JOURNAL OF MAPS
https://doi.org/10.1080/17445647.2022.2120836

Seafloor characterisation of the offshore sector around Scoglio d'Affrica islet (Tuscan Archipelago, northern Tyrrhenian sea)

Daniele Spatola [a,b], Daniele Casalbore [a,c], Martina Pierdomenico [d], Alessia Conti [c], Sabina Bigi [a], Michela Ingrassia [c], Roberta Ivaldi [e], Maurizio Demarte [e], Simone Napoli [a] and Francesco Latino Chiocci [a,c]

[a]Department of Earth Sciences, Sapienza University, Rome, Italy; [b]Department of Geosciences, University of Malta, Msida, Malta; [c]Institute of Environmental Geology and Geo-Engineering, National Research Council, Rome, Italy; [d]Institute for the Study of Anthropic Impact and Sustainability in the Marine Environment, Italian National Research Council (IAS-CNR), Rome, Italy; [e]Italian Hydrographic Institute, Genova, Italy

ABSTRACT

We present a very high-resolution bathy-morphological map of the offshore sector around the Scoglio d'Affrica islet (northern Tyrrhenian Sea, Italy). The study area covers a sector of 45 km^2, between 3 and 85 m depth. Its central part, i.e. the apex of the Ridge, is characterised by a flat or gently sloping seafloor, where three mud volcanoes, and 250 pockmarks are recognised. Differently, the western and eastern Ridge flanks are steeper and characterised by 60 quasi-rectilinear escarpments and small ridges, more than 20 morphological highs, and elongated channels occasionally floored by bedforms. The seafloor shallower than 40 m is covered by *Posidonia oceanica*, forming compact and continuous or fragmented meadows intermingled with sandy patches. The main map represents the bathy-morphological setting of the area, which is largely affected by fluid seepage, providing insights for habitat mapping and preliminary marine geohazard assessment due to the violent gas outburst from mud volcanoes.

ARTICLE HISTORY
Received 31 May 2022
Revised 24 August 2022
Accepted 30 August 2022

KEYWORDS
Multibeam bathymetry; Mud volcanoe; Pockmark; Bedform; *Posidonia oceanica*; Elba-Pianosa ridge

1. Introduction

The area of interest is a shallow water (< 85 m w.d.) area surrounding the Scoglio d'Affrica islet, which is located in the southernmost Elba-Pianosa Ridge, approximately 40 km south of Elba Island (Figure 1). This ridge is a prominent morpho-structural feature elongated about N-S for about 150 km, that separates the Tuscany Shelf to the east from the Corsica Basin to the west (Cornamusini et al., 2002). The Elba-Pianosa Ridge summit generally lies at depths <80 m, shallowing close to the main islands of the Tuscan Archipelago (Figure 1). The islands are very different from each other, with near-circular plutons at Elba and Montecristo islands, volcanic rocks at Capraia Island (∼ 35 km north of Elba Island) and sedimentary rocks outcropping at Pianosa Island and Scoglio d'Affrica islet.

The Elba-Pianosa Ridge is composed of a thick (up to 4 km) Eocene-Early Miocene siliciclastic succession, which is the result of duplex geometries due to the Oligocene orogenic phase (Cornamusini et al., 2002; Pascucci, 2005). The siliciclastic succession is covered by shallow-marine Pleistocene deposits that are mainly formed by sands and clays (Cornamusini et al., 2002). Dredged rocks from the Elba-Pianosa Ridge consist of both oceanic cover units and Triassic carbonates having an Adria continental plate affinity (Bigi et al., 1992). In the 1970s, the Elba-Pianosa ridge was drilled by two exploration wells, i.e. Martina 1 and Mimosa 1 published in VIDEPI (http://unmig.sviluppoeconomico.gov.it), that have revealed the presence of hydrocarbon gas in the Early Miocene sandy levels and in the Eocene flysch formation, with very high content of CH_4 (up to 98%). Fluids are thought to migrate from local fluid (deep) reservoirs through normal faults affecting the thick Eocene-Early Miocene siliciclastic succession (Pascucci, 2005). In the study area, submarine methane emissions have been studied since the 1960s, when (Del Bono & Giammarino, 1968) documented and sampled gases seeping from *Posidonia oceanica* meadows, even in this case the CH_4 content was close to 90%.

In 2017, a violent outburst generated a column of dirty water rising up to 10 m above the sea surface that was documented by local fishermen, boosting new researches focusing on fluid emissions in this area (Casalbore et al., 2020; Saroni et al., 2020). The main focus of this paper is to provide the first bathy-morphological map of Scoglio d'Affrica islet offshore (Tuscan Archipelago, northern Tyrrhenian Sea) at 1:

CONTACT Daniele Spatola daniele.spatola@uniroma1.it
Supplemental map for this article is available online at https://doi.org/10.1080/17445647.2022.2120836.

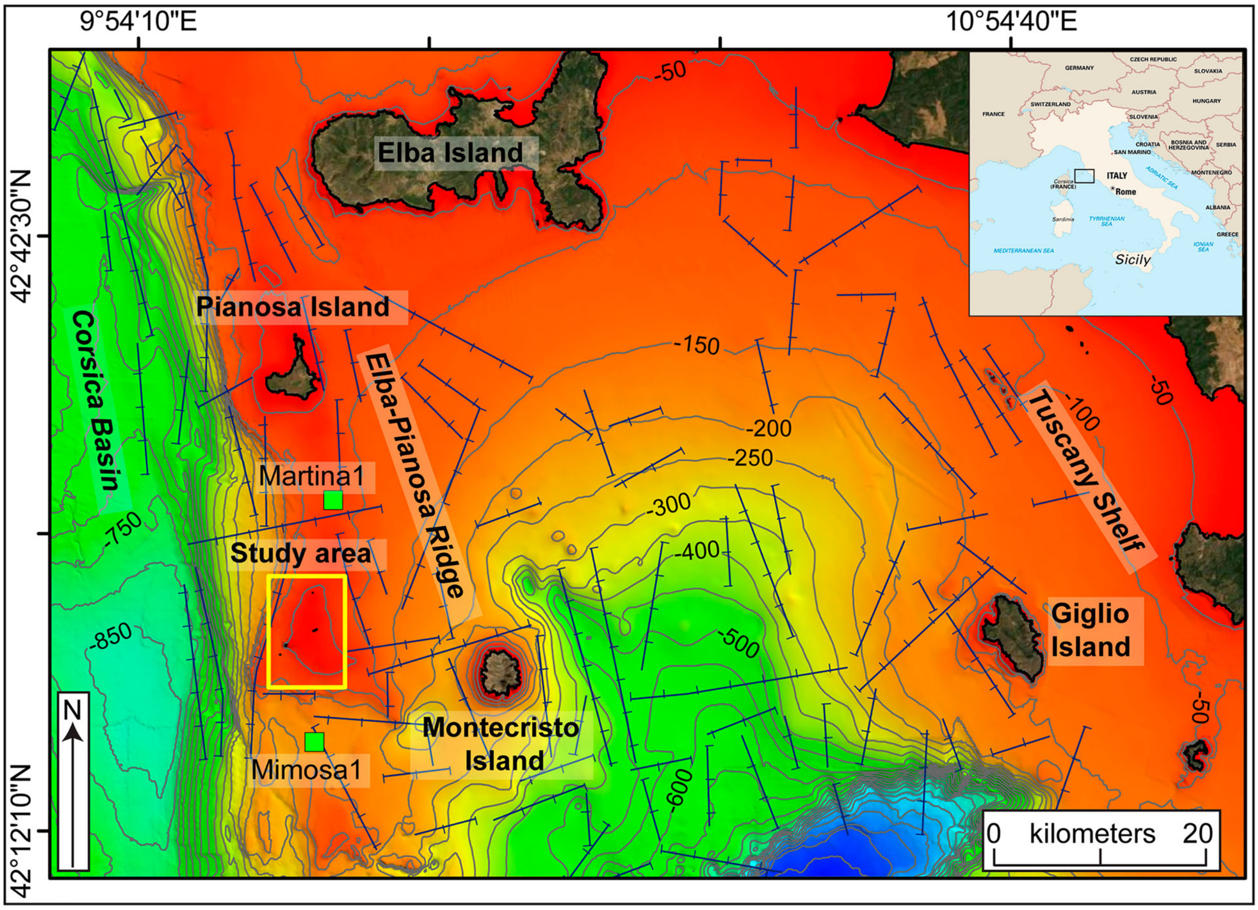

Figure 1. Location map of the study area (yellow box) showing the principal morphological and structural features (faults are denoted in blue; sources from Bigi et al., 1992), and the location of the two offshore wells (Martina1 and Mimosa1). Bathymetry interval: isobaths in dark grey at 50 m equidistance. Background bathymetry from EMODnet bathymetry (http://www.emodnet-bathymetry.eu).

25,000 scale through the analysis of a high-resolution Digital Elevation Model (DEM). It can be a baseline study for better understanding of the geological processes that control the morphology of the area, providing insights for a first assessment of the threat posed by these outbursts to the navigation safety. The main map also provides the base for a habitat mapping of the area around the Scoglio d'Affrica islet, which is part of the National Park of the Tuscan Archipelago characterised by a shallow water setting with relatively little fishing activity.

2. Data and methods

The study is based on very high-resolution bathymetry data acquired in July 2017 by Italian Hydrographic Institute by using hull-mounted multibeam echosounder systems (i.e. Kongsberg EM2040 and EM2040C multibeam systems, both working at a frequency of 200/400 kHz). Data positioning was achieved using the DGPS FUGRO 9205 GNSS, with Marinestar HP + G2 corrections. Processing of the raw bathymetric data was performed with CARIS Hips&Sips, version 9.0.13, including correction for heading, pitch, heave and roll. Sound velocity corrections were also applied by using sound velocity profiles collected with a Valeport MiniSVP probe. Tidal correction was also applied using data from the ISPRA gauge at Marina di Campo (Elba Island) belonging to the 'National Tide gauge' (https://www.mareografico.it). The final Digital Elevation Model (DEM) was obtained by gridding the soundings with a final cell size of 0.5 m using the CUBE algorithm. The accuracy of the multibeam data is approximately 1 m on the horizontal plane and 0.3 m on the vertical plane for data collected down to a depth of 45 m. The accuracy of the bathymetric data acquired at greater depths decreases to 1.22 m for the horizontal and 0.64 m for vertical planes (more detail in Casalbore et al., 2020). The DEM was exported as ASCII ESRI files to ArcMap 10.8. ASCII ESRI files were transformed to raster files which were used to generate the main map.

3. Geomorphological map of Scoglio d'Affrica islet offshore

The study area occupies a surface of ~ 45 km^2 in the water depth range between 3 and 85 m. It is characterised by a flat or gently sloping sector down to ~50 m depth, corresponding to the top of the Elba-Pianosa Ridge, passing downslope to a steeper seafloor that marks the upper flanks of the ridge. Based on the main seafloor elements and small-scale topographic characteristics (e.g. roughness, presence of morphological highs or depressions), the seafloor is classified into 7 areas, each of them dominated by a morpho-acoustic facies (hummocky, subdued hummocky, smooth, smooth with small-scale roughness, dimpled facies, area with bedforms, and bedrock), and 5 main types of morphological features (escarpments, ridges, morphological highs, mud volcanoes, and pockmarks) (Figure 2 and Main Map). The interpretation of the different morpho-acoustic facies and morphological features is ground-truthed (where available) by

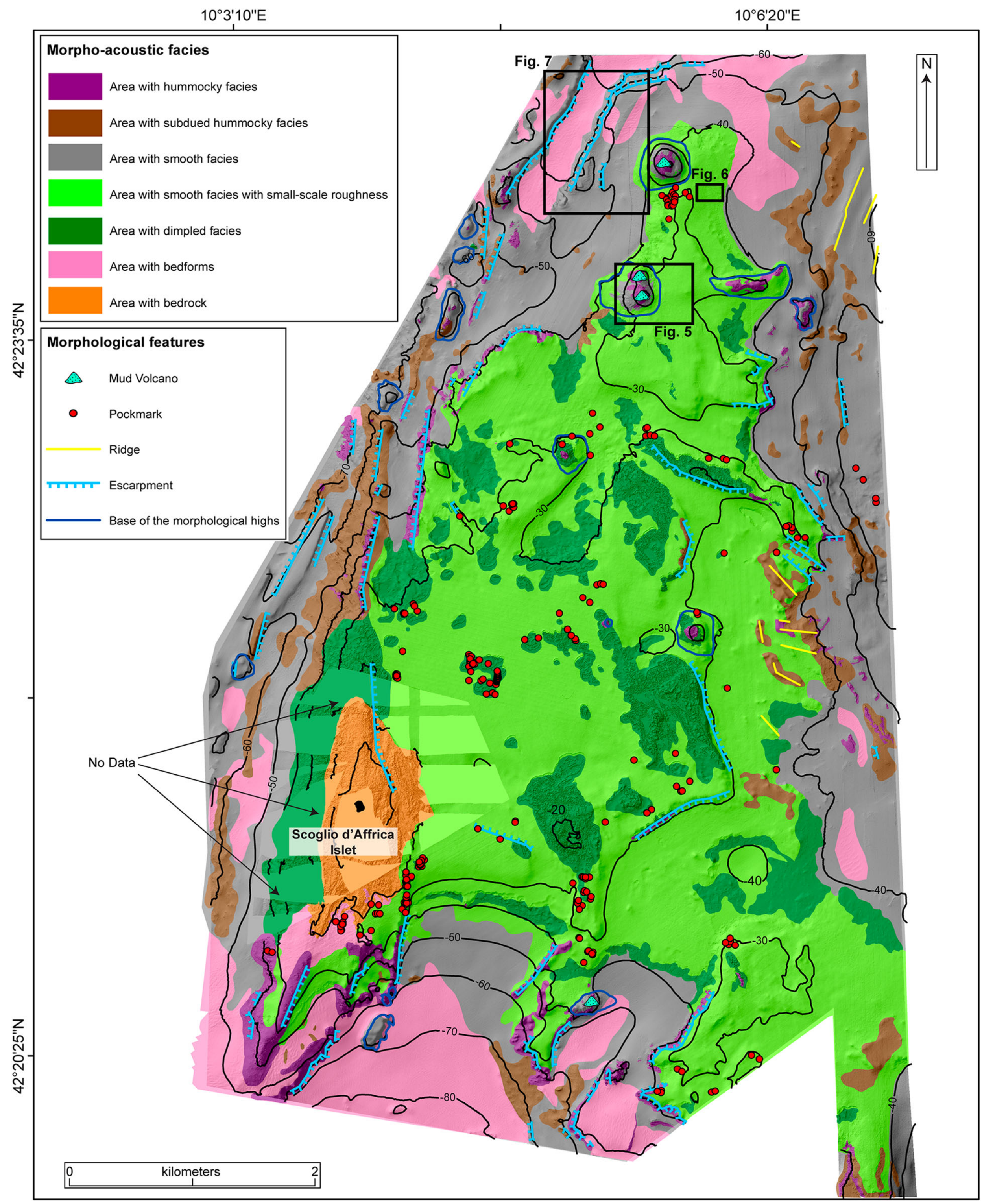

Figure 2. Bathy-morphologic map of the offshore sector around the Scoglio d'Affrica islet draped over the shaded relief map of the seafloor, showing the main morpho-acoustic facies (MFA) and morphological features identified across the study area. Isobaths are drawn at 10 m intervals. Black squares represent localisation of Figures 5–7.

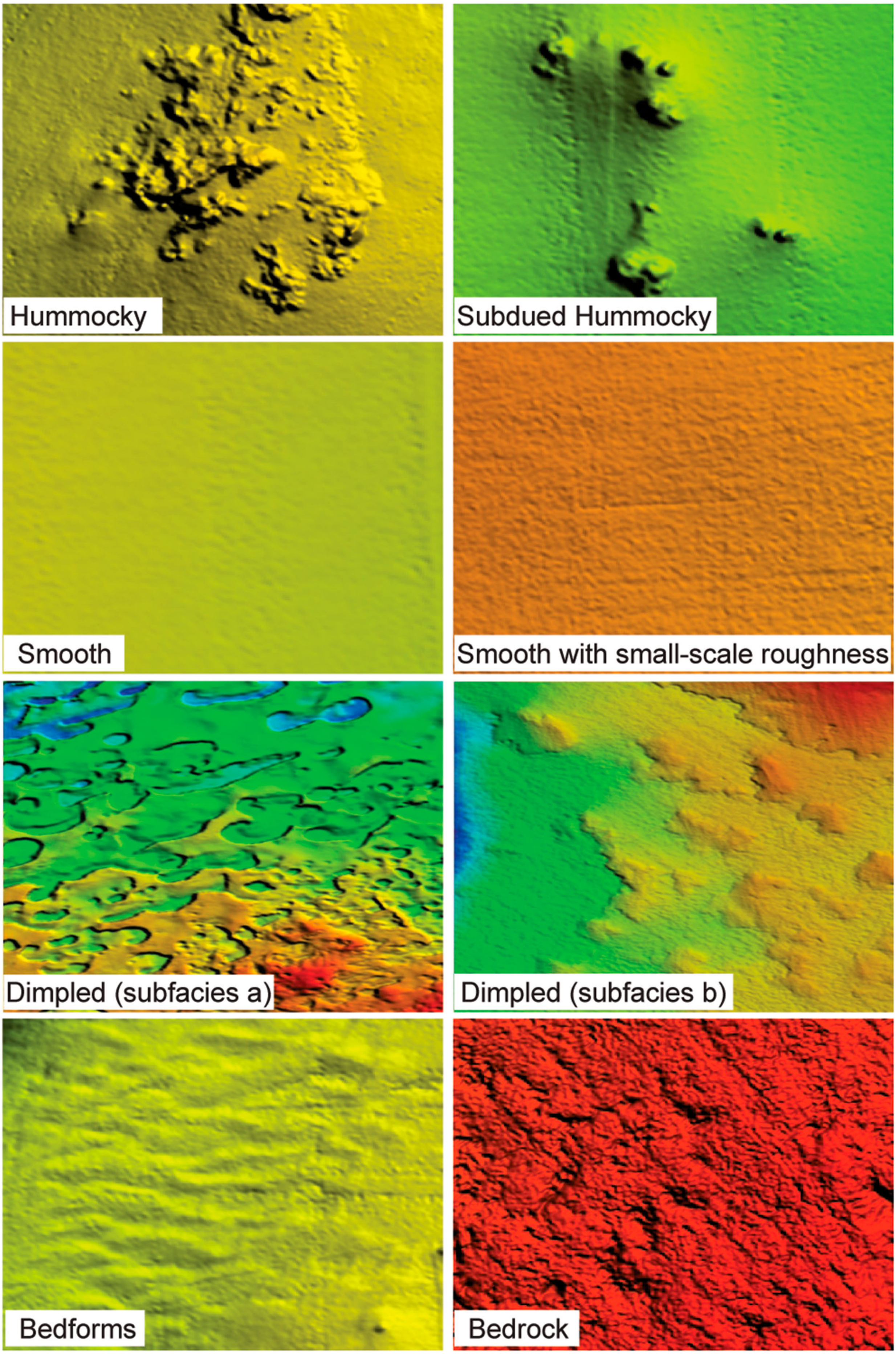

Figure 3. The main seafloor morpho-acoustic facies (MFA) identified by using high resolution multibeam echosounder data.

previous observations from literature (e.g. Casalbore et al., 2020; Ferretti et al., 2021; Saroni et al., 2020).

3.1. Morpho-acoustic facies (MFA)

We identify and map, across the study area, seven main morpho-acoustic facies (MFA) and present our main observations accordingly (Figure 3).

- *Hummocky MFA* is characterised by a very rough topography due to the presence of several sub-meter and metre-scale positive reliefs with squared or angular shape (Figure 3). It is mainly located in the upper flanks of the main morphological highs and mud volcanoes (Figure 2) as well as along the escarpments (see 3.2), covering an area of ~ 1.5 km^2 (4% of the surveyed seafloor; Figure 2 and Figure 4). This facies is formed by coalescence of sub-meter and metre scale blocks, as observed through ROV dives in the northern part of the study area by (Casalbore et al., 2020; Ferretti et al., 2021).
- *Subdued hummocky MFA* is quite similar to the previous facies, but it is generally characterised by a smooth topography occasionally interrupted by the occurrence of scattered or isolated positive reliefs ranging in size from metres to sub-meter and with squared or angular shape (Figure 3). It is mostly located in the deeper sectors (i.e. to the south and along the upper flanks of the Elba Pianosa Ridge), and covers an area of ~2.6 km^2 (6% of the surveyed seafloor; Figures 2 and 4).
- *Smooth MFA* is characterised by a smooth and featureless seafloor (Figure 3). It is located both in the deepest part of the study area, below 40 m depth (Figure 2) and along the flanks of mud volcanoes (Figure 2), covering an area of approximately 12 km^2 (27% of the surveyed seafloor; Figure 4). ROV dives performed along the flanks of mud volcanoes show a prevalent unvegetated seafloor consisting mainly of mud breccias alternated with bioclastic sand/gravel (Ferretti et al., 2021).
- *Smooth facies with small-scale roughness MFA* is characterised by an overall smooth seafloor on which is superimposed a smaller-scale roughness (in the order of few metres in plan-view and few decimeters high; Figure 3) and covers an area of approximately 16 km^2 (36% of the surveyed seafloor) (Figures 2 and 4). The small-scale roughness is due to the presence of *Posidonia oceanica* meadows, that have been widely documented in the area, above 40 m depth, by ROV inspections and scuba dives (Casalbore et al., 2020; Del Bono & Giammarino, 1968; Ferretti et al., 2021; Papi et al., 1992). Such small-scale seafloor roughness allowed to differentiate in the study area the seagrass-covered and unvegetated seafloor.
- *Dimpled MFA* shows a seafloor with an uneven character, due to the presence of irregular depressions and small positive reliefs (Figure 3). It is identified mainly in the central part of the study area and covers a total area of ~ 5 km^2 (14% of the surveyed seafloor; Figures 2 and 4). This morpho-acoustic facies can be subdivided into two subfacies (Figure 3). *Dimpled MFA* subfacies a is more extensive and is characterised by the presence of negative features from few metres to tens of metres wide and up to 2 m deep, showing ovoid, elongated or irregular shapes. These negative features correspond to 'intermatte' areas, i.e. sandy patches that interrupt the continuity of the *P. oceanica* meadows, as observed by ROV dives (unpublished data). *P. oceanica* meadows commonly show these natural forms with sizes similar to those observed in the study area (i.e. (Abadie et al., 2015; Savini, 2011)). *Dimpled MFA* subfacies b, was mapped only in the south-eastern sector of the study area, covering area smaller than 1 km^2, and it is characterised by the presence of only positive features up to 1 m high resting above a regular seafloor. The subfacies b may be linked to the presence of small isolated patches of *P. oceanica* meadows, which is widespread in the surrounding sectors.
- *Bedforms MFA* shows the occurrence of bedforms with arcuate shape in plan-view that are downslope asymmetric in cross-section, with lee side sloping up to 15° (Figure 3). Bedform have maximum wave lengths and wave heights of approximately 8 m and 25 cm, respectively. Fields of bedforms totally cover an area of approximately 4.5 km^2 and have been locally observed both within the channel beds (10% of the surveyed seafloor; Figures 2 and 4), and across the upper flanks of the Elba pianosa Ridge, at different water depth (Figure 2).
- *Bedrock MFA* is characterised by a very rough seafloor topography and covers an area of ~ 1.2 km^2 of the seafloor, surrounding the Scoglio d'Affrica islet (3% of the surveyed seafloor; Figures 2–4). Since the islet is build-up of Pleistocene to Holocene organogenic limestones (Motteran & Ventura, 2005), we infer that this articulated facies is indicative of limestone outcrops (Figure 2).

3.2. Morphological features

The lack of other geophysical data (e.g. seismic reflection profiles) and extensive ground-truth (e.g. near-bottom visual observations and seafloor sampling) did not permit a positive classification of the mapped features. However, the acoustic multibeam data allow us to identify 5 main seafloor morphological features that are linked to tectonic, fluid-related and erosive-depositional processes organised as follows (Figure 2 and Main Map).

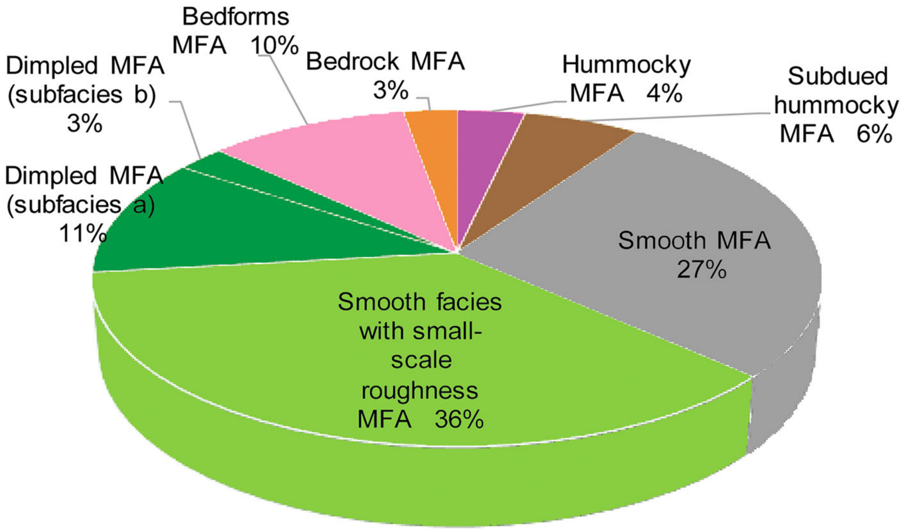

Figure 4. Pie chart showing the percentages of the areal fraction of each morpho-acoustic facies across the study area.

Escarpments are formed by almost straight break-in-slopes, with a maximum length of ~ 1500 m and relief up to 30 m (Figure 2). Approximately 70 escarpments mainly oriented NE-SW and N-S are recognised in the north-western and north-eastern sectors of the study area (i.e. along the flanks of the Elba-Pianosa Ridge), even if they are locally present also in the southern part. They have the same orientation of the general tectonic trend of the area (Pascucci, 2005) and thus could be interpreted as the seafloor expression of faults scarps affecting the study area.

Ridges are elongate positive features, up to 700 m long and 5 m high. They are mainly restricted to the eastern part of the study area between 30 and 60 m depth (Figure 2) while in the northern part they aligned with the NE-SW trend of most of the escarpments. In the central-eastern part, there is a cluster of 5 ridges with variable orientations. Their origin is difficult to ascertain without any additional data, but the most reliable interpretation is as piercement structures or bedrock outcrops.

Morphological highs are positive features, with diameters ranging from 65 to 390 m, heights from 7 to 35 m, and areas from 2000 to 110,000 m^2 (Figure 2). These features mainly occur as isolated features, generally having circular or elliptical shape, and only in few cases irregular. They are located both along the NW sector at depths greater than 40 m and on the central sector at depths shallower than 40 m. In this latter case, the four largest

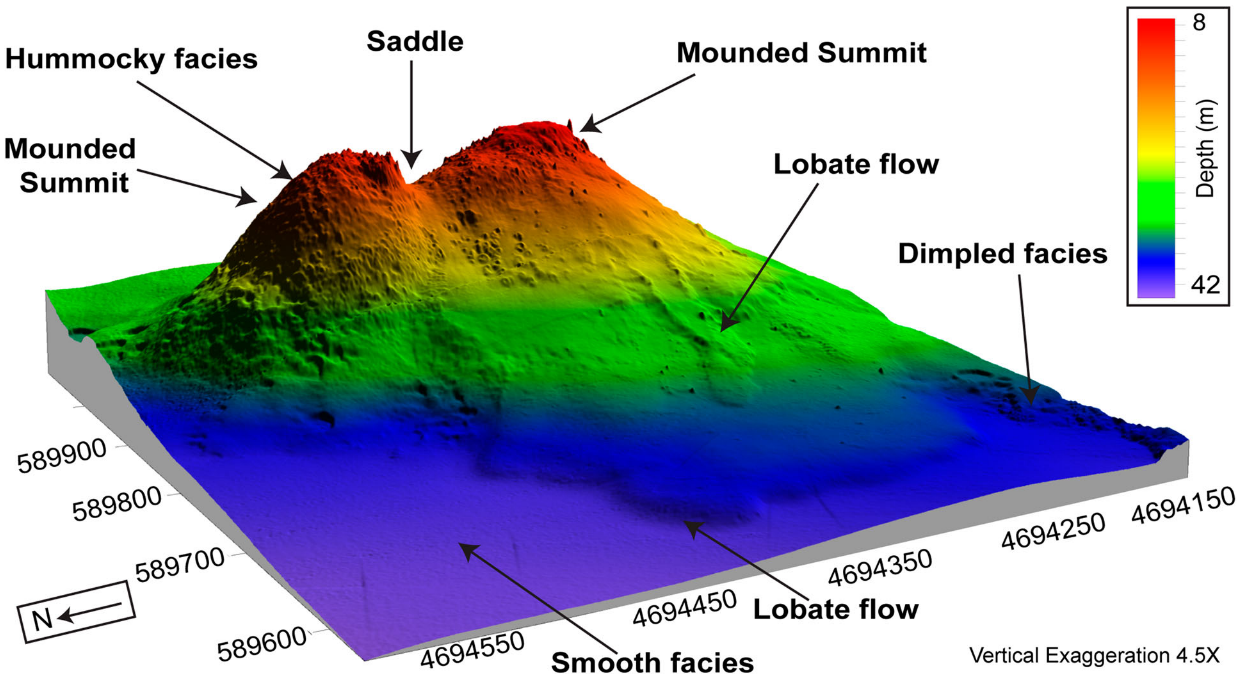

Figure 5. 3D bathymetric digital elevation model of the Scoglio d'Affrica MV1 (SdAMV1; Casalbore et al., 2020), where lobate flows are present. The location is shown in Figure 2.

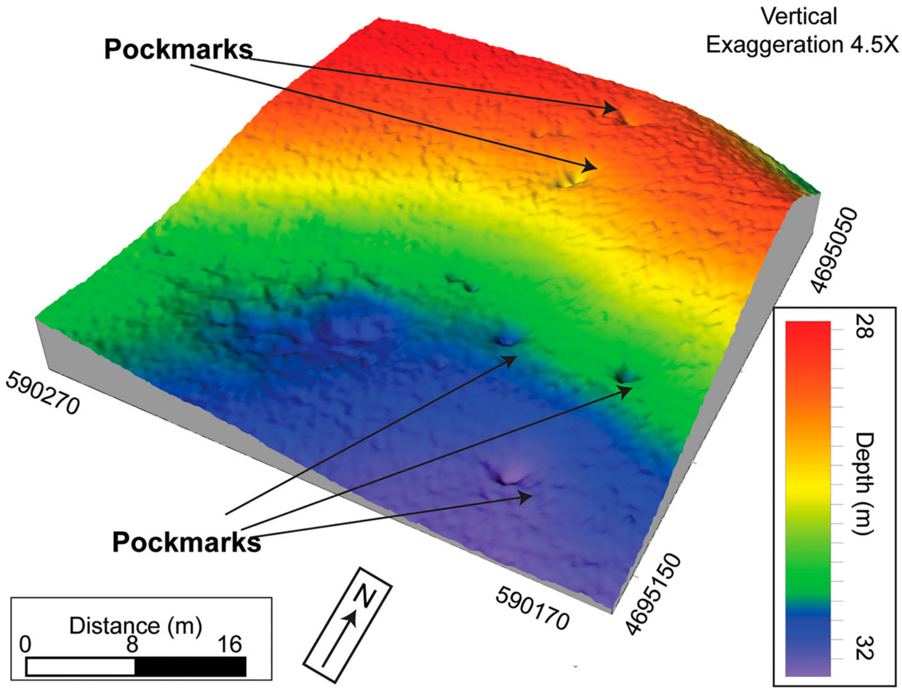

Figure 6. 3D bathymetric DEM showing a cluster of pockmarks. Location of the surface 3D multibeam bathymetry is shown in Figure 2.

morphological highs (in diameter and height) are located in a depth range of 7–25 m. They are mound-shaped and have generally flat summit, while lobate flows are often observed along their flanks (Figure 5). Both the summit and upper flanks of these features are characterised by smooth and hummocky morpho-acoustic facies (see section 3.1). Based on the available morphobathymetric data and direct observations (Casalbore et al., 2020; Ferretti et al., 2021; Saroni et al., 2020) most of these features can be interpreted as *mud volcanoes* (Figure 2; *sensu* Kopf, 2002; Milkov, 2000). Particularly, the mud volcano shown in Figure 5 was responsible for a violent gas outburst in March 2017 rising for 10 m above the surrounding sea level, as observed by local fishermen (Casalbore et al., 2020). It is also noteworthy that the mud volcano is actually the result of the coalescence of two mounds closely spaced which form an elongated ridge NNW-SSE oriented, in agreement with local structural trends, indicating a tectonic control in its development (Casalbore et al., 2020).

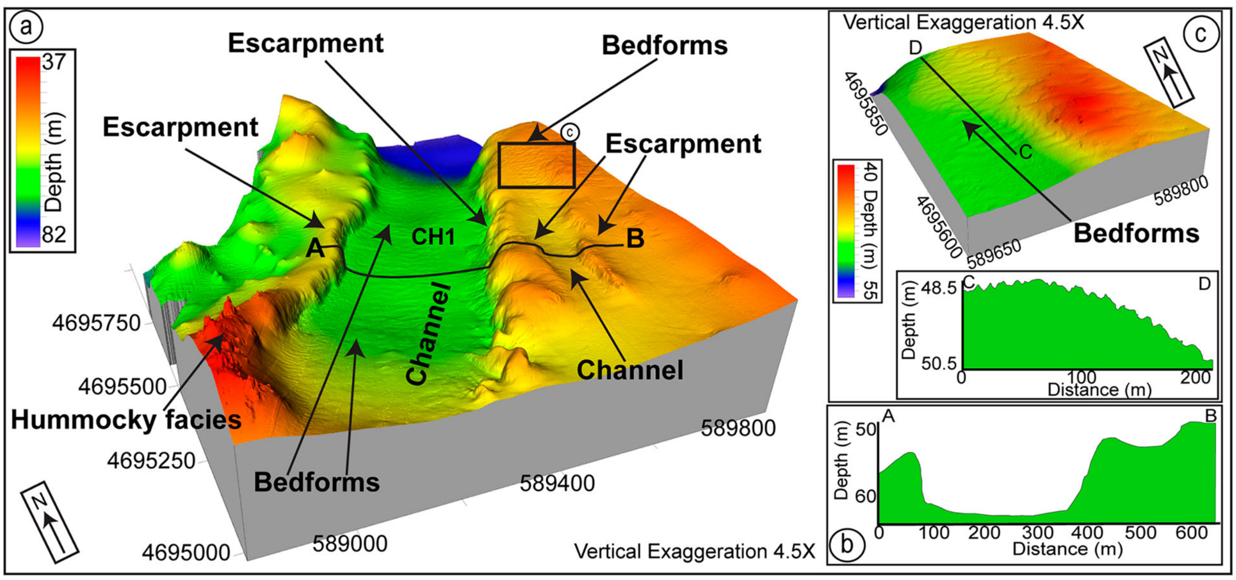

Figure 7. (a) 3D bathymetric digital elevation model showing the channelised feature (CH1). Location of the surface 3D multibeam bathymetry is shown in Figure 2. (b) Bathymetric profile across CH1 (location in 7a). (**c**) Zoom 3D bathymetric digital elevation model of the bedforms with relative bathymetric profile.

With the available data, we are unable to constrain our interpretation for all the morphological highs mapped in the study area. Some of them could be interpreted as rocky outcrops. However, taking into account their morphology, cross-sectional profile which show high similarity with the mud volcanoes described all over the word, and also considering their closeness to the identified mud volcanoes, these morphological highs could also have an origin linked to the mud volcanism of the area. Alternatively, they could be generically interpreted as '*Piercement structures*' (Judd & Hovland, 2007; Kopf, 2002; Mazzini & Etiope, 2017) related to the seafloor deformation associated with a rising mud diapirism, especially for those outcropping along the external sectors of the study area.

Pockmarks are small-scale circular or slightly elongated depressions, with a mean diameter of 15 m and depth shallower than 2.5 m. They can have U or V-shaped cross-section and are organised either as isolated, clustered or aligned along prevalent N-S trend, almost parallel to the N-S oriented escarpments (Figure 6). More than 250 sub-circular depressions are observed in the study area, mainly occurring in the depth range of 20–70 m (Figure 2). The morphology and size of the pockmarks around Scoglio d'Affrica islet are similar to those observed elsewhere in the Mediterranean Sea (Hovland et al., 1984; Micallef et al., 2022, 2019; Savini et al., 2009; Spatola et al., 2018a, 2018b; Taviani et al., 2013) and their origin is linked to the well-documented methane emissions in the study area (Casalbore et al., 2020; Del Bono & Giammarino, 1968; Ferretti et al., 2021; Saroni et al., 2020).

Channelised features. In the north-western part of the study area a channel (*sensu* Dove et al., 2020) is present and it is oriented NNE-SSW (CH1 in Figure 7), is more than 1600 m long and ~ 400 m wide (Figure 2). The cross-sectional profile of the channel is rather symmetric with walls up to 17 m high with gradients varying from a few degrees to about 35°. CH1 walls are scared by several small scars. The channel is U-shaped in cross-section (Figure 7). The channel floor gently (1° to 7°) slopes toward NE, starting at 40 m and continuing to the centre of the surveyed area. A second smaller channel runs parallel to CH1 for some 250 m (i.e. CH2 in Figure 7). The channels are probably floored by sediments, as suggested by the presence of bedforms (see chapter 3.1).

4. Conclusions

The very high-resolution bathymetric map presented in this work, describes at a scale of 1: 25,000 the distribution of morpho-acoustic facies and morphological features characterising the shallow marine sector around the Scoglio d'Affrica islet. On the whole, there is a marked morphological difference between the central part of the study area, corresponding to the top of the Elba-Pianosa Ridge and the peripheral areas, i.e. the ridge flanks. The first one hosts several mud volcanoes and numerous pockmarks, while outer ridge flanks the seafloor in both the western and the eastern parts is mainly dominated by escarpments and ridges, along with channels sometimes floored by fields of bedforms. Furthermore, small-scale roughness observed on the high-resolution bathymetric data allows recognising the presence of extensive *P. oceanica* meadows, settled on the seafloor above ~ 40 m depth and characterised by different morpho-acoustic facies, from compact to highly fragmented meadows intermingled with sandy patches of various shape and size. It is noteworthy that the distribution of the morpho-acoustic facies seems to be often independent from water depth (apart from the previous P. *oceanica* meadows due to biological reason), highlighting the variability and dynamics of geological and oceanographic processes in this area. The map allows to better define the character of this segment of the Elba-Pianosa Ridge, underlining the significant role of tectonics and of the active mud and fluid migration and escape processes in the shaping of the seafloor. It also provides insights for habitat mapping, especially in light of the widespread presence of *P. oceanica* meadow, which is listed among the most important ecosystems in the Mediterranean Sea. Finally, considering the shallow water setting of some active mud volcanoes, the high magnitude of the outburst occurred in 2017, and the maritime traffic in the area especially during summer touristic season, this study may also contribute to the hazard assessment of the area.

Software

Caris Hips&Sips 8.1.7 was used to process multibeam data and to generate the marine DTM, while Global Mapper 15 was used to visualise data using shaded relief maps, contour maps and slope gradient maps in order to perform morphological analyses, and extract morphological features from the DTM. The design of the final map presented in this work was produced using ArcMap 10.8 (http://www.esri.com/arcgis/) with additional refinement using the open source Inkscape software.

Acknowledgements

Multibeam bathymetry was acquired by the Istituto Idrografico della Marina, and thus we gratefully acknowledge the work of the captain and crews of the Italian Navy R\V Aretusa and the small boat MBN 1206. We are grateful to the National Park of the Tuscan Archipelago (www.islepark.it), the Tuscan Archipelago Carabinieri department, Capitaneria di Porto of Portoferraio, and the base of the National Research Council of Italy (CNR – IGG) for their support during the surveys. We thank Polina

Lemenkova, Chris Orton, and Willian Ney Cassol for their constructive comments.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was funded by Sapienza University project 'MARENDOGAS ' and by the 'dipartimento d'eccellenza' project. This work has also been financially supported by the 'Presidenza del Consiglio dei Ministri–Dipartimento della Protezione Civile ' (Presidency of the Council of Ministers Department of Civil Protection); this publication, however, does not reflect the position and the official policies of the Department. D.S. is founded by PON – "Research and Innovation" 2014-2020.

Data availability statement

Ideografico della Marina (IIM) for institutional purposes, so their access will be available by contacting the IIM reference people (robertaivaldi@marina.difesa.it, maurizio.demarte@marina.difesa.it) upon reasonable request. Similarly, ROV dive was collected by CNR-IGAG for Civil Protection purposes so their access will be available by contacting D.C. daniele.casalbore@uniroma1.it and the corresponding author upon request.

ORCID

Francesco Latino Chiocci http://orcid.org/0000-0002-4584-2258

References

Abadie, A., Gobert, S., Bonacorsi, M., Lejeune, P., Pergent, G., & Pergent-Martini, C. (2015). Marine space ecology and seagrasses. Does patch type matter in Posidonia oceanica seascapes? *Ecological Indicators*, *57*, 435–446. https://doi.org/10.1016/j.ecolind.2015.05.020

Bigi, G., Cosentino, D., Parotto, M., Sartori, R., & Scandone, P. (1992). Structural model of Italy 1: 500,000. *CNR Progetto Finalizzato Geodinamica*.

Casalbore, D., Ingrassia, M., Pierdomenico, M., Beaubien, S. E., Martorelli, E., Bigi, S., Ivaldi, R., DeMarte, M., & Chiocci, F. L. (2020). Morpho-acoustic characterization of a shallow-water mud volcano offshore Scoglio d'Affrica (Northern Tyrrhenian Sea) responsible for a violent gas outburst in 2017. *Marine Geology*, *428*, 106277. https://doi.org/10.1016/j.margeo.2020.106277

Cornamusini, G., Lazzarotto, A., Merlini, S., & Pascucci, V. (2002). Eocene-Miocene evolution of the north Tyrrhenian Sea. *Bollettino della Società Geologica Italiana*, *1*, 769–787.

Del Bono, G. L., & Giammarino, S. (1968). Rinvenimento di manifestazioni metanifere nelle Praterie a Posidonie sui fondi marini prospicienti lo «Scoglio d'Africa» nell'Arcipelago Toscano. *Atti Ist. Geol. Univ. Genova*, *6*.

Dove, D., Nanson, R., Bjarnadóttir, L. R., Guinan, J., Gafeira, J., Post, A., Dolan, M. F. J., Stewart, H., Arosio, R., & Scott, G. (2020). A two-part seabed geomorphology classification scheme:(v. 2). *Part 1: Morphology Features glossary*.

Ferretti, R., Caccia, M., Coltorti, M., & Ivaldi, R. (2021). New approaches for the observation of transient phenomena in critical marine environment. *Journal of Marine Science and Engineering*, *9*(6), 578. https://doi.org/10.3390/jmse9060578

Hovland, M., Judd, A. G., & King, L. H. (1984). Characteristic features of pockmarks on the north Sea floor and Scotian shelf. *Sedimentology*, *31*(4), 471–480. https://doi.org/10.1111/j.1365-3091.1984.tb01813.x

Judd, A., & Hovland, M. (2007). *Seabed fluid flow: The impact on geology, biology and the marine environment*. Cambridge University Press.

Kopf, A. J. (2002). Significance of mud volcanism. *Reviews of Geophysics*, *40*(2), 2-1–2-52. https://doi.org/10.1029/2000RG000093

Mazzini, A., & Etiope, G. (2017). Mud volcanism: An updated review. *Earth-Science Reviews*, *168*, 81–112. https://doi.org/10.1016/j.earscirev.2017.03.001

Micallef, A., Averes, T., Hoffmann, J., Crutchley, G., Mountjoy, J. J., Person, M., Cohen, D., Woelz, S., Bury, S. J., Ahaneku, C. V., Spatola, D., Luebben, N., Miserocchi, S., Krastel, S., Torelli, M., & Omosanya, K. O. (2022). Multiple drivers and controls of pockmark formation across the Canterbury Margin, New Zealand. *Basin Research*, *34*(4), 1374–1399. https://doi.org/10.1111/bre.12663

Micallef, A., Spatola, D., Caracausi, A., Italiano, F., Barreca, G., D'Amico, S., Petronio, L., Coren, F., Facchin, L., Blanos, R., Pavan, A., Paganini, P., & Taviani, M. (2019). Active degassing across the Maltese islands (Mediterranean Sea) and implications for its neotectonics. *Marine and Petroleum Geology*, *104*, 361–374. https://doi.org/10.1016/j.marpetgeo.2019.03.033

Milkov, A. V. (2000). Worldwide distribution of submarine mud volcanoes and associated gas hydrates. *Marine Geology*, *167*(1-2), 29–42. https://doi.org/10.1016/S0025-3227(00)00022-0

Motteran, G., & Ventura, G. (2005). Aspetti geologici, morfologici e ambientali dello Scoglio d'Africa (Arcipelago Toscano): Nota preliminare. *Atti Della Societa Toscana di Scienze Naturali, Memorie Serie A*, *110*, 51–60.

Papi, I., Pardi, G., Lenzini, S., Cecchi, L. B., & Cinelli, F. (1992). Benthic marine flora in the Tuscan Archipelago. A first contribution: Isles of Capraia, Elba, Formiche di Grosseto, Giglio, Scoglio d'Africa, Montecristo and Giannutri. *Plant Biosystem*, *126*, 549–593. https://doi.org/10.1080/11263509209430305

Pascucci, V. (2005). The Tuscan shelf south of the Elba Island (Italy) as imaged by the Crop M12A line. *Bollettino della Società geologica italiana*, *3*, 167–178.

Saroni, A., Sciarra, A., Grassa, F., Eich, A., Weber, M., Lott, C., Ferretti, G., Ivaldi, R., & Coltorti, M. (2020). Shallow submarine mud volcano in the northern Tyrrhenian sea, Italy. *Applied Geochemistry*, *122*, 104722. https://doi.org/10.1016/j.apgeochem.2020.104722

Savini, A. (2011). Side-scan sonar as a tool for seafloor imagery: Examples from the Mediterranean continental margin. In N. Kolev (Ed.), *Sonar systems* (pp. 299–322).

Savini, A., Malinverno, E., Etiope, G., Tessarolo, C., & Corselli, C. (2009). Shallow seep-related seafloor features along the Malta plateau (Sicily channel - Mediterranean Sea): Morphologies and geo-environmental control of their distribution. *Marine and Petroleum Geology*, *26*(9), 1831–1848. https://doi.org/10.1016/j.marpetgeo.2009.04.003

Spatola, D., Micallef, A., Sulli, A., Basilone, L., & Basilone, G. (2018a). Evidence of active fluid seepage (AFS) in the southern region of the central Mediterranean Sea. *Measurement*, *128*, 247–253. https://doi.org/10.1016/j.measurement.2018.06

Spatola, D., Micallef, A., Sulli, A., Basilone, L., Ferreri, R., Basilone, G., Bonanno, A., Pulizzi, M., & Mangano, S. (2018b). The Graham Bank (Sicily Channel, central Mediterranean Sea): Seafloor signatures of volcanic and tectonic controls. *Geomorphology*, *318*, 375–389. https://doi.org/10.1016/j.geomorph.2018.07.006

Taviani, M., Angeletti, L., Ceregato, A., Foglini, F., Froglia, C., & Trincardi, F. (2013). The Gela Basin pockmark field in the strait of Sicily (Mediterranean Sea): Chemosymbiotic faunal and carbonate signatures of postglacial to modern cold seepage. *Biogeosciences Discussions*, *10*(7), 4653–4671. https://doi.org/10.5194/bg-10-4653-2013