Marine Pollution Bulletin 64 (2012) 1895–1910

Contents lists available at SciVerse ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Deep-sea foraminifera from the Cassidaigne Canyon (NW Mediterranean): Assessing the environmental impact of bauxite red mud disposal

C. Fontanier [a,b,c,*], M.-C. Fabri [d], R. Buscail [e], L. Biscara [c], K. Koho [f], G.J. Reichart [f], D. Cossa [g], S. Galaup [h], G. Chabaud [c], L. Pigot [h]

[a] Laboratory of Recent and Fossil Bio-Indicators, CNRS UMR 6122 LPGN, University of Angers, 2 Boulevard Lavoisier, 49045 Angers Cedex, France
[b] Laboratory for the Study of Marine Bio-Indicators (LEBIM), 85350, Ile d'Yeu, France
[c] Environnements et Paléoenvironnements Océaniques et Continentaux, CNRS UMR 5805 OASU, University of Bordeaux I, Avenue des Facultés, 33405 Talence Cedex, France (CNRS Delegation)
[d] Ifremer, Centre Méditerranée, Laboratoire Environnement Ressources, 83500 La Seyne sur Mer, France
[e] CNRS and Univesity of Perpignan, CEntre de Formation et de Recherche sur les Environnements Méditerranéens, UMR 5110 CNRS, 52 Avenue Paul Alduy, 66860 Perpignan Cedex, France
[f] Department of Earth Sciences – Geochemistry, Faculty of Geosciences, Utrecht University, P.O. Box 80.021, 3508 TA Utrecht, The Netherlands
[g] Ifremer, Centre Méditerranée, Laboratoire Biogéochimie des Contaminants Métalliques, 83500 La Seyne sur Mer, France
[h] ENSEGID – IPB – EA 4592, 1 allée Daguin, 33607 Pessac, France

ARTICLE INFO

Keywords:
Bauxite red mud
Cassidaigne Canyon
Benthic foraminifera
Organic compounds
Hydro-sedimentary pollution
Trace elements

ABSTRACT

Benthic foraminiferal assemblages were investigated from two sites along the axis of the Cassidaigne Canyon (NW Mediterranean Sea). Both areas are contaminated by bauxite red mud enriched in iron, titanium, vanadium and chromium. These elemental enrichments are related to bauxite-derived minerals and various amorphous phases. At the shallowest station located very close to the pipe outlet, the benthic living foraminiferal community is characterised by a very low diversity and by an unusual dominance of *Gyroidina umbonata* and *Bulimina marginata*. The mechanical stress related to downslope transport of red mud is a likely source of hydro-sedimentary pollution precluding the settlement of diverse fauna. The living and dead foraminiferal faunas from the deepest site are typical of oligo-mesotrophic conditions prevailing in natural environments. There, bauxite residues have obviously no environmental impact on foraminiferal faunas. The bioavailability of trace metals is likely low as elemental enrichments were not observed in foraminiferal test chemistry.

1. Introduction

In deep-sea environments, spatial and temporal dynamics of benthic foraminifera (Eukaryota, Rhizaria) are constrained by many physico-chemical parameters (e.g. organic detritus, redox conditions in the sediment, hydro-sedimentary processes prevailing at the sediment–water interface) (see reviews by Gooday, 2003; Jorissen et al., 2007). Among these natural abiotic factors, the organic-matter flux reaching the sea floor constitutes the main food source for heterotrophic benthos, and is considered as the most important ecological constraint for foraminiferal faunas (e.g. Gooday, 2003; Jorissen et al., 2007). The organic-matter flux acts also indirectly like an ecological limiting factor when it induces either temporary or long-term hypoxia in the sediment (i.e. oxygen minimum zone) (e.g. Jannink et al., 1998; Gooday et al., 2000; Kurbjeweit et al., 2000; Schumacher et al., 2007). In peculiar environments such as submarine canyons, sediment gravity flows and other hydro-sedimentary processes may supply organic detritus and inorganic particles to the deep ocean. There, foraminiferal faunas are characterised either by more or less advanced recolonisation stages occurring after physical disturbance (e.g. turbidity currents) or by equilibrium phases related to gradual organic matter focussing (e.g. eutrophication) (e.g. Hess et al., 2005; Koho et al., 2007, 2008; Fontanier et al., 2008a,b, Hess and Jorissen, 2009; Duros et al., 2011). Due to their relatively short life cycle, environmental change can be quickly recorded via changes in the assemblage structure. Therefore, foraminifera make ideal candidates for monitoring of environmental stress. In addition, simultaneously the pollution signal (such as heavy metals) can be recorded in their calcite shell, or test (de Nooijer et al. 2007; Rumolo et al. 2009; Munsel et al. 2010). The high fossilisation potential of foraminiferal tests also bears the advantage that the

* Corresponding author at: Laboratory of Recent and Fossil Bio-Indicators, CNRS UMR 6122 LPGN, University of Angers, 2 Boulevard Lavoisier, 49045 Angers Cedex, France. Tel.: +33 (0)6 21 91 93 48; fax: +33 (0)2 41 73 53 52.
E-mail addresses: christophe.fontanier@univ-angers.fr, c.fontanier@epoc.u-bordeaux1.fr (C. Fontanier).

0025-326X/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpolbul.2012.06.016

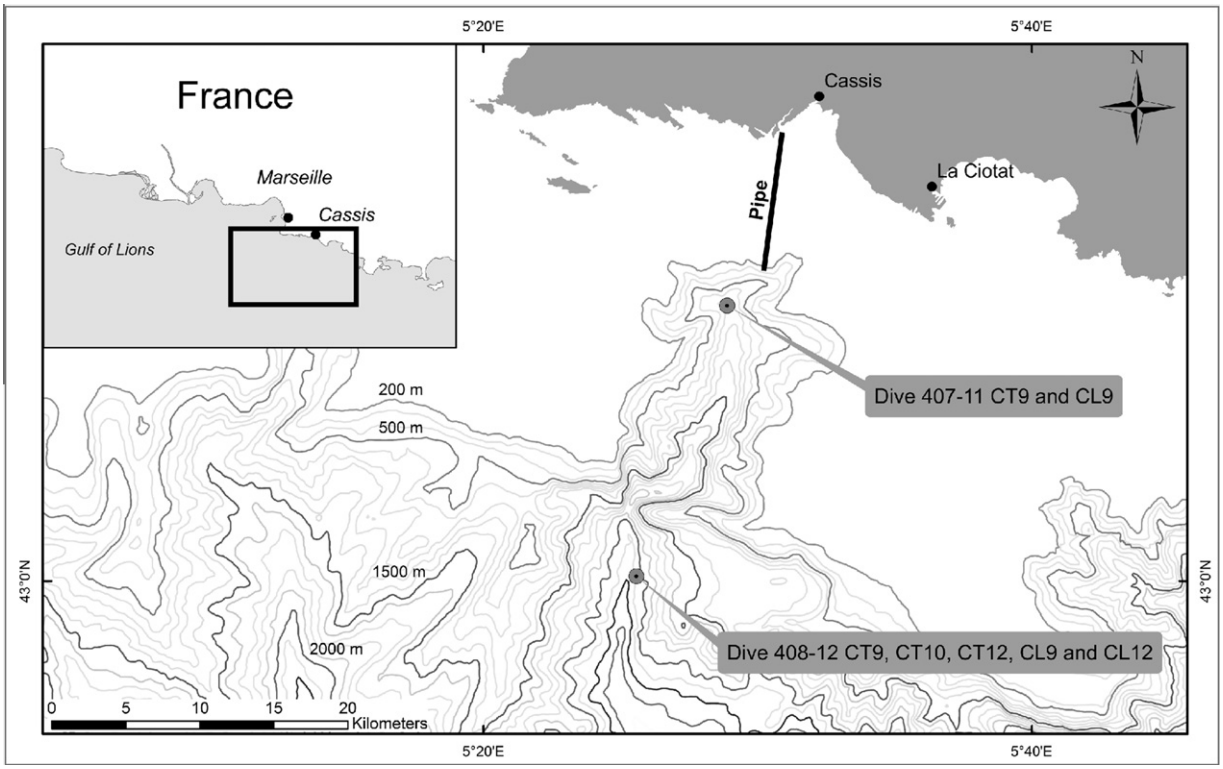

Fig. 1. Bathymetry, study area and location of both investigated sites in the Cassidaigne Canyon (Gulf of Lions, NW Mediterranean Sea).

environmental history of the area can be reconstructed, and the initiation of the anthropogenic influence can be pinpointed (Elberling et al., 2003). In this paper, we investigate the potential impact of bauxite red mud dumping on deep-sea foraminiferal faunas living in the Cassidaigne Canyon (Western Mediterranean Sea). We study the foraminiferal communities sampled at two stations located along the canyon axis at ~725 m and ~1530 m depths (Fig. 1, Table 1). Sediment samples were collected by a remote operated vehicle, the ROV VICTOR-6000, during the ESSROV2010 cruise (September 2010). Valuable *in situ* observations (video and high-resolution images) were performed at both sites. The main objective of our study is to assess the putative environmental impact of putative bauxite residues disposal on benthic life. According to the proximity to the pipe devoted to red mud disposal, living foraminiferal communities (i.e. biocoenoses) might be differently affected by the deposits. If strongly adverse (e.g. toxic) conditions exist, azoic sediment might be observed. In order to investigate the potential toxicity of sediments, we describe the diversity of living (stained) foraminifera in relation to environmental conditions prevailing at both sites. To constrain the ecological interpretations of benthic foraminiferal faunas, elemental analysis of solid fraction, grain-size distribution of sediments, mineralogical composition and sedimentary organic matter are analysed. Dead foraminiferal faunas (i.e. thanatocoenoses) were also investigated. A geochemical study of trace elements in calcareous shell of living (stained) foraminifera is carried out. Iron, manganese, chromium, vanadium and titanium behave as redox sensitive species in the sediment (Lea, 1999; Hyacinthe et al., 2001). Their mobilisation in pore water as dissolved species depends on (1) mineral forms of related oxi-hydroxides and (2) the organic-matter mineralisation within the sediment. The contribution of trace metals in calcareous foraminifera at both investigated stations might inform us on (1) their concentration in pore water and, finally, on (2) their potential bioavailability as toxic agents in the benthic ecosystems.

2. Study area

The Cassidaigne Canyon is located in the eastern part of the Gulf of Lions (NW Mediterranean). Its head borders the Cassis Bay, only 8 km away from the coast (Fig. 1). Compared to other canyons from the Gulf of Lions, the Cassidaigne Canyon is short in length (<50 km) and presents very steep flanks. In the deeper part of the canyon, two narrow passages (only 1 km in width) are located 3 km and 17 km away from the shelf break (170 m depth). The surface waters circulation are characterised by the Northern Current (NC) which forms the northern branch of the cyclonic Liguro-Provençal Current (LPC) (Béthoux and Prieur, 1983; Millot, 1990). The NC follows the continental margin from the Provence coast to the coast of Catalonia. It is related to a permanent shelf-slope density front separating low salinity shelf waters from denser open-sea waters (Astraldi et al., 1994; Flexas et al., 2002). Below the surface waters (~200 m depth), spreads the Levantine Intermediate Water (LIW) which is characterised by a salinity maximum (~38.5) and a relative temperature maximum (>13 °C). The Western Mediterranean Deep Water (WMDW) occurs below LIW with a diffusive boundary at 500–800 m (Béthoux and Prieur, 1983; Béthoux et al., 2002). It is generally characterised by a rather homogeneous temperature (~13 °C) and salinity (38.40–38.45) (Béthoux and Prieur, 1983; Béthoux et al., 2002). The related seasonal vertical mixing leads also to the upward transport of nutrients from intermediate waters into the surface layers and a relative important annual primary production compared to the more oligotrophic eastern Mediterranean Sea (Diaz, 2000). In relation to wind and coast-line direction and, possibly, to the Cassidaigne Canyon, the most intense upwelling of the Gulf of Lions is located within the Cassis Bay above the Cassidaigne Canyon (Albérola and Millot, 2003).

Since 1967, the Gardanne alumina refinery (Gardanne Pechiney, Alcan, Rio Tinto alumina refinery, France) has been disposing of