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Original article

Sediment (grain size and clay mineralogy) and organic matter quality control on living benthic foraminifera

Contrôle du sédiment (granulométrie et minéralogie des argiles) et de la qualité de la matière organique sur les foraminifères benthiques vivants

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Abstract

The paleoecological interpretation of fossil foraminiferal assemblages depends on an understanding of the ecological processes operating at the present. This study investigates both the quality of organic matter (OM) by elemental analysis as well as the sediment grain size and clay mineralogy to understand their relative influence on distribution and abundance of benthic foraminifera. This study is carried out on 15 samples regularly spaced from the mudflat to the tidal marsh. The results indicate that grain size is the most limiting parameter. Living (stained) benthic foraminiferal density and species richness are both very low within coarser sediments. OM is the second limiting factor. The density of foraminifera is the lowest and the species richness is the highest with the lowest organic carbon (C_{org}) contents and $C/N < 12$. Conversely, when the C_{org} is very high and $C/N > 12$, the density is high and the species richness medium. A high smectite proportion within the clay-size fraction seems to favor the development of *Miliammina fusca*. *Trochammina inflata* and *Jadammina macrescens* are both favored by an increase of organic carbon proportion but *Trochammina inflata* preferentially feeds on algal-derived OM when compared with *Jadammina macrescens*.

Résumé

L'interprétation paléoécologique des assemblages de foraminifères fossiles dépend d'une bonne compréhension des processus écologiques qui opèrent aujourd'hui. Cette étude se focalise sur la qualité de la matière organique par des analyses élémentaires ainsi que sur la granulométrie du sédiment et la nature de la fraction argileuse et précise le degré de contrôle de ces paramètres sur la faune de foraminifères benthiques. Cette étude a été menée sur 15 échantillons régulièrement espacés entre des environnements de vasière intertidale et de marais maritime. La taille des grains est le facteur le plus limitant. La densité et la richesse spécifique des foraminifères benthiques vivants (colorés) sont faibles dans les sédiments les plus grossiers. La matière organique est le second paramètre limitant. La densité des foraminifères est la plus faible et la richesse spécifique la plus forte lorsque la proportion de carbone organique (C_{org}) est faible et $C/N < 12$. Au contraire lorsque C_{org} est fort avec $C/N > 12$, la densité est forte et la richesse spécifique intermédiaire. Une forte proportion de smectite semble favoriser le développement de *Miliammina fusca*. *Trochammina inflata* et *Jadammina macrescens* sont toutes les deux favorisées par une augmentation de carbone organique. *Trochammina inflata* se nourrit préférentiellement de matière organique dont l'origine algaire est plus prononcée que pour *Jadammina macrescens*.

Keywords: Benthic foraminifera ecology; Sediment grain size; Clay mineralogy; Organic matter quality

Mots clés : Écologie des foraminifères benthiques ; Granulométrie des sédiments ; Minéralogie des argiles ; Qualité de la matière organique

1. Introduction

The paleoecological interpretation of fossil foraminiferal assemblages depends on the understanding of the ecological processes operating at present. The aim of ecological studies is to determine the relationship between the biota and the

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environment. Despite repeated ecological studies of benthic foraminifera, the exact control of environmental forcing on benthic foraminifera is still not fully understood. In marginal marine environments, the distribution of benthic foraminifera cannot simply be described in terms of oxygen and nutrient availability, as it is described in deep sea (see discussion in Van Der Zwaan et al., 1999), since many other factors could play a major role (Murray, 1991, 2001). For instance, Hayward et al. (1996), while reviewing the environmental factors influencing the faunal distribution in a New Zealand tidal inlet, noted that the main factors influencing foraminiferal distribution, in decreasing order of importance, are: tidal exposure, salinity, percentage of mud, proximity of the open sea, organic carbon, phosphate content and intertidal vegetation type. These parameters vary over a wide range, overwhelming any variations of other proxies. In areas where these dominant parameters display slighter variations, other parameters, especially sediment grain-size and mineralogy as well as the OM quantity and quality, may show significant variability, and thus control the distribution and abundance of benthic foraminifera.

The effects of sediment grain-size on foraminiferal density and diversity are still a matter of debate. Indeed, based on the observations of faunal density and diversity, Diz et al. (2004), suggest that very coarse substrates provide a favorable settlement for living benthic foraminifera, whereas other studies reveal that a high proportion of fine particles favor benthic foraminifera (e.g., Debenay et al., 2001).

The effects of OM on foraminifera are also very complex. A few studies indicate that organic waste seems to favor both diversity and density of the foraminifera populations (Bandy et al., 1964a, 1964b, 1965; Cearreta, 1988; Debenay et al., 2001). By contrast, other authors observe a decrease of density, specific richness and/or diversity index when the OM content increases (Setty, 1976; Schafer et al., 1991, 1995). Nevertheless, some studies report no significant effect of the OM contents on foraminiferal assemblages (Setty and Nigam, 1982). In summary, the presence of OM seems to favor foraminifera development until it becomes toxic when its proportion in the sediment increases (Alve, 1991).

The main objectives of this study are to investigate both the quality and quantity of OM as well as sediment grain size and mineralogy in order to understand up to what level these parameters control the benthic foraminiferal distribution and abundance.

2. Material and methods

2.1. Study area

The study was carried out on the tidal flat of the Canche estuary (Pas-de-Calais, France; Fig. 1) a ca. 9 km^2 intertidal area at the end of a 96 km long river having a relatively small drainage basin of 1407 km^2. Sampling was carried out along a 325 m cross shore transect (Fig. 1). Sediment samples were collected from 15 stations regularly spaced at 25 m interval. Four stations are located on the mudflat (stations 1 to 4), one station is located on the transition area between the mudflat and the salt marsh (station 5), and eight are located on the salt marsh (stations 6 to 13). Station 110 is located in a small drainage creek close to station 11. Station 14 is located within a large drainage creek behind a sea wall. The mudflat was typically free of vegetation (Table 1). The transition between the mudflat and the lower salt marsh was partly colonized by *Salicornia herbacea* and *Puccinellia maritima* (Table 1) with rare occurrence of *Spartina maritima*. The high marsh was mostly covered by *Agropyrum pungens* with some patches of *Obiones portulacoides* (Table 1). The Canche estuary is a well-mixed estuary. In spring tide conditions, the seawater broadly enters the estuary. The salinity within the salt marsh is homogeneous and reaches that of marine water. During neap tide, salt marshes are free of marine water and mudflat is only influenced by river water. Salt marshes may then be dehydrated with high salinity during sunny days and under freshwater influence during rainy days. Water temperature closely follows the sea temperature and that of the river. Values range between 9 °C in winter and 18 °C in summer. These values can be minimized or exceeded in restricted ponds during winter and summer.

2.2. Sampling method

At each station, a constant volume of 150 cm^3 of superficial sediment (the uppermost 1 cm) was scraped off. The potential bias due to the patchiness of microorganisms was limited by mixing sub-samples collected over 1 m^2, using a pseudoreplication procedure (Hurlbert, 1984; Debenay and Guillou, 2002). Such a procedure that scraps only small scattered parts of the sampling station also prevents sampling disturbed sediments and loss of surface layer. This study was carried out on superficial samples because, even if foraminifera can live as deep as 30 cm in the

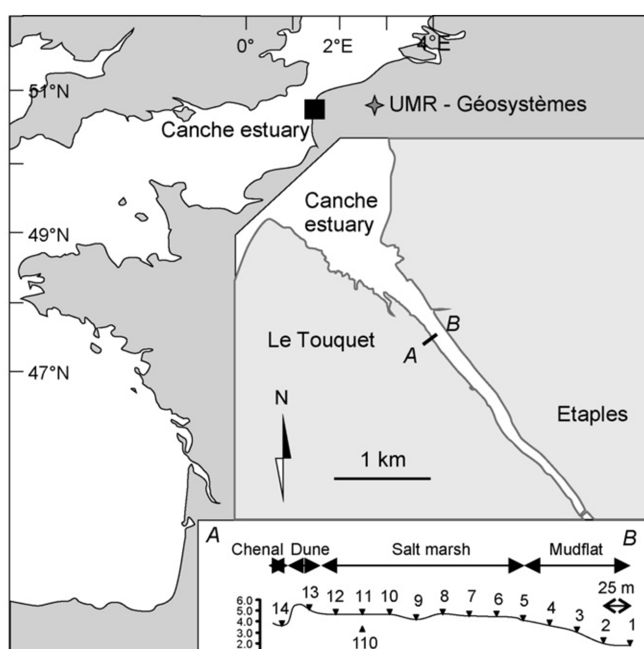

Fig. 1. Study area and location of the 15 sampling stations.
Fig. 1. Zone d'étude et localisation des 15 stations de prélèvements.