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Megafaunal distribution and assessment of total methane and sulfide consumption by mussel beds at Menez Gwen hydrothermal vent, based on geo-referenced photomosaics

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ABSTRACT

The Menez Gwen hydrothermal vents, located on the flanks of a small young volcanic structure in the axial valley of the Menez Gwen seamount, are the shallowest known vent systems on the Mid-Atlantic Ridge that host chemosynthetic communities. Although visited several times by research cruises, very few images have been published of the active sites, and their spatial dimensions and morphologies remain difficult to comprehend. We visited the vents on the eastern flank of the small Menez Gwen volcano during cruises with RV Poseidon (POS402, 2010) and RV Meteor (M82/3, 2010), and used new bathymetry and imagery data to provide first detailed information on the extents, surface morphologies, spatial patterns of the hydrothermal discharge and the distribution of dominant megafauna of five active sites. The investigated sites were mostly covered by soft sediments and abundant white precipitates, and bordered by basaltic pillows. The hydrothermally-influenced areas of the sites ranged from 59 to 200 m^2. Geo-referenced photomosaics and video data revealed that the symbiotic mussel *Bathymodiolus azoricus* was the dominant species and present at all sites. Using literature data on average body sizes and biomasses of Menez Gwen *B. azoricus*, we estimated that the *B. azoricus* populations inhabiting the eastern flank sites of the small volcano range between 28,640 and 50,120 individuals with a total biomass of 50 to 380 kg wet weight. Based on modeled rates of chemical consumption by the symbionts, the annual methane and sulfide consumption by *B. azoricus* could reach 1760 mol CH_4 yr^{-1} and 11,060 mol H_2S yr^{-1}. We propose that the chemical consumption by *B. azoricus* over at the Menez Gwen sites is low compared to the natural release of methane and sulfide via venting fluids.

1. Introduction

Hydrothermal vents were first discovered in 1977 and have been the focus of many studies since then (Lutz and Kennish, 1993; Van Dover, 2000). Especially the discovery of non-photosynthesis-fueled ecosystems associated with these systems, with abundant and diverse endemic fauna, excited the interest of a multitude of scientists from various disciplines. However, hydrothermal vent systems are located in depths without natural sunlight where the field of view for researchers and cameras diving with submersibles or remotely operated vehicles (ROV) is extremely limited despite the use of powerful lights. Hence, more than 30 years after the first discovery, the overall structure of hydrothermal venting sites and the distribution of the associated fauna are often only known from images providing close-up views of limited sections of vents, while only very few detailed maps of entire sites have been published (Barreyre et al., 2012; Bell et al., 2012; Escartín et al., 2008).

Detailed descriptions of the distribution of the faunal assemblages at hydrothermal vent systems that are available in the literature are mostly based on drawings or geo-referenced GIS layers that are drawn from video data. Such data are available in particular from the Endeavor hydrothermal field on the Juan de Fuca Ridge (Juniper et al., 1998; Sarrazin et al., 1997), from the Broken Spur vent field (Copley et al., 1997) and the Logatchev site on the Mid-Atlantic Ridge (MAR) (Gebruk et al., 2000a), and from the Lucky Strike system, at which the faunal distribution on a large chimney structure was described (Cuvelier et al., 2009). Such maps give valuable qualitative information on the distribution of the faunal patches and the layout of the sites but they rely on hand drawings from observations of video material and precision of inferred areas of cover is likely to be limited. Some works (Durand et al., 2002; Juniper et al., 1998; Sarrazin et al., 1997), however, focused particularly on the issue of improving

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the accuracy of spatial measurements from video imaging by drawing the contours on a background geology map of the site. In those cases, geo-referencing data of the basemap were obtained either from passive reference markers that were captured on video images (Durand et al., 2002) or from long baseline (LBL) navigation data that were correlated to the images (Delaney et al., 1992; Sarrazin and Juniper, 1998; Sarrazin et al., 1997). All these methods can be very efficient and can be applied in areas with sharp topographic contrasts.

An alternative approach is to use geo-referenced photo-mosaics to map the faunal distribution. Image mosaicking involves assembling several overlapping images together to form a composite image of a larger scene. The mosaic is then geo-referenced into a geographic information system (GIS), and areas can be computed. Such a method can provide a significantly quicker way to study areas with low to moderate relief. In addition, contours of features of interest can be drawn onto the geo-referenced image material directly. Similar methods have been used to successfully map faunal communities at different scales and in various types of environments. Examples include large-scale studies of faunal distribution at the Håkon Mosby Mud Volcano (Jerosch et al., 2007, 2006) and at the Regab pockmark (Olu-Le Roy et al., 2007), and small-scale studies at the Chowder Hill mound on the Juan de Fuca Ridge (Grehan and Juniper, 1996), at cold seeps in the Gulf of Mexico (Lessard-Pilon et al., 2010a, 2010b) and at discrete sites of hydrothermal activity on the Eastern Lau Spreading Center (Podowski et al., 2009).

Analyses of hydrothermal fauna usually focus on the distribution of the assemblages or on population structure in relation to the environment, and sometimes give density and biomass estimates per unit areas (Lutz and Kennish, 1993; Ramirez Llodra et al., 2007). However, the overall spatial distributions of faunal assemblages and animal abundances or biomasses at entire vent sites have rarely been quantified (e.g. Gebruk et al., 2000a; Podowski et al., 2009). Such knowledge is valuable as it gives information on the size of hydrothermal faunal populations, and can be used to infer chemical consumption rates. In a context where seabed methane emissions are considered to contribute noticeably to the global carbon budget (Judd, 2003), it is important to evaluate the relative significance of faunal methane consumption against methane effluxes in hot fluid emissions.

In this study, we use high-resolution bathymetry data together with areal photomosaics to provide for the first time detailed maps and descriptions of five sites of active venting from the Menez Gwen system in the area of the previously reported marker position PP30/31 (Desbruyères et al., 2001). The Menez Gwen hydrothermal vent field was chosen for this study because it is a volcanic structure where hydrothermal activity was believed to be concentrated over small areas. It has been visited by several cruises and the faunal communities hosted by the vent field have been the focus of many biological studies (Comtet and Desbruyères, 1998; Dixon et al., 2001; Fouquet et al., 1994; Riou et al., 2010; Sarradin et al., 2001, 1999; Shank and Martin, 2003; Von Cosel et al., 1999). However, descriptions and images of the sites of venting activity remain poor and quantitative data on dimensions, size of populations and biomasses are scarce.

Ship- and autonomous underwater vehicle- (AUV) based bathymetry surveys were conducted in September–October 2010 during cruises POS402 and M82/3 to the Menez Gwen hydrothermal vent field on the Mid-Atlantic Ridge. Five sites of active venting activity were intensively studied during twenty ROV dives. Using GIS, we provide measurements of surfaces covered by dominant species of megafauna, and estimates of the minimum biomass of *Bathymodiolus azoricus*. Also, we use published values of size, density and substrate uptake rates for *B. azoricus* at Menez Gwen to infer total methane and sulfide consumption rates at the scale of a vent site. The final goal of this study is to assess the significance of faunal methane and sulfide consumption against natural methane and sulfide release within vent fluids.

2. Site description

The Menez Gwen segment of the Mid-Atlantic Ridge is about 55 km long (Parson et al., 2000), and stretches from 38°03′N to 37°35′N in a S-SW to N-NE direction (Fig. 1). A large volcano with a mean diameter of 15 km is present near the center of the segment, and it reaches up to about 800 m above the surrounding seafloor (Fig. 1a). The top part is divided into two halves by a 9-km long axial graben of similar orientation to the ridge segment that forms a 300 to 400-m deep and 2-km wide valley across the volcano.

Several recently formed minor volcanoes are scattered across the northern part of the graben. The largest of them is about 1 km wide, up to 200 m high (Fig. 1b) and its highest point reaches up to 800 m water depth. The surface rocks of this young volcano are composed of fresh lava and some volcanic breccia (Fouquet et al., 1995; Ondréas et al., 1997). The lava has no sediment cover and it has been suggested that the entire small volcano built up during the latest eruptive episode (Ondréas et al., 1997). The hydrothermal activity at Menez Gwen is mainly concentrated on the southern and eastern flanks of this small volcano (Fig. 1b) (Charlou et al., 2000; Desbruyères et al., 2001). Although the Menez Gwen hydrothermal vents have been visited several times by research cruises, information on the morphology and geological composition of active sites is scarce and concentrates on two locations on the southern flank of the volcano (Fig. 1b). One of them (PP10/F11) is characterized by a 50-m wide mound with a low elevation and 2-m high anhydrite chimneys, which are surrounded by barite-rich precipitates; the other (D9, PP11, F12) is an escarpment topped by a chimney, which is bordered by pillow lava and crumbled rock (Charlou et al., 2000; Desbruyères et al., 2001; Fouquet et al., 1997, 1994). Such information is not available for sites on the eastern volcano flank.

Menez Gwen is part of the Azores Marine Park and possible future access restrictions to the southern sites may lead future research to focus on the eastern area. The sites of hydrothermal activity studied during the cruise M82/3 (2010) were therefore located in this area. More specifically, they were located on the eastern flank of the small volcano close to its summit (Fig. 1b and c), and between 850 and 814 m depth. In 20 dives, five major sites were found in the area: Atos 10, Cage Site, Marker 4, White Flames, and Woody. Apart from Atos 10, which was named after a marker deployed during the ATOS cruise in 2001 (Sarradin et al., 2001), the site names were those assigned during the cruise M82/3 in September–October 2010.

Large megafauna is composed of the bivalve species *Bathymodiolus azoricus*, the caridean shrimps *Chorocaris chacei*, *Mirocaris fortunata* and *Alvinocaris* sp. aff. *stactophila*, numerous gastropods, mainly *Lepetodrilus atlanticus* and *Protolira valvatoides*, the crab *Segonzacia mesatlantica* and the large non-hydrothermal crab *Chaceon affinis* (Desbruyères et al., 2001; Galkin and Goroslavskaya, 2010; Gebruk et al., 2000b; Ramirez Llodra et al., 2000; Von Cosel et al., 1999). Smaller animals are even more diverse (Galkin and Goroslavskaya, 2010), but are not discernible in video and photo materials.

3. Methods

3.1. Bathymetric surveys

Swath-mapping surveys were conducted during the M82/3 cruise with the hull-mounted multi-beam echosounder (MBES)