Deep-Sea Research I 57 (2010) 1120–1136

Contents lists available at ScienceDirect

Deep-Sea Research I

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

First insights into the structure and environmental setting of cold-seep communities in the Marmara Sea

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ARTICLE INFO

Article history:
Received 10 November 2009
Received in revised form
20 May 2010
Accepted 26 May 2010
Available online 2 June 2010

Keywords:
Marmara Sea
Cold seep
Benthic fauna
Biological diversity
Environmental conditions
Chemosynthetic

ABSTRACT

A brackish-water cold seep on the North Anatolian Fault (NAF) in the Marmara Sea was investigated with the Nautile submersible during the MarNaut cruise in 2007. This active zone has already been surveyed and revealed evidence of active seeping on the seafloor, such as bubble emissions, patches of reduced sediments, microbial mats and authigenic carbonate crusts. MarNaut was the first opportunity to sample benthic communities in the three most common microhabitats (bioturbated and reduced sediments, carbonate crust) and to examine their relationships with environmental conditions. To do so, faunal communities were sampled and chemical measurements were taken close to the organisms. According to diversity indices, the bioturbated microhabitat exhibited the highest taxonomic diversity and evenness despite a lower number of samples. Conversely, the reduced sediment microhabitat exhibited the lowest taxonomic diversity and evenness. The carbonate crust microhabitat was intermediate although it had the highest biomass. Multivariate analyses showed that (1) fauna were relatively similar within a single microhabitat; (2) faunal community structure varied greatly between the different microhabitats; (3) there was a link between faunal distribution and the type of substratum; and (4) chemical gradients (i.e. methane, oxygen and probably sulphides) may influence faunal distribution. The estimated fluid flow velocity (0.4–0.8 m/yr) confirmed the presence of fluid emission and provided evidence of seawater convection in the two soft-sediment microhabitats. Our results suggest that the reduced sediments may represent a harsher environment with high upward fluid flow, which restrains seawater from penetrating the sediments and inhibits sulphide production, whereas bioturbated sediments can be viewed as a bio-irrigated system with sulphide production occurring at greater depths. Therefore, the environmental conditions in reduced sediments appear to prevent the colonization of symbiont-bearing fauna, such as vesicomyid bivalves, which are more often found in bioturbated sediments. Fluid flow appears to control sulphide availability, which in turn influences the horizontal and vertical distribution patterns of fauna at small spatial scales as observed at other seep sites.

1. Introduction

Submarine hydrocarbon seeps, often referred to "cold seeps", are commonly found on continental shelves and margins worldwide (Dimitrov, 2002; Judd and Hovland, 2007; Milkov, 2000). In these habitats, ascending fluids are enriched by dissolved reducing gas (mainly CH_4 and H_2S), which create particular environmental conditions that support a singular fauna with similarities to those found in deep-sea hydrothermal vents (Hecker, 1985; Sibuet and Olu, 1998). Chemosynthesis-based seep communities were discovered for the first time on the Florida Escarpment in the Gulf of Mexico (Paull et al., 1984) and more than 60 seep sites (Campbell, 2006; Levin, 2005; Sibuet and Olu, 1998) are now known throughout the world's oceans. Seep sites are found in different geological settings, both on active margins (subduction areas, trenches, accretionary prisms) and passive margins (continental shelves, delta complexes) and at depths ranging from 10 m (Jensen et al., 1992) to at least 7300 m (Jumars and Hessler, 1976). Their common feature is the discharge of fluid, gas and mud through various geological structures such as pockmarks, brine lakes or mud volcanoes (Hovland et al., 2002;

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doi:10.1016/j.dsr.2010.05.011

Judd and Hovland, 2007; Milkov, 2000). At very active sites, such as in the Black Sea, gas flares may be observed in extremely large numbers (Artemov et al., 2007; Egorov et al., 1998).

Cold-seep ecosystems are home to chemosynthetic communities composed of a number of endemic vesicomyid, solemyid and mytilid bivalves, as well as several siboglinid polychaetes that are often the dominant macro- and megafauna (Bergquist et al., 2003, 2005; Levin and Mendoza 2007; Levin et al., 2003; Luth et al., 1999; Olu et al., 1996, 1997; Olu-Le Roy et al., 2004, 2007; Paull et al., 1984; Sahling et al., 2002; Sibuet and Olu, 1998). One of the key adaptations of species to seep habitats is their association with bacterial endosymbionts, which ensure chemosynthetic primary production through the oxidation of the reduced compounds contained in the seeping fluids (Cavanaugh, 1983; Childress et al., 1986; Dubilier et al., 2008; Fisher, 1990). Thus, these taxa rely on seeping fluids for their nutrition and survival, and their spatial distribution is a reliable indicator of the presence of chemical fluxes at the sediment–water interface (Levin, 2005; Sibuet and Olu, 1998). Other heterotrophic species live in association with seep chemosynthetic species, benefiting from these enriched environments (Tunnicliffe et al., 2003) and also relying on organic inputs derived from neritic (coastal) and terrestrial organic material (Gage, 2003).

Recent studies on seep ecosystems have highlighted the vast heterogeneity of habitats and associated faunal assemblages at small spatial scales that range from the sampling unit (dm scale) to the geological structure (km scale) on which the assemblages are found (Vanreusel et al., 2009). Although there are some similarities between structures and regions, each newly discovered seep area may have its own signature in terms of faunal structure, diversity and chemical conditions. Previous studies have suggested that the composition and intensity of fluid seepage are the major factors structuring the distribution of seep fauna (Levin, 2005; Sibuet and Olu, 1998). Other driving forces, such as depth (Sibuet and Olu, 1998), substratum type (Olu et al., 1996; Sahling et al., 2003), oxygen concentration (Bergquist et al., 2005; Levin and Gage, 1998), biological interactions (Bergquist et al., 2003) and hydrographic regime (Luth and Luth, 1998; Luth et al., 1999), have also been suggested to play a role on species distribution patterns.

Recently, the deep-sea sites of the Marmara Sea (40–41°N; 26–30°W) have received more attention from the scientific community, mainly because of the seismic hazard in the Istanbul area. This intra-continental sea, located on the North-Anatolian Fault zone (NAF), is tectonically active (Armijo et al., 2004; Le Pichon et al., 2001; Sengor et al., 2005). Submarine earthquakes constitute a potential threat for human populations (Ambraseys, 2000; Ambraseys and Finkel, 1991; Ansal et al., 2009; Hubert-Ferrari et al., 2000; Oglesby et al., 2008). These earthquakes influence gas emissions (Hovland et al., 2002) as confirmed by the presence of gas flares in the Izmit Gulf following the 1999 Kocaeli earthquake (Alpar, 1999). Subsequent investigations have revealed cold seeps in the deep basins of the Marmara Sea along the main fault, on secondary fault branches and on the anticline ridges (Armijo et al., 2005; Geli et al., 2008; Halbach et al., 2004; Zitter et al., 2008). The most common evidence for fluid expulsion in the Marmara Sea is the presence of black patches of reduced sediments associated with microbial mats and authigenic carbonate crusts (Zitter et al., 2008). While these generally correspond to zones of diffuse flow, focused flow of brackish water has been observed at two sites (Zitter et al., 2008). Moreover, cold seeps can release hydrocarbons as a separate gas phase, and even as oil (Bourry et al., 2009; Geli et al., 2008). Seeps can be thus characterised by gas flares, brackish-water springs or diffuse emission, depending on the dominant mode of fluid emission.

In 2007, the MarNaut cruise represented the first opportunity to sample the fauna associated with the cold-seep ecosystems of the Marmara Sea and to characterise the abiotic conditions of this basin of the eastern Mediterranean Sea. The present study aims to describe the structure of the benthic communities in the three most common microhabitats of a brackish-water cold seep and relate community structure to local environmental factors. Even though these objectives were hindered by sampling limitations, this study represents a fundamental step in advancing our understanding of the ecology and biogeography of chemosynthetic seep species within the larger Mediterranean context.

2. Materials and methods

2.1. Study area

Located between 40–41°N and 26–30°W, the Marmara Sea is the easternmost semi-enclosed basin of the Mediterranean Sea, and connects the Black Sea to the Aegean Sea via the Bosphorus and Dardanelles Straits. It is subdivided into four major basins from east to west: the Çinarcik, Kumburgaz, Central and Tekirdağ basins, with a maximum depth of about 1260 m in the Central basin (Fig. 1).

Preliminary visual observations of the Marmara Sea seafloor and the associated epibenthic communities were carried out using the ROV *Victor 6000* during the MARMARASCARPS cruise in 2002 (Armijo et al., 2005; Zitter et al., 2008). Our observations and sampling were carried out five years later during the MarNaut cruise (2007) on the R/V *L'Atalante* with the manned submersible *Nautile*. During this cruise, exploratory dives were carried out to map seepage occurrences and faunal distributions at selected sites in the four major basins. Five sampling dives took place at the brackish-water spring described in this study. One of these dives was dedicated to sampling the mega- and macrofauna and characterising the environmental features in the north-east Central basin (40°51.27′N–28°10.19′W) at a depth of 1120 m (Fig. 1).

2.2. Sampling site

The chosen seep site harboured a mosaic of microhabitats. Three of these were selected and sampled: (1) the bioturbated sediment microhabitat (Bio) was characterised by brown sediments with small bioturbation holes (Fig. 2a); (2) large patches of reduced sediment microhabitat (Red) were covered by short polychaete tubes and were surrounded by Bio patches (Fig. 2b); and (3) sparse carbonate crusts were located a couple of meters from Red patches and collectively constitute the Carbonate Crust microhabitat (CC, Fig. 2c).

Environmental characterisation of each microhabitat was conducted before sampling fauna to avoid any disturbance that could be caused by this sampling. Temperature and salinity measurements were performed using the MicroCat autonomous sensor (F. Harmegnies, Ifremer). Mean values were computed after deploying the sensor for 1 min above the organisms and as close as possible to the seafloor using *Nautile*'s manipulator arm. Water and sediment samples were then taken for chemical analyses using 200 ml titanium bottles and tube corers (30 cm long; 5.4 cm inner diameter), respectively. Complete sampling details are given in Table 1. Unfortunately, due to time constraints imposed by the use of a manned submersible, the physico-chemical sampling could not be completed above Bio and was not performed above CC. Sediments were also sampled with blade corers (Bayon et al., 2009; Menot et al., 2009, area:0.02 m^2,