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The impact of easily oxidized material (EOM) on the meiobenthos: Foraminifera abnormalities in shrimp ponds of New Caledonia; implications for environment and paleoenvironment survey

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ABSTRACT

This study was carried out in shrimp ponds from New Caledonia, in order to determine the cause of the exceptional proportion of abnormal tests (FAI) (often >50%, sometimes >80%). FAI was positively correlated to the quantity of easily oxidized material (EOM) deposited on the bottom of the ponds and to the sediment oxygen demand, and negatively correlated to redox. These results suggest that a very high FAI is a potential indicator for great accumulations of native organic matter, leading to a high sediment oxygen demand. When studying ancient sediments in core samples, exceptional abundances of abnormal tests may indicate periods of high accumulation of EOM, and therefore of oxygen depletion. This finding should help in better management of aquaculture ponds, but should also allow new insight into the interpretation of sedimentary records, providing a useful proxy for paleoenvironmental reconstructions.

1. Introduction

Morphological abnormalities in foraminiferal tests have long been reported and their significance discussed (e.g., Arnal, 1955; Boltovskoy, 1957; Seiglie, 1964; Boltovskoy and Wright, 1976). Abnormalities have been related to environmental stress, including salinity stress (e.g. Ayala-Castañares and Segura, 1968; Tufescu, 1968; Closs and Madeira, 1968; Zaninetti, 1982; Almogi-Labin et al., 1992), and the impact of pollution, mainly by heavy metals and organic matter, which has been considered with greater attention since the 1980's (e.g., Vénec-Peyré, 1981; Setty and Nigam, 1984; Alve, 1991, 1995; Yanko et al., 1994, 1998; Alve and Olsgard, 1999). Recently, an increasing number of papers are being published dealing with the impact of pollution on foraminiferal morphology (e.g., Samir and El Din, 2001; Coccioni et al., 2003, 2005; Elberling et al., 2003; Armynot du Châtelet et al., 2004; Saraswat et al., 2004; Vilela et al., 2004; Bergin et al., 2006; Nigam et al., 2006; Le Cadre and Debenay, 2006; Burone et al., 2006; Bouchet et al., 2007; Frontalini and Coccioni, 2008; Romano et al., 2008; Nikulina et al., 2008). Some studies deal more specifically with the impact of organic matter (Caralp, 1989; Burone et al., 2006, 2007). Most of these authors consider that foraminiferal abnormalities are potentially valuable indicators of natural stress and/or pollution in present environments. They also have tentatively been used for the interpretation of past environments as far as the Cretaceous (Ballent and Carignano, 2008).

Uncertainties still exist concerning the relationship between the level of morphological abnormalities and the nature and magnitude of pollution, since the response of benthic foraminifera to stress resulting from highly changing natural environmental parameters such as salinity, temperature or pH superimpose onto the impact of anthropogenic pollution (Geslin et al., 2000, 2002; Debenay et al., 2001; Nigam et al., 2008). Moreover, low rates of abnormalities may be found in highly polluted areas such as Santos Harbor (Brazil), whereas abnormalities are reported from low pollution areas (Geslin et al., 2002). The bioavailability of pollutants, often neglected, certainly plays a major role in test deformation (Armynot du Châtelet et al., 2003).

In laboratory cultures of *Ammonia* under normal conditions, 1% of tests were found to be abnormal (Stouff et al., 1999b). This proportion was considered as normal in unspoiled environments (Alve, 1991), while highly variable values have been reported as resulting from environmental stress: e.g., 2–3% (Yanko et al., 1994); 3.5% (Yanko et al., 1998); 5% (Seiglie, 1975); up to 7% (Alve, 1991); 10–20% (Sharifi et al., 1991); more than 10% (Coccioni et al., 1997); 30% (Lidz, 1965); up to 11.1% (Samir, 2000). Romano et al. (2008) recorded up to 47.3% of abnormal tests of *Miliolinella*

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subrotunda and *Elphidium advena* near an industrial plant operated on the coastal area of Bagnoli (Italy). In the inner zone of Montevideo Bay, Burone et al. (2006) recorded 72.7% of abnormal hyaline specimens in sediments with high organic load and low oxygen, associated with pollution by Cr and Pb.

Only a few studies have been carried out on foraminiferal assemblages specifically affected by aquaculture, mainly in the Atlantic Ocean (Schafer et al., 1995; Scott et al., 1995; Bouchet et al., 2007) and in the Red Sea (Angel et al., 2000). As far as we know, the only studies dealing partially with foraminifera in shrimp farms are those from Luan and Debenay (2005), and Debenay and Luan (2006). The high input of organic matter and the wide variety of chemical and biological products used in ponds of semi-intensive and intensive shrimp farming may leave persistent, potentially toxic residues. They are likely to have a negative impact on the environment (e.g., Gräslund and Bengtsson, 2001), including foraminifera living in shrimp ponds.

The aim of this work is to investigate the response of foraminifera in semi-intensive shrimp ponds that have different environmental characteristics, with special attention to the accumulation of EOM, including native organic matter.

Pond bottom conditions are affected to a large extent by the accumulation of organic matter, such as dead algae, shrimp faeces and feed residues. This native, reactive, organic matter associated with reduced inorganic species (such as sulfides, Fe and Mn ions) constitute the active oxygen demanding pool, which leads to high oxygen consumption and the development of reducing conditions (Boyd, 1995; Avnimelech and Ritvo, 2003). The conventional method used for determination of organic matter in fresh sediments is based on a very aggressive oxidation (Walkley and Black, 1934). By this method, both fresh reactive organic matter, such as recently settled algae or feed residues, and very stable humic compounds accumulated in the soil are included in the measured value. The inability to differentiate between the two types of organic substrates and the commonly relative high background of stable organic matter make it difficult to characterize changes in the reactive fraction. Moreover, during the preparation for this conventional procedure, the samples are exposed to the air, heated and dried, which leads to the loss of very active inorganic reducing components and some organic compounds (e.g. low molecular volatile organic acids). In short, the conventional method measures quite correctly a large background, but partly ignores an unknown and probably important pertinent signal. This is why Avnimelech et al. (2004) proposed a method to enable determination of the redox capacity in fresh sediment samples using a relatively mild oxidation procedure with minimal treatment and exposure to the atmosphere, which allow the measure of the EOM.

2. Study area

Semi-intensive shrimp farming is widely distributed along the west coast of New Caledonia Main Island (Grande Terre). In New Caledonia, chemicals such as Copper compounds (elimination of external protozoans and filamentous bacterial diseases in post-larval shrimps), formalin (antifungal agent and control of ectoparasites), or antibiotics are not used, contrary to what is generally done in most of South-East Asian shrimp farms (review in Gräslund and Bengtsson, 2001). After shrimp harvest, the ponds are treated by drying for several weeks, and turning subsoil by tilling to enhance oxidation of organic matter and other reduced substances. The growing cycle lasts about four months.

Samples were collected from three shrimp farms with different characteristics (Figs. 1 and 2). Two stations were selected in a pond of Saint Vincent shrimp farm (SV): Station SVA was located on a clean bottom whereas station SVB was located in an area of moderate accumulation of organic matter, where the soil never completely dried (permanent seepage). Two other stations were selected in a pond of SeaFarm shrimp farm (SF): one in an area with a high organic matter accumulation due to rotating currents induced by the paddle wheel aerator (station SF1), the second one outside of this area (station SF2). Six ponds were selected in Aigue-Marine shrimp farm (AM): two on sedimentary bottoms (stations ST1 and ST2), one on schist rocks without any sedimentary deposits, which impede to properly turn subsoil by tilling (station S2), one on a bottom made of schist fragments mixed with silt and clays (station S1), and two on bottoms fertilized by a layer of vegetable soil added before filling the ponds with marine water (stations TV1 and TV2). Seepage prevents ponds ST1 and ST2 to dry completely and organic matter and other reduced substances cannot be entirely oxidized. Due to easy access to the sea, a high water exchange system is used where water supplies consist of open-sea water, keeping salinity between 32‰ and 39‰. Water renewal varies from 0% to 30% per day, depending on shrimp biomass, and progressively increases with time. Post larvae are introduced about two weeks after the ponds were filled at a density of 18–20 individuals per square meter. Artificial feeding (pelleted food), which comprises 0.025% of mineral premix (Zn sulfate, Mn sulfate, Cu sulfate) is provided in all the ponds. Feeding rates range from about 6 kg per ha per day at the time of introduction of post larvae to about 60 kg per ha per day before shrimp harvest.

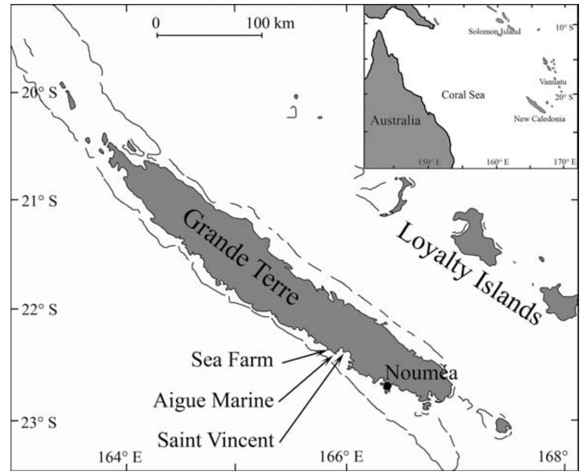

Fig. 1. Location map of the study area.

3. Material and methods

The study was carried out during two successive hot seasons. Sediment samples were collected weekly at each station during a whole growing cycle, giving a total number of 170 samples. Sampling began just after the filling of the ponds and stopped after shrimp harvest. The first sampling occurred in February 2006 at stations SV and SF, and in December 2006 at the other stations. At each station, a sediment core was hand collected by means of a pvc tube, 25 cm in diameter and 5 cm long. Immediately, fifty redox measurements were carried out in the sediment with a micro redox electrode (pH/mv meter WTW 315i). The sediment sample for foraminiferal analysis was collected in the upper 2 cm of this core: About 40 cm^3 of sediment were collected, and immediately frozen for preservation. At the station with schist rock bottom a special metallic corer was used to penetrate the schist rock and then collect the thin layer of surface sediment.

At the time of sampling, the following parameters were measured in the water column, 10 cm above the bottom: temperature; salinity; dissolved oxygen; ammonium. In the sediment, the