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Abstract

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Keywords (separated by '-')	Ischia - Naples Bay - Buried volcanic edifices - Multibeam bathymetry - Seismic stratigraphy
Footnote Information	The results presented here were derived from the scientific and technical activities related to the mapping of marine geology of the Ischia Island (“Isola d’Ischia”, map 464, at the scales 1:25,000 and 1:10,000). The marine geologic mapping offshore of the Campania region was accomplished under the direction of Prof. B. D’Argenio and in part Dott. E. Marsella. Marine geological survey of the southeastern Ischia offshore at water depths ranging between 30 and 200 m has been carried out by Dott. Gemma Aiello on the basis of data collected at sea. **Electronic supplementary material** The online version of this article (doi:10.1007/s12210-012-0204-2) contains supplementary material, which is available to authorized users.

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Electronic supplementary material	Below is the link to the electronic supplementary material.**Fig ESM1 (Online Resource 1)**: Sidescan Sonar photomosaic showing the hummocky facies located in the western offshore of Ischia, between Punta del Soccorso and Punta Imperatore. And interpreted as debris avalanche deposits. (TIFF 73081 kb)**Fig ESM2 (Online Resource 2)**: Sketch section, showing the geometric relationships between systems tracts and the distribution of siliciclastic facies in the depositional sequences bounded by unconformities. Systems tracts: HST: highstand; TST: transgressive; LST: lowstand; FSST: falling stage (modified after Vail et al. 1977; Christie-Blick 1991; Helland-Hansen and Gielberg 1994). (TIFF 2393 kb)**Fig ESM3 (Online Resource 3):** The southern Ischia coastal cliff at the “Grotta del Mavone” cave (see the text for further explanation). (TIFF 36951 kb)**Fig ESM4 (Online Resource 4)**: Seismic profile L39 recorded in the southern Ischia offshore (Punta del Chiarito) and its geologic interpretation. (TIFF 10990 kb)**Fig ESM5 (Online Resource 5)**: The coastal cliff at the Scarrupata di Barano. (TIFF 46348 kb)**Fig ESM6 (Online Resource 6)**: Seismic profile L47 recorded in the southeastern Ischia offshore at Punta San Pancrazio and its geologic interpretation. (TIFF 9325 kb)

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Stratigraphic and structural setting of the Ischia volcanic complex (Naples Bay, Southern Italy) revealed by submarine seismic reflection data

Gemma Aiello · Ennio Marsella · Salvatore Passaro

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Abstract High-resolution seismic reflection profiles (Sparker Multitip) offshore southern Ischia Island (Naples Bay) are presented, together with a geological interpretation of their volcanic, structural and sedimentary features. In this frame, new seismo-stratigraphic evidences on buried volcanic structures and overlying Quaternary deposits of the southeastern offshore of the Ischia Island are discussed to highlight their implications on the marine geophysics and volcanology. The Ischia Bank is a large and flat relic volcanic edifice with steep slopes, merging on the continental shelf. The age of this monogenic volcano is unknown, lacking a direct datation of its basement. It represents the eruptive center of the pyroclastic fall cropping out onshore in the eastern sectors of the island, ranging in age from 8 to 6 ky BP. In the eastern Ischia offshore relic volcanic edifices, mostly formed by hialoclastites, have been investigated through high-resolution seismics. They represent remnants of hydro-magmatic volcanic vents and suggest a subaqueous emplacement. Regional seismic sections in the southeastern Ischia offshore, across buried volcanic structures, are finally presented and discussed.

Keywords Ischia · Naples Bay · Buried volcanic edifices · Multibeam bathymetry · Seismic stratigraphy

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Electronic supplementary material The online version of this article (doi:10.1007/s12210-012-0204-2) contains supplementary material, which is available to authorized users.

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1 Introduction

High-resolution seismic reflection profiles offshore southeastern Ischia Island are presented to give a geological interpretation of its volcanic, structural and sedimentary features. In this frame, new seismo-stratigraphic evidences on buried volcanic structures and related Quaternary deposits in the southeastern offshore of the Ischia Island, particularly in the southern continental slope of Ischia and Ischia Channel, are presented.

A densely spaced grid of single-channel seismic profiles has been recently acquired and interpreted in the frame of research programs of marine cartography (CARG Project) financed by the Campania Region (Sector of Soil Defence, Geothermics and Geotechnics) during the mapping of the marine areas of the geological sheet n. 464 "Isola d'Ischia" at the scale 1:25,000 (Figs. 1, 2). Some of the collected seismo-stratigraphic data are interpreted and discussed to highlight new implications of the structural and stratigraphic setting of the Ischia volcanic complex (Naples Bay, southern Tyrrhenian sea), focusing, in particular, on the southeastern offshore of the island.

The seismic grid was recorded using a Sparker Multitip seismic source. The marine data acquisition and the related mapping around the Ischia Island were performed down to

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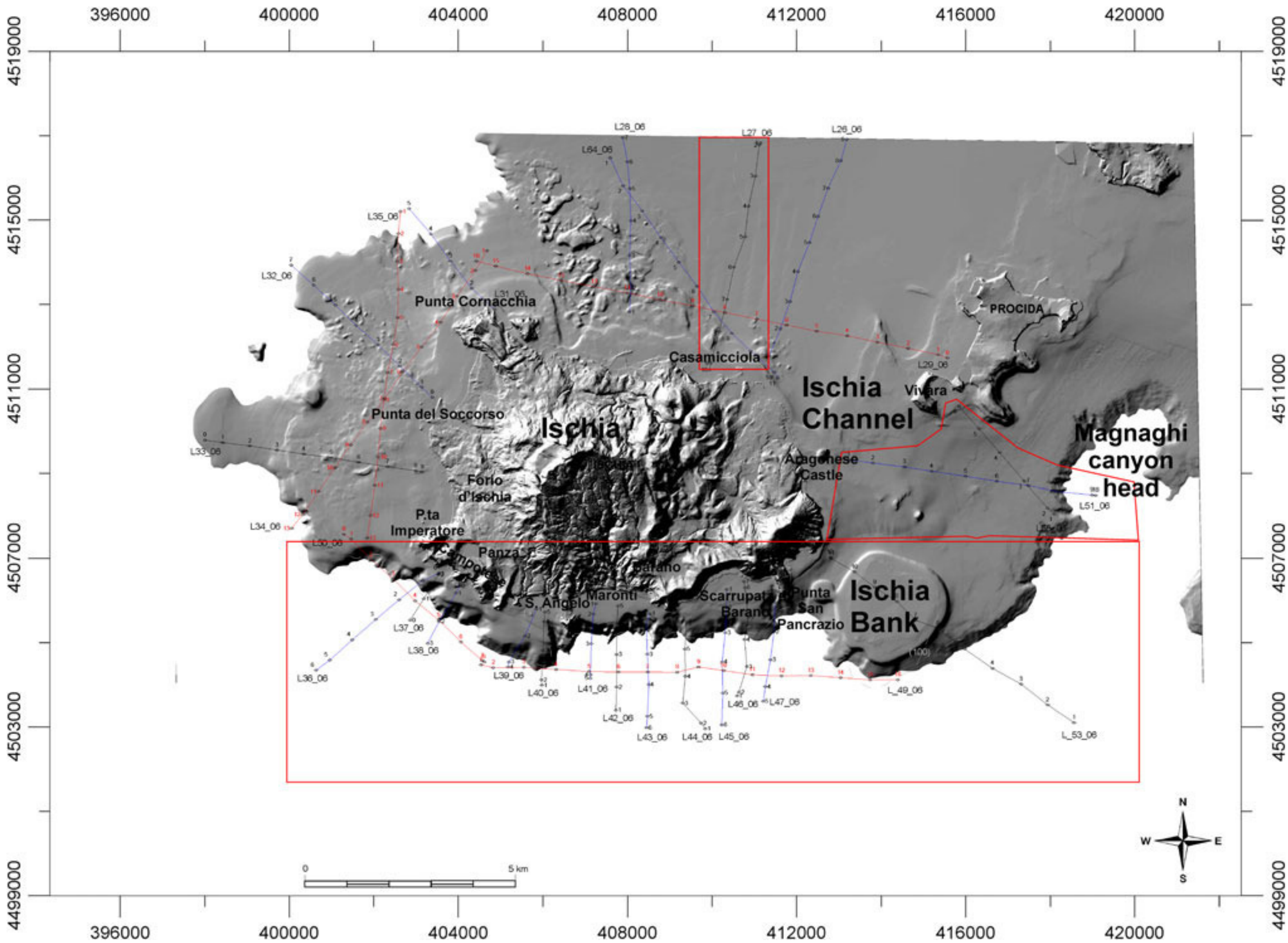

Fig. 1 Onshore/offshore DEM of Ischia Island and analyzed Sparker seismic grid. *Red figures* indicate the studied sections

the 200 m isobath (Geological Map n. 464 "Isola d'Ischia"; scale 1:25,000; 2010; in press; Aiello et al. 2009b).

The seismic lines have been plotted on the marine DEM of the Ischia Island, allowing a detailed geological interpretation of the main morpho-structures occurring at the sea bottom (Fig. 1). The seismic grid consists of 13 dip seismic lines in the southern Ischia offshore, running perpendicularly to the shoreline and 2 tie lines, parallel to the shoreline (Fig. 2). Particular attention has been paid to the geological interpretation of seismic lines that cover the southeastern offshore of the island, from Punta Imperatore (southwestern Ischia) to the Aragonese Castle (eastern Ischia; Fig. 3).

The Ischia Island is an alkalitrachytic volcanic complex, whose eruptive activity lasted from the Late Pleistocene up to historical times (Vezzoli 1988). The oldest rocks date back to about 150 ky and crop out in several sectors of the coastal belt of the island, particularly in the "Scarrupata di Barano" (Fig. 2), a steep slope located in the south-eastward sectors of the island and its offshore. This evidence concurs with the suggestion of a resurgent caldera, about 10 km across, where eruptive activity and tectonics gave rise to the uplift of the Mount Epomeo fault block (Walzer 1984; Orsi et al. 1991; Acocella et al. 2004; Carlino et al. 2006; Brown et al. 2008). In this regard, the main eruptive events of the Ischia–Procida–Phlegrean system suggest at least five eruptive cycles, ranging in age from 135 ky BP to historical times (Gillot et al. 1982; Chiesa et al. 1985; Poli et al. 1987, 1989; Rosi and Sbrana 1987; Vezzoli 1988).

The southern submerged margin of Ischia differs from the adjacent marine sectors of the island, forming a narrow continental shelf, from which several retreat canyons depart. A morphological sketch map, based on the geological interpretation of multibeam bathymetry, shows the principal morpho-structural lineaments occurring around the island (Fig. 3; Aiello et al. 2009a). Three important areas of accumulation of debris avalanche are located in the northern, western and southern offshore of the island, while the main canyon heads are located in its northwestern offshore ("Testata di Punta Cornacchia"; "Canalone di Forio"; Fig. 3).

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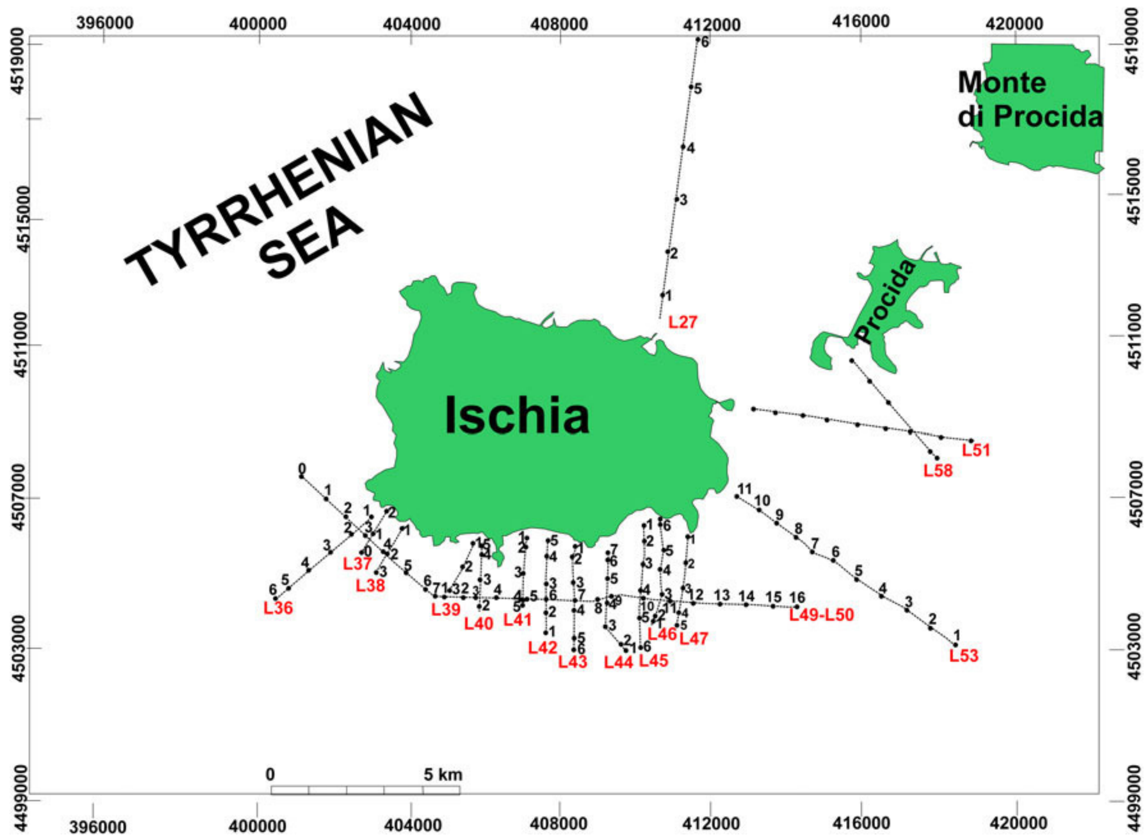

Fig. 2 Seismic grid of Sparker Multitip profiles in the southern Ischia offshore

In the northern and western Ischia offshore, Sidescan Sonar profiles have been also recorded (Fig. ESM1—Online Resource 1). Hummocky topography occurs at water depths ranging between 30 and 100 m (Fig. ESM1—Online Resource 1). However, these features could not be correlated onshore with evident slide scars. Heterometric blocks ("block facies") are buried and interstratified with pelitic sediments ("matrix facies"). The deposits reach the Banco di Forio tuff cone and are interposed between a submerged depositional terrace and a more recent coastal wedge of marine sediments (Budillon et al. 2003a; Aiello et al. 2009b).

A new seismo-stratigraphic setting of southeastern Ischia offshore is herein proposed, concurring with a better knowledge of the stratigraphic relationships between the southeastern volcanic seismic sequences, previously unknown with such a detail, and the Late Quaternary depositional sequence. Their stratigraphic architecture on the steep slopes off southern Ischia was practically unknown. We think that the regional seismic sections discussed in this paper, aside from their scientific content, will allow a better geological management and monitoring of the coastal zones of the Campania region, with particular regard to the stability of the volcanic areas, contributing moreover to the detailed knowledge of the Ischia offshore.

2 Geological setting

The volcanic areas of the Phlegrean Fields and of the Ischia, Procida and Vivara islands share the same tectonic setting and a common origin of their alkali–potassic magmas, which characterize the Campania volcanoes. These magmas are subdivided into an ultra-potassic series (leucitites and leucitic phonolites, in the Somma–Vesuvius volcanic complex) and a potassic series (trachybasalts, latites, trachytes and phonolites, in the Ischia and Procida islands and in the Phlegrean Fields). The whole region pertains to the eastern Tyrrhenian margin, located on a thinned continental lithosphere, transitional with respect to the oceanic sectors of the Tyrrhenian bathyal plain (Kastens et al. 1986, 1988).

The lithospheric extension, accompanying the opening of the Tyrrhenian basin from Pliocene to recent times, has controlled a strong vertical kinematic and translational tectonics in the upper crust, where the uprising of highly differentiated magmas occurred, mostly along Apenninic (NW–SE) and anti-Apenninic (NE–SW) structural lineaments. This evidence among others is testified by the drilling of andesitic rocks in the subsurface northward of the Phlegrean area (Ortolani and Aprile 1978; Aiello et al. 2011a).

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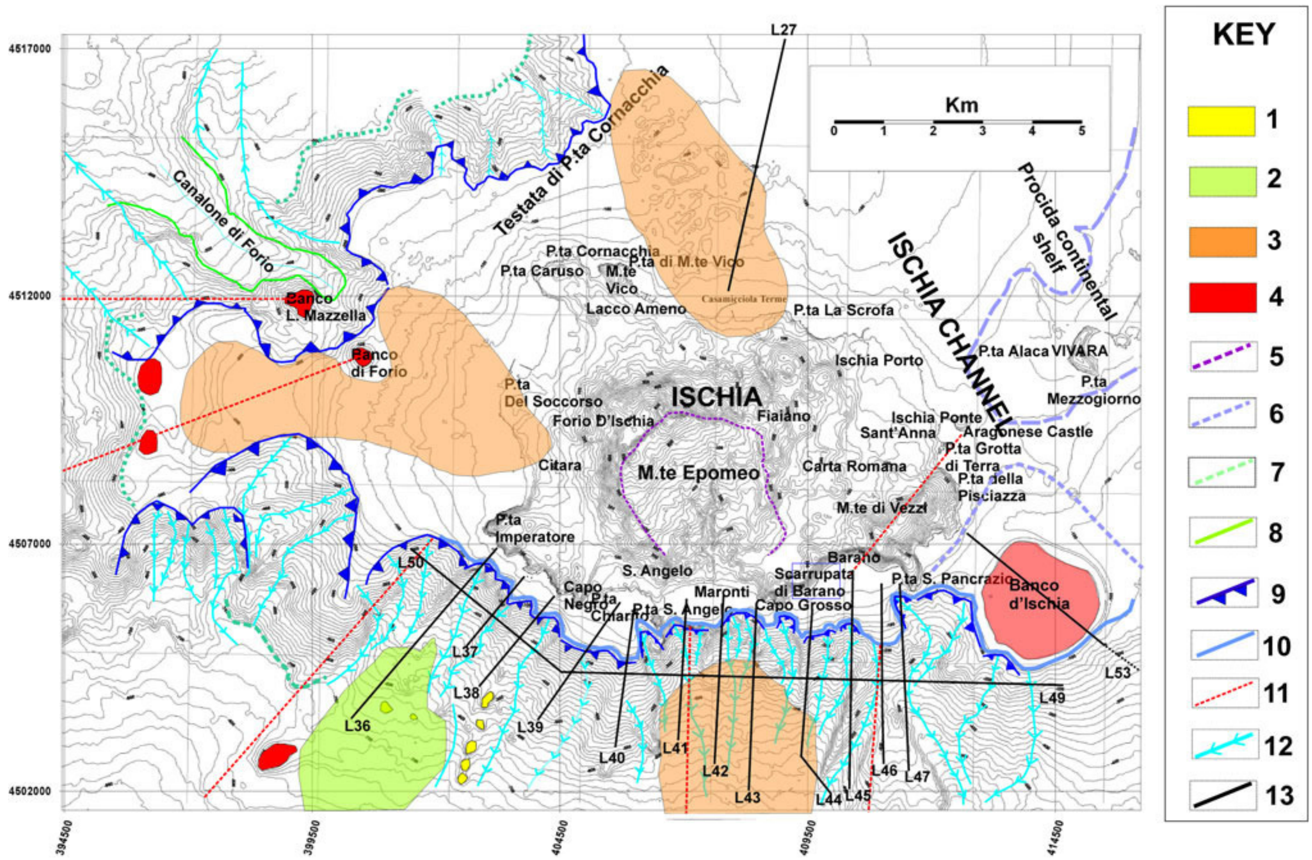

Fig. 3 Sketched morphological map of Ischia Island, based on the geological interpretation of the multibeam bathymetry (Aiello et al. 2009a, modified). Main morpho-structural features and quoted localities: *1* slope fan; *2* creeping; *3* hummocky facies, corresponding to debris avalanche deposits; *4* volcanic edifice; *5* calderic rim; *6* depositional terrace rim; *7* slope break; *8* channel levee; *9* retreating canyon head; *10* retreating shelf break; *11* buried normal fault; *12* drainage axis, and *13* location of seismic profiles

The Ischia Island extends over a surface of 42 km^2 and reaches a maximum height of about 787 m at the Epomeo Mt. (Fig. 4) resulting from the volcano-tectonic uplift of the corresponding caldera during the last 30 ky (Orsi et al. 1991; Acocella et al. 1997; Acocella and Funiciello 1999). On the Ischia Island, volcanic deposits resulting from both explosive and effusive eruptions extensively crop out, building volcanic edifices. Some of them are still well preserved, while others are completely eroded or buried (Forcella et al. 1983; Gillot et al. 1982; Luongo et al. 1987; Vezzoli 1988). Also landslide deposits, derived from the accumulation and cementation of fragments of pre-existing volcanic rocks, are widely documented (Guadagno and Mele 1995; Mele and Del Prete 1998; De Vita et al. 2006, 2007; Iovino and Perriello Zampelli 2007; Vingiani and Terribile 2007; de Alteriis and Violante 2009).

The main volcanologic event is the eruption of the Green Tuffs of the Epomeo Mt. that occurred about 55 ky ago, controlling the downthrowing of the central sector of the island due to the formation of a caldera (Orsi et al. 1991). The volcanic activity of the island has been influenced by complex geological processes of calderic resurgence that started about 30 ky ago. The uplift, related to this last event, has been evaluated in the order of 800–1,100 m (Barra et al. 1992a, b).

Three main eruptive cycles have been distinguished on the base on radiometric datations (Civetta et al. 1991), considering the trend of both Sr isotopic composition and trace elements. Each eruptive period was characterized by magmatic fractioning, allowing for compositional variations of the volcanic products.

The first period (55–33 ky BP) started with the eruption of the Epomeo Green Tuffs, characterized by ignimbrites, which deposited both offshore (in an area actually located in the central sector of the island) and now exposed onshore at the Epomeo. The subaerial volcanic products of the Epomeo Green Tuffs crop out at Monte Vico, Sant'Angelo and along the Scarrupata di Barano (Fig. 4; see Fig. 3 for location). After their outbreak, the volcanic activity continued with several explosive eruptions, lasting up to 33 ky.

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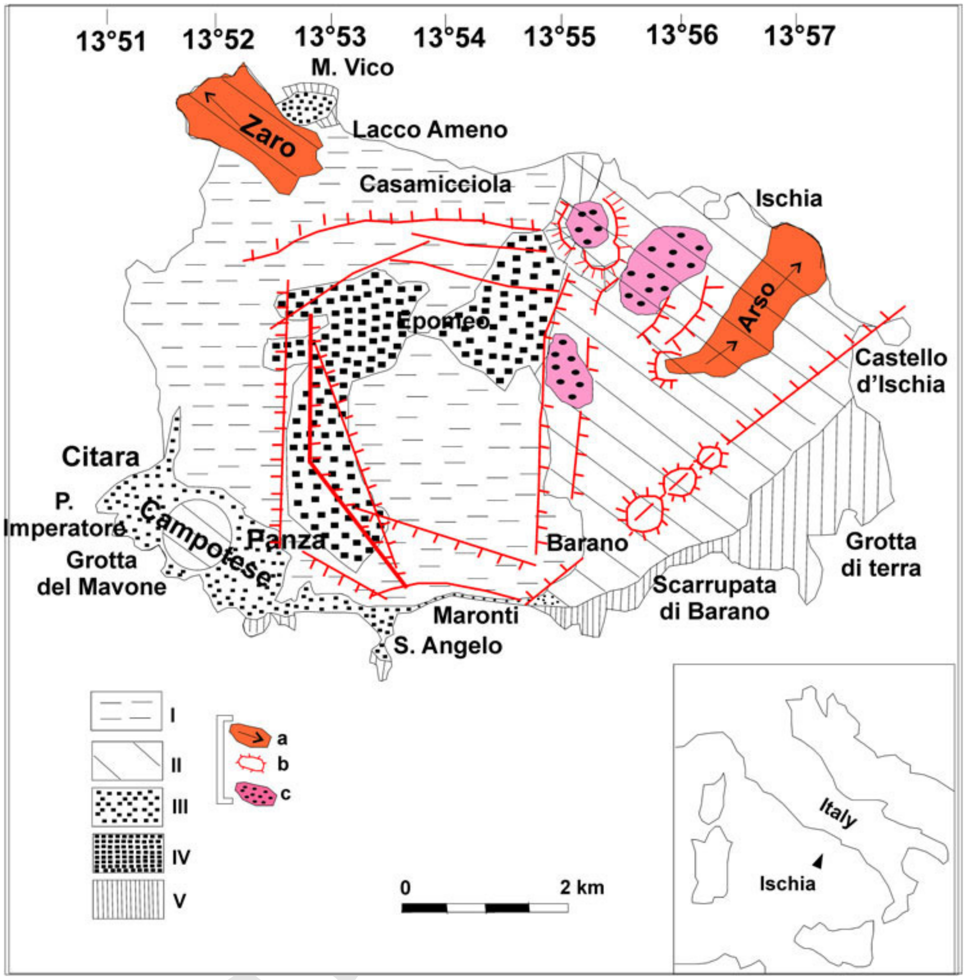

Fig. 4 Geological sketch map of Ischia Island (modified after Gillot et al. 1982; Poli et al. 1987). *I* scree and mud flows; *II* volcanic units younger than 10,000 years (*a* lava dome; *b* crater; *c* dome); *III* older volcanic rocks (between 20,000 and 33,000 years ago); *IV* Green Tuff of Mount Epomeo; *V* first volcanic complex, now dismantled (including the first and the second phase of Ischia activity); *VI* faults

The corresponding volcanites crop out both along the coastal cliffs of Sant'Angelo and Punta Imperatore (southwestern Ischia; Figs. 3, 4) and at Citara and Monte Vico (Citara-Serrara Fontana Formation; Figs. 3, 4). Some authors have differentiated these volcanic products into several lithostratigraphic units, erupted by different volcanic centers located in the southwestern and northwestern sectors of Ischia (Chiesa et al. 1985; Fig. 4).

The second period (28–18 ky BP; Civetta et al. 1991) started with the eruption of the Grotta di Terra volcanic center (28 ky BP), whose products, fed by trachybasaltic magmas, are exposed along the southeastern coasts of the island. The volcanic activity continued up to 18 ky BP. The corresponding volcanites crop out at Grotta del Mavone, Monte di Vezzi, Sant' Anna, Carta Romana and between Punta Imperatore and Sant'Angelo (Vezzoli 1988; see Fig. 3 for location).

The third period began at about 10 ky BP (Civetta et al., 1991) after a relatively long stand of volcanic activity and continued up to historical times, with the so-called Arso lava flow (1302 DC; Vezzoli 1988). This period was characterized also by lava domes and by explosive activity, generating tuff rings and pyroclastic fall deposits.

During this period, many eruptive centers were active in the Ischia graben, a depression located in the central sector of Ischia (Orsi et al. 1994). The Zaro lava flow and the pyroclastic deposits cropping out at Punta del Chiarito (Vezzoli 1988) pertain to this period of activity.

The last eruption in the Ischia Island occurred in February of 1302, when a crater opened in the Fiaiano area (Fig. 3) and large lava flow erupted, from 100 to 500 m (Arso lava flow), that reached the beach between the Ischia harbor and Ischia Ponte and destroyed the ancient town of Geronda. At present, only a fumarolic and hydrothermal activity has been registered.

The tectonics of the island is characterized by NW–SE and NE–SW trending extensional faults, Plio-Quaternary in age (Acocella and Funiciello 1999; Acocella et al. 2004). Field data have been collected to explain both the tectonic setting of the Ischia Island, interpreted as a resurgent dome uplifted for almost 800 m in the last 33 ky, and the deformational patterns related to this resurgence. NW–SE

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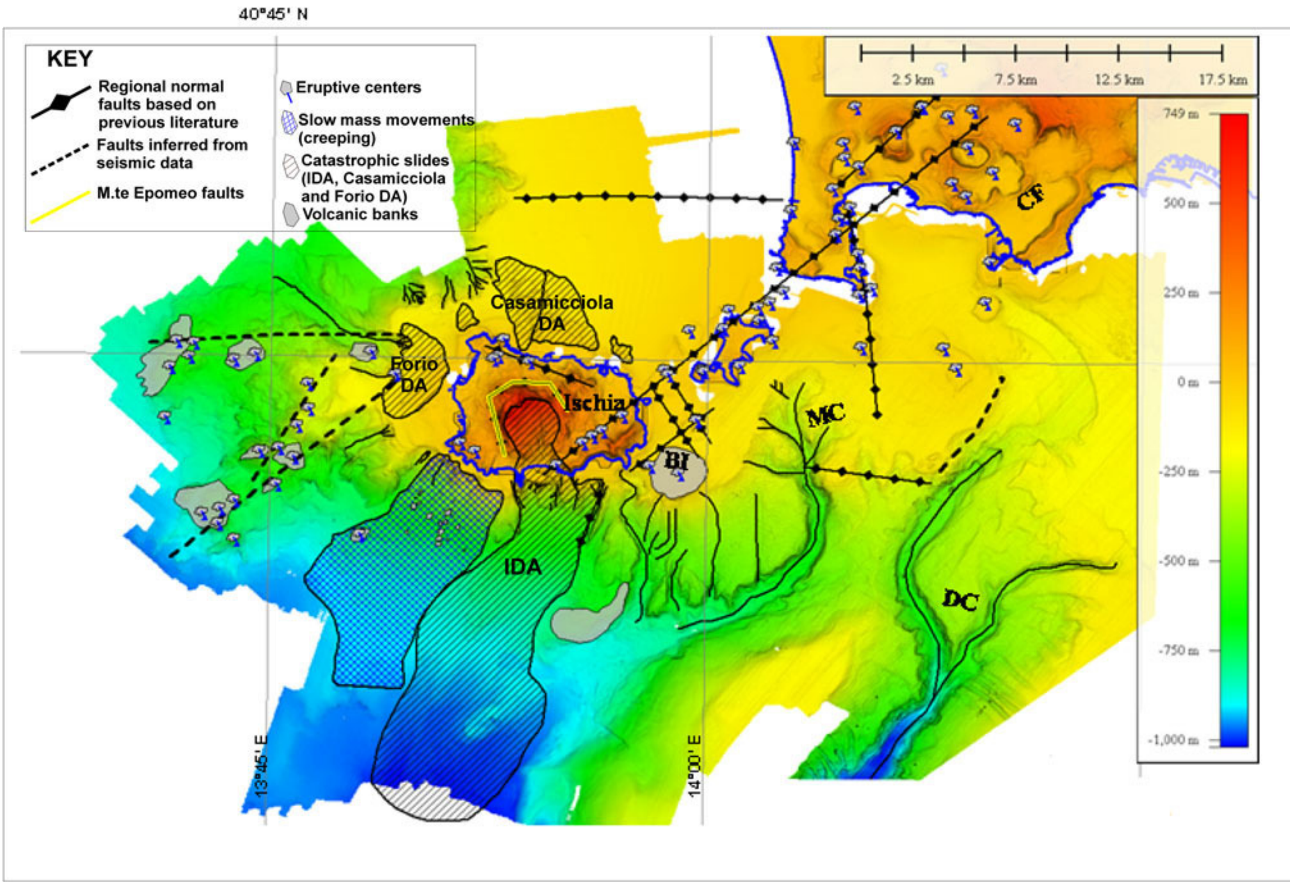

Fig. 5 Digital elevation model of the Island of Ischia and its offshore and geological interpretation of the main morpho-structural lineaments. *BI* Ischia Bank, *DC* Dohrn Canyon, *MC* Magnaghi Canyon, *CF* Campi Flegrei. In the legend: **a** after de Alteriis et al. 2006; **b** after Paoletti et al. 2009; **c** after de Alteriis and Violante 2009

and NE–SW trending extensional fault systems predominate all over the island, suggesting a close relationship with the extensional structures of the southern Apennines (D'Argenio et al. 1973; Bigi et al. 1992).

Marine exploration of the Ischia offshore showed great improvement in the last 10 years, due to surveys carried out by IAMC-CNR of Naples in the frame of the GNV (National Group of Volcanology) activity and CARG projects. These surveys resulted in a multibeam coverage that allowed the exploration of the whole area surrounding the island (Chiocci and de Alteriis 2006; Aiello et al. 2009a, b, 2011b). The Ischia offshore is characterized by several monogenic edifices aligned along the NE–SW system of faults that connects the southeastern sector of Ischia to the island of Procida and to the Phlegrean Fields (de Alteriis and Toscano 2003; de Alteriis et al. 2006). These edifices have been mainly formed through subaqueous explosive eruptions, documented by the hialoclastites from a potassic magma of latitebasaltic-latitic composition (Di Girolamo and Rolandi 1976; Di Girolamo et al. 1984). Marine geophysical surveys revealed collapsed volcanic edifices located to the W and SW of the

Table 1 Characteristics of the Multibeam system

SEATBAT 8111	
Manufacturer	Reson
Model	SeaBat 8111
Installation	Hull mounted
Number of beams	101
Beamwidth across track	1.5°
Beamwidth along track	1.5°
Center-to-center beam separation	1.5°
Max swath	150°
Max swath coverage	7.4 × water depth
Operating frequency	100 kHz
Pulse length	Variable, operator selectable
Depth range	600 m (max scale 1,400 m)
Max ping rate	35 swaths/s
Max vessel speed	20 knots
Stabilization	Pitch stabilization within ±10°
Sound probe	Reson SVP 25?
Acquisition software	PDS2000
Processing software	PDS2000

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Ischia Island, a sector of the seafloor characterized by strong residual magnetic anomaly fields. A westward submerged continuation of the Ischia volcanic structure, representing a remnant of the emergent top of a larger, E–W trending volcanic complex, has been also inferred, based on marine geophysical data (Bruno et al. 2002).

3 Data and methods

3.1 Multibeam bathymetry

The multibeam swath bathymetry presented here (Fig. 5) was carried out in September to November 2001, by using a Reson Seabat 8111 Multibeam sonar system, which works properly in the 50–600 m depth range, onboard the Thetis R/V.

The multibeam system, interfaced with a differential global positioning system (DGPS), mounted on the keel of the ship, was composed of a ping source of 100 kHz, 150° for the whole opening of the transmitted pulse and a 101 beams receiver, with a beam opening of 1.5°. Sound velocity profiles (CTD) were regularly recorded and applied every 8 h (Table 1).

The data were processed by using the PDS2000 software (Reson-Thales), according to the IHO standard (IHO 1998), with a real-time acquisition control and partial beam exclusion filtering (particularly for what concerns lateral beams) applied to the bathymetric data directly onboard. Subsequently, the off-line swath editing and de-spiking were carried out. The digital terrain model (DTM) generation and rendering of the whole dataset were reorganized in a MXN matrix (DTM) having a grid cell of 20 × 20 m.

3.2 Seismic sections

Seismic acquisition was carried out using a multielectrode sparker system (SAM96 model). The advantages of the Multitip Sparker include shorter pulse lengths for an equivalent energy discharge, as well as an increase in peak pressure, i.e., the amplitude of the outgoing acoustic wave. The sparker source used in this survey generated 200 J in the 200–2,000 frequency range.

Ship positioning was determined using a GPS system with an accuracy of 1 m. All seismic sections were recorded graphically on continuous paper sheets with a vertical recording scale of 0.25 s. The best vertical resolution was approximately 1 m for the sparker data.

This seismic grid covering the southeastern sector of Ischia Island facilitated the stratigraphic correlations between seismic sections and revealed structural and stratigraphic variations along the seismic lines.

The proposed stratigraphy derives from the type of data utilized in marine geology (reflection seismics) and from the methods of seismic interpretation (high-resolution sequence stratigraphy). The geological structures recognized through the seismic interpretation are acoustically transparent seismic units, representing the volcanic acoustic basement and the systems tracts of the Late Quaternary depositional sequence (SDTQ, in Fabbri et al. 2002). The depositional systems, referred respectively to the sea-level fall (FST; Helland-Helland Hansen and Gjelberg 1994), sea-level lowstand (LST) and related internal subdivisions (Posamentier et al. 1991), transgressive phase (TST; Posamentier and Allen 1993; Trincardi et al. 1994) and sea-level highstand (HST), have been identified in the Late Quaternary depositional sequence of the Ischia offshore through seismo-stratigraphic analysis (Fig. ESM2—Online Resource 2).

4 Seismo-stratigraphic results

4.1 Seismic stratigraphy: applications to the Ischia volcanic complex

The seismic stratigraphy is an analytical methodology for the subsurface geological survey (Vail et al. 1977; Mitchum et al. 1977). It was developed from the end of the 1970s of the last century and particularly applied to the analysis of continental margins. The seismo-stratigraphic analysis is based on the recognition of the lower and upper terminations of seismic horizons and of their geometries (onlap, erosional truncation, downlap, toplap) with respect to the main unconformities bounding specific intervals defined “depositional sequences” (type 1 or type 2 sequence boundaries, according to Vail et al. 1984). This approach offers the opportunity to reconstruct the tectono-stratigraphic evolution of a sedimentary basin in relation to relative sea-level oscillations.

In the case of the Ischia Island, the occurrence of isolated volcanic bodies (intrusions, domes, volcanic necks and tabular, acoustically transparent seismic units) makes the sequence stratigraphic approach particularly complex for the geological interpretation of seismic profiles. While the volcanic bodies (i.e., lava flows, domes, intrusions) cannot be internally investigated by the reflection seismics because they are acoustically transparent, the seismic facies of the pyroclastic edifices and/or buried pyroclastic deposits may be on the contrary detected, due to their internal stratification. The marine sedimentation includes both the contribution of alluvial and marine sediments and the input of volcanites and volcaniclastic deposits originating from the eruptions of Ischia and Procida volcanic complexes.

According to the interval velocities already established (D'Argenio et al. 2004; Aiello et al. 2005, 2011b; Di Fiore et al. 2011), the thickness of the Pleistocenic–Holocenic

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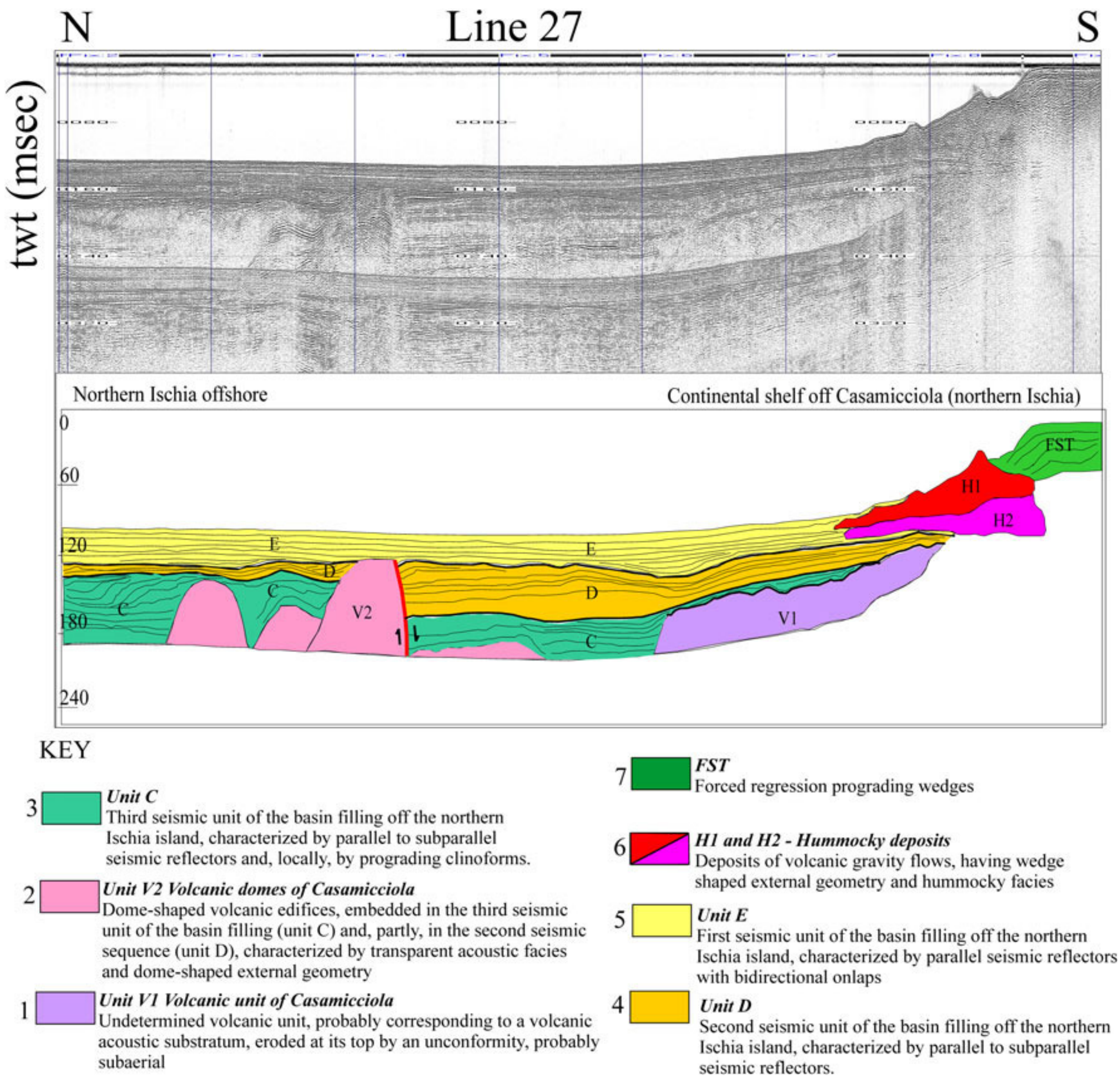

Fig. 6 Seismic profile L27 recorded offshore northern Ischia by Sparker Multitip seismic source and corresponding geologic interpretation (after Aiello et al. 2009a). The line runs from the continental shelf off Casamicciola (northern Ischia), toward the northern offshore Ischia. Forced regression prograding wedges characterize the stratigraphic architecture of the continental shelf (FST). Two superimposed wedges of chaotic deposits suggest a multi-phase event in the evolution of the debris avalanche off Casamicciola (H1 and H2).Note that three seismic units, separated by regional unconformities, occur in the basin filling

marine sediments in the Ischia offshore varies from 0.4 to 0.5 s twt (corresponding to about 340–425 m) to the north of the Ischia and Procida islands, to 0.2–0.3 s twt (corresponding to about 170–255 m) in the western Ischia offshore, while the sedimentary drapes, along all the southern continental slope of the island, reach several tens of meters.

Based on the seismic data discussed in this paper, the stratigraphic architecture of Ischia–Procida marine deposits has been interpreted in terms of systems tracts of the Late Quaternary depositional sequence. The external geometry and seismic facies, together with the identification of a downlap (flooding) surface, support the interpretation of part of the seismic sequences as TST deposits. The Ischia–Procida TST sediments are characterized by fillings with onlap geometries on the flanks and on the top of the underlying volcanic units. Some of the upper intervals are instead interpreted as HST deposits, characterized by parallel-to-slightly prograding seismic reflectors, downlapping the underlying flooding surface.

4.2 Geologic interpretation of seismic profiles

4.2.1 Seismic profile L27 (north Ischia)

In the northern offshore of Ischia, a simplified stratigraphic scheme based on the interpretation of a high-resolution seismic profile has been drawn up (L27; Aiello et al. 2009a; Fig. 6). It is briefly discussed here to clarify our

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geological understanding of the Casamicciola hummocky deposits and related debris avalanches.

The Sparker L27 line runs from the continental shelf, off Casamicciola (northern Ischia; Fig. 3), toward the northern slope of Ischia into the Tyrrhenian Sea (Fig. 1). Forced regression prograding wedges (FST), pertaining to the Late Quaternary depositional sequence, have been identified on the continental shelf. Debris avalanche deposits (Casamicciola debris avalanche; Budillon et al. 2003a; Aiello et al. 2009a; de Alteriis and Violante 2009), having a wedge-shaped external geometry and chaotic facies, are arranged into two distinct, superimposed bodies (H1 and H2, Fig. 8). The hummocky deposits formed during two main, distinct volcano-tectonic events occurring on the continental shelf off Casamicciola. The two bodies, H1 and H2, are characterized by facies hetheropy with the upper seismic unit of the basin filling (unit E, Fig. 6).

The lower seismic unit of the basin filling is characterized by reflectors having a parallel seismic facies and shows bidirectional onlaps in correspondence of depressions formed at the top of the underlying seismic unit (unit C, Fig. 6).

The intermediate seismic unit of Ischia northern offshore (unit D, Fig. 6) is characterized by parallel-to-subparallel seismic reflectors. This unit shows a strong wedging in correspondence to a normal fault (fossilized by the erosional unconformity located at the top of the unit) and facies hetheropy with the upper part of dome-shaped, buried volcanic structures (unit V2, Fig. 6).

The upper seismic unit of the basin filling, off northern Ischia Island (unit E, Fig. 6), is characterized by parallel-to-subparallel seismic reflectors and, locally, by prograding clinoforms. The unit is slightly downthrown by a normal fault and shows facies hetheropy with the lower part of dome-shaped buried volcanic structures (unit V2, Fig. 6). In addition, even if the vertical displacement of the unit E by the normal fault is negligible, the occurrence of the fault is suggested by both the seismic facies (since the seismic reflectors are disrupted) and by the strong thickness variation of the unit E toward the northern Ischia offshore (Fig. 6). Moreover, based on seismo-stratigraphic evidence, the suggested fault line represents a preferential way for the emplacement of the volcanic domes of Casamicciola (unit V2, Fig. 6). These dome-shaped volcanic edifices are interstratified in both the lower and the intermediate seismic units of the basin filling (Fig. 6).

Dome-shaped volcanic edifices are in lateral contact with the lower seismic unit of the basin filling (unit C) and partly with a second unit (unit D). The volcanic bodies are suturated by the erosional truncation at the top of unit D (Fig. 6). An undetermined volcanic unit off Casamicciola, corresponding to the acoustic substratum (unit V1; Fig. 6), has been also identified. The volcanic acoustic basement shows seismic facies hetheropy with the unit C of the basin filling (Fig. 6) and is eroded at the top by a subaerial unconformity.

4.2.2 Seismic profile L57 (southeastern Ischia)

The seismic profile L57 crosses the southeastern and the eastern sectors of Ischia (Fig. 2). The line runs from the volcanic structure of the Ischia Bank to the Ischia Channel (Fig. 7), where it crosses "Il Pertuso" volcanic edifice and reaches the Procida continental shelf. The seismo-stratigraphic analysis has allowed the identification of volcanic and sedimentary seismic units. A volcanic acoustic basement (unit V2-B1 Fig. 7), characterized by an acoustically transparent seismic facies, indicates the occurrence of lavas and pyroclastites genetically related to the main morphostructure of the Ischia Bank. FST deposits have been identified on both the slopes of the bank (Fig. 7). The top of the volcanic structure is overlain by a thin drape of bioclastic sands and gravels, cropping out at the sea bottom.

The unit of Ischia Channel (unit V3-CI, Fig. 7) is made of pyroclastites and lavas genetically related to relic hydromagmatic volcanic edifices of eastern Ischia, presumably older than the Vivara Volcano (Scandone et al. 1991; de Alteriis et al. 1994). Another volcanic seismic unit, probably pyroclastic in nature, underlies the marine deposits of the Ischia Channel (volcanic unit, uncertain attribution, Fig. 7). In correspondence to the "Il Pertuso" volcanic structure, this unit appears in lateral contact with the volcanic sequence of the Ischia Channel (unit V3-CI, Fig. 7).

Proceeding toward the Procida shelf, the V3-CI volcanic sequence grades laterally into a relic wedge, probably Pleistocene in age, characterized by prograding clinoforms.(Fig. 7). This wedge is overlain by a pyroclastic unit, onlapping depressions and channel-type erosional morphologies, genetically related to the last eruptive phases of the Procida Island.

4.2.3 Seismic profile L50 (southwestern Ischia)

The seismic profile L50 crosses the southwestern offshore of the Ischia Island, from the continental shelf, west of Punta Imperatore, to the continental slope located southward of Capo Negro (Fig. 2). The line meets three main submarine canyons (Fig. 8), pertaining to the southern Ischia canyon system, respectively, located at water depths of 173 m (canyon 1), 240 m (canyon 2) and 285 m (canyon 3). The three canyon thalwegs are bounded by levees that may evolve into extensive channel–levee complexes.

A volcanic acoustic basement has also been identified (Fig. 8), dipping from the continental shelf off Punta Imperatore toward the southwestern Ischia offshore. Based on

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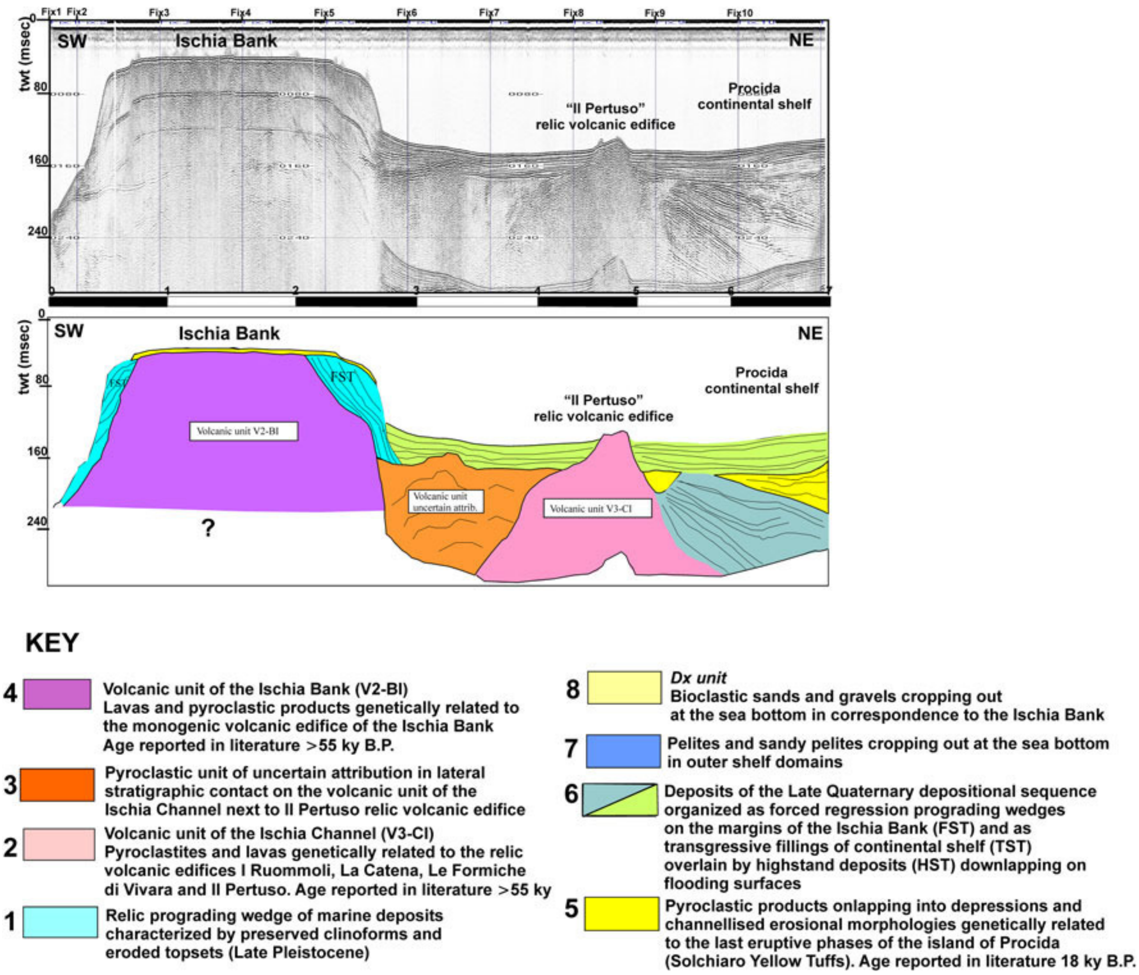

Fig. 7 Seismic profile L57 located in the southeastern and eastern sectors of the Ischia Island (Ischia Bank—Il Pertuso volcanic edifice—Procida continental shelf) and its geologic interpretation

land–sea correlation, this basement could be linked to the lavas cropping out at Punta Imperatore (southwestern Ischia), represented by alkali–trachytic gray lavas, dating to about 116–123 ± 6 ky (Vezzoli 1988). The top of the volcanic acoustic basement appears strongly incised, probably in a subaerial environment.

A wide pyroclastic edifice has been recognized, buried in the continental shelf (Fig. 8). This edifice is interstratified in the FST deposits, recognized on the continental shelf off Punta Imperatore, where Quaternary sediments are truncated by an erosional unconformity, overlain by thin highstand deposits.

A relic Pleistocene prograding wedge has also been identified in correspondence to the western canyon, offshore southwestern Ischia, where it overlies the volcanic acoustic basement corresponding to the Punta Imperatore lavas. This wedge is overlain by a marine seismic unit, which seems to be syntectonic, since it appears to be deposited during the activity of the normal fault downthrowing the volcanic acoustic basement.

4.2.4 Seismic profile L36 (southwestern Ischia)

The seismic profile L36 runs from the continental shelf of Punta Imperatore (south-western Ischia) toward the continental slope (Tyrrhenian Sea), where an inclined volcanic acoustic basement has been identified. A thin sedimentary drape covers the acoustic basement in the whole continental slope, where a thick sedimentary unit has been recognized at the toe of slope, probably related to slope deposits. On the continental shelf, HST, TST and LST deposits have been identified (Fig. 9).

4.2.5 Seismic profile L38 (southwestern Ischia)

The seismic profile L38 (Fig. 10) crosses the southwestern Ischia offshore (Forio d'Ischia) toward the southwestern Ischia slope (Figs. 1, 2). In particular, the section has been recorded on the continental shelf off Grotta del Mavone (Fig. ESM3—Online Resource 3), one of the largest cavities of Ischia (D'Ambra 1992). This cavern is located in the

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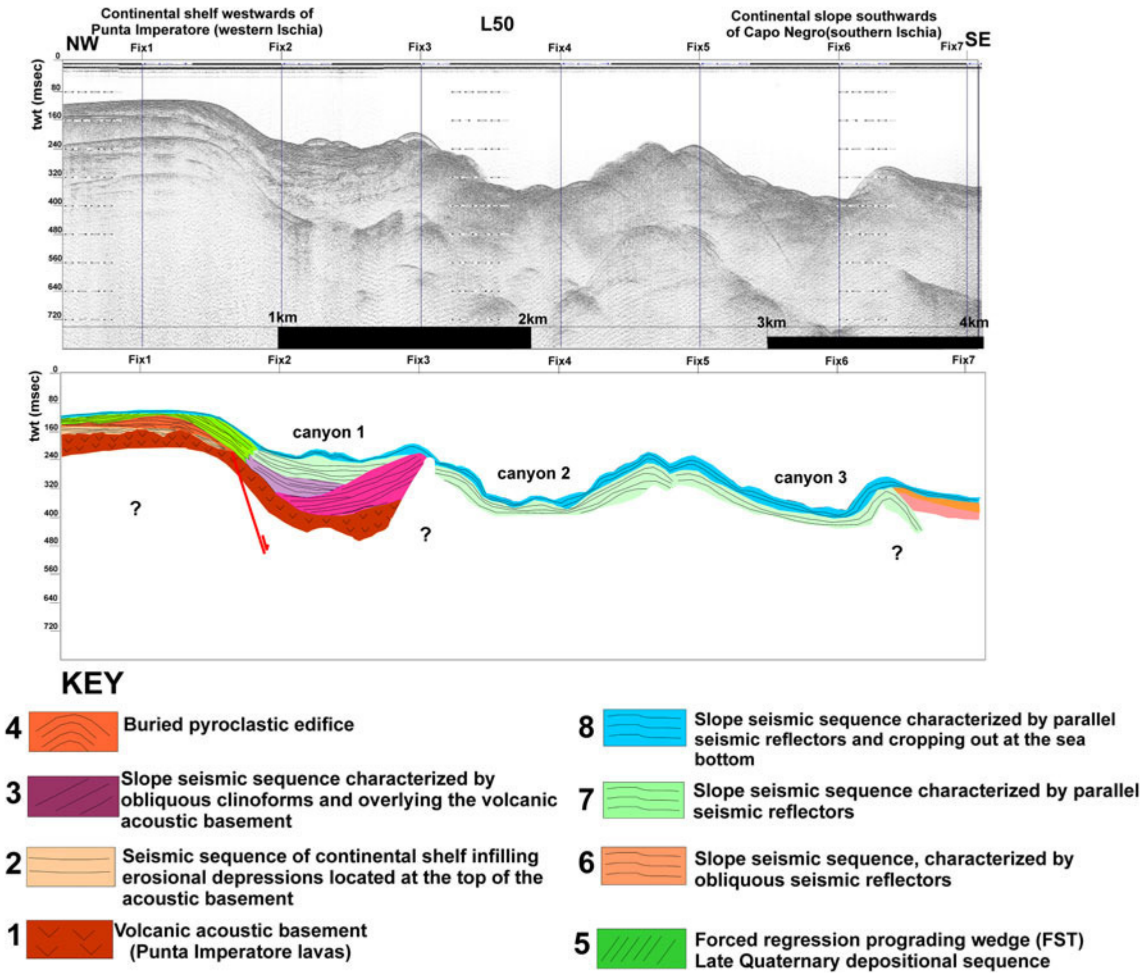

Fig. 8 Seismic profile L50, located in the southwestern sector of Ischia Island and corresponding geologic interpretation. Note the occurrence of three main canyons, pertaining to the southern Ischia canyon system

homonymous bay, next to the Campotese wood (Forio d'Ischia; Fig. ESM3—Online Resource 3). Off the Grotta del Mavone, the continental shelf is narrow and the depositional shelf break is located at 35/40 m (Fig. 10). The continental slope is steep and shows hints of mass wasting. The seismo-stratigraphic analysis allowed to identify a volcanic acoustic basement under the continental slope, genetically related to the Grotta del Mavone lava domes and adjacent volcanic rocks (Fig. 10). The stratigraphic architecture of the continental shelf is characterized by the Late Quaternary depositional sequence (progradational HST, TST and HST deposits).

4.2.6 *Seismic profile L39 (southern Ischia—Punta del Chiarito)*

The seismic profile L39 crosses the southern Ischia offshore (Punta del Chiarito) toward the southern Ischia slope (Figs. 1, 2). A volcanic sequence of well-stratified deposits crops out between Punta del Chiarito and Punta S. Angelo (Vezzoli 1988). It is formed of tuffs and pumiceous lapilli as well as by pomiceous tuffs and breccias, originating from pyroclastic fluxes and surges and attributed to the Faro di Punta Imperatore Formation. Dome-shaped components of the volcanic basement crop out at the sea bottom of the inner shelf at about 30 m bsl (Budillon et al. 2003b). At Punta del Chiarito and Capo Negro, the products of explosive eruptions are associated with the lavas. These products are overlain by lava accumulations that, being resilient to the volcanic eruptions more than other materials, have originated the three promontories (Punta del Chiarito, Capo Negro and Punta San Pancrazio).

The seismo-stratigraphic analysis of the L39 seismic section (Fig. ESM4—Online Resource 4) has revealed the occurrence on the continental slope of the volcanic acoustic basement, genetically related to the Punta del Chiarito lava dome (eruptive center of Monte Sant'Angelo). This substratum is unconformably overlain by a wide relic prograding wedge, probably Middle–Late Pleistocene in age. On the slope a thick wedge of Holocene deposits unconformably overlies the relic progradational unit. On the

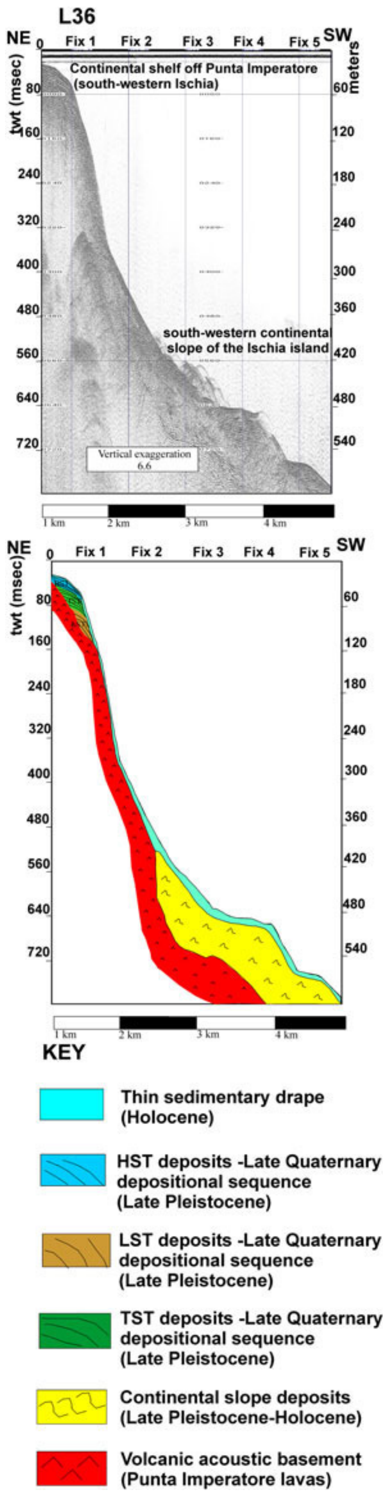

Fig. 9 Seismic profile L36, located in the southwestern sector of Ischia Island and its geologic interpretation. The profile runs from west to east in the southwestern Ischia offshore. Depth conversion on the right applies to the sea bottom

continental shelf, the TST deposits are characterized by retrogradational patterns and are unconformably overlain by HST deposits, with progradational geometries.

4.2.7 Seismic profiles L41, L42 and L43 (southern Ischia—Maronti)

Three seismic profiles have been recorded off the Maronti littoral belt and toward the continental slope (Figs. 1, 2), which in this sector appear steeper than in the adjacent offshore areas of southern Ischia (Fig. 11). The seismic profile L41, recorded in the western Maronti sector, shows in continuity the volcanic acoustic basement from the shelf to the slope (Fig. 11a). A lava dome, buried below 300–360 m of volcaniclastic deposits, has been identified. TST and HST deposits characterize the stratigraphic architecture of the narrow continental shelf. The steep slope is draped by a Holocene wedge thickening from 180 to 360 m of water depth.

The seismic line L42 has been recorded in the center of the bay (Fig. 11b) and similar seismo-stratigraphic units have been recognized on the L42 line. The volcanic acoustic substratum crops out along the slope under a thin Holocenic drape, while a relevant canyon's head has been recognized on the upper slope.

The seismic profile L43 has been recorded in the eastern Maronti sector (Fig. 11c). The stratigraphic architecture of the narrow shelf is characterized by LST, TST and HST deposits. On the upper slope, a rocky terraced surface has also been recognized, at water depths ranging from 140 to 180 m, while a canyon head has been recognized at the foot of the slope. Also in this case, on the narrow continental shelf, LST, TST and HST deposits have been identified.

4.2.8 Seismic profiles L44, L45 and L46 (southern Ischia—Barano)

The seismic profiles L44, L45 and L46 have been recorded in the Barano Bay (Figs. 1, 2) in correspondence to the Scarrupata di Barano (Fig. 12). This area has been recently studied in detail through geophysical techniques, which have been applied to the landslide of Monte Di Vezzi (Di Maio et al. 2007) that occurred in April 2006 involving the northern slope of Ischia (Di Nocera et al. 2007). The Monte di Vezzi belongs to a ridge stretching in a counter-Apenninic (NE–SW) direction, bordered to the southeast by a regional normal fault that also originated in the Ischia graben (Vezzoli 1988). The succession of volcanic events is represented along the outcrop of the Scarrupata di Barano marine cliff (Vezzoli 1988; Di Maio et al. 2007; Fig. ESM5—Online Resource 5). In the stratigraphic section, domes and lava flows of the pre-Green Tuff activity crop out (La Guardiola lavas, upper and lower Scarrupata di Barano Formation, domes and lava flows of Monte di Vezzi). During the eruptive phases of the post-Green Tuff cycles, these lavas have been covered by the products

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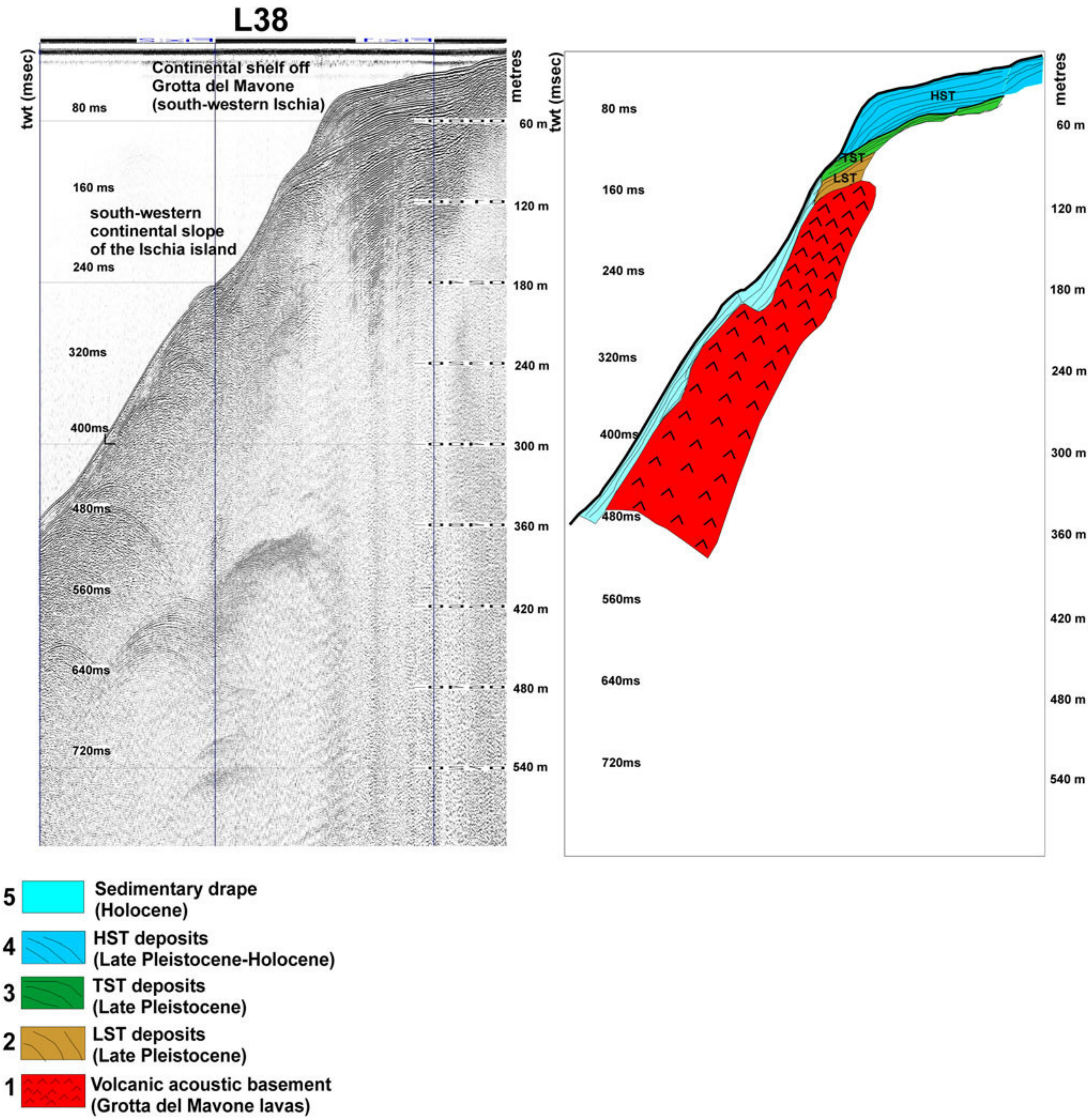

Fig. 10 Seismic profile L38 located in the southwestern sector of Ischia Island, offshore the Grotta del Mavone cavity and its geologic interpretation

derived from several pyroclastic eruptions of other centers, as follows: (a) Monte di Vezzi—not welded pumice flows from the Monte Epomeo Green Tuff; (b) S.Costanzo Formation, made up of well-stratified, whitish tuffs with pumices and lapilli; (c) Monte di Vezzi Formation, consisting of bedded pumice fall breccias and brown scoriaceous layers; and (d) Piano Liguori Formation, made of interbedded white ashes and pumice layers.

The seismic profile L44 (Fig. 12a) has been recorded in the western Barano sector. Here, a narrow continental shelf, characterized by the Late Quaternary depositional sequence (LST, TST and HST deposits) grades into the Scarrupata di Barano, ranging in depth between 100 and 540 m. The volcanic acoustic substratum is very thick and appears organized into two main seismic units (Barano 1 and Barano 2 seismic units) separated by an erosional unconformity. They

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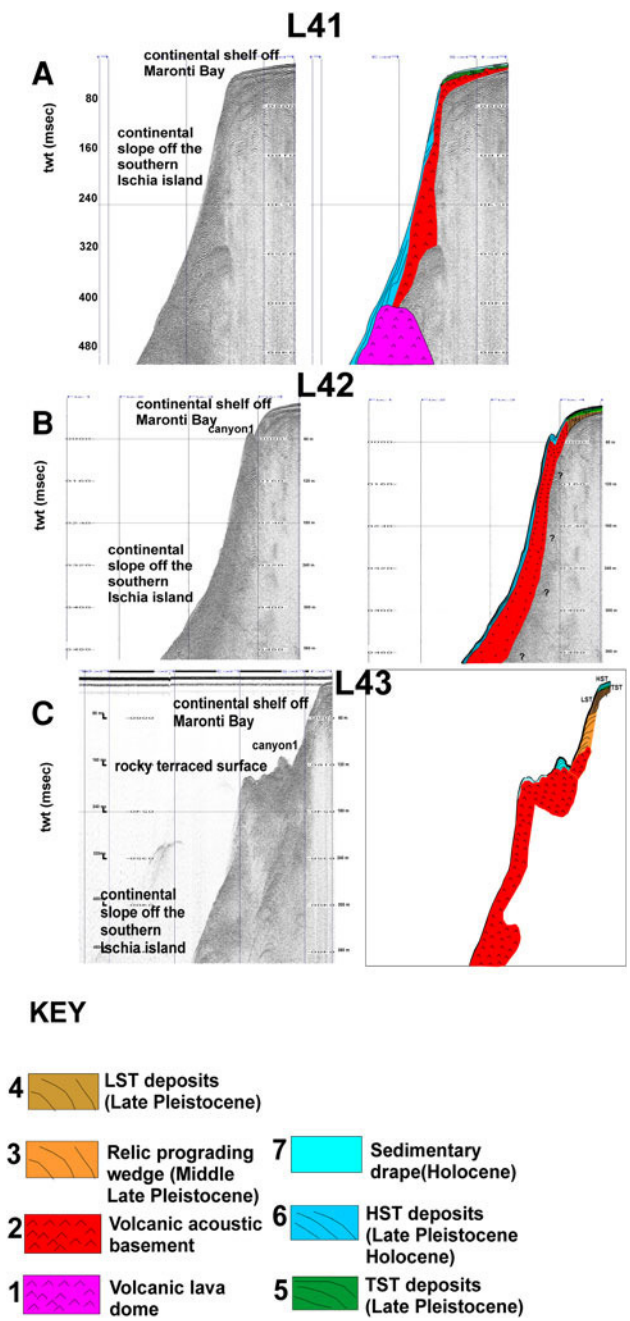

Fig. 11 Seismic profiles L41 (**a**), L42 (**b**) and L43 (**c**) recorded off the Maronti coastal area and its geologic interpretation

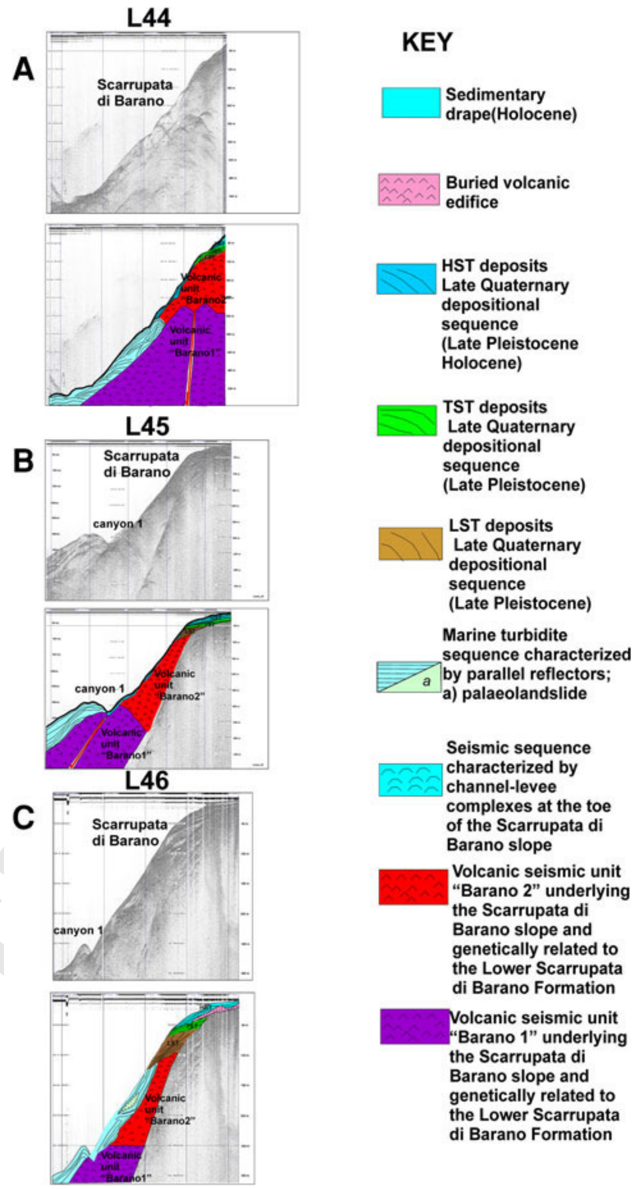

Fig. 12 Seismic profiles L44 (**a**), L45 (**b**) and L46 (**c**) recorded off the Scarrupata di Barano and its geologic interpretation

should be genetically related with the upper and lower Scarrupata di Barano formations, both composed of tuffs and tuff-breccias. A thick seismic sequence, characterized by channel–levee complexes and deposited at the toe of the Scarrupata di Barano, has been also recognized at water depths between 300 and 540 m. Here, the upper slope is characterized by a thin Holocene drape, overlying the volcanic substratum of the Barano 1 unit.

The seismic profile L45 (Fig. 12b), recorded in the central Barano sector, shows a volcanic substratum, organized into the already mentioned, acoustically transparent seismic sequences Barano 1 and Barano 2. A submarine canyon incises the volcanic deposits of the Barano 1 sequence at water depths of 360 m. In correspondence with the canyon, a normal fault downthrows the volcanic deposits.

Downslope, at water depths ranging between 360 and 440 m, a thick seismic sequence deposited at the foot of the Scarrupata di Barano and characterized by channel–levee complexes has been observed.

Finally, the seismic profile L46 (Fig. 12c), recorded in the eastern Barano sector, has shown a buried pyroclastic volcanic edifice, interstratified with the highstand sediments, while the transgressive deposits correspond to a thin retrogradational sequence. The lowstand deposits are

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characterized by prograding reflectors, erosionally truncated at their top. In the same Barano sector of the continental slope, a thick turbidite sequence occurs, showing parallel reflectors with an interstratified landslide, evidenced by disrupted and chaotic seismic reflectors.

4.2.9 Seismic profile L47 (southeastern Ischia)

The seismic profile L47 has been recorded from the Punta San Pancrazio offshore toward the Tyrrhenian Sea (southeastern Ischia continental slope, Fig. 1) at water depths ranging between 50 and 360 m (Fig. ESM6—Online Resource 6). The oldest products cropping out onshore testify that an explosive activity occurred in correspondence to this corner of the island. They are made of pumices and scorias ("Formazione di Carrozza"), forming the internal structure of Monte di Vezzi and crop out along the slope toward the San Pancrazio beach.

Three main explosive phases followed, whose products represent the lower interval of the Scarrupata di Barano. They are represented by about 100 m of pyroclastic flow deposits, with ashes including pumices. Seismic stratigraphy features are similar to those observed in the Barano area (Figs. 12, ESM6—Online Resource 6). Also, the volcanic acoustic basement is organized into two main seismic units (Barano 1 and Barano 2), separated by an erosional unconformity.

A wide palaeo-canyon has been recognized at the top of the volcanic units. It is filled with pyroclastic deposits, characterized by acoustic facies from transparent to chaotic. A marine turbidite seismic sequence, characterized by parallel-to-progradational reflectors, crops out at the sea bottom. The San Pancrazio canyon has been clearly recognized on this seismic line. The thalweg of the canyon reaches a present water depth of about 150 m. On the flank of the canyon, a leveed seismic sequence develops.

4.2.10 Seismic profile L51 (Ischia–Procida)

The seismic profile L51 has been recorded in the eastern Ischia offshore, starting from the Tyrrhenian slope toward the Magnaghi canyon (Fig. 13). The line continues in the Ischia Channel, crossing I Ruommoli volcanic edifice and terminates in correspondence of the Aragonese Castle (Ischia Ponte). The Ischia Channel separates the Ischia Island from the Vivara inlet and represents the narrowest entry into Naples Bay, linking the latter to the Gaeta Gulf. The channel extends in an NW–SE direction with a minimum width of about 2.35 km between the inlet of Aragonese Castle and Punta D'Alaca, the western margin of the Vivara inlet (Figs. 1, 2). Sea bottoms have generally a low water depth, reaching a maximum at about 14–15 m in the narrowest point between the two islands. The so-called

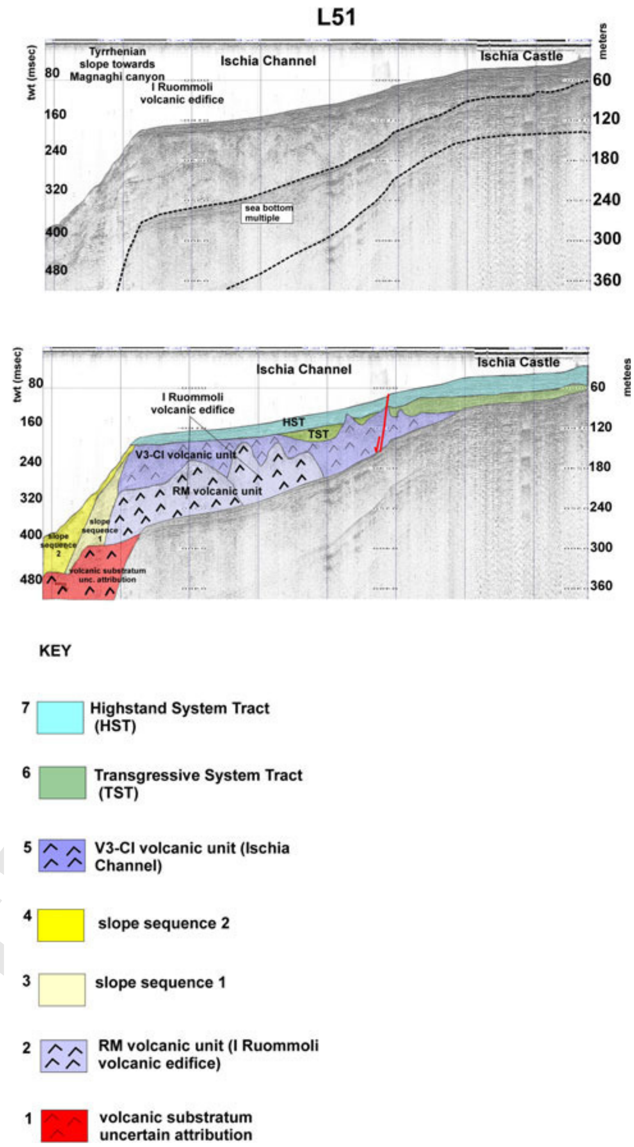

Fig. 13 Seismic profile L51 recorded between the Ischia Channel and the Procida continental shelf and its geologic interpretation

"Formiche di Vivara" becomes visible: a group of rocky inlets or non-emerging rocky outgrowths on the sea bottom, representing the uplifted part of a saddle reaching 4–5 m of water depth. A volcanic substratum, of uncertain attribution, underlies the volcanic unit of "I Ruommoli", formed by two mound-shaped coalescent volcanic edifices (Fig. 13). The corresponding seismic unit, acoustically transparent, is herein called RM volcanic unit. It is unconformably overlain by the V3-CI unit, (volcanic unit of the Ischia Channel) whose top is eroded by a subaerial unconformity, giving rise to small intra-platform basins, infilled by the TST deposits. On the eastern continental shelf of Ischia, from the Aragonese Castle to the Ischia Channel, highstand deposits appear to be well developed and range in average thickness between 40 and 20 m.

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5 Seismo-stratigraphy and Ischia geologic evolution

Volcanic complexes occurring in the subsurface of the Ischia and Procida islands and linked to their eruptive phases evidence a significant submarine instability. It is worth recalling here that the Ischia offshore is characterized by alkali–potassic volcanic rocks (trachytes, latites, alkali-basalts) and pertains to a volcanic complex emplaced during the last 55 ky. Accordingly to Chiesa et al. (1985) and Poli et al. (1987), the eruptive activity of the Ischia Island may be subdivided into four main phases:

1. Prior to 150 ky BP: emplacement of pyroclastic products and intercalated lava flows, without clear origin, if from a single or from multiple volcanic sources.

2. From 150 to 75 ky BP: extensional tectonics giving rise to the growth of numerous lava domes and the production of pyroclastic materials. The semicircular distribution of the domes seems to indicate the presence of a caldera rim. These first two phases suggest an ancient volcanic complex, probably much larger than the present Ischia Island and now almost completely dismantled, predating the eruption of the ignimbritic tuffs of Mount Epomeo.

3. From 55 to 20 ky BP: emplacement of the Monte Epomeo Green Tuff, an ignimbrite which covered the coastal relief and filled the depression at the center of the island. The volcanic vent opened in the southern sectors of the island and the eruptive activity continued in several volcanic centers (Citara-Serrara Fontana Formation, Rittmann 1930). The last activity resulted in mostly lavas that occurred at the Campotese volcano.

4. From 10 ky BP to 1302 AD: in this phase, the eruptive activity was mainly concentrated in the Ischia graben. This structure is clearly identified both by the faults generated during the rapid uplift of the volcano-tectonic horst of Mount Epomeo and by NE–SW (counter-Apenninic) trending normal faults. The Zaro lava flow (1302 AD) was the only eruption outside the Ischia graben (Fig. 4). This phase is characterized by lava flows and by a minor fall-out of pyroclastic deposits from monogenic volcanoes.

The geological interpretation of the marine DEM (Figs. 3, 5) and of high-resolution seismic reflection profiles allowed us to identify important, often multi-phase, submarine instability processes, both catastrophic (debris avalanches; Fig. 6) and continuous (creep and accelerated erosion along canyons; Fig. 8).

Debris avalanches, occurring on the northern, western and southern submerged flanks of Ischia Island (Figs. ESM1—Online Resource 1, 6), are mainly controlled by the volcano-tectonic uplift of the Mount Epomeo block, related to a calderic resurgence during the last 30 ky (Walzer 1984; Orsi et al. 1991; Acocella and Funiciello 1999; Acocella et al. 2004). The most important among them is the Ischia Debris Avalanche (IDA), having southward dispersal axes and transporting large blocks up to 40–50 km away from the island (Chiocci and de Alteriis 2006). The origin of this event has been attributed to a land–sea catastrophic collapse, involving the southern flank of the island, confirmed by the large scar of southern Ischia, well evident on the DEM (Chiocci and de Alteriis 2006). Our volumetric evaluation of the IDA, based on DEM analysis, has given values in the order of 1.5 km^3, coherent with those estimated by Chiocci and de Alteriis (2006) on the basis of seismic profiles and piston cores.

Differently from the IDA, the hummocky facies, occurring on the western flank of the island (Fig. ESM1—Online Resource 1) and on the northern side of the Casamicciola harbor (Fig. 6), do not appear to be related to evident slide scars. The complex topography of the sea bottom shown by multibeam bathymetry highlights the occurrence of heterometric blocks, reaching a size of several hundred meters across, fallen along the slopes and interstratified within a sandy–silty matrix. The matrix derives both from the volcaniclastic sediments, originally deposited on the slopes, and from the failure of sediments previously accumulated on the inner shelf. The debris avalanche deposits are only partly covered by recent marine sediments, pointed out by the interpretation of Sidescan Sonar photomosaics (Fig. ESM1—Online Resource 1). Seismic reflection profiles also suggest that both the deposits occurring off Casamicciola (northern Ischia; Fig. 6) and Forio (western Ischia; Fig. ESM1—Online Resource 1) may be the result of two distinct, superimposed and catastrophic events (Aiello et al. 2009b).

Relevant canyon systems have been observed in the Ischia offshore, through multibeam bathymetry. The main canyon's heads are located in the northwestern Ischia offshore ("Testata di Punta Cornacchia", "Canalone di Forio"; Fig. 1). The southern slope of Ischia, characterized by abrupt slopes, mainly showing the volcanic deposits of the old eruptive cycles, is incised by many submarine canyons. In particular, the seismic profile L50 (Fig. 8) has shown three main submarine canyons, pertaining to the southern Ischia canyon system and, respectively, located between Punta Imperatore and Capo Negro. Their NE–SW trend indicates a possible structural control along NE–SW (counter-Apenninic) structural lineaments. This is coherent with previous structural studies suggesting the occurrence of Plio-Quaternary NW–SE and NE–SW trending extensional fractures (Acocella and Funiciello 1999).

On the southwestern border of the Ischia volcanic dome, small NW–SE extensional faults, with throws in the order of 1 m, are widespread (Acocella and Funiciello 1999), while larger faults with the same trend and dipping to the NE form high-angle reverse faults with throws in the order of several hundred of meters. These faults, evident at about

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1 km NW of Serrara Town and detected in the field, are connected with the fault system active during the dome uplift (Acocella and Funiciello 1999). The above fault zone borders the dome and extends into the volcanic deposits older than the Green Tuff of the Epomeo Mt., through the Panza and Campotese vents. It coincides with an extended fault scarp, characterized by gravimetric and Rn-anomalies and by fumarolic activity (Maino and Tribalto 1971; Nunziata and Rapolla 1987; Vezzoli 1988).

Large submarine canyons occur also off the Maronti Bay (southern Ischia; Fig. 11a–c). They exhibit a dominant N–S trend and begin in correspondence to some embayments of the shelf break, more retreated than in the adjacent sectors of the southern offshore. A long canyon starts from the Punta San Pancrazio promontory (southwestern Ischia) and another one from the Ischia Bank volcanic edifice. Moreover, the N–S trend of the Maronti canyons seems to suggest a structural control on these incisions. The N–S fractures located at the borders of the resurgent blocks also suggest that the above structures are related to the caldera resurgence.

These systems may be considered as connecting fractures, locally accommodating the displacement of the pre-existing regional faults during the resurgence (Acocella and Funiciello 1999). Finally, it has to be mentioned that an important regional normal fault, NE–SW trending, starts from Maronti and extends along the whole southwestern sector of the island, up to Ischia Ponte (Aragonese Castle), and bounds to the southeast the Ischia graben.

6 Final remarks

The main seismic sequences of the southeastern Ischia offshore have been restored through the geological interpretation of high-resolution (Sparker) seismic reflection profiles. Regional seismic sections have been assembled based on their geologic interpretation to improve the understanding of the structural and stratigraphic characteristics of the island offshore and taking into account the volcanology and the stratigraphy of the onshore sequences (Vezzoli 1988; Orsi et al. 2004; Brown et al. 2008) for a coherent geological interpretation.

To this purpose, the southwestern Ischia offshore, between Punta Imperatore and Sant'Angelo promontories, has been investigated analyzing five seismic sections, perpendicular to the shoreline (L36, L37, L38, L39 and L40; Figs. 9, 10, ESM4—Online Resource 4) and one tie section (L50; Fig. 8). In this sector, the Ischia continental shelf is very narrow and the Late Quaternary deposits are thin and restricted sideway. The shelf break, however, seems to be depositional. The most important seismic unit detected in this sector is the volcanic acoustic basement, cropping out on the slope below a thin Holocene sedimentary drape, genetically corresponding to the Punta Imperatore lavas (Fig. 8). Continental slope deposits, ranging in age from the Late Pleistocene to the Holocene, have also been recognized.

Based on the most recent literature, the following sequence of events may have occurred at Punta Imperatore promontory: (a) alkalitrachytic lavas (117 ky BP) cover (b) a pyroclastic breccia emplaced before the (c) Monte Epomeo Green Tuff (Brown et al. 2008). The above breccia is overlain by a (d) thick pumice fall breccia, with several intercalated scoria layers. A whitish ignimbrite (e), related to the Epomeo Green Tuff eruptions, follows and fills a small valley cut into thick fall deposits (Orsi et al. 2004). On the southern slope of the promontory, this sequence is unconformably covered by (f) the products of the Scarrupo di Panza eruption, and by (g) the pyroclastic units of the 28–18 ky period of Ischia volcanic activity.

A new pyroclastic stratigraphy by Brown et al. (2008) for the Ischia Island covers the period from 75 to 50 ky BP. Their volcanological data indicate that during this period, the largest eruptions recorded on the island occurred. So, as to its early volcanism, Ischia appears considerably more active than previously thought. In particular, the stratigraphy of the volcanic sequences cropping out at Punta Imperatore has been deeply revised. In the basal part of these sequences outcropping the coastal cliffs, (a) lavas aged about 118 ky BP (Vezzoli 1988) have been identified. They are overlain by (b) undifferentiated pumice fall deposit, whose age is uncertain.

These latter deposits are in turn unconformably overlain by (a) the Monte Epomeo Green Tuffs (MEGT in Brown et al. 2008) consisting of heterolithic pyroclastic breccias and ignimbrites; (b) the La Roia Tephra, consisting of well-sorted, graded pumice lapilli, overlying a paleosol developed in the above extracaldera MEGT lithic breccia and passing up into (c) a paleosol overlain by distal ashfall deposits of the Chiummano Tephra. They are covered by (d) the Schiappone Tephra, consisting of pumice fall deposits covered by (e) ignimbrites, which in turn are overlain by (f) the Citara Formation (45 ky BP; Vezzoli 1988).

On the L38 seismic profile, the volcanic acoustic basement, outcropping on the southwestern submarine slope of Ischia, is quite thick and genetically related to the Grotta del Mavone lavas (Fig. 10). On the continental shelf, the HST deposits appear well developed and the shelf break seems to be depositional.

At the base of the Grotta del Mavone promontory, alkalitrachytic lavas (28 ky BP) are exposed (Orsi et al. 2004). On the coastal cliff between Grotta del Mavone (Fig. ESM3—Online Resource 3) and Punta Imperatore, a stratigraphic section through the Scarrupo di Panza volcano

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is exposed. It consists of a thick sequence of intensely welded scoriae, while at Grotta del Mavone (toward the south) and at Punta Imperatore (toward the north) the above lavas include alternating layers of pumice fall and welded scoriae.

The continental shelf and slope off the Punta del Chiarito promontory have been investigated through the geological interpretation of the L39 seismic profile (Fig. ESM4—Online Resource 4). Here, the shelf is wider than in the previously mentioned sectors and TST and HST deposits have been recognized. The TST deposits unconformably overlie an erosional truncation at the top of a well-stratified, thick seismic unit, corresponding to a relic prograding wedge. The latter unit in turn overlies the volcanic acoustic basement, genetically related to the Punta del Chiarito lava dome and/or to the eruptive center of Sant'Angelo (Fig. ESM4—Online Resource 4).

The coastal cliff between Punta del Chiarito and S. Angelo is carved into the surge deposits forming the top of the Sant'Angelo promontory, while the Punta del Chiarito promontory is composed of alkalitrachytic lava flows, unconformably overlain by the youngest pyroclastic unit of the Sant'Angelo sequence (Orsi et al. 2004). More to the west, the Capo Negro promontory is composed of alkalitrachytic lava flows overlain by the same pyroclastic unit, which is in turn overlain by two thick pyroclastic units, the youngest of which dated at 20 ky BP (Orsi et al. 2004).

A revised stratigraphy of the Sant'Angelo coastal cliff has been presented by Brown et al. (2008). In the Torre S. Angelo volcanic sequence, the basal outcrops start with lavas (100 ky BP; Gillot et al. 1982), overlain by interbedded ignimbrites and pumice fall deposits. They are in turn unconformably overlain by tephra, forming two volcanic units. The lower unit is made of interbedded decimeter-thick pumice fall deposits and dark-brown ignimbrites. The upper one includes two monomictic breccias separated by pumice fall deposits.

The Maronti area has been investigated through three dip seismic profiles (L41, L42 and L43; Fig. 11a–c) and a tie one (L39, fix 2–8; Fig. ESM4—Online Resource 4). Here, the continental shelf is narrow with respect to the adjacent areas. The TST and HST deposits are thin and restricted. The volcanic acoustic basement is thick and continuous from the shelf toward the slope. On the L41 line, a volcanic lava dome has been individuated through seismic interpretation (Fig. 11a). Moreover, the L42 line has shown a canyon head on the upper slope at a water depth of 60 m (Fig. 11b). The acoustic basement crop out on the continental slope under a thin drape of Holocene deposits. On the line L43, a main canyon has been individuated at a water depth of 120 m and the rocky terraced surface, well detected also through Multibeam bathymetry, develops at water depths ranging between 120 and 180 m (Fig. 11c).

The Maronti beach extends between Punta della Signora and Sant'Angelo promontories. Coastal outcrops are the product of the dismantling of the Monte Epomeo structure that recently formed landslides and mud flows, covering older debris avalanches. At the base of the Sant'Angelo promontory, an alkalitrachytic lava dome (100 ky BP; Orsi et al. 2004) is overlain by ash flows, pyroclastic flows and fall deposits. They belong to the explosive volcanism that preceded the Epomeo eruption (Brown et al. 2008). These deposits are overlain by pyroclastic deposits dated at about 55 and 20 ky BP.

The Barano Bay has been investigated through three seismic sections (L44, L45 and L46; Fig. 12a–c), while the Punta San Pancrazio offshore, having the same geologic characteristics of Barano, has been studied through the seismic line L47 (Fig. ESM6—Online Resource 6). A thick volcanic acoustic substratum has been recognized under the Barano Bay through seismic profiles on the slope of the Scarrupata di Barano. On the lower slope, the volcanic substratum is overlain by a thick seismic sequence, characterized by channel–levee complexes.

Two seismic units, named Barano 1 (the lower unit) and Barano 2 (the upper unit), have been identified in the volcanic substratum through seismic stratigraphy (Fig. 12a–c) and tentatively correlated with the lower and upper Scarrupata di Barano formations.

Offshore Punta San Pancrazio geological characteristics similar to those of the Barano Bay have been recognized on the seismic line L47 (Fig. ESM6—Online Resource 6). The Barano 1 and Barano 2 seismic sequences have been identified in the volcanic acoustic basement. Moreover, a small volcanic lava dome has been recognized on the top of the Barano 1 sequence, laterally grading into a palaeocanyon, infilled by an acoustically transparent seismic unit, probably pyroclastic in nature (Fig. ESM6—Online Resource 6). The slope off San Pancrazio is characterized by a marine turbiditic sequence lying on the volcanic acoustic basement and characterized by parallel-to-progradational seismic reflectors (Fig. ESM6—Online Resource 6).

The San Pancrazio promontory is composed of a sequence of lavas belonging to the Monte di Vezzi volcanic complex that are intercalated to pyroclastic deposits. The upper part of this sequence includes the Epomeo Green Tuffs (Orsi et al. 2004). Next is the Scarrupata di Barano, a sea cliff extending from Punta San Pancrazio to La Guardiola promontories (Fig. ESM5—Online Resource 5). Along this cliff, the stratigraphic relationships among the products of the oldest activity may be observed. The massive yellow–white ignimbrite, which forms most of the top of the cliff and is marked at its base by a scoria layer, has been correlated with the Epomeo Green Tuffs (Vezzoli 1988; Fig. ESM5—Online Resource 5).

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The stratigraphy of the Scarrupata di Barano has been deeply revised (Brown et al. 2008). In the basal part of the sea cliff, the Upper Scarrupata di Barano Formation has been recognized. It is unconformably overlain by the Chiummano Tephra, consisting of lithic-rich pyroclastic density current deposits. They are overlain by the Schiappone Tephra, composed of two members. The first member consists of pumice fall deposits passing upward to welded pumice fall deposits, while the second member, the last of the stratigraphic succession, consists of ignimbrites.

Further information on the seismo-stratigraphic framework of the Ischia–Procida offshore is based on the interpretation of the seismic line L51 (Fig. 13). The line shows a buried volcanic edifice overlain by a prograding wedge and then by the Magnaghi canyon volcanites and volcanoclastites (Fig. 13). Aggrading and prograding sequences of Procida–Ischia continental shelf have also been identified. The stratigraphic relationships with the Banco di Ischia volcanic structure have been shown by the regional seismic section L57 (Fig. 7).

In conclusion, the contribution of the seismic stratigraphy to the knowledge of the geologic history of Ischia has allowed to supplement the volcanologic and geologic information based on field outcrop data with the new data of the seismic stratigraphy, as resulting from the new geological map of Ischia at the scale 1:25,000 already redacted and now in the course of printing (Aiello et al. 2009b).

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