Available online http://amq.aiqua.it
ISSN (print): 2279-7327, ISSN (online): 2279-7335

Alpine and Mediterranean Quaternary, 28 (2), 2015, 99 - 110

INFLUENCE OF FLUID EMISSIONS ON SHALLOW-WATER BENTHIC HABITATS OF THE PONTINE ARCHIPELAGO (TYRRHENIAN SEA, ITALY)

Michela Ingrassia[1,2], Letizia Di Bella[1], Francesco Latino Chiocci[1,2], Eleonora Martorelli[2]

[1] Department of Earth Science, University of Rome Sapienza, Rome, Italy
[2] CNR-IGAG (Istituto di Geologia Ambientale e Geoingegneria), UOS Roma, Rome, Italy
Corresponding author: M. Ingrassia <michela.ingrassia@uniroma1.it>

ABSTRACT: An active fluid emission area located off the eastern coast of Zannone Island (western Pontine Archipelago) has been studied in order to investigate benthic assemblages related to vent-activity. The fluid escape feature is a giant depression (about 0.5 km^2) located on the outer shelf, between 110 and130 m water depth.
Evidences of active emissions were detected by ROV observations and sediment sampling, whereas integration of high-resolution multi-beam bathymetry, backscatter and ground-truth data allowed us to characterize and identify different seafloor types (e.g., lithified seafloor and sandy sediment). Moreover, the analysis of ROV videos and grab samples allowed the definition of the benthic assemblages (micro and megafauna) living within the vent-areas and in the nearby seafloor.
This study shows results from the first integrated analysis of the morpho-acoustic, sedimentological and biological characteristics of the northern sector of the Zannone giant depression, highlighting great differences between vent and non-vent seafloor areas. In vent areas, the seafloor is characterized by high morphological complexity and peculiar benthic habitats strongly controlled by dissolution processes, indicating “extreme” conditions due to active fluid emissions.

KEYWORDS: active venting; benthic assemblages; foraminifera; shallow-vents; Tyrrhenian Sea

1. INTRODUCTION

Extreme Marine Environments (EMEs), as hydrothermal vents and cold seeps, have been found over a wide depth range from coastal to the abyssal zones (Hovland & Judd, 1988; Dando et al., 1999; Tarasov et al., 2005; Judd & Hovland 2007). The most common technology in discovering active marine fluid emission sites is the record of backscatter values in water column, even if often underestimate small-scale venting features (Nakamura et al., 2013). Recent progress in high-resolution swath mapping techniques and near bottom geophysical surveys (deep-tow manned submersible, remotely-operated vehicle-ROV, autonomous underwater vehicle-AUV) have permitted to image seafloor morphology in great detail, increasing our knowledge on fluid related features (e.g. Tivey & Dyment, 2010).

During the last decade attention has been mainly devoted to the biological aspects related to the EMEs, mainly because the occurrence of specific biological communities can be used as indirect proxy to determine the chemical composition of the fluid emitted from the seafloor (Sibuet & Olu, 1998; Sahling et al., 2002; Levin & Mendoza, 2007; Foucher et al., 2009). Besides, these particular settings may offer unique opportunities to the discovery of new marine species (Takai et al., 2006; Danovaro et al., 2010). Moreover, micro communities inhabiting these extreme environments assume an important role both in creation and degradation of organic matter and energy, therefore they could be considered a key factor to quantify the amount of greenhouse gases affecting the oceanic chemistry (Dimitrov, 2002).

Seafloor areas affected by hydrothermal activity are mainly found in shallow marine environment (Dando et al., 1999; Melwani & Kim, 2008), but few complete studies about distribution of benthic assemblages have been published, e.g. in the Tyrrhenian Sea (Panieri et al., 2003, 2005; Panieri, 2006), Aegean Sea (Dando et al., 1995a,b), South Pacific Ocean (Kamenev et al., 1993; Pichler et al., 1999; Tarasov et al., 1999), North Atlantic ocean (Botz et al., 1999), Gulf of Mexico (Melwani & Kim, 2008) and in the shallow sub-polar region of the Mid Atlantic Ridge (Fricke et al., 1989). More studies are available for cold seep environments (Sibuet & Olu 1998; Levin, 2005). Several physical parameters, such as temperature, substrate type, number of emissions, age, concentration of gases (H_2S, CH_4 and H_2) and precipitation of heavy metals, can affect the diversity and spatial distribution of the benthic communities (Childress & Fisher, 1992; Dando et al., 1995b; Sibuet & Olu, 1998; Tarasov, 1999). At shallow water sites the primary production is based both on chemosynthetic and photosynthesis processes (Sorokin et al., 1998; Namsaraev et al., 1994; Tarasov et al., 2005) leading to the scarce occurrence of vent-obligate taxon, respect to those found in deeper sites (Dando, 2010).

In this paper the first integrated analysis of the morpho-acoustic, sedimentological and biological characteristics of the northern sector of the Zannone Giant Pockmark (described by Ingrassia et al., 2015a), located 3 km away from the eastern coast of Zannone Island (western Pontine Archipelago), is presented. This result together with direct observations through video-imaging and foraminiferal analysis on recovered samples allowed us to describe the influence of venting activity on sediment characteristics and on micro and mega benthic assemblages.

2. STUDY AREA

The study area is located about 35 km from the Latium coastline in the central Tyrrhenian Sea (Italy), on the seafloor surrounding the western Pontine Archipelago (Fig. 1). The western Pontine Archipelago has a volcanic origin and is located on a structural high where Meso-Cenozoic basement is overlain by volcanic units of Pliocene and Pleistocene age (Zitellini et al., 1984). The Archipelago was affected by extensional tectonics due to the spreading of the Tyrrhenian back arc basin (Kastens & Mascle, 1990), that favored volcanic activity and formation of a very steep, NW-SE trending continental slope and a NE-SW oriented structural high (Conti et al., 2013). Two main stages of volcanism have been recognized in the history of this group of islands. The first stage occurred between 4.2-2.9 Ma (Cadoux et al., 2005) with the emplacement of rhyolites followed by intrusion of Na-rich rhyolitic dikes in marine environment (Barberi et al., 1967; Savelli, 1983) with hydrothermal activity recorded at Ponza Island (Altaner et al., 2003). Subsequently, the volcanic activity was characterized by the production of rhyolites and trachytes between 1.6-0.9 Ma (Bellucci et al., 1997; Cadoux et al., 2005).

A narrow and steep insular shelf, with an average slope of 1°, characterizes the seafloor surrounding the western Pontine Archipelago. The insular shelf present a complex morphology due to the occurrence of several volcanic, biogenic buildups (Martorelli et al. 2003, Chiocci & Martorelli, in press) and several fluid escape features (Ingrassia et al., 2015a). Sedimentation on the insular shelf is mainly represented by carbonate sediment composed of foraminifera, coralline algae, bryozoans, ostracods, sponge spicules etc (Martorelli et al., 2011). The most important known marine biocenosis are represented by the *Posidonia oceanica* meadows, coarse sands and fine gravels under the influence of bottom currents, coastal detritic bottom, coralligenous (Martorelli et al., 2011) and presence of antipatharian corals (Ingrassia et al., 2015b).

The shelf break is found at a water depth ranging between 90-160 m and it is characterized by a complex trend in the southern sector, where erosive features (channels and canyons) carved the steep continental slope (Chiocci et al., 2003). The continental slope is mainly characterized by the occurrence of muddy sediment and sparse volcanic outcrops (Conti et al., 2013). Finally two tectonically-controlled basins (Palmarola and Ventotene), characterized by high Plio-Quaternary sedimentation rates (Zitellini et al., 1984), are located at a water depth ranging between 500-800 m.

2.1. Background

As reported by Ingrassia et al. (2015a) an active fluid emission area, named Zannone Giant Pockmark (ZGP), was discovered in 2009 (Fig. 2 a and b). The ZGP lies in water depth ranging between 110-130 m and it is formed by the coalescence of at least three major craters. Within the ZGP seafloor three main morphological sectors characterized by hummocky, irregular and regular seafloor have been defined. Moreover, about 50 small pockmarks and 28 positive features (mound and cones) were found. Across the northern sector of the ZGP, bubble streams and acoustic plumes indicate the presence of an ongoing fluid emission activity from the seafloor. Water sampling by Niskin bottles highlighted the presence of CO_2, CH_4 and C_2H_6 in fluid emissions. Moreover, seismic profiles showed the occurrence of intense deformation of Late-Quaternary lowstand deposits and Holocene highstand deposits, linked to the fluid emissions.

3. MATERIAL AND METHODS

3.1. Acoustic data

Bathymetry and backscatter data were acquired by the multibeam echosounder system (Kongsberg EM 3002D - 300 kHz), during a research cruise "*MAGIC IGAG 10/09*" carried out on November 2009 on board of the *R/V Maria Grazia* (by CNR-IGAG). Navigation data was D-GPS positioned and sound velocity parameters were collected via multiple Conductivity, Temperature and Depth (CTD) casts.

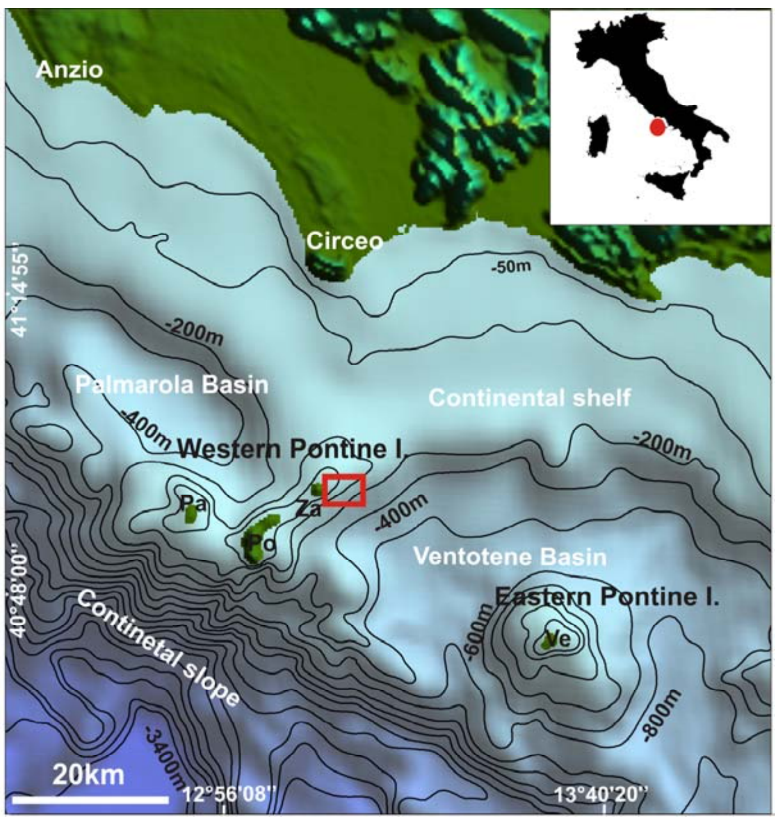


Fig.1 - Bathymetry (by GEBCO Digital Atlas) of the southern Latium continental margin. Red box indicate location of the study area. Pa=Palmarola; Po=Ponza; Za=Zannone; Ve= Ventotene.

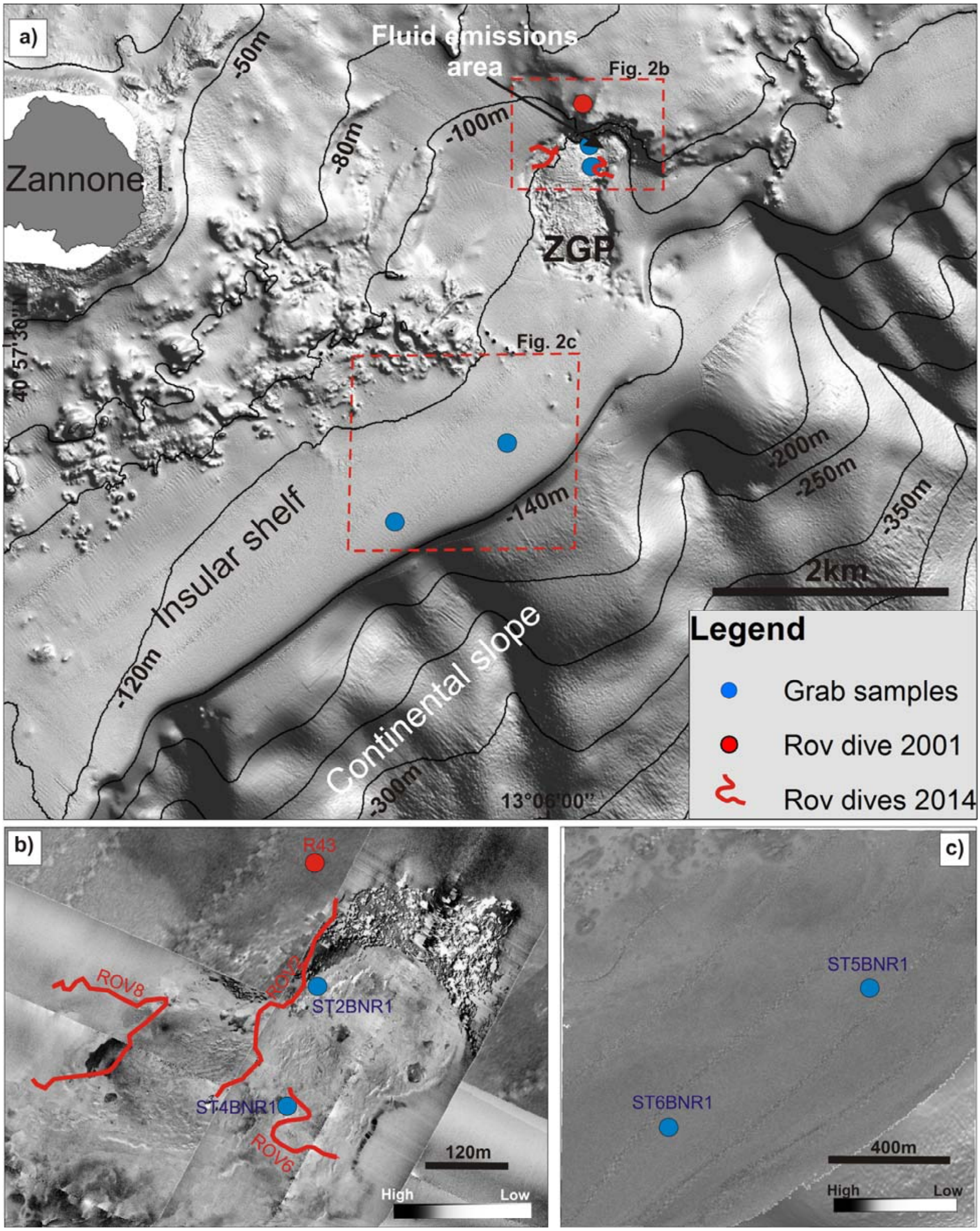


Fig. 2 - **a**) Shaded relief image (grid size of 5 m) of the seafloor surrounding the eastern part of Zannone Island, with the location of grab samples and track of video observations; **b**) Detail of the backscatter mosaics (both SSS and multibeam) obtained for the northern sector of the ZGP (Zannone Giant Pockmark); **c**) Detail of the multibeam backscatter mosaic for the non-vent seafloor areas located on the outer insular shelf.

Backscatter data were acquired by the EG&G 260 Side Scan Sonar (SSS) during a research cruise (*MAGIC IGAG 2012*) carried out on February 2012 on board *R/V Urania* (by CNR-IGAG).

Bathymetric data were post-processed using the software *CARIS HIPS & SIPS 8.1.7*. Sensor data were merged and corrected for the effect of tide, attitude sensors (roll, pitch and heave) and sound velocity variation. Acquisition and processing of multibeam data are detailed described in Casalbore et al. (2014). For this work, digital terrain models (DTMs) were produced at a resolution varying from 1 to 5 m (Fig. 2a). Visualization of DTMs was obtained using the software *Global Mapper 15*.

Backscatter data were processed through the *GeoCoder tool* using the software *Caris HIPS & SIPS 8.1.7*. This processing allowed to obtain different multibeam backscatter mosaics (pixel resolution varying from 1-0.5 m; Fig. 2b and c) and an ultra-high resolution SSS mosaic (0.2 pixel; Fig. 2b). Backscatter signatures were classified according to their textures via a qualitative description.

3.2. Ground-truth data (sediment and biological evidence)

Sediment, biological and video data (Fig. 2) were acquired during two research cruises the "*S.G.N. 2001",* carried out on July 2001, and the "*BOLLE 2014"* carried out on June 2014 aboard to the R/V Urania.

In 2001, 68 video observations were acquired by the *Hyball2* ROV system and in 2014 13 dives were performed using the *Pollux III* (GEI) ROV system. This ROV was equipped with an underwater acoustic tracking positioning system (ultra-short baseline, USBL) that provided detailed records of the seafloor tracks.

Four sediment samples (Tab. 1 and Fig. 2) were collected with a Van Veen grab during the research cruise "*BOLLE 2014".* Sample locations were identified during the video transect acquisition, in order to obtain representative biological and sedimentological information in both vent and non-vent seafloor areas. On board all the samples were visually described, photographed and preserved by freezing.

3.2.1. Foraminiferal faunal analysis

For each of the four collected grab samples (Fig. 2) a significant undistributed surface sample (0-1 cm thick) was considered for preliminary environmental characterization of the studied area by mean of living and dead benthic foraminiferal assemblages. In this respect, the sediment samples were stained and preserved in a solution of 2 g/l of Rose Bengal of ethanol as described by Lutze & Altenbach (1991) and Schönfeld et al. (2012). After 15 days, the samples were wet-sieved through a 63 μm sieve and then dried at 60°C. In each sample Rose Bengal stained foraminifers with well-preserved tests were counted, hand-picked and identified using a binocular microscope. The classification of the species has been made on the base of recent Mediterranean and extra-Mediterranean foraminiferal literature data (Jorissen, 1987, 1988; Cimerman & Langer, 1991; Sgarrella & Moncharmont-Zei, 1993; Sen Gupta et al., 2009; Frezza et al., 2010; Milker et al., 2012). The species diversity was quantified using the á-Fisher index (Fisher et al., 1943) calculated using the PAST (PAlaeontological STatistics) version 1.38 data analysis package (Hammer et al., 2001).

4. RESULTS

Integration of high-resolution bathymetry and backscatter data allowed to recognize the main characteristics of the seafloor around the sampled stations (grabs) and of the nearby seafloor areas (Fig. 3). Moreover, the ground-truth data (biological and sedimentological evidence) allowed us to determine the main differences between vent and non-vent areas.

4.1. Vent seafloor areas

Herein a geophysical and sedimentological/biological description of the two grab samples (ST2BNR1 and ST4BNR1, Fig. 2b), located in the vent area, is given.

ST2BNR1 was recovered at 137 m water depth, within an elongated depression located in the northern sector of the ZGP (Fig. 2b and Fig. 3a). This depression is 217 m long, 65 m wide and has an average slope of 10°. Moderate to high intensity values and several acoustic shadows (Fig. 2b and Fig. 3a) characterize the seafloor surrounding the sampled station, as evidenced by the backscatter data. This grab recovered sandy sediment and pieces of hard-lithified sediment (Fig. 3a) with a strong sulfur smell.

ROV2 shows different types of seafloor both in correspondence and around the sampled station (Fig. 2a and b). To the south, the seabed is floored by sandy sediment, sometimes covered by bacterial mats, characterized by the occurrence of several small pockmarks with centimetric size (Fig. 4a). One specimen of sea urchin, belonging to the family Cidaridae (Fig. 4b), represents the benthic megafauna. The second type of seafloor is characterized by the presence of larger depressions (Fig. 4c), with occurrence of small positive cones. Only few specimens of fishes, jumping on the seafloor, were observed. In the north-eastern sector the seafloor is characterized by occurrence of coarse sediment (Fig. 4d). No direct evidences of fluid emissions were detected via video observations (e.g. bubble streams) on the seafloor surrounding the ST2BNR1 station. However water column backscatter data show the occurrence of a 40-70 m high, well defined acoustic flare (Ingrassia et al., 2015a).

X-ray diffraction revealed as in this station the inorganic fraction is mainly constituted of quartz, glass, rare feldspars, native sulfur and barite. No living microfauna

Code	Latitude	Longitude	Depth (m)	Location
ST2BNR1	40° 58' 21" N	13° 06' 06" E	137	Vent-seafloor
ST4BNR1	40° 58' 15" N	13° 06' 05" E	133	Vent-seafloor
ST5BNR1	40° 57' 13" N	13° 05' 43" E	126	Non-vent seafloor
ST6BNR1	40° 56' 56" N	13° 05' 12" E	127	Non-vent seafloor

Tab. 1 - List of the grab samples considered in this study (geographic coordinates).

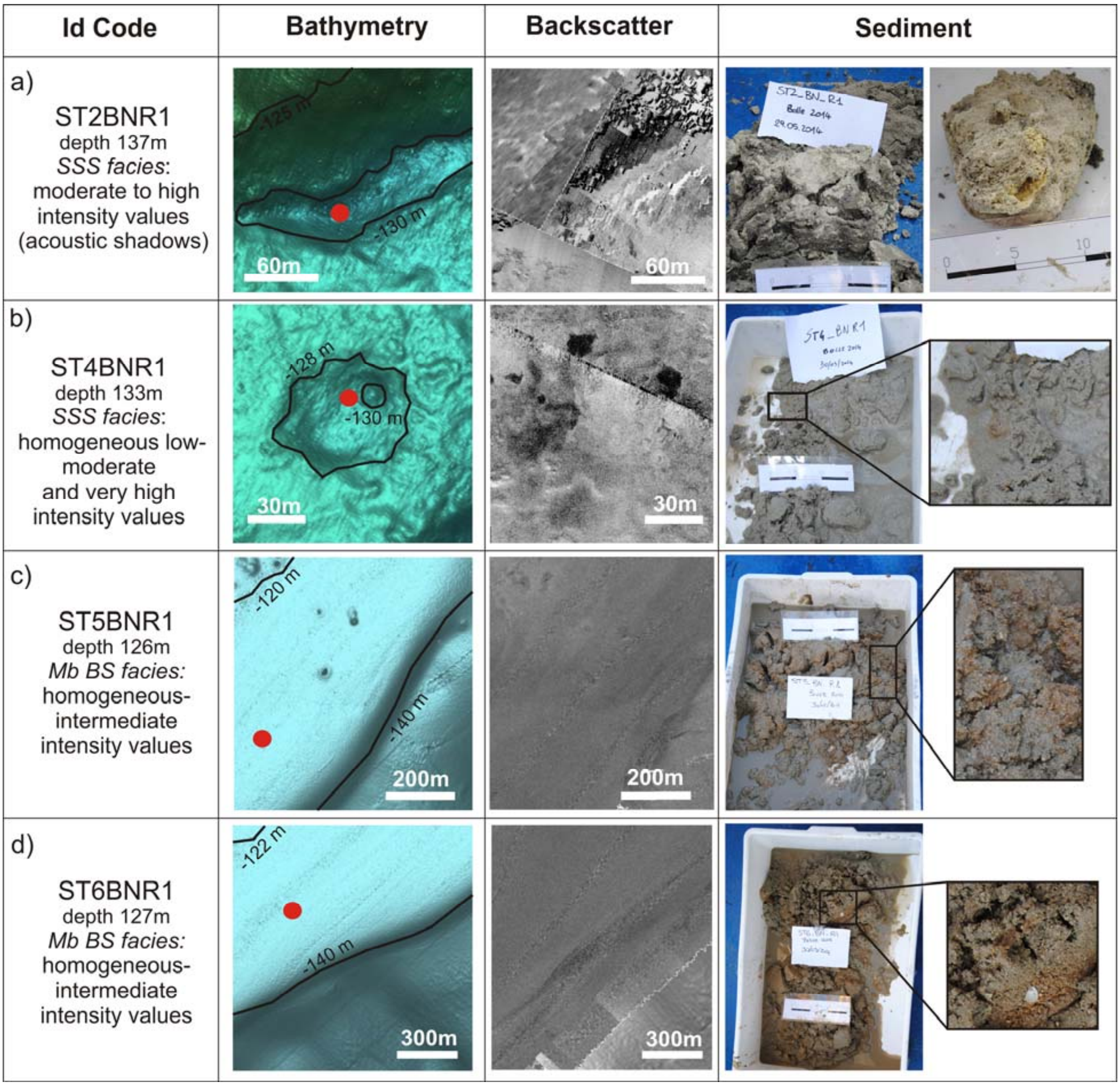


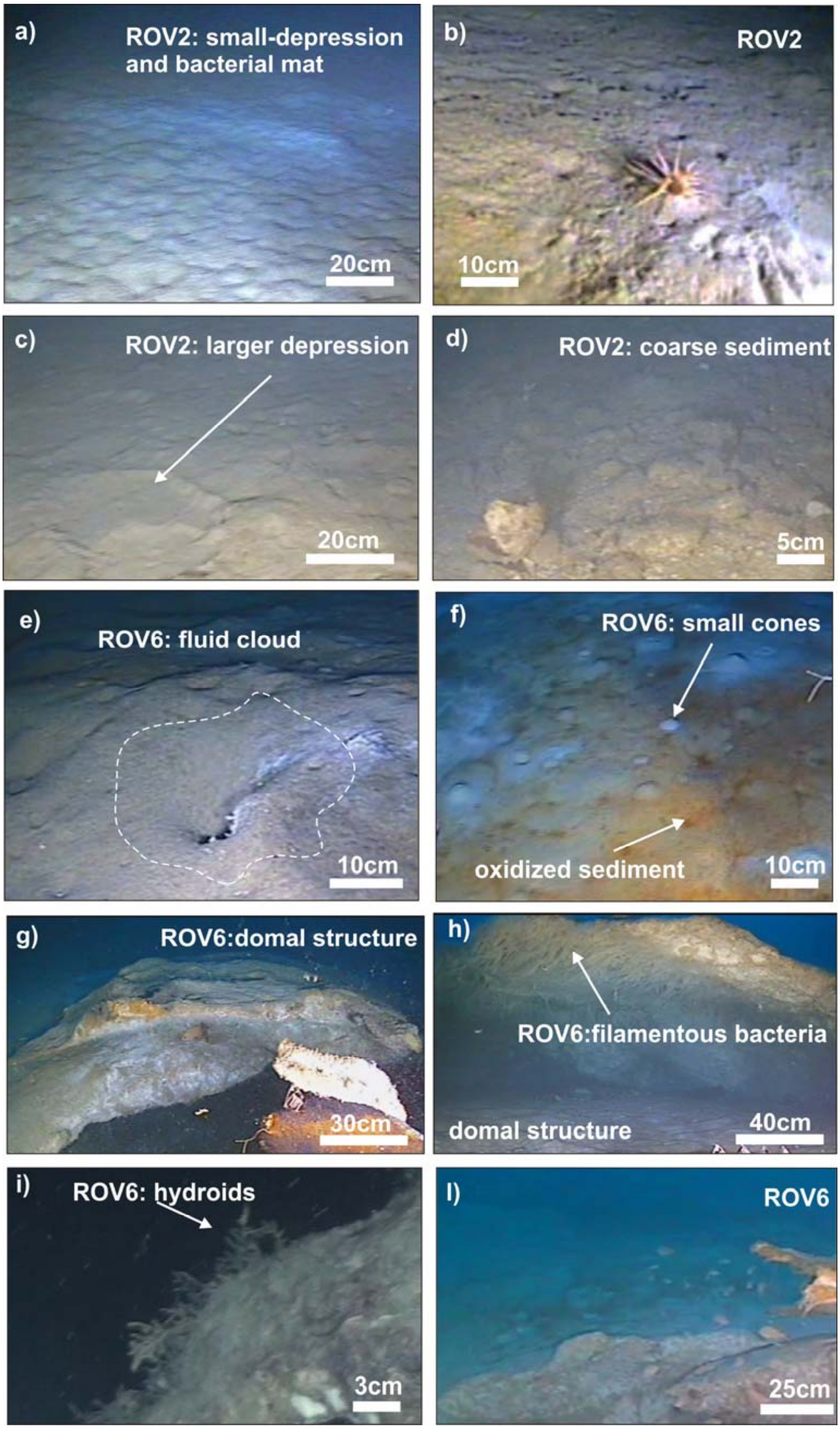
Fig. 3 - Summary of the acoustic facies (bathymetry and backscatter) and sediment characteristics for each sampled stations.

were observed at this station.

ST4BNR1 was recovered at 133 m water depth, within a complex pockmark (Fig. 2a, b) composed of two small depressions characterized by a total length of 78 m, width of 65 m and average slope of 5°. Within the complex pockmark the backscattered signal is homogeneous and varies between low and moderate intensities (Fig. 3b); in contrast the seafloor around the rim of the pockmark is characterized by very high backscattering strength (Fig. 3b). The grab recovered well sorted sandy sediment with traces of oxidation (Fig. 3b).

ROV6 shows different types of seafloor both in correspondence and around the sampled station (Fig. 2a and b). Along the north-eastern flank of the complex pockmark (close to the grab station) at least six active emissions, associated to bubbles streams or cloud of fluids (Fig. 4e), were observed. No continuous fluid emissions are observed on the pockmark floor that is composed of oxidized sandy sediment, characterized by centimetric (5-10 cm) circular depressions and small cones, with occurrence of widespread bacterial mats (Fig. 4f). No megafauna was observed both nearby to the active emissions points and on the pockmark floor.

Lithified sediments, forming domal structures (Fig. 4 g, h and i), were observed in correspondence of the rim of the pockmark. In some cases, these structures are characterized by presence of flange-like features, where filamentous bacteria (Fig. 4h) and hydroids (Fig. 4 i) are present. Moreover, fish schools of *Anthias anthias* were observed swimming in the proximity of the domal


a)
ROV2: small-depression and bacterial mat
20cm
b)
ROV2
10cm
c)
ROV2: larger depression
20cm
d)
ROV2: coarse sediment
5cm
e)
ROV6: fluid cloud
10cm
f)
ROV6: small cones
oxidized sediment
10cm
g)
ROV6:domal structure
30cm
h)
ROV6:filamentous bacteria
domal structure
40cm
i)
ROV6: hydroids
3cm
l)
ROV6
25cm

structures (Fig. 4 l).

X-ray diffraction revealed as in this station the inorganic fraction is dominant. It is mainly constituted of quartz, glass and rare feldspars. Instead, only siliceous spicules and very rare living agglutinated foraminifers represent the organic fraction. The dominant morphotypes are trochoid and elongated species mainly attributed to species pertaining to *Trochammina*, *Reophax* and *Lagenammina* genera. The specimens show very small sizes with shell diameters <30 ìm, exclusively constituted of quartz particles. No porcellanaceous and hyaline tests were recorded and the dead assemblage was completely absent, as a result, faunal density and species diversity are extremely low.

4.2. Non-vent seafloor areas

Two grab samples were collected in non-vents seafloor areas (Fig. 2a and c). These samples were analyzed in order to obtain a comprehensive background of the type of habitats present in the study area.

ST5BNR1 and **ST6BNR1** samples were recovered on the outer shelf of Zannone Island, at about 2.5 km from the ZGP, in a water depth of about 126 m (Fig. 2a and c). The sampled stations are placed on a flat seafloor (Fig. 2a and Fig. 3c, d) characterized by average slope value of 0.7°. Backscatter intensity is rather homogeneous with intermediate values (Fig. 3c and d). Both the samples recovered sediment composed of sandy sediment with traces of oxidization and bivalve shells (Fig. 3c and d).

No video observations are available in the correspondence of ST5BNR1 and ST6BNR1 stations.

In both samples inorganic fraction is scarce and mainly constituted of quartz, calcite, and volcanic clasts. The organic fraction is very abundant; it is represented by sponge spicules, ostracods, pteropodes, briozoa, mollusk fragments and foraminifers. Among these components, benthic foraminifers dominate the sediment residue. Foraminiferal tests are generally well-preserved although the dead assemblage is more abundant than the living one. A total of 59 species were recognized. The species diversity performed on the total assemblage is high with á-Fisher index value of 21.02. The total assemblage is characterized by *Asterigerinata planorbis, Cassidulina* spp.*, Elphidium* spp., *Lobatula lobatula*, *Rosalina* spp., *Uvigerina* spp. and frequent miliolids (*Miliolinela* spp. *Biloculinella* spp., *Pseudotriloculina* spp.). In detail, the living assemblage is characterized by *Miliolinella subrotunda, Biloculinella labiata, Biloculinella depressa, Quinqueloculina* spp., *Nubecularia lucifera, Uvigerina mediterranea, Hoeglundina elegans, Cassidulina* spp., *Spiroloculina excavata.*

ROV dives R43, ROV2 and ROV8, showing the main characteristics of the non-venting areas, were acquired on the seafloor located close to the northern escarpment and along the north-western rim of the ZGP (Fig. 2a and b), in a water depth ranging between 84–120 m.

R43 displays occurrence of widespread biodetritic sandy sediment with a significant amount of coralline algae, e.g. pralines (Fig. 5a and b), whereas no mud sediment was observed. The benthic megafauna is represented by sea urchins belonging to the families Cidaridae and Echinidae (Fig. 5a and b). ROV2 shows the occurrence of several rocky outcrops interspersed with sandy sediment along the north escarpment of the ZGP (Fig. 5c) with holothurians, sea stars (Fig. 5d), sea urchins (Cidaridae) and school of *A. anthias.* Moreover, the video images reveal traces of anthropogenic impacts as fishing activities (Fig. 5e) and presence of a lost cable (Fig. 5f). Finally, ROV 8, located 200 m NW from the ZGP (Fig. 2a and b), shows occurrence of sandy sediment with a large number of sea urchins belonging to the family Cidaridae.

5. DISCUSSIONS

5.1. Non-vent *vs* vent seafloor areas

The analysis of morphological and backscatter data as well as sedimentological and biological information derived by ground-truth data highlight significant differences between vent and non-vent areas. Non-vent areas are characterized by a smooth seafloor, with low backscatter intensity due to sandy sediment without occurrence of fluid escape features. This is the normal seafloor environment for the outer shelf of the Pontine seafloor, where lowstand deposits are present, as described in Martorelli et al. (2011) and Chiocci & Martorelli (in press). This environment hosts different benthic fauna (sea urchins -Cidaridae and Echinidae-, holothurians, coralline algae, etc.) and school of *A. anthias*. Here, the foraminiferal assemblages (dead and living) appear strongly diversified with high faunal density, suggesting a stable environment. On the base of the ecological characteristics of species, the assemblages can be related to mesothrophic-oligothrophic and well oxygenated bottom conditions. This is confirmed by the dominance of epifaunal (miliolids, *A. mamilla, L. lobatula*) and shallow infaunal species (*Cassidulina* spp., *Uvigerina* spp.) that usually live in environments with supply of fresh organic matter continually provide by currents (Langer, 1993; Hayward et al., 2013; Nardelli et al., 2010; De Rijk et al., 2000). Similar assemblages are common and widespread on the seafloor of the whole western Pontine Archipelago, as shown by Frezza et al. (2010).

On the contrary within the vent-areas, the seafloor is characterized by a complex morphology, encompass-

Fig. 4 - Selected ROV-images taken in correspondence of the sampled vent-seafloor areas. **a)** Bacterial mat on sandy sediment with occurrence of several small depressions**; b**) sea urchin (Cidaridae) on sandy sediment; **c)** sandy sediment with presence of large depression; **d)** coarse sediment; **e)** cloud-fluid emission from the sandy seafloor; **f)** oxidized sandy sediment with occurrence of widespread bacterial mats, several centimetric circular depressions and small cones; **g)** domal structure with visible flange like feature; **h)** domal structure with filamentous bacteria; **i)** specimens of hydroids observed on the domal structure; **l)** school of *A. anthias* swimming in the proximity of the domal structure.

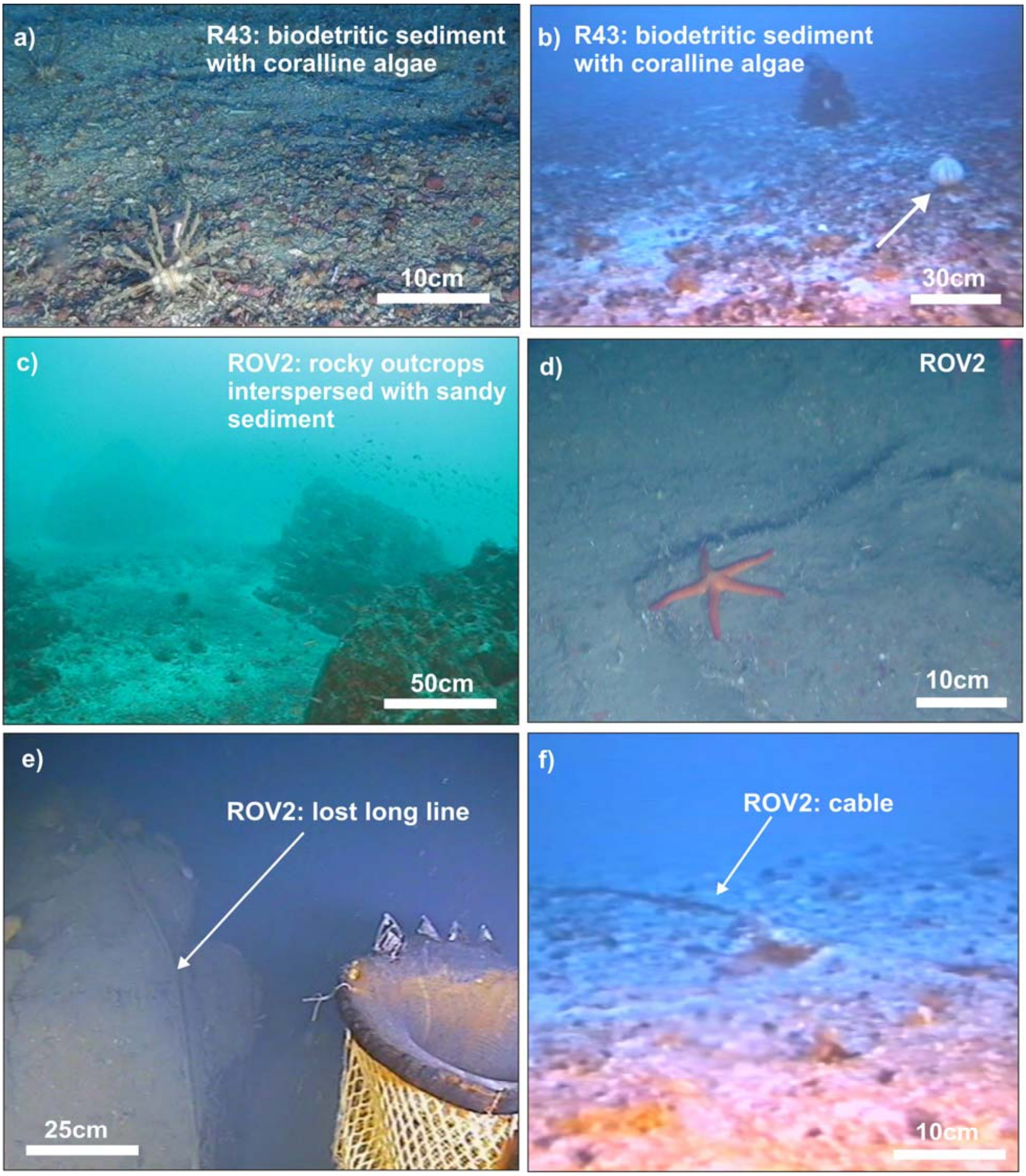


Fig. 5 - Selected seafloor ROV-images taken in correspondence of the sampled non-vent seafloor areas. **a)** Coralline algae and sea urchin (Cidaridae) on biodetritic sediment; **b)** biodetritic sediment with occurrence of a specimen of sea urchin belonging to the family Echinida (white narrow); **c)** rocky outcrops interspersed with sandy sediment **d)** specimen of sea star on hard sediment; **e)** lost long-line gear on rocky outcrop; **f)** lost cable on biodetritic sediment.

ing pockmarks of various size, dome and cones structures, and different types of substrata (lithified sediment, crusts, sandy sediment, etc.). The detection of lithified sediment inside the ZGP and not on the nearby seafloor (non-vent areas) strengthens the interpretation of these features as vent-related crusts. According to Tarasov et al. (2005), Canet et al. (2006) and Griffith & Paytan (2012), presence of barite and native sulfur, white bacterial mats and several centimetric small pockmarks, provides further evidence of relevant continuous fluid emissions in this area. Moreover, as indicated in section 4.1, some of these structures appear characterized by the development of flange-like features, similar in aspect to those commonly observed along the lateral side of vertical and large sulphide chimneys (Kerr, 1997), formed by hydrothermal circulation in deep water settings (Tivey, 2007). As no flange-like features have been reported in shallow water environment, their finding within the ZGP (at about -130 m) updates the knowledge on environment condition leading the formation of these peculiar structures.

As a whole, the occurrence of different seafloor types seem reflect a high complexity and variability of both seafloor morphology and sediment characteristics, that in many cases change at metric scale (e.g. transition from dome structures to pockmarking sandy sediment).

The main benthic assemblages found in the vent-areas are represented by widespread bacterial mats, sea urchins belonging to the family Cidaridae, hydroids and presence of schools of *A. anthias* (Fig. 4g, h, i and l). The broad presence of bacterial mats observed only within the floor of the ZGP, close or directly above vent emissions, indicate that occurrence of fluid emissions in shallow-water environment plays a direct control on bacterial mats distribution; this evidence is consistent with observations obtained by Levin et al. (2000) and Tarasov et al. (2005). No obligate megafaunal assemblages were observed close to the vent emissions and in their proximity, actually megafauna is completely absent on vent emissions. After all, one of the common factor limiting the colonization of benthic megafauna is represented by the concentration of hydrogen sulphide (Vismann, 1991). The appreciable sulfur smell detected in the ST2BNR1 grab sample suggests the occurrence of fluids moderately enriched in H_2S, which could be toxic for the organisms. In more distal areas from venting zones, the distribution of the megafauna appears rather similar to that observed on the non-vent seafloor; this result is in agreement with other reference studies (i.e. Dando et al 1995b; Thiermann et al., 1997; Morri et al., 1999; Tarasov et al., 1999).

A different situation arise from the analyses of foraminifera that indicate major differences between vent and non-vent areas. In fact, the typical microfaunal assemblage of vent-areas is represented by oligotypic foraminifera constituted exclusively of agglutinant species. This assemblage is very different, for structure and composition, from the associations recorded at the same depth (around 126 m) in areas located outside the ZGP, which are not influenced by fluid emissions. In the vent areas the abrupt decrease of faunal density and species diversity associated to the decrease in shell size of the living specimens, indicates a stressed environment unfavorable to benthic life. The exclusive presence of agglutinant species, in fact, suggests chemical and physical conditions not suitable for carbonate shell formation and/or preservation, both hyaline and porcelanaceous tests.

As the fluids emitted from the seafloor, located in the northern sector of the ZGP, are characterized by enrichment in CO_2 (Ingrassia et al., 2015a), acidification of water might explain the lack of carbonate tests in the foraminiferal assemblages (Uthicke et al., 2013). Moreover acidification might be enhanced by local enrichment in CO_2 produced by bacterial activity through anaerobic methane oxidation reaction (Sen Gupta et al., 2009; Dando, 2010; Wankel et al., 2012). The lack of dead foraminiferal assemblages (both benthic and planktonic) suggests the occurrence of strong dissolution processes, confirmed by the sediment composition (only quartz) from which the organisms take and agglutinate their tests by mean of organic cement (Cimerman & Langer, 1991). Agglutinant species, above all *Trochammina* spp. that are the most abundant, seem to be the most resistant to the ZGP stressed environment showing an opportunistic behavior. This hypothesis is supported by the record of similar assemblages found in other vent-seafloor areas located in the Tyrrhenian Sea (Aeolian Arc), although they appear more abundant and diversified (Panieri et al., 2003, 2005; Panieri, 2006) than those analyzed in this study.

6. CONCLUSIONS

In the present study the morpho-acoustic, sedimentological and biological characteristics of the northern sector of the ZGP have been analyzed. Results from this study highlight great differences among the morphology, sedimentology and microfauna characters between vent and non-vent seafloor areas. On the contrary, the distribution of the megafaunal assemblages highlights a different situation. In fact, the benthic megafauna observed in vent-seafloor areas seems to represent a subgroup of the typical environment condition, while megafaunal assemblages are completely absent in areas affected by active venting. In vent-areas, the benthic foraminiferal assemblages highlight the complete lack of both hyaline and porcelanaceous tests suggesting the presence of strong dissolution processes. For all these aspects the shallow water fluid emissions site (ZGP) could be considered as an extreme environment and a natural laboratory for studying the effects of CO_2 enriched fluids on benthic communities, with particular interest for the organisms that produce calcareous skeletons.

ACKNOWLEDGEMENTS

This research was performed in the framework of the Flagship Project RITMARE (SP4-WP2-A1). Crews of R/V *Urania* and *Maria Grazia* are gratefully acknowledged for their precious work. We would also thank the reviewers, Daniele Casalbore and Romana Melis, and the Editor Andrea Sposato for their valuable comments and suggestions that greatly improved the quality of the manuscript.

REFERENCES

Altaner S.P., Ylagan R.F., Savin S.M., Aronson J.L., Belkin H.E., Pozzuoli A. (2003) - Geothermometry, geochronology, and mass transfer associated with hydrothermal alteration of a rhyolitic hyaloclastite from Ponza Island, Italy. Geochimica et Cosmochimica Acta, 67(2), 275-288.

Barberi S., Borsi S., Ferrara G., Innocenti F. (1967) - Contributo alla conoscenza vulcanologica e magmatologica delle isole dell'Arcipelago Pontino. Mem. Soc. Geol. It., 6, 581-606.

Bellucci. F., Grimaldi M., Lirer L., Rapolla A. (1997) - Structure and geological evolution of the Island of Ponza, Italy: inferences from geological and gravimetric data. Journal of Volcanology and Geothermal Research, 79, 87-96.

Botz R., Winckler G., Bayer R., Schmitt M., Schmidt M., Garbe-Schoenberg D., Stoffers P., Kristjansson J.K. (1999) - Origin of trace gases in submarine hydrothermal vents of the Kolbeinsey Ridge, north Iceland. Earth and Planetary Science Letters, 171, 83-93.

Cadoux A., Pinti D.L., Aznar C., Chiesa S., Gillot P.Y. (2005) - New chronological and geochemical constraints on the genesis and geological evolution of Ponza and Palmarola Volcanic Islands (Tyrrhenian Sea, Italy). Lithos, 81, 121-151.

Canet C., Prol-Ledesma R.M., Escobar-Briones E., Mortera-Gutiérrez C., Lozano-Santa Cruz R., Linares C., Cienfuegos E., Morales-Puente P. (2006) - Mineralogical and geochemical characterization of hydrocarbon seep sediments from the Gulf of Mexico. Marine and Petroleum Geology, 23, 605-619.

Casalbore D., Bosman A., Martorelli E., Sposato A., Chiocci F.L. (2014) - Mass wasting features on the submarine flanks of Ventotene volcanic edifice (Tyrrhenian Sea, Italy) In: Submarine Mass Movements and Their Consequences, (Eds Krastel et al) 6th International Symposium, Advances in Natural and Technological Hazards Research, 37, 285-293. DOI 101007/978-3-319-00972-8 25

Childress J.J., Fisher, C.R. (1992) - The biology of hydrothermal vent animals: physiology, biochemistry and autotrophic symbioses. Oceanography and Marine Biology - An Annual Review, 30, 337-441.

Chiocci F.L., Martorelli E., Bosman A. (2003) - Cannibalization of a Continental Margin By Regional Scale Mass Wasting: An Example From the Central Tyrrhenian Sea. Submarine Mass Movements and Their Consequences. Advances in Natural and Technological Hazards Research, 19, 409-416.

Chiocci F.L., Martorelli E. (in press) - Note illustrative e Carta Geologica in scala 1:50.000 delle aree marine del Foglio 413 Borgo Grappa. ISPRA. Carta Geologica d'Italia.

Cimerman F., Langer M.R. (1991) - Mediterranean Foraminifera. Academia Scientiarum et Artium Slovenica, Ljubljana, 30, 1-118.

Conti M.A., Girasoli D.E., Frezza V., Conte A.M., Martorelli E., Matteucci R., Chiocci F.L. (2013) - Repeated events of hardground formation and colonisation by endo-epilithozoans on the sediment-starved Pontine continental slope (Tyrrhenian Sea, Italy). Marine Geology, 336, 184-197.

Dando P.R., Hughes J.A., Leahy Y., Niven S.J., Taylor L.J., Smith C. (1995a) - Gas venting rates from submarine hydrothermal areas around the island of Milos, Hellenic Volcanic Arc. Continental Shelf Research, 15, 913-929.

Dando P.R., Hughes J.A., Thiermann F. (1995b) - Preliminary observations on biological communities at shallow hydrothermal vents in the Aegean Sea. In: Parson, L.M., Walker, C.L., Dixon, D.R. (Eds.), Hydrothermal Vents and Processes, Geological Society Special Publication, 303-317.

Dando P.R., Stüben D., Varnavas S.P. (1999) - Hydrothermalism in the Mediterranean sea. Progress in Oceanography, 44(1), 333-367.

Dando P.R. (2010) - Biological communities at marine shallow water vent and seep sites. In S. Kiel, ed. Springer, the Netherlands. The vent and seep biota: topics in geobiology. Vol. 33, 333-378.

Danovaro R., Company J.B., Corinaldesi C., D'Onghia G., Galil B., Gambi C., Gooday A.J., Lampadariou N., Luna G.M., Luna M.G., Morigi C., Olu K., Polymenakou P., Ramirez-Llodra E.R., Sabbatini A., Sardà F., Sibuet M., Tselepides, A. (2010) - Deep-sea biodiversity in the Mediterranean Sea: The known, the unknown, and the unknowable. PloS one, 5(8), 1-25.

De Rijk S., Jorissen F.J., Rohling E.J., Troelstra S.R. (2000) - Organic flux control on bathymetric zonation of Mediterranean benthic foraminifera. Marine Micropaleontology, 40, 151-166.

Dimitrov L.I. (2002) - Mud volcanoes-the most important pathway for degassing deeply buried sediments. Earth-Science Reviews, 59(1), 49-76.

Fisher R.A., Corbet A.S., Williams C.B. (1943) - The Relation Between the Number of Species and the Number of Individuals in a Random Sample of an Animal Population. Journal of Animal Ecology, 12 (1), 42-58.

Foucher J.P., Westbrook G., Boetius A., Ceramicola S., Dupré S., Mascle J., Mienert J., Pfannkuche O., Pierre C., Praeg, D. (2009) - Structure and drivers of cold seep ecosystems. Oceanography, 22(1), 92-109.

Frezza V., Pignatti J.S., Matteucci R. (2010) - Benthic foraminiferal biofacies in temperate carbonate sediment in the western Pontine Archipelago (Tyrrhenian Sea, Italy). Journal of Foraminiferal Research, 40 (4), 313-326.

Fricke H., Giere O., Stetter K., Alfredsson G.A., Kristjansson J.K., Stoffers P., Svavarsson J. (1989) - Hydrothermal vent communities at the shallow subpolar Mid-Atlantic Ridge. Marine Biology, 102, 425-429.

Griffith E.M., Paytan A. (2012) - Barite in the ocean-occurrence, geochemistry and palaeoceanographic applications. Sedimentology, 59(6), 1817 -1835.

Hammer Ø., Harper D.A.T., Ryan P.D. (2001) - PAST: Paleontological Statis-tics Software Package for Education and Data Analysis. Palaeontol Electron, 4, 1-9.

Hayward B.W., Sabaa A.T., Grenfell H.R., Neil H., Bostock H. (2013) - Ecological distribution of recent deep-water foraminifera around New Zealand. Journal of Foraminiferal Research, 43 (4), 415-442.

Hovland M., Judd A.G. (1988) - Seabed pockmarks and seepages: impact on geology, biology and the marine environment. Londonm Graham & Trottman Ltd, pp. 293.

Ingrassia M., Martorelli E., Bosman A., Macelloni L., Sposato A., Chiocci F.L. (2015a) - The Zannone Giant Pockmark: first evidence of a giant complex seeping structure in shallow-water, central Mediterranean Sea, Italy. Marine Geology, 363, 28-51.

Ingrassia M., Macelloni L., Bosman A., Chiocci F.L., Cerrano C., Martorelli E. (2015b) - Black coral (Anthozoa, Antipatharia) forest near the Western Pontine Islands (Tyrrhenian Sea). Marine Biodiversity. Published online 24 Feb, 2015. DOI: 10.1007/s12526-015-0315-y.

Jorissen F.J. (1987) - The distribution of benthic foraminifera in the Adriatic Sea. Marine Micropaleontology, 12, 21-48.

Jorissen F.J. (1988) - Benthic foraminifera from the Adriatic Sea: principles of phenotypic variation. Utrecht Micropaleonto-logical Bulletin, 37, 1-174.

Judd A.G., Hovland M., (2007) - Seabed Fluid Flow: Impact on Geology, Biology and the Marine Environment. Cambridge University Press, Cambridge, UK, pp. 475.

Kamenev G.M., Fedeev V.I., Selin N.I., Tarasov V.G., Malakhov V.V. (1993) - Composition and distribution of macroand meiobenthos around sublittoral hydrothermal vents in the Bay of Plenty, New Zealand. New Zealand Journal of Marine and Freshwater Research, 27, 407-418.

Kastens K.A., Mascle J. (1990) - The geological evolution of the Tyrrhenian Sea: an introduction to the scientific results of ODP Leg 107. In Proceedings of the Ocean Drilling Program, Scientific Results (Vol. 107, 3-26). College Station, TX (Ocean Drilling Program).

Kerr R.C. (1997) - Heat transfer and hydrothermal fluid flow at flanges on large seafloor sulphide structures. Earth and planetary science letters, 152(1), 93-99.

Langer M. (1993) - Epiphytic Foraminifera. Marine Micropaleontology, 20, 235-265.

Levin L.A., James D.W., Martin C.M., Rathburn A.E., Harris L.H., Michener R.H. (2000) - Do methane seeps support distinct macrofaunal assemblages? Observations on community structure and nutrition from the northern California slope and shelf. Marine Ecology Progress Series, 208, 21-39.

Levin L.A. (2005) - Ecology of cold seep sediments: interactions of fauna with flow, chemistry, and microbes. Oceanography and Marine Biology Annual Review, 43, 1-46.

Levin L.A., Mendoza G.F. (2007) - Community structure and nutrition of deep methane-seep macrobenthos from the North Pacific (Aleutian) Margin and the Gulf of Mexico (Florida Escarpment). Marine Ecology, 28(1), 131-151.

Lutze G., Altenbach A. (1991) - Technik and Signifikanz der Lebendfärbung benthischer Foraminiferen mit Bengalrot. Geologisches Jahrbuch A128, 251-265.

Martorelli E., Chiocci F.L., Conte A.M., Bellino M., Bosman A., (2003) - Affioramenti vulcanici sottomarini dell'Arcipelago Pontino occidentale: caratteri petrologici e morfoacustici. Atti del 4° Forum Italiano di Scienze della Terra - FIST GEOITALIA 2003 - Bellaria, 16-18/9/2003.

Martorelli E., D'Angelo S., Fiorentino A., Chiocci F.L. (2011) - Non-tropical carbonate shelf sedimentation. The Archipelago Pontino (central Italy) case history, in: P.T. Harris, E.D. Baker (Eds.). Seafloor Geomorphology as Benthic Habitats, Elsevier, Amsterdam (Chapter 31), 449-454.

Melwani A.R., Kim S.L. (2008) - Benthic infaunal distributions in shallow hydrothermal vent sediments. Acta Oecologica, 33(2), 162-175.

Milker Y., & Schmiedl G. (2012) - A taxonomic guide to modern benthic shelf foraminifera of the western Mediterranean Sea. Palaeontologia Electronica,15 (2), 1-134.

Morri C., Bianchi C.N., Cocito S., Peirano A., De Biasi A.M., Aliani S., Pansini M., Boyer M., Ferdeghini F., Pestarino M., Dando P. (1999) - Biodiversity of marine sessile epifauna at an Aegean island subject to hydrothermal activity: Milos, eastern Mediterranean Sea. Marine Biology, 135, 729-739.

Nakamura K., Toki T., Mochizuki N., Asada M., Ishibashi J.I., Nogi Y., Yoshikawa S., Miyazaki J.I., Okino, K. (2013) - Discovery of a new hydrothermal vent based on an underwater, high-resolution geophysical survey. Deep Sea Research Part I: Oceanographic Research Papers, 74, 1-10.

Namsaraev B.B., Bonch-Osmolovskaya E.A., Kachalkin V.I., Miller Yu.M., Propp L.N., Tarasov V.G. (1994) - Microbiological processes of circulation of carbon in shallow-water vents of the southwest Pacific. Microbiology, 63, 100-111.

Nardelli M.P., Jorissen F.J., Pusceddu A., Morigi C., Dell'Anno A., Danovaro R., De Stigter H.C., Negri A. (2010) - Living benthic foraminiferal assemblages along a latitudinal transect at 1000m depth off the Portuguese margin. Micropaleontology, 56 (3-4), 323-344.

Panieri G., Gamberi F., Marani M., Barbieri R. (2005) - Benthic foraminifera from a recent, shallow-water hydrothermal environment in the Aeolian Arc (Tyrrhenian Sea). Marine Geology 218, 207-229.

Panieri G., Barbieri R., Gamberi F., Marani M. (2003) - Hydrothermal vents in the Aeolian Arc: Effects on benthic foraminifera. In EGS-AGU-EUG Joint Assembly 6-11 April, Nice (France).

Panieri G. (2006) - The effect of shallow marine hydrothermal vent activity on benthic foraminifera (Aeolian Arc, Tyrrhenian Sea). The Journal of Foraminiferal Research, 36(1), 3-14.

Pichler T., Veizer J., Hall G. E. (1999) - The chemical composition of shallow-water hydrothermal fluids in Tutum Bay, Ambitle Island, Papua New Guinea and their effect on ambient seawater. Marine Chemistry, 64(3), 229-252.

Sahling H., Rickert D., Lee R.W., Linke P., Suess E. (2002) - Macrofaunal community structure and sulfide flux at gas hydrate deposits from the Cascadia convergent margin, NE Pacific. Marine Ecology Progress Series, 231, 121-138.

Savelli C. (1983) - Età K/Ar delle principali manifestazioni riolitiche dell'Isola di Ponza. Rendiconti della Società Geologica Italiana, 6, 39-42.
Schönfeld J., Alve E., Geslin E., Jorissen F., Korsun S., Spezzaferri S. and Members Of The Fobimo Group (2012) - The FOBIMO (FOraminiferal BIo-MOnitoring) initiative towards a standardised protocol for soft-bottom benthic foraminiferal monitoring studies. Marine Micropaleontology, 94-95, 1 -13.
Sen Gupta B.K., Lobegeier M.K. and Smith L.E. (2009) - Foraminiferal Communities of Bathyal Hydrocarbon Seeps, Northern Gulf of Mexico: A Taxonomic, Ecologic, and Geologic Study. Louisiana State University Coastal Marine Institute Louisiana, pp. 178.
Sgarrella F., Moncharmont-Zei M. (1993) - Benthic Foraminifera of the Gulf of Naples (Italy): systematics and autoecology. Bollettino della Società Paleontologica Italiana, 32(2), 145-264.
Sibuet M., Olu K. (1998) - Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. Deep Sea Research Part II: Topical Studies in Oceanography, 45(1), 517-567.
Sorokin Yu.I., Sorokin P.Yu., Zakuskina O.Yu. (1998) - Microplankton and its functional activity in zones of shallow hydrotherms in the western Pacific. J. Plankton Research, 20, 1015-1031.
Takai K., Nakagawa S., Reysenbach A.L., Hoek J. (2006) - Microbial ecology of midocean ridges and back-arc basins. In: Christie, D.M., Fisher, C.R., Lee, S.-M., Givens, S. (Eds.), Back-Arc Spreading Systems-Geological, Biological, Chemical, and Physical Interactions. Geophysical Monograph Series, 166. American Geophysical Union, Washington, DC, 185-213
Tarasov V.G., Gebruk A.V., Shulkin V.M., Kamenev G.M., Fadeev V.I., Kosmynin V.N., Malakhov V.V., Starynin D.A., Obzhirov A.I. (1999) - Effect of shallow-water hydrothermal venting on the biota of Matupi Harbour (Rabaul Caldera, New Britain Island, Papua New Guinea). Continental Shelf Research, 19, 79-116.
Tarasov V.G., Gebruk A.V., Mironov A.N., Moskalev L. I. (2005) - Deep-sea and shallow-water hydrothermal vent communities: two different phenomena? Chemical Geology, 224(1), 5-39.
Thiermann F., Akoumianaki I., Hughes J.A., Giere O. (1997) - Benthic fauna of a shallow-water gaseohydrothermal vent area in the Aegean Sea (Greece). Marine Biology, 128, 149-159.
Tivey M.K. (2007) - Generation of seafloor hydrothermal vent fluids and associated mineral deposits. Oceanography, 20(1), 50-65.
Tivey M.A., Dyment J., (2010) - The magnetic signature of hydrothermal systems in slow-spreading environments. In: Rona, P.A., Devey, C.W., Dyment, J., Murton, B.J. (Eds.), Diversity of Hydrothermal Systems on Slow Spreading Ridges. Geophysical Monograph Series 188. American Geophysical Union, Washington, DC, 43-66.
Uthicke S., Momigliano P., Fabricius K.E. (2013) - High risk of extinction of benthic foraminifera in this century due to ocean acidification. Scientific reports, 3, 1-5. DOI: 10.1038/srep01769.
Vismann B. (1991) - Sulfide tolerance: physiological mechanisms and ecological implications. Ophelia, 34(1), 1-27.
Wankel S.D., Adams M.M., Johnston D.T., Hansel C.M., Joye S.B., Girguis P.R. (2012) - Anaerobic methane oxidation in metalliferous hydrothermal sediments: influence on carbon flux and decoupling from sulfate reduction. Environmental microbiology, 14(10), 2726-2740.
Zitellini N., Marani M., Borsetti A. (1984) - Post-orogenic tectonic evolution of Palmarola and Ventotene basins (Pontine Archipelago). Memorie della Società Geologica Italiana, 27, 121-131.

Ms. received: May 18, 2015
Final text received: June 10, 2015