (Epstein et al., 1953). The carbon isotopic composition of a carbonate shell depends on seawater dissolved inorganic carbon, metabolic dissolved inorganic carbon and, in some cases, of carbone derived from oxidation of methane (Hein et al., 2006; Lorrain et al., 2004; Romanek et al., 1992).

Today, there is no simple and reliable model to interpret the $\delta^{18}O$ and $\delta^{13}C$ variations observed in carbonate shells. Several previous studies have been undertaken on bivalve shells from cold seeps and hydrothermal vents (Rio et al., 1988, 1992; Schöne and Giere, 2005; Hein et al., 2006), but no comparisons were realized between these two environments or between bivalve species. In this study, we present such a comparison for the first time, focusing on the nature of venting (i.e. cold seeps *versus* hydrothermal vents), the calcium carbonate mineralogy (i.e. calcite *versus* aragonite), the type of symbiotic bacteria present in bivalve gills (methanotrophic and/or sulfide-oxidizing bacteria), the bivalve genus and the site location. The principal objective is to examine the $\delta^{18}O$ and $\delta^{13}C$ data set from these bivalve shells in order to extract information on the geochemical environmental variability of cold seeps and hydrothermal vents, as well as on biological deep-sea bivalve characteristics. This first attempt to calibrate the ''bivalve shell tool'' on modern specimens is also important for its increasing use on fossil systems. A large number of ancient deep-sea cold seep sites have already been identified (Campbell, 1992; Campbell and Bottjer, 1995; Taviani, 2001; Peckmann et al., 2002). The use of the isotopic composition of carbon to identify such fossil ecosystems is so already established, based on the presence of ^{13}C-depleted authigenic carbonates (Majima et al., 2005; Mae et al., 2007). Through our study, we hope to access to more environmental, chemical or biological information concerning these ecosystems.

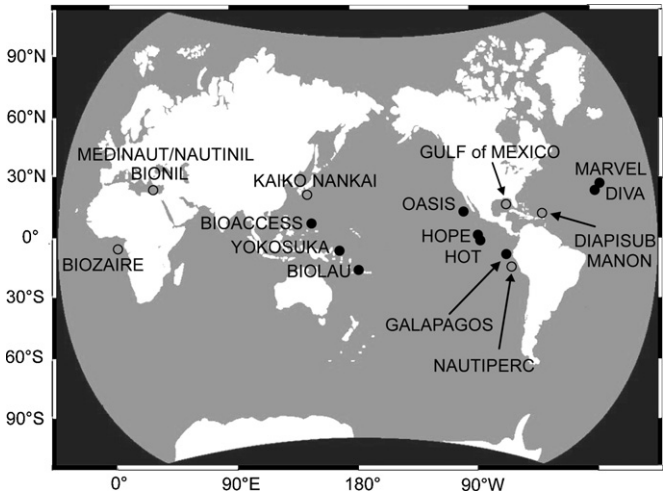

Fig. 1. Location of the studied sites. Empty circles: cold seeps; filled circles: hydrothermal vents.
Localisation des sites étudiés. Cercles vides : suintements froids ; cercles pleins : sources hydrothermales.

2. Materials and methods

One hundred and eight bivalve shells were collected alive or recently dead directly on the seafloor using submersibles, during 18 oceanographic cruises at 15 cold seeps sites and 12 hydrothermal sites (Fig. 1; Tables 1 and 2; Appendix A). Four bivalve genera, *Bathymodiolus*, *Calyptogena*, *Vesicomya* and *Lucina,* were studied as they represent the most common bivalves from the deep sea megafauna found in hydrothermal and cold seep sites (Fig. 2; Tables 1 and 2; Appendix A).

Lucina, *Calyptogena* and *Vesicomya* harbor sulfide-oxidizing bacteria, whereas *Bathymodiolus* harbors methanotrophic and/or sulfide-oxidizing bacteria (Bergquist et al., 2004; Dubilier et al., 1998; Duperron et al., 2005; Fiala-Médioni et al., 1986, 1994, 2002; Olu et al., 1996; Pond et al., 1998; Van Dover, 2000; Von Cosel et al., 1994; Von Cosel and Olu, 1998, Table 3).

Sample preparation: All shells were cleaned with H_2O_2 in a neutral pH solution in order to remove organic matter, commonly called periostracum. In the median part of the shell (in the length interval of 1–2 cm from the umbo to 1–2 cm from the ventral margin) and only in the outer layer of the shell, an aliquot of 50 mg of carbonate powder was removed with a dental drill (Fig. 2). The carbonate powder was analyzed by XRD to determine the mineralogy of the carbonate shells. *Calyptogena* and *Lucina* genera are mostly composed of aragonite, whereas *Vesicomya* and *Bathymodiolus* are calcitic (Blanc-Valleron, personal communication, Table 3).

Stable isotope compositions of carbonate samples were measured on the CO_2 obtained by conventional acid digestion with 100% orthophosphoric acid at 25 °C. The CO_2 was analyzed by means of a dual inlet-triple collector mass spectrometer VG-SIRA 9.

The oxygen and carbon isotopic compositions ($\delta^{18}O$ and $\delta^{13}C$) are expressed in the conventional δ notation and reported in ‰ relative to the international reference V-PDB (Craig, 1957):

$$\delta‰\ \text{V-PDB} = \frac{(\text{R sample} - \text{R reference})}{(\text{R reference})} \times 1000,$$

where R is the isotopic ratio of heavy to light oxygen and carbon isotopes: $^{18}O/^{16}O$ and $^{13}C/^{12}C$. The analytical precision (2σ) is $\pm$ 0.083‰ for $\delta^{18}O$ and $\pm$ 0.059‰ for $\delta^{13}C$.