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Spiculosiphon oceana (foraminifera) and its affinity to intermediate stress conditions in the Panarea hydrothermal complex (Mediterranean Sea)

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Abstract

Spiculosiphon oceana Maldonado, López-Acosta, Sitjà, Aguilar, García & Vacelet, 2013 is a Mediterranean endemic giant stalked foraminifer described as a potential bio-indicator of acidic environments, thanks to its ability to cope with stressful chemical conditions. Here, we present the first record and the first video images of living specimens of this giant foraminifera in the Panarea Volcanic Complex (PVC; southern Tyrrhenian Sea), representing the third discovery worldwide. Specimens of *S. oceana* were identified through microscopic and remotely operated vehicle (ROV) image analyses, in two different areas characterised by water column physico-chemical parameters typical of the non-vented areas, but with some evidence of hydrothermal alteration. This new finding enhances knowledge on the ecology of *S. oceana*, enlarges its known spatial distribution, and corroborates its affinity to intermediate stress conditions related to hydrothermal activity.

Keywords: Large astrorhizids, Shallow hydrothermal system, Ocean acidification, Panarea Island, Aeolian archipelago

Introduction

Spiculosiphon oceana Maldonado et al. 2013 is a recently discovered endemic species of the Mediterranean Sea and is one of two species of the genus *Spiculosiphon* Christiansen 1964 recognised worldwide. These are large astrorhizids with a distinctive stalked test comprised of sponge spicules directly agglutinated in an organic wall (Maldonado et al. 2013; Di Bella et al. 2016, 2018). The type species, *Spiculosiphon radiatus* Christiansen 1964, was discovered in a Norway fjord at 100 m depth, while *S. oceana* was first described by Maldonado et al. (2013) at 153 m depth on a soft bottom on the "Seco de Palos" Seamount (western Mediterranean Sea, Spain). Probably another species of this genus, called *Spiculosiphon* cf. *radiata*, was recognised 18 years ago by Onno Gross in a dark sublittoral cave in the north-west Mediterranean Sea, but this record was never published (Maldonado et al. 2013).

The distinctive traits among the known species mainly concern the size: *S. radiata* is 2 cm long, while *S. oceana* is a giant foraminifer that can reach 3–4 cm in length (Maldonado et al. 2013). In addition, these foraminifera have a peculiar test standing on a hollow tube, that in *S. oceana* is characterised by a bulb-like proximal end, not observed in *S. radiatus*, that penetrates into the substratum but is never anchored permanently to it, and a globe-like capitate region (the distal end of the tube). Most of the test stands out of the marine bottom and is comprised of fragments of siliceous sponge spicules disposed along the major axis of the stalk. In the globe-like region, the spicules are arranged in a less agglutinated structure that allows the extrusion of the pseudopodia that, in turn, are sustained by a spherical crown built by radiating tracts of highly selected aciculate spicules. The resulting body morphology allows *S. oceana* to capture small planktonic demersal prey such as crustaceans or calcareous foraminifera (Maldonado et al. 2013).

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A recent study reported the occurrence of *S. oceana* on the Zannone Hydrothermal Field (central Tyrrhenian Sea), highlighting its ability to cope with chemical conditions related to hydrothermal fluid emissions (Di Bella et al. 2016). This finding led to the speculation that *S. oceana* could be considered as a proxy of acidic environments (Di Bella et al. 2018).

Here, we present another record of *S. oceana* in the Mediterranean Sea, in the PVC (southern Tyrrhenian Sea). This new finding can enhance our knowledge of the distribution and habitat of *S. oceana*, and confirm its affinity to intermediate stress condition and its importance as a bio-indicator of recent ocean acidification processes related to hydrothermal activity.

Material and methods

Spiculosiphon oceana was discovered in November 2013, during the research cruise PANA13_04 conducted onboard the RV Astrea of ISPRA to explore the Panarea hydrothermal area, in particular the eastern slope of the north-northeast trending extension, north of Basiluzzo Islet (Fig. 1).

In this area, the hydrothermal activity is linked to radial volcano-tectonic processes that affect the slope, as evidenced by the presence of small-scale gullies radiating from the edge (Fig. 2a; Savelli et al. 1999; Romagnoli et al. 2013). Fe-rich deposits are widely distributed on the shelf edge (80–90 m), where they form crusts of iron-oxyhydroxides covered by silt deposits. While, on the steep slope (140–210 m) they give rise to numerous small chimneys of soft mud (black and red crusts with yellowish-orange precipitates on top), containing abundant semi-consolidated crusts of Fe-Mn oxyhydroxides (Gamberi et al. 1997, 1998; Savelli et al. 1999; Bortoluzzi et al. 2014).

Benthic communities were investigated by means of an ROV *Pollux II* equipped with a Nikon D80 high-

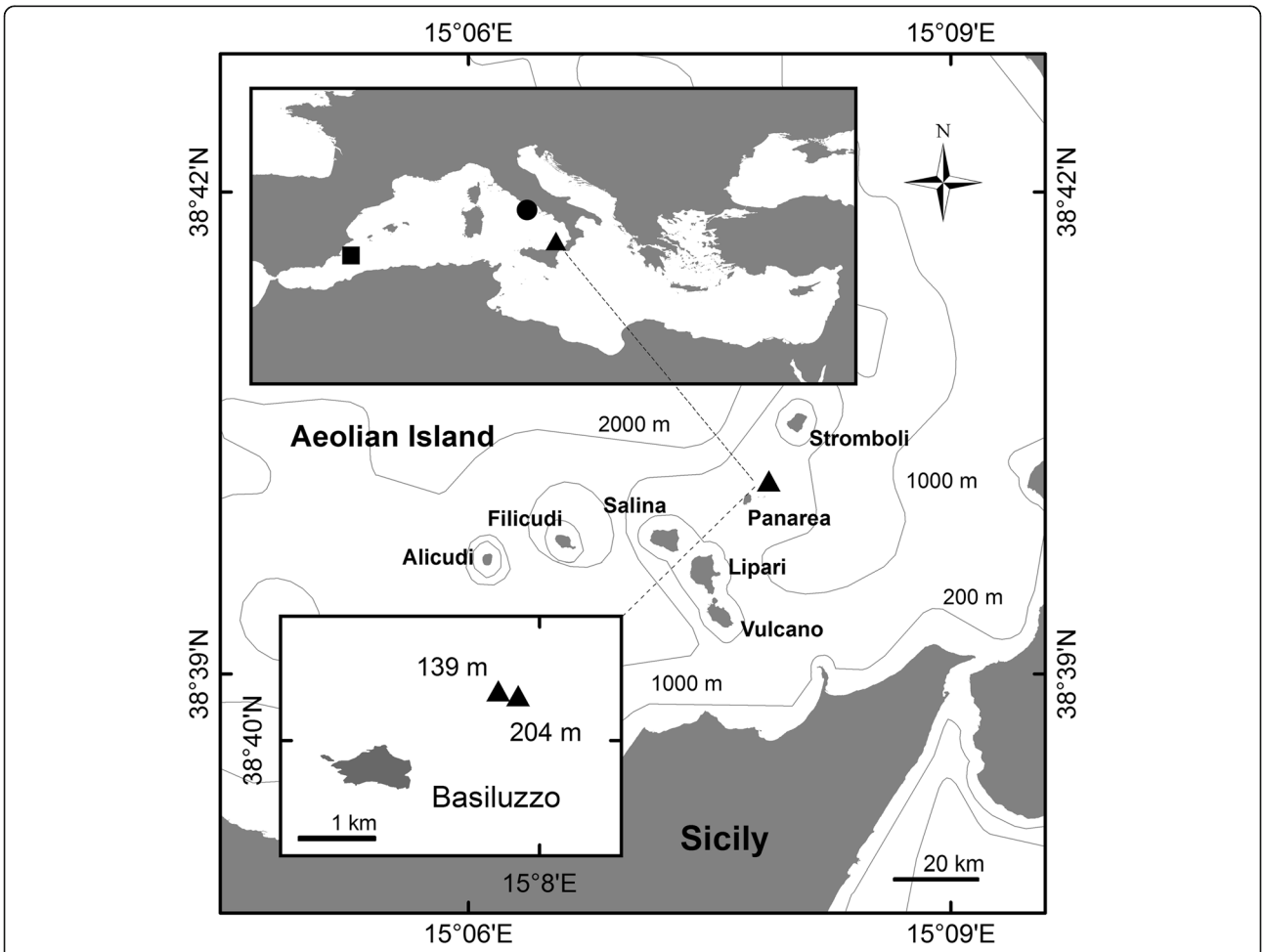

Fig. 1 Map of the study area showing the sites where *Spiculosiphon oceana* was identified along the Basiluzzo slope in the Panarea Volcanic Complex (the black triangles in the bottom-left box). Sites of previous records of the species in the Mediterranean Sea were reported in the top-left box: the black square indicates the first record in the "Seco de Palo" Seamount (Maldonado et al. 2013) and the black circle indicates the record in the Zannone Hydrothermal Field (Di Bella et al. 2018)

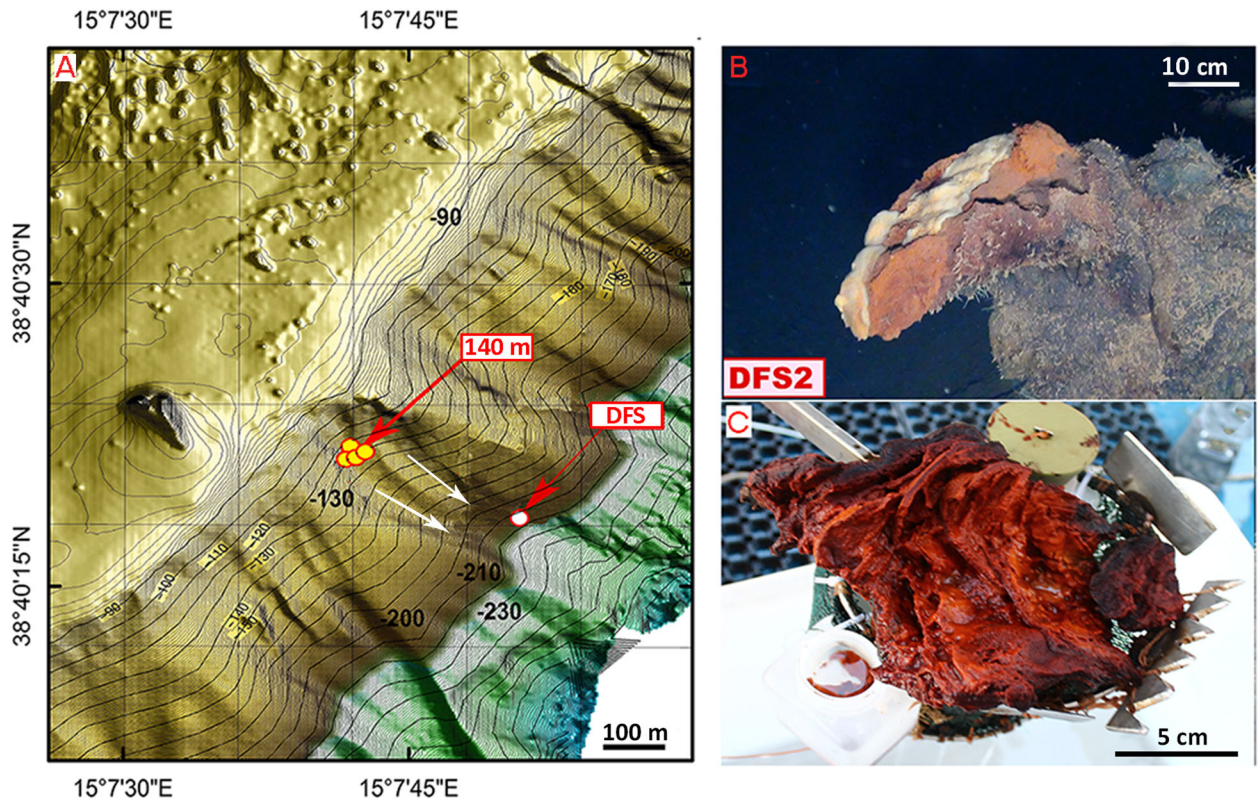

Fig. 2 (**a**) High-resolution swath bathymetry map of the Basiluzzo Fe-rich hydrothermal field depicting the location of the diffuse ferruginous seep DFS2 (204 m), on which the specimen of *S. oceana* was collected, and of the site at 140 m where a patch of several specimens was identified and photographed by the ROV, small scale gullies (white arrows) are also reported; (**b**) picture of DFS2; (**c**) picture of the DFS portion sampled by the ROV basket net

resolution camera and a Sony HDR-CX560V full HD video camera. Two parallel laser pointers providing a 10-cm scale to measure in situ seafloor structures and macrobenthic organisms, and a small basket net enabling the collection of samples were also provided. One specimen of *S. oceana* was collected and preserved in situ in 90% ethanol solution and then analysed under a stereomicroscope Zeiss discovery v.8 equipped with micro-camera Axio-Cam vs40 v4.8.20. Water column data of temperature, salinity and pH were also acquired by a CTD SBE 911. A Crison pH 25 sensor was also used onboard to acquire data from the collected samples.

Results

The analysed specimen of *Spiculosiphon oceana* was identified and photographed during the microscopic analysis of smooth sediments a few centimeters-thick, consisting of an Fe-encrusted deposit collected by the ROV from the top of a hydrothermal diffusive pinnacle-like structure described by Bortoluzzi et al. (2017) as a diffusive ferruginous seep (DFS), named DFS2 (Fig. 2).

This 2 m-high DFS was located at 204 m depth on the steep eastern slope of the Panarea platform elongation (north of the Basiluzzo islet) and was the result of a continuous and focused Fe-oxyhydroxide seafloor deposition of hydrothermal origin. It was characterized by the lack of visible gas bubbling and fluid emission, and by a top covered by thick reddish-orange iron-rich deposits containing complex and stratified communities of mainly ammonium- and iron-oxidising chemoautotrophs belonging to *Thaumarchaeota*, *Nitrospira*, and *Zetaproteobacteria* (Bortoluzzi et al. 2017). The main water column parameters, recorded in the area, showed rather constant temperature values of 14.1–14.3 °C, from 120 to 210 m depth. At the same depths, the acquired salinity was about 38.4 PSU, and the pH data ranged from a value of 8.1 to 8 (Table 1). The pH sensor, used onboard to acquire data from the collected sample, measured pH = 5 inside DFS2 structure.

The analysed specimen of *S. oceana* was recognised by its peculiar body morphology. Observation under the stereomicroscope allowed the identification of a fragment of the stalked test bearing the typical capitate region, but lacking the bulb-like structure (Fig. 3).

The stalk appeared as a rod (> 1.5 cm length) built by broken, agglutinated needle-like spicules (including a

Table 1 Main physico-chemical parameters measured close to the sea bottom (5 m asb), by the CTD SBE 911 probe, in the two areas *S. oceana* was found (DFS and 140 m) and in the site of hydrothermal fluids active emission

	DFS	140 m	Emission area
Coordinates	N 38°39′18.37″ E 15°06′52.52″	N 38°40′21.11″ E 15°07′42.57″	N 38°39′18.37″ E 15°06′52.52″
Water depth (m)	204	140	85
Temperature (°C)	14.3	14.1	14.5
Salinity (PSU)	38.4	38.2	37.8
pH	8.0	8.1	7.9–7

few long-shafted triaenes; Fig. 4a) disposed according to the major axis of the test, but slightly twisting around it (Fig. 4b) and arranged as reported in the specimens described by Maldonado et al. (2013) and Di Bella et al. (2018). Some sand grains were observed attached externally to the stalk (Fig. 4c), while, some broken portions of the test showed the internal organic layer (Fig. 4d).

The capitate structure appeared as a tangle of broken fragments of irregularly-shaped spicules arranged in a globular nucleus from which solid tracts (~ 1.5 mm length), composed by afew monoaxial spicules, radially extended (Fig. 5b). The analysed specimen of *S. oceana* showed only one of the radiating tracts, the others were probably broken during sampling and laboratory manipulation.

However, a detailed analysis of the ROV images, conducted after the identification of *S. oceana* in the study area, revealed several living specimens (> 20) with the typical stalked test (> 3.5 cm length; maximum measured length = 4.2 cm) and the globelike structure with the whole set of radiating tracts. These specimens were found standing out in iron-rich soft bottoms surrounding non-effusive hydrothermal structures at 140 m depth on the steep Basiluzzo slope (Figs. 2a and 5a), where only few Scyphozoa polyps (Cnidaria) were identified (Fig. 6). At these depths, no fluid emissions were observed; the temperature and salinity profiles in the water column were typical of the non-vented areas, as by the pH values (Table 1). Vent areas, affected by low temperature acidic fluids emission (Table 1), were located at a distance of about 2.3 km from the areas where *S. oceana* were found, at 85 m depth in the southeastern sector of the Basiluzzo hydrothermal system (Fig. 7).

Discussion

The morphology of the stalked agglutinated astrorhizid analysed under the stereomicroscope and observed in ROV images, corresponds to that of the species originally described by Maldonado et al. (2013). Indeed, as reported, it is a giant foraminifer (> 3.5 cm) standing on a hollow stalk, built with highly-selected, long and thin spicule fragments, with a capitate globe-like structure bearing 20–30 slender radiating tracts not spiny, plumose or subdivided (Fig. 5).

Our finding represents the first record of *Spiculosiphon oceana* in the Panarea Volcanic Complex, the third in the whole Mediterranean Sea and the second record

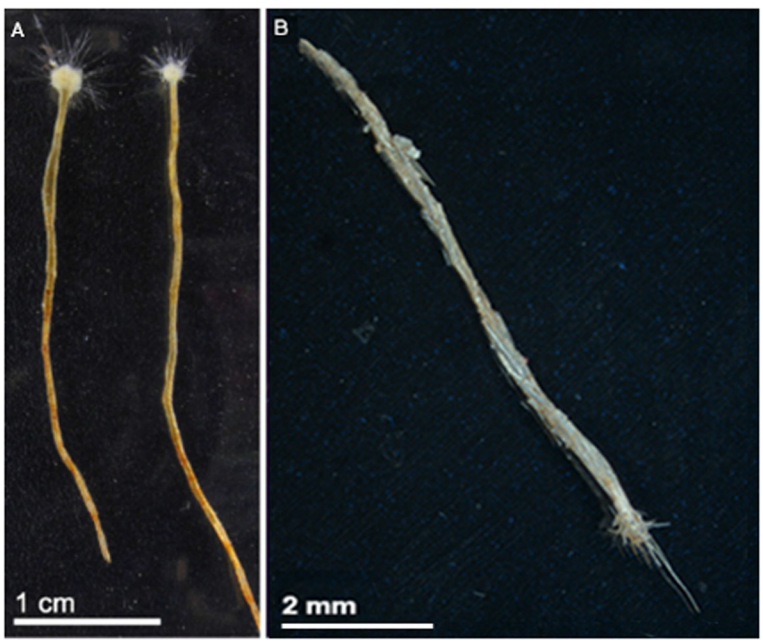

Fig. 3 (**a**) General view of the holotype and the paratype (from left to right, respectively) of *S. oceana* (from Maldonado et al. 2013); (**b**) photo of *S. oceana* sampled on the DFS2 in the Panarea Volcanic Complex, taken under the stereomicroscope

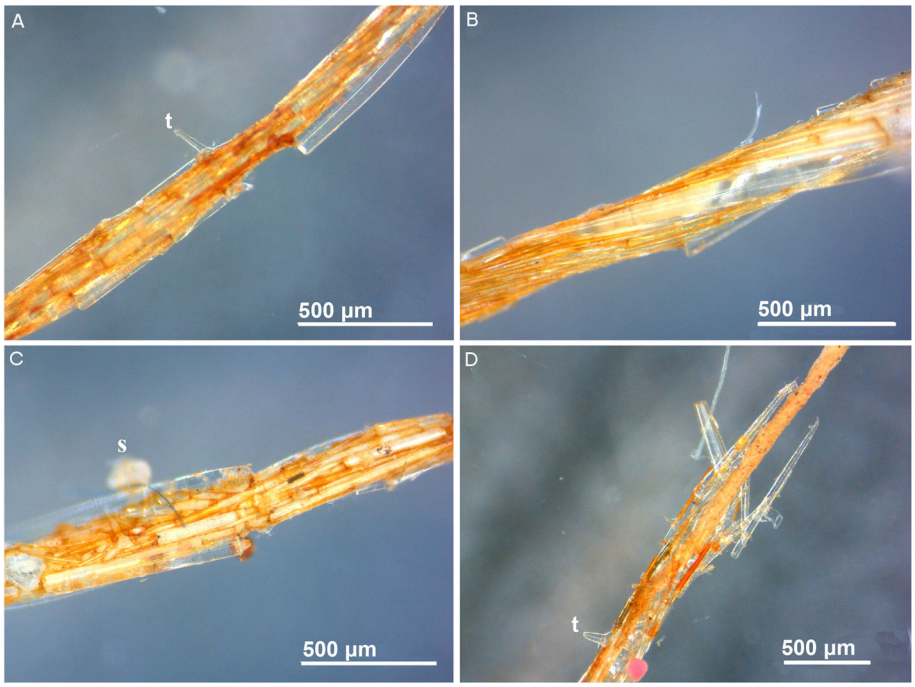

Fig. 4 Photos of the test of *S. oceana* collected on DFS2 in the Panarea Volcanic Complex, taken under the binocular microscope: (**a**) detail of the needle-like spicule fragments along with a three-rayed spicule (triaene = t); (**b**) detail of the arrangement of the spicule fragments slightly twisting around the major axis of the stalk; (**c**) details of the test of the stalk with densely packed spicules and attached sand grain (s); (**d**) broken portions of the test showing the internal wall

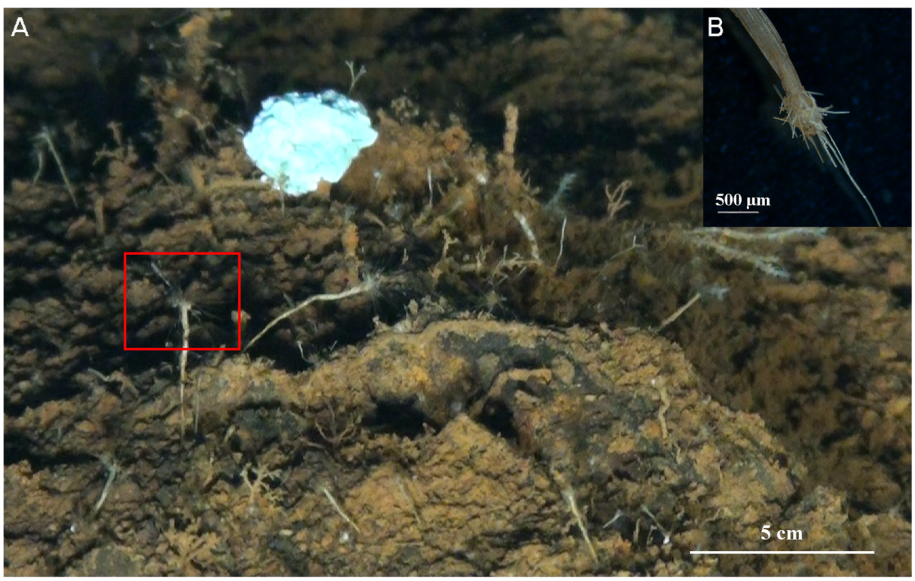

Fig. 5 (**a**) ROV image showing specimens of *S. oceana* standing out of the iron-rich soft bottoms surrounding non-effusive hydrothermal structures at 140 m depth on the Basiluzzo slope; (**b**) globelike region of the collected specimens of *S. oceana*, showing the irregular arrangement of spicules composing the nucleus from which a solid tract extended

Fig. 6 Seafloor images showing the occurrence of *S. oceana* and the identified polyps of Scyphozoa (Cnidaria) on the seabed at 140 m depth on the Basiluzzo slope

in a shallow-water hydrothermal area (the first being the Zannone Hydrothermal Field; Di Bella et al. 2016, 2018).

Previous studies recorded specimens of *S. oceana* temporally anchored on sand and detritic bottoms at depths ranging from 116 to 153 m (Maldonado et al. 2013; Di Bella et al. 2016, 2018). The observations of *S. oceana* along the Basiluzzo slope in the PVC extend the bathymetric distribution of the species down to 204 m. Specimens of *S. oceana* were recorded in two different areas characterised by absence of active fluid emissions and water column physicochemical parameters typical of the non-vented areas, although the presence of numerous DFS and iron and sulfur deposits and the low pH measured inside DFS seemed to indicate a shallow depth level of hydrothermal alteration (Bortoluzzi et al. 2014, 2017).

The collection of a few centimeters-thick Fe-encrusted deposit on the top of a DFS (204 m water depth) allowed us to reveal the presence of *S. oceana* in the PVC, then ROV underwater observations at – 140 m led to the identification of at least 20 specimens (maximum measured length = 4.2 cm; Fig. 5a) that may be many more considering the individuals shown in the Fig. 6. The specimens were found with most of the tests standing out of an almost defaunate soft bottom surrounding non-effusive

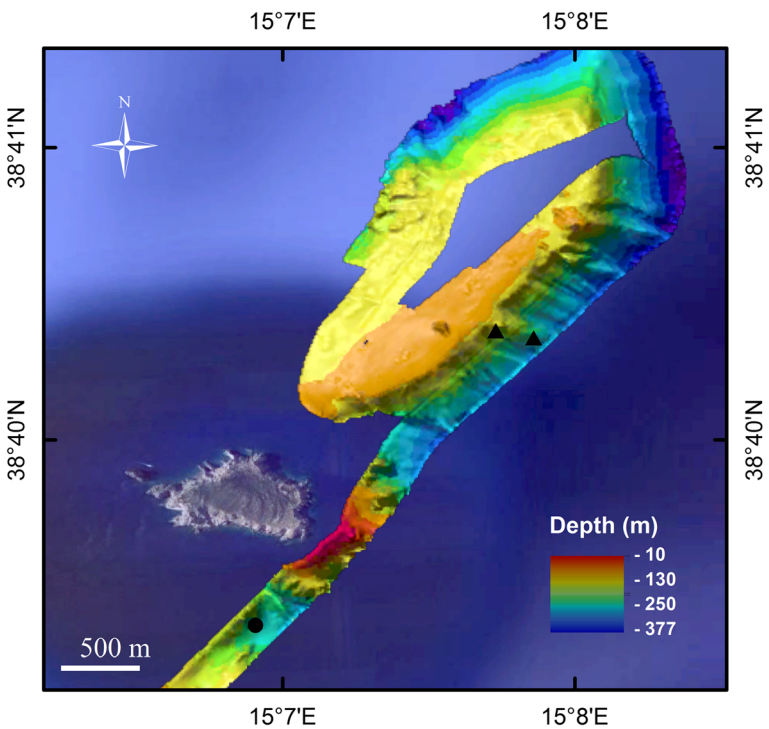

Fig. 7 Map of the investigated area around the Basiluzzo islet (PVC) reporting the two sites where *S. oceana* was identified (black triangles) and the site of active acidic hydrothermal emissions (black circle)

hydrothermal structures and characterised by evidence of authigenic Fe-rich precipitation and sulfur deposition, typically observed along the northeast continental platform and down to the slope of Basiluzzo Islet (Marani and Gamberi 1997; Gamberi et al., 1999; Savelli et al. 1999; Esposito et al. 2015). In the two sampling areas, and more in general around 140 m depth, the sulphur deposits became more frequent and were commonly associated with microbial mats, that, as suggested by Di Bella et al. (2018), could represent an important food source available for *S. oceana* in hydrothermal habitat. On the other hand, the giant foraminifer was not found in the identified vent site, located at a distance of about 2.3 km, and characterised by active emission of low temperature acidic fluids, with pH rapidly decreasing from 8 to 7 near the sea bottom (Table 1).

These findings agree with the ecological features described by Di Bella et al. (2018) for *S. oceana* in the Zannone Hydrothermal Field (western Pontine Islands) where this giant foraminifer was not recorded in areas with strong hydrothermal emissions and most of the observed specimens were recorded in areas up to a distance of about 2 km from fluid emissions. This distribution pattern confirms the link between *S. oceana* and intermediate stress conditions that the foraminifer can cope with thanks to its peculiar morphological characteristics, while it seems to not tolerate the extreme acidic conditions of active venting fields.

Conclusions

This new record of *Spiculosiphon oceana* helps to understand the ecology of the species and enlarge its known bathymetric distribution. The wide living population of the foraminifer, showed for the first time in the present work in an area with some evidences of hydrothermal alteration (DFS, authigenic iron and sulphur precipitation and microbial mats) corroborates its affinity to intermediate stress conditions related to hydrothermal activity, strengthening the hypothesis, expressed by Di Bella et al. (2018), that this giant foraminifer could be considered a bio-indicator of acidic environments.

Abbreviations

Asb: Above sea bottom; DFS: Diffusive Ferruginous Seep; PSU: Practical Salinity Unit; PVC: Panarea Volcanic Complex; ROV: Remotely Operated Vehicle

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Authors' contributions

VE was the major contributor in conceptualize and writing manuscript and in analyzing ROV's images and video footage and sampled specimens of *Spiculosiphon oceana*. SC contributed to identify and sample the species and contributed to the revision of the text. GS and MB contributed to analyze and describe the collected specimens. CD contributed to revise the manuscript. FA and TE were responsible of the funding acquisition and project administration and contributed to the conceptualization and revision of the text. All authors read and approved the final Manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Ethics approval

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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