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SCIENCE

Geohazard features of the north-western Sicily and Pantelleria

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ABSTRACT
We present maps of geohazard features identified across north-western Sicily and Pantelleria in the framework of the Magic project (MArine Geohazard along Italian Coasts), which involved Italian marine geological researchers in 2007-2013. These seafloor features were recognized using high-resolution bathymetry data and rely on the morphological expression of the seafloor and shallow sub-surface processes. The north-western Sicily is a complex continental margin, affected by morphodynamic, depositional, and tectonic processes. The Egadi offshore is controlled by fault escarpments and alternating retreating and progradational processes. Ustica and Pantelleria submerged edifices show the effect of volcanic activity. The Ustica seafloor is interested in volcanic, tectonic, and gravitational instability processes, while the Pantelleria offshore underwent erosive-depositional processes and the effect of bottom currents. Two levels of interpretation are represented: the physiographic domain at a scale of 1:250.000 and the morphological units and morpho-bathymetric elements at a 1:100.000 scale.

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Magic project; multibeam bathymetry; geohazard; seafloor mapping

1. Introduction

The article illustrates the maps of Geohazard features of north-western Sicily and Pantelleria (Figure 1) produced by the Magic project (MArine Geohazard along Italian Coasts), a large coordinated initiative that involved the whole marine geological research community in Italy in 2007–2013. The features were derived from multibeam surveys and, therefore, mainly rely on all morphological expressions of seafloor and shallow sub-surface processes and events. Two levels of interpretation are presented: the map of the physiographic domain at a scale of 1:250.000 and the map of the morphological units and morpho-bathymetric elements (areas and vectors, respectively) at a 1:100.000 scale.

2. Study area: the north-western Sicily and Pantelleria

The continental margin off north-western Sicily, formed since the Neogene, is located in a transitional area between the Sicilian–Maghrebian Chain to the south and the Tyrrhenian Basin to the north and extends from the northern Sicilian continental shelf to the Marsili Basin (Figures 2 and 3; Sulli et al., 2013). In this sector, there are different morphological elements: (i) an about 8-km-wide continental shelf, characterized by an average slope of 1.5°; (ii) a continental slope, separated in an upper and a lower segment by flat areas at 1500 m depth; and (iii) a bathyal plain at 3000 m depth (Lo Iacono et al., 2014). During the quaternary, active morphogenesis in the continental shelf and slope and along the coastal zone has been strongly influenced by climate change, glacio-eustatic sea level changes, and the slow uplift of the N-Sicilian sector (Pepe et al., 2003; Sulli et al., 2012, 2021).

Along the northern Sicilian margin, different tectonic mechanisms coexist such as (a) a compressional, related to the formation of the Apennine–Maghrebian thrust belt, which acts at the collisional margin between the African and the Eurasian plates (Catalano et al.,

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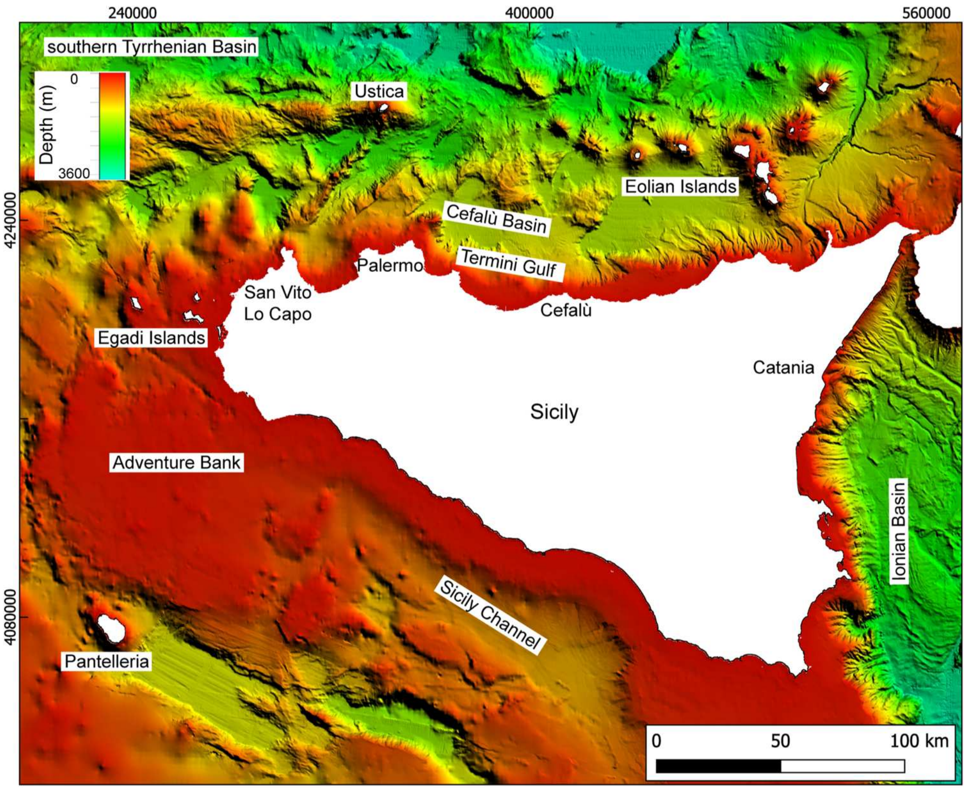

Figure 1. Geographical–geomorphological setting of the north-western Sicily and Pantelleria region. Background bathymetry from EMODnet bathymetry (http://www.emodnet-bathymetry.eu).

1994); (b) an extensional, related to the development of the back-arc zone of the Ionian–Tyrrhenian subduction complex (Faccenna et al., 1996); and (c) a transcurrent, between the before mentioned regions in two sectors (Bousquet & Lanzafame, 1995; Figure 3).

The Sicilian–Maghrebian Chain is composed of three layers: (1) Sicilide and Numidian Flysch units; (2) Meso-Cenozoic units of the deep sea; and (3) Meso-Cenozoic carbonates of the shallow sea (Catalano et al., 1994). The crystalline Kabilo–

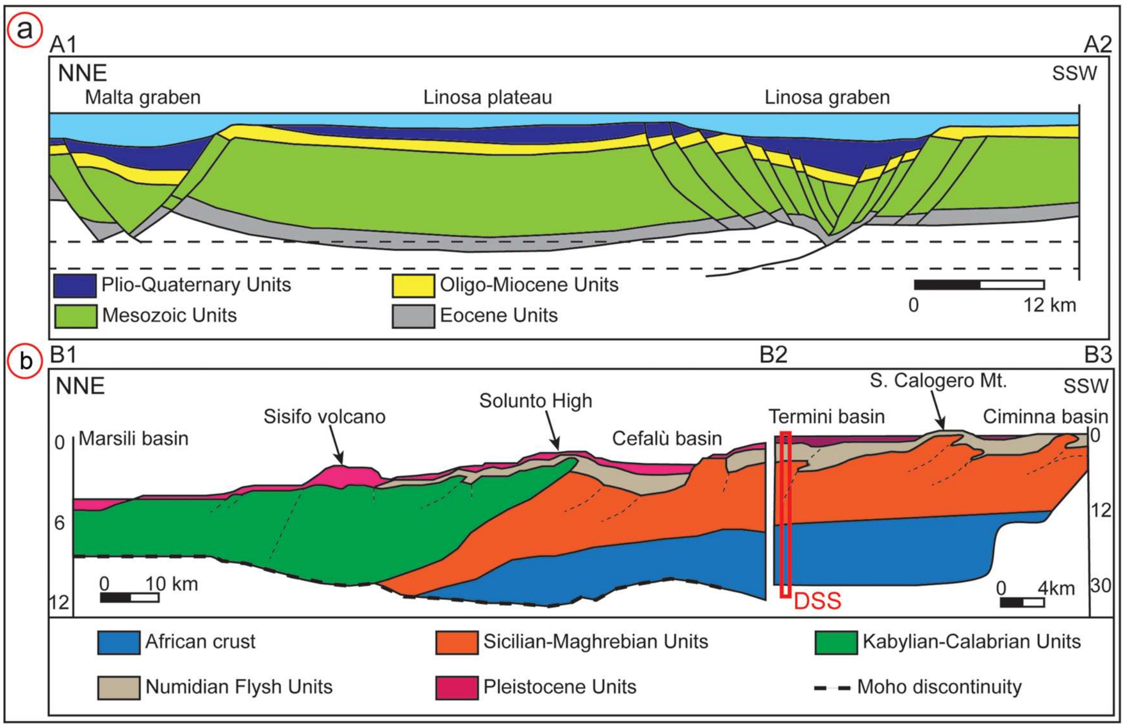

Figure 2. (a) Geological cross-sections from the Sicily Channel showing its stratigraphic and tectonic architecture (Civile et al., 2021 and reference therein). (b) Geological cross-sections from the Marsili Basin (Tyrrhenian Sea) to the Ciminna Basin (northern Sicily); DSS: deep seismic soundings (modified after Catalano et al., 2013).

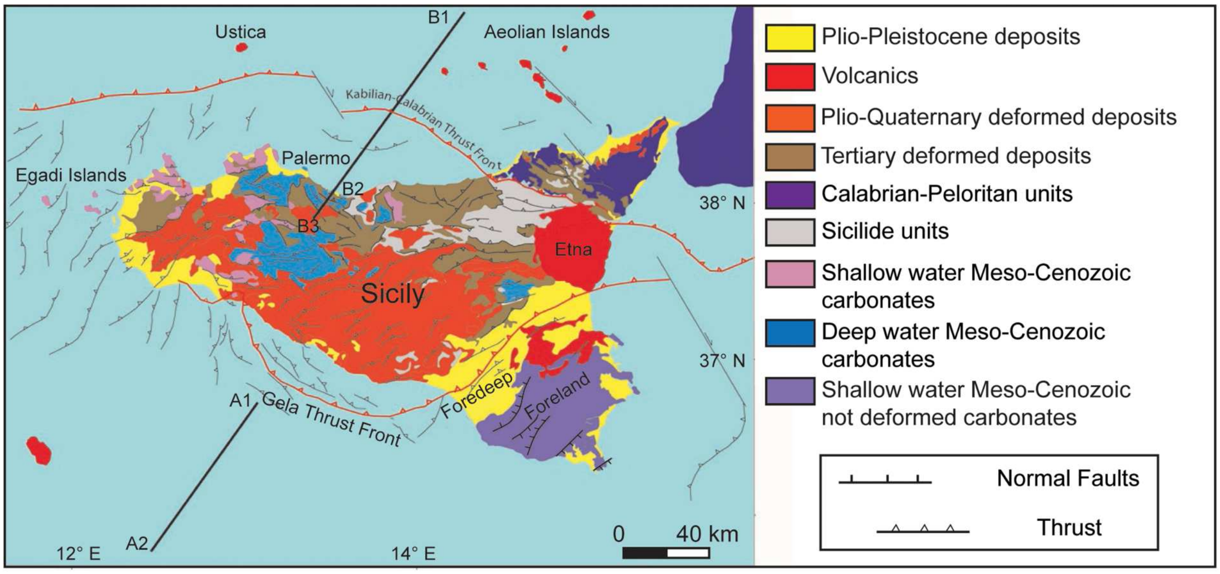

Figure 3. Structural map of Sicily and surrounding seas showing the stratigraphic units of Sicily, the main faults and thrust fronts. Locations of the geological cross-sections in Figure 2 are denoted in black (modified after Catalano et al., 2000).

Calabride unit overlies on the Sicilian–Maghrebian Chain along the front of Drepano, ESE–WNW trending, still active during the Pliocene (Sulli, 2000). Since the Messinian, the chain has been affected by extensional tectonics, followed by intra-mountain basin openings, bordered by listric growth faults, and filled by thick sedimentary successions (Fabbri et al., 1981). In the Late Pliocene–Early Pleistocene, a compressive tectonic phase caused the reactivation of E–W trending normal faults and the inversion of the basins (Agate et al., 2000).

During the Neogene–Quaternary, in the central Mediterranean Sea, tectono-magmatic features developed, like the one located in the N-Sicilian continental slope, where Aceste and Anchise submarine volcanoes formed (5.3–3.5 Ma), together with Ustica and the western sector of the Eolian Arc (<1 Ma) (Argnani & Savelli, 1999). Ustica Island is the top portion of a large volcano that rises from 3000 m depth (Sulli et al., 2020, 2021) and whose volcanic evolution occurred during five cycles of activity from 735 to 130 ka (De Vita et al., 1998). The southern Tyrrhenian Sea is characterized by different types of seismicity related to (a) processes of subduction of the Ionian plate; (b) the activities of magma chambers, with a maximum focus depth of 5 km; and (c) the upper plate seismicity with compressional focal mechanisms in the western sector, extensional in the central and eastern sectors, and strike-slip mechanisms between the Eolian Islands and the Peloritani Mountains (Agate et al., 2000; Giunta et al., 2009).

The Sicily Channel has been an active rifting zone since the Late Miocene, where it is possible to distinguish the Adventure Bank, the Gela Basin, Pantelleria, Linosa and Malta grabens (interpreted like pull-apart basins), the Maltese and Tunisian platform, and volcanic banks (Figure 2) (Colantoni, 1975; Spatola et al., 2018a; Todaro et al., 2021). The volcanic islands of Pantelleria and Linosa, the numerous seamounts, submarine banks and various volcanic events located along the NW–SE fault systems, and N–S strike-slip faults, represent the main expression of extensional tectonics (Civile et al., 2010; Corti et al., 2006). Pantelleria is a strato-volcano composed of 94% trachytes and peralkaline rhyolites known as Pantellerites (Parello et al., 2000). The Sicily Channel is characterized by a thinned continental lithosphere (60–70 km), and the Moho is 30- to 35-km-deep near the Sicilian coasts and about 20–25 km in correspondence of the three grabens (Agius et al., 2022; Civile et al., 2008). The Sicily channel seismicity is connected to the rifting that generates shallow earthquakes with low intensity (Calò & Parisi, 2014; Farrugia et al., 1987).

3. Methods and software

This study is based on a dataset acquired during a number of oceanographic surveys carried out in the framework of the MaGIC project. Research expeditions were carried out onboard the RVs Urania and Maria Grazia (CNR), R/V Universitatis (Conisma), and R/V Explora (OGS). In all the scientific expeditions, data were geo-referenced using a 'Differential Global Positioning System', and the attitude of the vessel was compensated through a motion sensor. Several CTD probes were collected to calibrate the sound velocity propagation within the seawater.

Bathymetric data were processed using the PDS-2000 software: post-processing steps included the processing of navigation data, the graphic removal of erroneous beams, noise filtering, and correction for sound velocity (more detail in Lo Iacono et al., 2011; Lo Iacono et al., 2014; Spatola et al., 2021). The resulting Digital Terrain Models (DTMs) were produced using different cell size resolutions, according to the water depth, and merged in a final 20 m resolution DTM. Global Mapper 10 was used to visualize data using shaded relief maps, contour maps, and slope gradient maps in order to perform morphological analyzes, and extract morphological features from the DTM.

The design of the final map presented in this work was produced using the open-source QGis (https://qgis.org) with additional refinement using the open-source Inkscape software. All the maps were produced using the interpretative and cartographic standards proposed by Chiocci and Ridente (2011). The legend of the 'Physiographic Domain map' is present on the map, while the legend of the 'Morphological Units and Morpho-bathymetric Elements map' is present as a separate table.

4. Maps of morphological units and morpho-bathymetric elements

4.1. Cefalù (MaGIC sheet 24)

The area represented by the Sheet 24 'Cefalù' lies in the central portion of the northern Sicily continental margin, extending from the coast up to the parallel of latitude 38° 17′ and including areas of shelf, slope, and intra-slope basin (Cefalù Basin in Figures 1 and 2(b)). Along this segment of the margin, the coast describes a large inlet, between Capo Zafferano and Capo Plaia, where the Gulf of Termini Imerese is hosted (Figure 1). The continental shelf is between 2.2-km-wide and more than 11-km-wide and displays an average slope between 1 and 2°. The area has been divided into two sections: one to the west between Cape Mongerbino and the mouth of the river Imera and another to the east between the mouth of the river Imera and the coast in front of S. Ambrogio village. These two areas, with very different morpho-structural settings, are separated by a feature that is developed in an NW–SE direction, where the extension of the continental shelf abruptly changes. The western sector is characterized by an intra-platform basin filled by a Plio-Quaternary prograding succession that unconformably rests on the pre-Pliocene substrate (Pepe et al., 2005). The basin fill, confined by a threshold elongated in a WNW–ESE direction, has favored the outward accretion of the margin, resulting in the increased wideness of the platform in this section. The western and wider part of the shelf is characterized by elongated, up to several km long, morphological relieves that are about 10 m high and located between 80 and 120 m in depth. The edge defines the platform between 125 and 160 m depth; it is retreating in front of Cape Plaia, deeply scoured by the canyon head.

The continental slope is widely affected by channelized gullies/canyons, which mainly develop following a straight course along the direction of maximum slope, strings of pockmarks (Pennino et al., 2014; Spatola et al., 2018b) and slide headscarps, widespread mainly in the junction zone between the slope and the Basin of Cefalù or in correspondence of the major fault escarpments (Sulli et al., 2012). Eastward, the threshold stops at the NW–SE tectonic lineament, beyond which the platform is narrower and steeper. Also, the slope shows different features between the two sections, resulting in narrower and steeper to the east, where we can observe a greater number of channelized gullies/canyons. Recent and/or active tectonic features deeply affect the shelf-to-slope system, by supporting the gravitational instability of the seabed and generating numerous channelized gullies and submarine landslides (Sulli et al., 2018). Along the margin, sub-vertical faults displace the Pleistocene–Quaternary succession also affecting the seabed and controlling the thalweg of the Cape Plaia Canyon (Lo Iacono et al., 2014). Other tectonic features along the shelf generated elongated morphological relieves with an E–W and NW–SE trending, which act as thresholds for the sediment. The recent tectonic activity is accompanied by a mild earthquake activity, characterized by low magnitude (2 <Md <3) and hypocenters depth <15 km, that is distributed along the platform and along the slope (Billi et al., 2010; Dignan et al., 2020).

4.2. Palermo (MaGIC sheet 25)

The Sheet 25 'Palermo' is characterized by the presence of the 'Gulf of Castellammare' and the 'Gulf of Palermo', which are separated by a quasi-rectilinear ridge representing the offshore extension of Palermo mounts (Figure 1). In this area, the continental shelf-slope system is characterized by striking differences concerning the continental shelf width and steepness, the nature and depth of the shelf edge, and the morphological features occurring along the seafloor. In the area, the morphology of the margin reflects the effects of different processes: the last eustatic oscillation, the activity of recent or still active tectonic features, and the gravitational instability. In detail, the continental shelf is between 2.5 and 8 km wide, with an average slope between 1° and 1.5°, and the edge is located between 120 and 165 m depth. An enhanced, upward concave break of slope, observed between 70 and 90 m depth in the Palermo Gulf and between 95 and 125 m depth in front of the Palermo mounts, represents the boundary that separates the inner and outer sectors of the shelf. Along the inner one, relict morphologies (paleocliffs, beach rocks, and marine abrasion terraces), which formed during the last sea level rise, are clearly recognized in the bathymetric data. This separation between the inner and outer shelf is absent in the Gulf of Castellammare (the western part). The continental slope domains stretch from the edge of the shelf down to about 1400 m depth, with average slope values between 5.5° and 8° (maximum values are observed along the flanks of the submerged Barra High, north of the Gulf of Palermo). Along both the Gulf of Castellammare and the Gulf of Palermo, the continental slope is scoured by numerous submarine canyons that constitute preferential pathways for the transport of sediments from the platform to the peri-Tyrrhenian intraslope basins (Lo Iacono et al., 2011, 2014). These sediments locally are reworked by bottom currents that form small contouritic drift deposits (Spatola et al., 2021). When comparing the two gulfs, canyons show very different morphological characters as a consequence of their different formation and evolution (Lo Iacono et al., 2014). The main differences concern the headscarp shape and the role played by the gravity mass movements that are more extensive along the canyon walls in the Palermo Gulf (Lo Iacono et al., 2011; Sulli et al., 2018). The seafloor both in the Gulf of Castellammare and the Gulf of Palermo is punctuated by more than 80 pockmarks U- or V-shaped cross-section and is either aligned along a prevalent N–S direction or occurred as isolated features and at times organized in small clusters (Pennino et al., 2014; Spatola et al., 2018b).

Also, in the area in front of the Palermo mounts, channelized gullies/canyons are well developed, the largest of which reaches a length of about 9 km and a depth of nearly 100 m. The canyons evolved through concurrent top-down turbiditic processes and bottom-up retrogressive mass failures were probably controlled by the activity of faults NNW–SSE and NE–SW-oriented (Lo Iacono et al., 2011). Tectonic features with these trends are widely distributed within the sheet (e.g. strings of pockmarks); they document a recent tectonic activity that generates an articulation of the seabed with morphological highs and lows separated by fault-forming scarps up to 300-m high. Some of the observed faults are also active and seismogenic, as documented by the distribution of earthquake epicenters. Indeed, focal mechanism solutions of seismic sequences of 1998 (M 5.2) and 2002 (M 5.6), whose solutions reveal compressive mechanisms NW–SE and ENE–WSW oriented, are aligned with some of the tectonic structures recognized.

4.2.1. Ustica (MaGIC sheet 26)

The Sheet 26 ‘Ustica’ is largely occupied by the volcanic edifices of Ustica and Anchises, which form a ridge approximately elongated in the E–W direction, which rises from 2500 m depth along the south-western margin of the Tyrrhenian bathyal plain (Figures 1 and 3). These two volcanic edifices show different characteristics: alkaline affinity and Pleistocene age for Ustica, and calc-alkaline affinity and probably Pliocene age for Anchises. The top of the Anchise Volcano is now submerged at 535 m depth, while the top of Ustica originated from an island that rises up to 245 m above the sea level. A narrow continental shelf encompasses the island, characterized by a marine abrasion surface (Furlani et al., 2017) shaped on the volcanic bedrock and covered with a thin layer of volcanoclastic and bioclastic sediments.

The insular shelf of Ustica Island is wide and more continuous along the north-western offshore, where it attains a maximum amplitude of about 2 km. The shelf break, predominantly erosive, occurs between 100 and 130 m depth. The submarine slope of the volcano shows different characters in the northern and southern sectors.

The northern submarine slope, down to 1900m depth, is characterized by a number of volcanic cones, having different sizes and heights; some of them are recent, as suggested by the well-preserved morphology. These small volcanic morphologies are often aligned with the main regional tectonic features recognized both onshore and offshore, which are oriented ENE–WSW and NW–SE (Sulli et al., 2021). In some cases, the cones dam the sediment transport bounding subplanar limited areas along submarine escarpments, with a slope between 3° and 5°. The major volcanic cones occur from 290 to 1130 m depth and reach heights up to 890 m and gradients along the flanks of approximately 38°; their basis is never smaller than 1.5 km^2.

The southern sector is steeper (up to 13°) and almost devoid of volcanic cones. The greater steepness of the submarine slope in this area promotes the onset of widespread processes of gravitational instability, as evidenced by amphitheater slide crown large up to 1700m, and accumulations showing landslide blocks or hummocky seafloor topography.

An approximately E–W direction escarpment between Ustica and Anchises following the trend of a recent, major tectonic lineament, is known as Arso Fault (Sulli et al., 2021). It has also been recognized in the outcrop on the Island of Ustica. At the base of the southern slope, the large intra-slope basin of Ustica lies below 2100 m depth. On the surface of the basin, NE–SW-oriented volcanic dikes are present, whereas northward, the seabed at the base of the slope deepens gradually toward the south Tyrrhenian bathyal plain.

4.3. Capo San Vito (MaGIC sheet 27)

In the Sheet 27 ‘Capo San Vito’, the San Vito Peninsula bounds to the west of the Gulf of Castellammare, which is the widest inlet along the northern Sicilian coast (Figure 1). The gulf is hosted in a structural low filled up by Plio-Quaternary deposits (Sulli et al., 2021). To the north, the basin is partly confined by the 'San Vito High', a structurally controlled relief made up of pre-Pliocene units and bordered by steep fault escarpments (Sulli et al., 2021).

Moving to the west, beyond the San Vito High, there is the Erice Basin, a tectonic trough confined, toward the west, by the Banco Scuso High. Beyond this high, the seabed deepens toward the Valle of Levanzo, along the southern side of the Trapani Basin. This sector of the northern Sicilian margin is characterized by the alternation of positive and negative structural morphologies, which make varied and articulated the physiography of the shelf-to-slope system. As a consequence, we observe relevant bathymetric gradients: the seabed reaches a maximum depth of about 2000m inside the Erice Basin, while the top of the San Vito High, located 10 km far from the Erice Basin, is about 100 m depth. This depth gradient enhances mass wasting processes in submarine escarpments and also in the continental slope, where extensive slope failures are generated by erosive sedimentary flows.

The widest intra-slope highs are Banco Scuso and San Vito, which confine a sector of the continental slope affected by several erosional features, where the Cofano Canyon System extends to the Erice Basin. Banco Scuso is a separate platform, elongated in a north–south direction, between Erice Basin and Trapani Basin. Banco Scuso is bordered by steep and straight flanks controlled by NW–SE and NE–SW tectonic lineaments, which enhance gravity instability phenomena along the submarine escarpments, where landslide headscarps and canyons can be recognized. A narrow depression separates the San Vito High from the San Vito Peninsula. This threshold develops in an NNE–SSW direction toward the Ustica Basin.

The continental shelf shows a highly variable extension over short distances: it extends up to 12 km in the bay of Cofano, narrows to a few hundred meters or less around the Peninsula of San Vito, and reaches a width of more than 5 km in the western sector of the Gulf of Castellammare. Even the depth of the shelf edge varies considerably around the Peninsula of San Vito. The shelf edge is located between 150 and 160 m depth in the bay of Cofano and between 50 and 150 m depth along the coast of the Gulf of Castellammare. Rapid changes in the depth of the shelf break are observed around the northern edge of the Peninsula of San Vito, in correspondence to the headscarps of the canyons that are set up along tectonic lineaments.

4.4. Egadi (MaGIC sheet 28)

The Sheet 28 'Egadi' includes the Egadi Archipelago, which consists of the Favignana, Levanzo, Maraone, and Formica islands, located on the continental shelf contiguous to Sicily, and the Island of Marettimo, which is located on a platform separated from the Sicilian shelf by the Valley of Marettimo (Figure 1).

The Valley of Marettimo is a narrow-elongated depression in the NNW–SSE direction, with depths ranging between 120 and 400 m. The northern extension of the Mazara Channel develops between the Sicilian shelf and Adventure Bank and flows to the north inside the valley toward the Trapani Basin. The continuity of the valley is interrupted by E–W/ENE–WSW thresholds, which originate downstream a depression with the typical structure of the rhombic pull-apart basins. Due to its location, the Valley of Marettimo intercepts a part of the flow of water masses that are pushed by the Levantine Intermediate Water current (LIW) across the Strait of Sicily and spread to the western Mediterranean Sea. Along the valley, bottom currents originate both erosional and depositional sedimentary features (Gasparo Morticelli et al., 2016).

South of the archipelago, off the coast from Capo Lilibeo to Torre S. Teodoro, Isola Lunga delimits a restricted sector of shallow waters with a couple of islands: Isola Santa Maria and Isola Pantaleo. This area (Stagnone di Marsala) is one of the rare examples of protected coastal areas in Sicily. The archipelago hosts one of the largest marine protected areas in Italy, which was founded in 1991. Along the archipelago of the Egadi Islands, the continental shelf reaches a width of about 30 km, one of the major extensions along the southern Tyrrhenian–Sicilian margin.

On the seabed at different depth ranges, extensive flat surfaces separated by low-angle escarpments are found, together with morphologic relieves of variable size and composition, which are controlled by tectonic features, and where extensive coralligenous formations accumulate (Banco dei Pesci, Secca di Levanzo, and Secca del Toro). Bedforms characterized by various sizes and paleo-tombolos originated during the last sea level rise when the sea level was at a deeper level (Agnesi et al., 1993) are also present.

The continental shelf edge displays a very complex topography, alternating retreating and progradational segments. The continental shelf edge takes a straight course for long stretches, being controlled by recent structural lineaments (Gasparo Morticelli et al., 2016). These are evident, especially around Marettimo Island and along the continental slope, with a prevailing WNW–ESE and NNW–SSE direction. The progradational margin is well developed, especially in the area south-west of the Island of Favignana (D'Angelo et al., 2004).

4.5. Pantelleria (MaGIC sheet 30)

The Sheet 30 'Pantelleria' includes Pantelleria Island, which is located in the Sicily Channel, 85 km from the coasts of Sicily and 70 km off from Tunisia, and represents the emerged part (about 20%) of a larger volcanic edifice, whose base is located at about 1200 m depth (Figure 1). The Pantelleria volcanic complex has an eruptive history characterized by cyclic activity, with periods of quiescence followed by periods of low-energy eruptions and large explosive eruptions, often followed by effusive volcanism. Some of the largest explosive eruptions caused two caldera collapses, the most recent took place following the eruption of the Green Tuff (~ 45 ka BP, Mahood & Hildreth, 1986; Orsi et al., 1991). Over the past 30 ka, the caldera has been affected by the resurgence, with the uplifting and tilting of the Montagna Grande Block (836 m). The most recent activity at Pantelleria was a shallow submarine eruption that occurred in 1891. The eruption, about 5 km off the NW coasts of the island, was detected by the occurrence of floating 'lava balloon', hollow lava blocks, reaching a maximum diameter of 1.5 m (Riccò, 1892; Washington, 1909).

The island is actually affected by widespread hydrothermal vents, such as hot springs and thermal wells, low-flow-rate persistent fumaroles and emanations of pure CO_2 (mofettes). The volcanic edifice is elongated in the NW–SE direction, as a consequence of the main tectonic trends that controlled the opening and development of the Sicilian Channel rift (Figure 2). The insular shelf has different morphology around the edifice; in the NW sector, it extends for more than 4 km between the coastline and the shelf break, located at about 120 m depth, whereas it reaches 1.5 km of width in the SE sector. Conversely, in the NE and SW flanks, the insular shelf is narrow or totally absent, and the shelf break is located at ~100 m depth. Except for the NW sector, submerged depositional terraces, with the edge located between 40 and 50 m depth, can be locally observed around the island. The flanks of the Pantelleria volcanic edifice are characterized by several features related to volcanic activity and erosive-depositional processes. Specifically, volcanic cones, eruptive fissures and lava flows were recognized in both shallow and deep areas. A large volcanic field is located in the NW sector of the edifice and is composed of 26 centers characterized by a fresh morphology, including the vent responsible for the 1891 submarine eruption (Conte et al., 2014). Instability-erosive phenomena are widespread along the flanks, encompassing erosive channels and slide scars. A landslide deposit covering an area of about 14 km^2 was observed at the toe of the NW flank. Several erosive channels were also observed, sometimes indenting the insular shelf and the submerged depositional terrace up to 40–60 m depth, less than 100 m far from the coastline.

Contourite deposits, formed under the influence of bottom currents of the Sicily Channel, mainly occur at the base of the slope that borders the Pantelleria Basin (Martorelli et al., 2011). On the continental slope west of Pantelleria Island, between 250 and 500 m depth, several morphological reliefs interpreted as bioherms were observed. They are a few meters high and are characterized by a sub-circular shape in plan view.

5. Conclusions

The interpretation of multibeam data off north-western Sicily and Ustica and Pantelleria islands allowed us to identify and map the main potential geohazard elements characterizing these sectors of the Central Mediterranean. Both in the Ustica and in the Pantelleria regions, the main documented morphologies are mainly related to past and/or recent volcanic activity sometimes controlled by the tectonics affecting the areas. Besides the well-preserved volcanic morphologies, the Ustica seafloor is interested in tectonic processes and gravitational instability, while the Pantelleria offshore is mainly characterized by erosive-depositional processes often associated with bottom currents.

The north-western Sicily shelf-to-slope system, including the peri-Tyrrhenian intraslope basins, is characterized by seafloor morphologies with genesis linked to different geological processes (e.g. tectonics, fluid flow, and slope failure). In detail, the seafloor in the area is marked by a number of circular pockmarks, steep fault escarpments, channelized gullies/canyons, and mass transport deposits. These features, as well as the variable width and steepness of both the shelf and the slope, highlight the strong tectonic activity of the margin, the eustatic oscillation, active fluid seepage, and the gravitational instability.

Finally, the Egadi offshore is a more stable area, and its seafloor is affected mainly by a narrow-elongated channel (Marettimo Valley) that separates the Marettimo from the western Sicily shelf, which includes the Favignana and Levanzo islands. The distribution of the seafloor morphologies (e.g. fault escarpments) in the area suggests an important control by tectonics and alternating retreating and progradational processes.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

Department of Earth and Marine Science of the University of Palermo for institutional purposes, so their access will be available by contacting the reference people (attilio.sul-liunipa.it) upon reasonable request.

References

Agate, M., Beranzoli, L., Braun, T., Catalano, R., Frugoni, F., Favali, P., Pepe, F., Smriglio, G., & Sulli, A. (2000). The 1998 NW Sicily offshore earthquakes in the tectonic framework of the southern border of the Tyrrhenian Sea. *Memorie della Societa` Geologica Italiana*, *55*, 103–114.

Agius, M. R., Magrini, F., Diaferia, G., Kästle, E. D., Cammarano, F., Faccenna, C., Funiciello, F., & van der Meijde, M. (2022). Shear-velocity structure and dynamics beneath the Sicily Channel and surrounding regions of the central Mediterranean inferred from seismic surface waves. *Geochemistry, Geophysics, Geosystems*, *23*(10), e2022GC010394. https://doi.org/10.1029/2022GC010394

Agnesi, V., Macaluso, T., Orrù, P., & Ulzega, A. (1993). Paleogeografia dell'arcipelago delle Egadi (Sicilia) nel Pleistocene sup.-olocene. *Naturalista Siciliano*, *17*, 3–22.

Argnani, A., & Savelli, C. (1999). Cenozoic volcanism and tectonics in the Southern Tyrrhenian sea: Space-time distribution and geodynamic significance. *Journal of Geodynamics*, *27*(4), 409–432. https://doi.org/10.1016/S0264-3707(98)00025-8

Billi, A., Presti, D., Orecchio, B., Faccenna, C., & Neri, G. (2010). Incipient extension along the active convergent margin of Nubia in Sicily, Italy: Cefalù-Etna seismic zone. *Tectonics*, *29*(4), 1–20. https://doi.org/10.1029/2009TC002559

Bousquet, J.-C., & Lanzafame, G. (1995). Transition from Tyrrhenian basin extension to collisional tectonics: Evidence of NS compression during the recent Quaternary at Ustica (southern Tyrrhenian Sea, Italy). *Comptes rendus de l'Académie des sciences. Série 2. Sciences de la terre et des planètes*, *321*(9), 781–787.

Calò, M., & Parisi, L. (2014). Evidences of a Lithospheric fault zone in the Sicily Channel (Southern Italy) from instrumental seismicity data. *Geophysical Journal International*, *199*(1), 219–225. https://doi.org/10.1093/gji/ggu249

Catalano, R., Franchino, A., Merlini, S., & Sulli, A. (2000). Central western Sicily structural setting interpreted from seismic reflection profiles. *Memorie della Società Geologica Italiana*, *55*, 5–16.

Catalano, R., Infuso, S., & Sulli, A. (1994). The submerged Alpidic Chain from southern Sardinia shelf to the Pelagian rifting: Tectonic history. *Bollettino di Geofisica Teorica ed Applicata*, *36*(141–144), 139–158.

Catalano, R., Valenti, V., Albanese, C., Accaino, F., Sulli, A., Tinivella, U., Gasparo Morticelli, M., Zanolla, C., & Giustiniani, M. J. J. O. T. G. S. (2013). Sicily's fold–thrust belt and slab roll-back: The SI. RI. PRO. Seismic crustal transect. *Journal of the Geological Society*, *170*(3), 451–464. https://doi.org/10.1144/jgs2012-099

Chiocci, F. L., & Ridente, D. (2011). Regional-scale seafloor mapping and geohazard assessment. The experience from the Italian project MaGIC (Marine Geohazards along the Italian Coasts). *Marine Geophysical Research*, *32*(1–2), 13–23. https://doi.org/10.1007/s11001-011-9120-6

Civile, D., Brancolini, G., Lodolo, E., Forlin, E., Accaino, F., Zecchin, M., Brancatelli, G., & Billi, A. J. L. (2021). Morphostructural setting and tectonic evolution of the central part of the Sicilian Channel (Central Mediterranean). *Lithosphere*, *2021*(1), Article 7866771. https://doi.org/10.2113/2021/7866771

Civile, D., Lodolo, E., Accettella, D., Geletti, R., Ben-Avraham, Z., Deponte, M., Facchin, L., Ramella, R., & Romeo, R. (2010). The Pantelleria graben (Sicily Channel, Central Mediterranean): An example of intraplate 'passive' rift. *Tectonophysics*, *490*(3), 173–183. https://doi.org/10.1016/j.tecto.2010.05.008

Civile, D., Lodolo, E., Tortorici, L., Lanzafame, G., & Brancolini, G. (2008). Relationships between magmatism and tectonics in a continental rift: The Pantelleria Island region (Sicily Channel, Italy). *Marine Geology*, *251*(1), 32–46. https://doi.org/10.1016/j.margeo.2008.01.009

Colantoni, P. (1975). Note di Geologia marina sul Canale di Sicilia. *Giornale di Geologia*, *40*, 181–207.

Conte, A. M., Martorelli, E., Calarco, M., Sposato, A., Perinelli, C., Coltelli, M., & Chiocci, F. L. (2014). The 1891 submarine eruption offshore Pantelleria Island (Sicily Channel, Italy): Identification of the vent and characterization of products and eruptive style. *Geochemistry, Geophysics, Geosystems*, *15*(6), 2555–2574. https://doi.org/10.1002/2014GC005238

Corti, G., Cuffaro, M., Doglioni, C., Innocenti, F., & Manetti, P. (2006). Coexisting geodynamic processes in the Sicily Channel. *Geological Society of America Special Papers*, *409*, 83–96.

D'Angelo, S., Lenbo, P., & Sacchi, L. (2004). Terrazzi de posizionali sommersi al largo dell'Isola di Favignana (Isole Egadi). *Memorie Descrittive Carta Geologica D'Italia*, *LVIII*, 125–132.

De Vita, S., Laurenzi, M. A., Orsi, G., & Voltaggio, M. (1998). Application of 40Ar/39Ar and 230Th dating methods to the chronostratigraphy of Quaternary basaltic volcanic areas: The Ustica island case history. *Quaternary International*, *47*, 117–127. https://doi.org/10.1016/S1040-6182(97)00077-3

Dignan, J., Micallef, A., Mueller, C., Sulli, A., Zizzo, E., & Spatola, D. (2020). A scenario-based assessment of the tsunami hazard in Palermo, Northern Sicily, and the Southern Tyrrhenian Sea. *Geological Society, London, Special Publications*, *500*(1), 63–80. https://doi.org/10.1144/SP500-2019-181

Fabbri, A., Gallignani, P., & Zitellini, N. (1981). Geologic evolution of the Peri-Tyrrhenian Sedimentary Basins. In F. C. Wezel (Ed.), *Sedimentary Basins of Mediterranean Margins. C.N.R., Italian Project Oceanogr., 22 fig.* (pp. 101–126). Tecnoprint.

Faccenna, C., Davy, P., Brun, J.-P., Funiciello, R., Giardini, D., Mattei, M., & Nalpas, T. J. G. J. I. (1996). The dynamics of back-arc extension: An experimental approach to the opening of the Tyrrhenian Sea. *Geophysical Journal International*, *126*(3), 781–795. https://doi.org/10.1111/j.1365-246X.1996.tb04702.x

Farrugia, P., Apopei, I., & Bonjer, K. P. (1987). Observations of seismicity of the Sicily Channel. *Memorie della Società Geologica Italiana*, *38*, 329–340.

Furlani, S., Antonioli, F., Cavallaro, D., Chirco, P., Caldareri, F., Martin, F. F., Morticelli, M. G., Monaco, C., Sulli, A., Quarta, G., Biolchi, S., Sannino, G., de Vita, S., Calcagnile, L., & Agate, M. (2017). Tidal notches, coastal landforms and relative sea-level changes during the Late Quaternary at Ustica Island (Tyrrhenian Sea, Italy). *Geomorphology*, *299*, 94–106. https://doi.org/10.1016/j.geomorph.2017.10.004

Gasparo Morticelli, M., Sulli, A., & Agate, M. (2016). Sea-land geology of Marettimo (Egadi Islands, central Mediterranean Sea). *Journal of Maps*, *12*(5), 1093–1103. https://doi.org/10.1080/17445647.2015.1127858

Giunta, G., Luzio, D., Agosta, F., Calò, M., Di Trapani, F., Giorgianni, A., Oliveri, E., Orioli, S., Perniciaro, M., Vitale, M., & Adelfio, G. (2009). An integrated approach to investigate the seismotectonics of northern Sicily and southern Tyrrhenian. *Tectonophysics*, *476*(1-2), 13–21. https://doi.org/10.1016/j.tecto.2008.09.031

Lo Iacono, C., Sulli, A., & Agate, M. (2014). Submarine canyons of north-western Sicily (Southern Tyrrhenian Sea): Variability in morphology, sedimentary processes and evolution on a tectonically active margin. *Deep-Sea Research II*, *104*, 93–105. https://doi.org/10.1016/j.dsr2.2013.06.018

Lo Iacono, C., Sulli, A., Agate, M., Presti, V. L., Pepe, F., & Catalano, R. (2011). Submarine canyon morphologies in the Gulf of Palermo (Southern Tyrrhenian Sea) and possible implications for geo-hazard. *Marine Geophysical Research*, *32*(1-2), 127. https://doi.org/10.1007/s11001-011-9118-0

Mahood, G. A., & Hildreth, W. (1986). Geology of the peralkaline volcano at Pantelleria, Strait of Sicily. *Bulletin of Volcanology*, *48*(2–3), 143–172. https://doi.org/10.1007/BF01046548

Martorelli, E., Petroni, G., & Chiocci, F. L. (2011). Contourites offshore Pantelleria Island (Sicily Channel, Mediterranean Sea): Depositional, erosional and biogenic elements. *Geo-Marine Letters*, *31*(5-6), 481–493. https://doi.org/10.1007/s00367-011-0244-0

Orsi, G., Ruvo, L., & Scarpati, C. (1991). The recent explosive volcanism at Pantelleria. *Geologische Rundschau*, *80*(1), 187–200. https://doi.org/10.1007/BF01828776

Parello, F., Allard, P., D'Alessandro, W., Federico, C., Jean-Baptiste, P., & Catani, O. (2000). Isotope geochemistry of Pantelleria volcanic fluids, Sicily Channel rift: A mantle volatile end-member for volcanism in Southern Europe. *Earth and Planetary Science Letters*, *180*(3), 325–339. https://doi.org/10.1016/S0012-821X(00)00183-7

Pennino, V., Sulli, A., Caracausi, A., Grassa, F., & Interbartolo, F. (2014). Fluid escape structures in the north Sicily continental margin. *Marine and Petroleum Geology*, *55*, 202–213. https://doi.org/10.1016/j.marpetgeo.2014.02.007

Pepe, F., Sulli, A., Agate, M., Di Maio, D., Kok, A., Iacono, C. L., & Catalano, R. (2003). Plio-Pleistocene geological evolution of the northern Sicily continental margin (southern Tyrrhenian Sea): New insights from high-resolution, multi-electrode sparker profiles. *Geo-Marine Letters*, *23*(1), 53–63. https://doi.org/10.1007/s00367-003-0124-3

Pepe, F., Sulli, A., Bertotti, G., & Catalano, R. (2005). Structural highs formation and their relationship to sedimentary basins in the north Sicily continental margin (southern Tyrrhenian Sea): Implication for the Drepano Thrust Front. *Tectonophysics*, *409*(1–4), 1–18. https://doi.org/10.1016/j.tecto.2005.05.009

Riccò, A. (1892). Terremoti, sollevamento ed eruzione sottomarina a Pantelleria nella seconda metà dell'ottobre 1891. *Annali Ufficio Centrale Meteorologico e Geodinamico*, *XIV*(2), 130–156.

Spatola, D., Micallef, A., Sulli, A., Basilone, L., & Basilone, G. (2018b). 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.2018.06.058

Spatola, D., Micallef, A., Sulli, A., Basilone, L., Ferreri, R., Basilone, G., Bonanno, A., Pulizzi, M., & Mangano, S. (2018a). 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

Spatola, D., Sulli, A., Casalbore, D., & Chiocci, F. L. (2021). First evidence of contourite drifts in the North-Western Sicilian active continental margin (Southern Tyrrhenian Sea). *Journal of Marine Science and Engineering*, *9*(10), 1043. https://doi.org/10.3390/jmse9101043

Sulli, A. (2000). Structural framework an crustal characteristics of the Sardinia Channel alpine transect in the central Mediterranean. *Tectonophysics*, *324*(4), 321–336. https://doi.org/10.1016/S0040-1951(00)00050-0

Sulli, A., Agate, M., Lo Iacono, C., Lo Presti, V., Pennino, V., Polizzi, S., & Sassa, K. (2013). Submarine slope failures along the northern Sicilian Continental Margin (southern Tyrrhenian Sea) and possible implications for geohazard. In C. Margottini & P. Canuti (Eds.), *Landslide science and practice* (Vol. 5, pp. 41–48). Springer-Verlag. ISBN: 3642314260.

Sulli, A., Agate, M., Mancuso, M., Pepe, F., Pennino, V., Polizzi, S., Presti, V. L., Gargano, F., & Interbartolo, F. (2012). Variability of depositional setting along the north-western Sicily continental shelf (Italy) during late Quaternary: Effects of sea level changes and tectonic evolution. *Alpine and Mediterranean Quaternary*, *25*(2), 141–156.

Sulli, A., Agate, M., Zizzo, E., Gasparo Morticelli, M., & Lo Iacono, C. (2021). Geo-hazards of the San Vito peninsula offshore (southwestern Tyrrhenian Sea). *Journal of Maps*, *17*(3), 185–196. https://doi.org/10.1080/17445647.2020.1866703

Sulli, A., Zizzo, E., & Albano, L. (2018). Comparing methods for computation of run-up heights of landslide-generated tsunami in the Northern Sicily continental margin. *Geo-Marine Letters*, *38*(5), 439–455. https://doi.org/10.1007/s00367-018-0544-8

Sulli, A., Zizzo, E., Spatola, D., Morticelli, M. G., Agate, M., Iacono, C. L., Gargano, F., Pepe, F., & Ciaccio, G. (2020). Growth and geomorphic evolution of the Ustica volcanic complex at the Africa-Europe plate margin (Tyrrhenian Sea). *Geomorphology*, *374*, Article 107526. https://doi.org/10.1016/j.geomorph.2020.107526

Todaro, S., Sulli, A., Spatola, D., Micallef, A., Di Stefano, P., & Basilone, G. (2021). Depositional mechanism of the upper Pliocene-Pleistocene shelf-slope system of the western Malta Plateau (Sicily Channel). *Sedimentary Geology*, *417*, Article 105882. https://doi.org/10.1016/j.sedgeo.2021.105882

Washington, H. S. (1909). The submarine eruption of 1831 and 1891 near Pantelleria. *American Journal of Science*, *27*(158), 131–150. https://doi.org/10.2475/ajs.s4-27.158.131