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Submarine Stratigraphy of the Eastern Bay of Naples: New Seismo-Stratigraphic Data and Implications for the Somma-Vesuvius and Campi Flegrei Volcanic Activity

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Abstract: The submarine stratigraphy of the eastern Bay of Naples is studied through seismo-stratigraphic data correlated with borehole data. Multichannel seismic profiles are interpreted in order to reconstruct the stratigraphic relationships between the Quaternary marine seismic units and the volcanic acoustic substratum. Seven seismic units are recognized based on the geological interpretation of seismic profiles and using seismo-stratigraphic criteria. The top of the lowest seismic unit was correlated with the Campanian Ignimbrite (Southern Campania Volcanic Zone). The stratigraphic setting of the eastern Bay of Naples is characterized by NE-SW trending seismic structures, probably corresponding with tuff rings. These tuff rings can be compared with the Porto Miseno, the Archiaverno and Averno, and the Astroni tuff rings (Campi Flegrei). Offshore, the Somma-Vesuvius a seismic unit was interpreted as the fallout deposits representing the base of the AD 79 eruption. However, since a branch of the isopach of 5 m of the "Pomici di Avellino" pyroclastic deposits is very close to the Tyrrhenian coastline and near our GRNA01 and GRNA03 seismic profiles, we cannot exclude that the seismic unit could be also correlated with the deposits of this eruption.

Keywords: eastern Bay of Naples; high-resolution seismic reflection profiles; seismic units; tuff rings; pyroclastic flow deposits; Somma-Vesuvius; Campi Flegrei

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1. Introduction

The submarine structure of the Somma-Vesuvius volcano and the buried volcanic structures of the Naples Bay were extensively studied [1–7]. One important previously identified feature is a seismic reflector interpreted as evidence of a southwestwards lateral collapse of the volcano, probably between 35 and 11 ky B.P. ago [2]. In contrast, the eastern side of the volcanic complex is characterized by the occurrence of buried parasitic craters and pyroclastic deposits [1].

This paper interprets the submarine stratigraphy of the Gulf of Naples, focusing on the eastern Bay of Naples, based on multichannel seismic data. These data highlight the stratigraphic relationships between the Quaternary marine and volcanic deposits, with thick seismic units identified as the Campanian Ignimbrite (CI seismic unit) [8–15] and the Neapolitan Yellow Tuff (NYT seismic unit) [16–21].

This paper will show the seismic units corresponding with the Campanian Ignimbrite and the Neapolitan Yellow Tuff (NYT) deposits, seismic units interpreted as tuff rings, and an important new seismic unit, recognized offshore as the Somma-Vesuvius, which correlates with the fallout deposits representing the base of the AD 79 eruption sequence [22–28].

Gurioli et al. [25] delineated the area impacted by PDCs (pyroclastic density currents) at Somma-Vesuvius, focusing on the dispersal, thickness, and extent of the PDC deposits, generated during seven plinian and sub-plinian eruptions (Pomici di Base, Greenish Pumice, Pomici di Mercato, Pomici di Avellino, Pompeii Pumice, AD 472 Pollena, and AD 1631 eruptions. The maps of the total thickness of the PDC deposits for each eruption were constructed. Among the seven eruptions, five of them have dispersed PDCs radially, showing a preferential direction controlled by the location of the vents and by the palaeotopography. The PDCs from the Pomici di Avellino and Pompei Pumice eruptions have shown the most dispersed, broadest distributed deposits. Both the isopach maps and the features of the deposits have revealed that the PDC dispersal was controlled by the intensity of the eruption, by the location of the vent with respect to the Somma caldera wall and by the pre-existing topography.

2. Datasets and Methods

A multibeam bathymetric dataset was previously acquired as part of the CARG project of the Naples and Salerno Bays (http://www.isprambiente.gov.it/Media/carg/campania.html, accessed on 16 October 2022; Figure 1) [29]. The DEM (Digital Elevation Model) merges onshore and offshore data and shows the location of the seismic lines analyzed in this paper (Figure 1). Onshore data display the physiographic domains of the Somma-Vesuvius volcanic complex, the Campi Flegrei volcanic complex, the Ischia and Capri islands, and the Sorrento Peninsula (Figure 1). The seismic lines analyzed in this paper are located in the eastern sector of the Bay of Naples, from the Somma-Vesuvius offshore to the Naples town (Posillipo), and from Sorrento Peninsula offshore, covering an inner shelf to outer shelf physiographic domain.

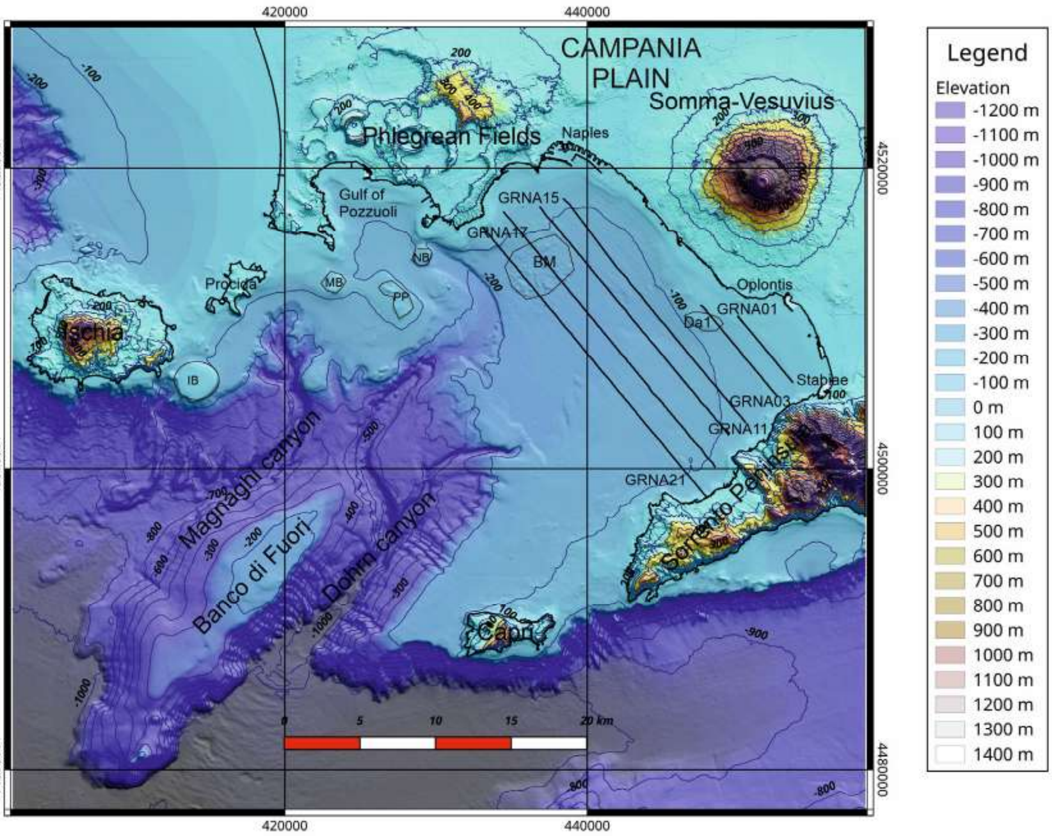

Figure 1. Sketch map showing the location of the seismic profiles superimposed on the Multibeam bathymetric map of Naples Bay. The main morpho-structural features of the Bay of Naples are also reported (Dohrn canyon, Magnaghi canyon, Banco di Fuori). Da1: debris avalanche; BM: Banco della Montagna; NB: Nisida Bank; PP: Pentapalummo Bank; MB: Miseno Bank; IB: Ischia Bank.

The seismic profiles were processed and interpreted with the aim of improving the geological knowledge of the eastern sector of Naples Bay, focusing in particular on the submarine flank of the Vesuvius volcano. The seismic data were collected previous to this study in the oceanographic cruise GMS00_05 [5], which took place during October–November

2000 in the Southern Tyrrhenian sea onboard of the R/V Urania (National Research Council of Italy). The seismic profiles GRNA01, GRNA03, GRNA11, GRNA17, and GRNA21, from the same cruise, are unpublished, and are herein processed and interpreted for the first time. The seismic profile GRNA15 was previously processed and interpreted by Aiello et al. [5] but is re-processed and re-interpreted here. Aiello et al. [5] provide additional details on the seismic acquisition parameters of the survey and methods for processing and interpretation of the seismic data.

The processing of the seismic lines was carried out using Seismic Unix software [30], including the extraction of the first channel from the shot gathers, application of Automatic Gain Control (AGC), and a spectral analysis of the seismic traces with a Fourier Transform and the application of a Butterworth bandpass filter (f = 40 Hz, 45 Hz, 240 Hz, 250 Hz).

The processing of the seismic data consisted of five steps. The first step was quality control and the assignment of the field geometry. The second step was editing the seismic traces to identify and remove spikes from the seismic record. The third step was top muting, to eliminate signals before the first arrivals of the seismic traces. The fourth step was the application of Automatic Gain Control (AGC), improving the normalization of the seismic traces. The fifth step was a velocity analysis aimed at removing move-out on the CDP (Common Depth Point) families and defining the velocity of the different seismic horizons. This yielded stacked seismic sections ready for the geological interpretation.

Geological interpretation of the seismic profiles was carried out using criteria of seismic stratigraphy [31–33]. A key concept is that the geometry of the seismic reflectors provides information on depositional geometry. Seismic reflectors correspond with significant contrasts in acoustic impedance, allowing for the calculation of transmitted vs. reflected acoustic energy. Seismo-stratigraphic analysis is carried out by identifying stratigraphic discontinuities and depositional sequences, reconstructing of the original geometry of the sedimentary bodies, and chronostratigraphic correlation. Planke et al. [34] developed the concept of the volcanic seismo-stratigraphy, which is the analysis of the seismic facies by mapping and geological interpretation of the units having the same seismic facies. However, individual volcanic deposits are sometimes difficult to image, requiring a knowledge of the seismic response of the different volcanic deposits.

In this paper, the identified seismic units are designated with letters, avoiding any lithostratigraphic or chronostratigraphic interpretation. Time-to-depth conversions of significant seismic reflectors were made, using an average velocity of the overlying Quaternary marine deposits of 1650 m/s. An average seismic wave velocity of 1650 m/s 1 within the first seismic units beneath the seafloor was assumed, as a result of test-calibration carried out in previous papers [35]. This conversion is necessary to allow the seismic reflector corresponding to the top of the seismic unit of the Campanian Ignimbrite, for example, to be correlated with the depth of these deposits at the “Trecase 1” exploration well [36] (Figure 2).

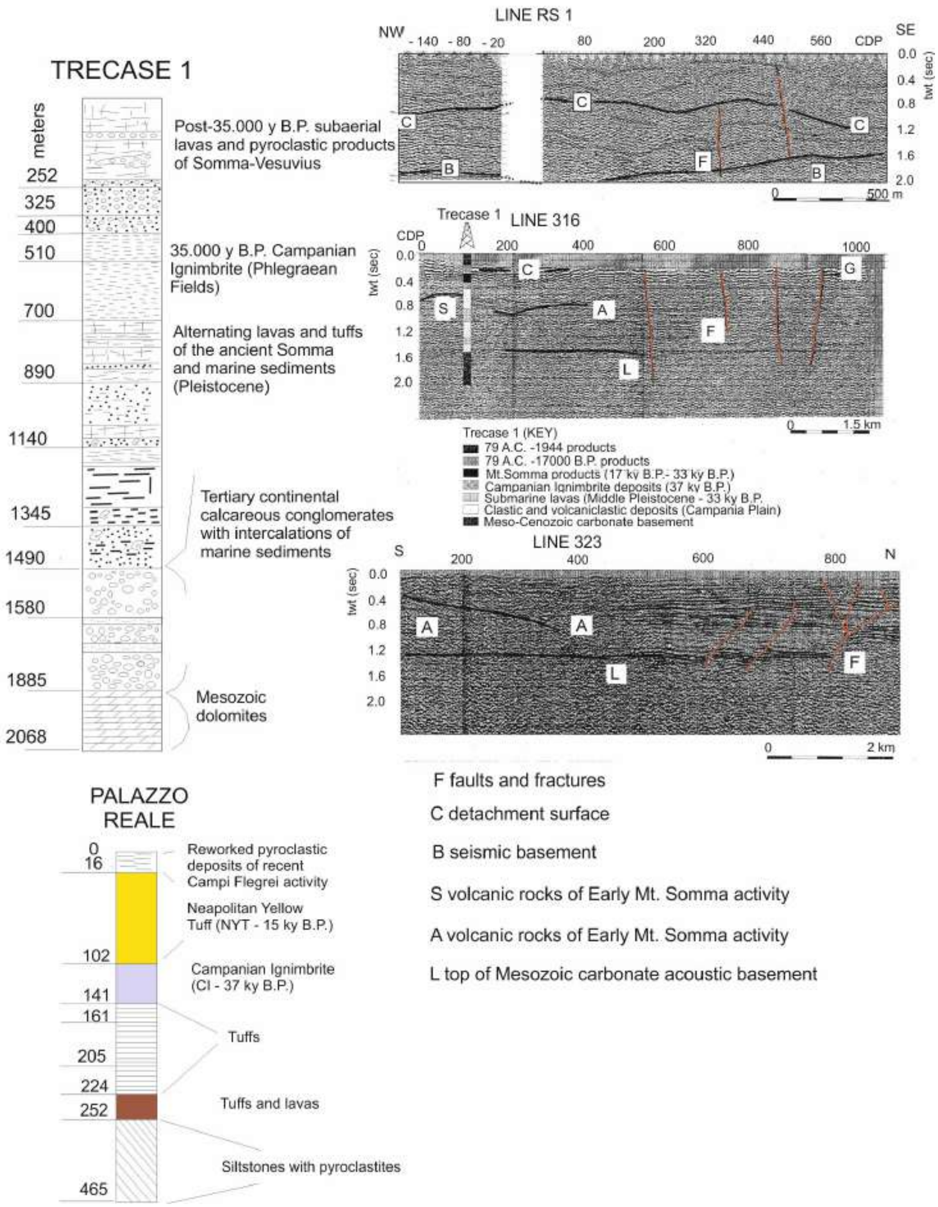

Figure 2. Sketch stratigraphy of the exploration well "Trecase 1" (modified after [36]), integrated with the seismic profiles recorded onshore in the Vesuvius area and calibrated by the Trecase 1 well (modified after [2]). The stratigraphy of the "Palazzo Reale" borehole (modified after [37]) has also been reported.

3. Geological Setting

The Bay of Naples lies in the southern part of a tectonic depression, namely the Campania Plain, produced by the regional tectonic subsidence that affected the Southern Tyrrhenian margin during the Pleistocene (Figure 1). It corresponds to a half-graben structure controlled by a NE-SW master fault running parallel to the "Banco di Fuori" structural high. The pre-Pleistocene basement crops out in the Sorrento Peninsula structural high. The age of basin formation is roughly Pleistocene based on the "Trecase 1" exploration well on land (Figure 2) [36]. A seismic profile located onshore in the Vesuvius area shows the main seismic reflectors (Figure 2) [2], corresponding with the acoustic basement, the faults mapped onshore in the volcanic complex [38], the seismic reflectors with a complex morphology, and the diffractions near the volcano (Figure 2).

The Quaternary volcanism of the Campania continental margin was controlled by three main rifting stages, allowing recognition of an ancient volcanic cycle, which was contemporaneous with the first rifting stage and of a young volcanic cycle, which acted simultaneously with the second and the third rifting stages [7]. This study established that the first rifting stage was Lower Pleistocene in age and was controlled by NE-SW trending normal faults. The second rifting stage, Middle Pleistocene in age, acted through NW-SE trending normal faults. The third rifting stage, Middle-Late Pleistocene in age, was controlled by the reactivation of previous fault systems and by N-S trending normal faults. The ancient volcanic cycle includes (among others) the V0 volcano [7] and the Parete volcano [39,40]. The volcanoes of the ancient cycle have a size comparable with that of the Somma-Vesuvius volcano and range in age between the Early Pleistocene and 0.4-0.1 My [7,41]. The Parete volcano is composed of thick basaltic and andesitic lavas, which were drilled by the "Villa Literno 2" and "Parete 2" wells [39,40,42] (Figure 3). The "Villa Literno 2" well has drilled the recent pyroclastic products, underlain by andesitic tuffs, having an average thickness of 150 m, underlain, in turn, by marine and transitional clastic deposits, thick about 650 m. These deposits overlie a thick volcanic sequence, composed of alternating lava and tuffs, thick about 2150 m, interpreted as the Villa Literno volcanic complex, recognized on the seismic profile Sister4_2 [39] and correlating with the "Parete 2" well (Figure 3). The "Parete 2" well has drilled a similar volcanic sequence, interpreted as the Parete volcano (Figure 3), and is overlain by recent pyroclastic products. The volcanoes of the young volcanic cycle include the lavas occurring in the subsurface of the Vesuvius volcanic complex ("Trecase 1" well) [35] (Figure 2), the Campanian Ignimbrite [11,13,43–51], and the eruptive sequence of the Vesuvius volcano (Figure 2).

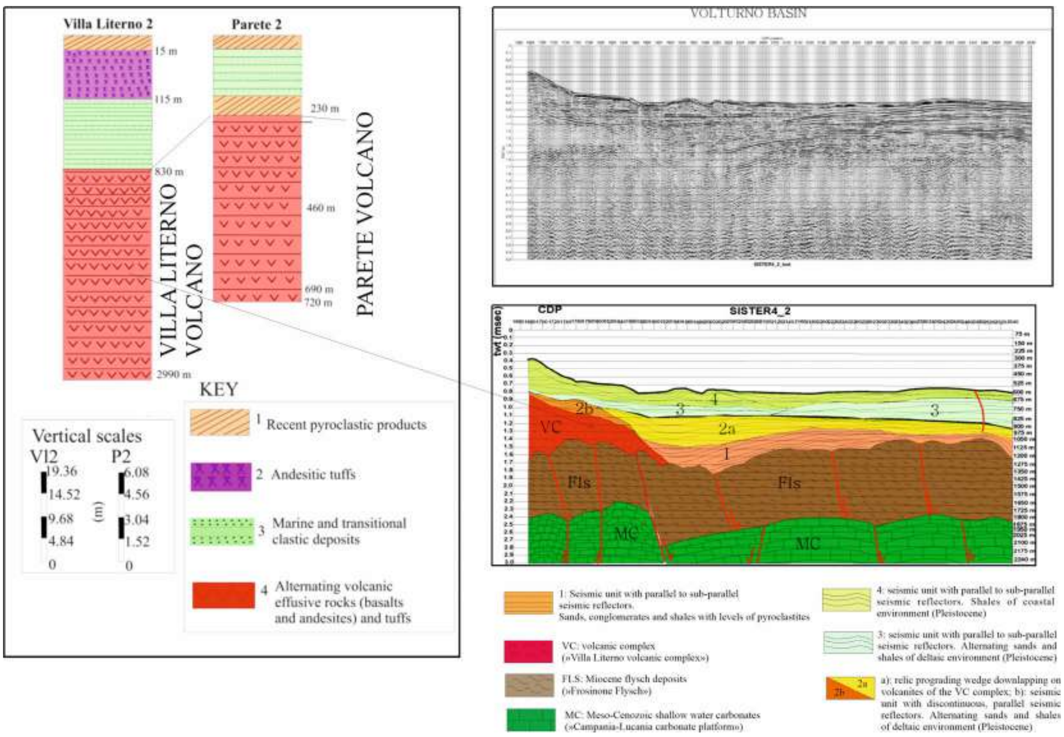

Figure 3. Sketch stratigraphy of the deep exploration wells "Villa Literno 2" and "Parete 2" (modified after [42]) showing the Villa Literno and Parete volcanic complexes and correlation of the Villa Literno volcanic complex with the seismic profile Sister4_2 (upper right) and corresponding geologic interpretation (lower right; modified after [40]).

In the northern Campania Volcanic Zone (CVZ), the stratigraphic data of more than 600 boreholes have allowed reconstruction of the stratigraphic architecture of the ignimbrite, lava flows, and marine deposits (Figure 4) [52]. The lowermost unit is composed of marine sediments (Tyrrhenian Layer M1), whose top was dated to 126 ky B.P. [53]. A volcanic unit overlies the marine deposits and is composed of massive ignimbrite deposits and lava flows. This unit is overlain by a succession of transitional and marine deposits, dated back to 55–50 ky (Tyrrhenian Unit M2) [54], overlain by the CI deposits [52,55–60]. The CI deposits are overlain by the Giugliano Ignimbrite (GI; Figure 4), while in the southern sector of the Campania Volcanic Zone, by grey Neapolitan Yellow Tuff (NYT) and by pyroclastic rocks younger than 10 ky.

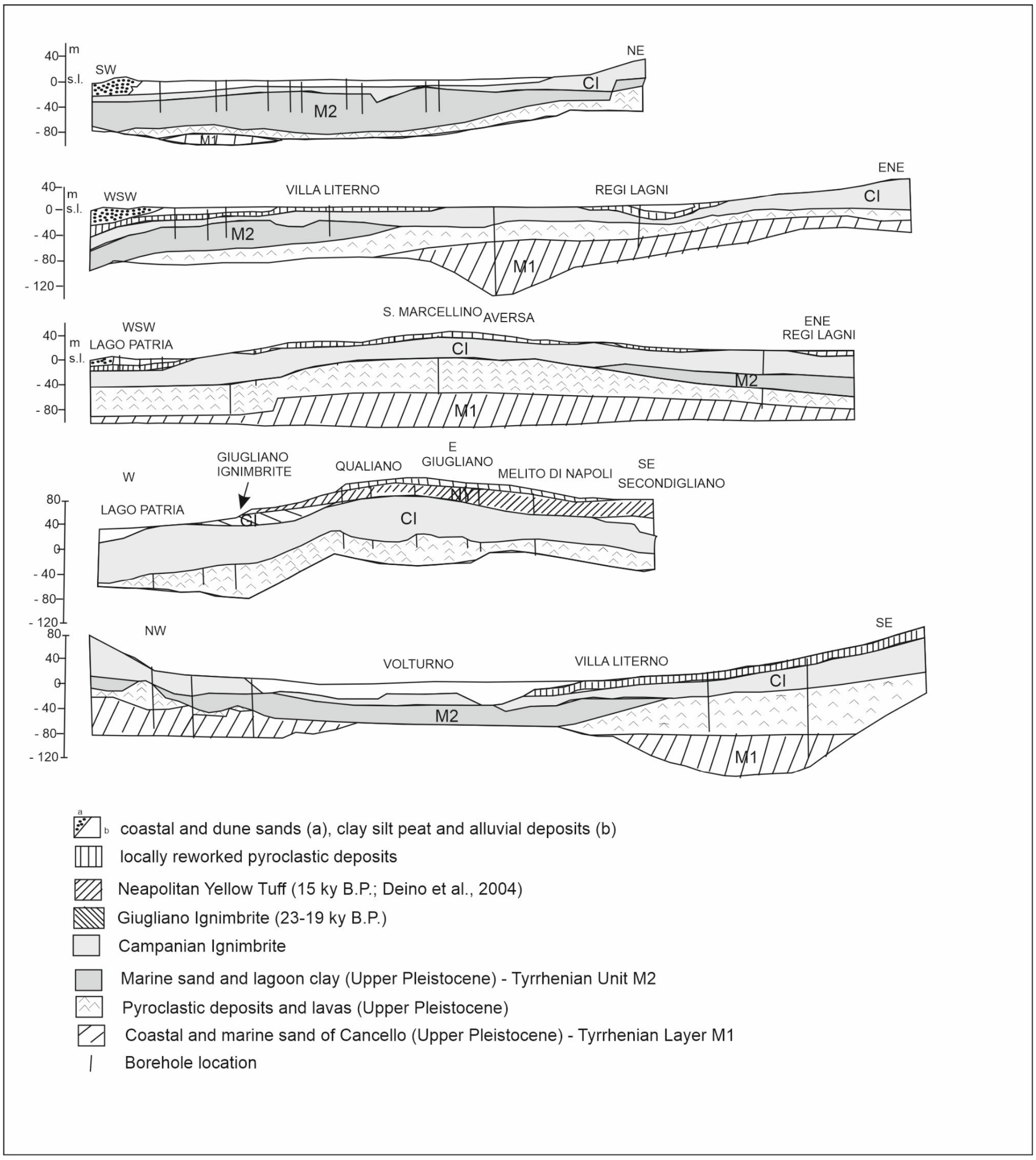

Figure 4. Geological sections and location of boreholes in the Northern Campania Volcanic Zone (N-CVZ; modified after [52]). Note that the Northern Campania Volcanic Zone (N-CVZ) is the broad area including the portion of the Campania Plain, which is characterized by intense volcanic activity, older than 12 ky B.P. [52]. The stratigraphic data of more than 600 boreholes were analyzed in order to construct the geological sections shown in the figure, showing the stratigraphic relationships between the volcanic units occurring in the subsurface of this sector of the Campania Plain.

The "Palazzo Reale borehole", whose stratigraphy is shown in Figure 2, has given key lithostratigraphic data on the Neapolitan Yellow Tuff (NYT) and on the Campanian Ignimbrite (CI) in the subsurface of Naples [37,52]. It represents a key lithostratigraphic column, taken from a borehole 465 m deep and drilled in 1845 in Naples, near the garden of Palazzo Reale (Figure 2) [37,52]. The stratigraphic column of the well has revealed that, below 16 m of reworked deposits of recent activity of Campi Flegrei, a sequence of Neapolitan Yellow Tuff, about 90 m thick, overlies a sequence of the Campanian Ignimbrite, about 40 m thick (Figure 2). The CI overlies a sequence of tuffs about 80 m thick. Such stratigraphy can be assumed as continuous in the eastern sector of the Bay of Naples. Previous seismo-stratigraphic studies have shown acoustically transparent thick ignimbrite sequences below the Bay of Naples, interpreted as the Campanian Ignimbrite and the Neapolitan Yellow Tuff [14,59].

Campi Flegrei is a complex volcanic area, characterized by monogenetic volcanoes, pyroclastic in nature (tuff cones, tuff rings, ash cones, cinder cones, huge calderas) and subordinately, by lava domes [8,10,11,42]. This volcanic area is located at the southwestern margin of the graben of the Campania Plain, between the Massico Mount and the Sebeto Plain [60–63]. This area represents the emerged northern margin of the Phlegrean caldera, which formed about 39 ky B.P. after the eruption of the Campanian Ignimbrite and the consequent down throwing of the Meso-Cenozoic basement [8–11,64–71].

The Campi Flegrei volcanic district includes numerous tuff rings [11]. One of the most important ones is the tuff ring of Averno, whose volcanology was studied in detail [72]. The tuff ring of Averno was dated at 3700 years B.P. and is a wide maar-type, lake-filled volcano [72]. Di Vito et al. [11] showed the characteristics of the volcanic units of the Campi Flegrei caldera younger than 12 ky B.P. Based on their interpretation, several tuff rings were distinguished, including the Porto Miseno volcano and the Archiaverno volcano. The Porto Miseno volcano is located above the volcanic deposits of the Bacoli volcano and below the deposits of the Capo Miseno volcano.

Somma-Vesuvius is a stratovolcano constituted by an older breached edifice (Mt. Somma) and an intra-caldera cone (Figure 5A; Mt. Vesuvius) [38,73–75]. The volcanic succession is composed of lava flows, interlayered with strombolian scoria fall deposits overlain by the deposits of four main Plinian eruptions [73]:

(i) 22,000 yr cal BP “Pomici di Base”;
(ii) 8900 yr cal BP “Mercato Pumice”;
(iii) 4300 yr cal BP “Avellino Pumice”; and
(iv) A.D. 79 “Pompeii Pumice”.

The pyroclastic deposits corresponding with these four eruptions were interpreted as important stratigraphic markers (Figure 5B) [73]. These intervals, respectively, are:

(i) B-M inter-Plinian, between “Pomici di Base” and “Mercato Pumice”;
(ii) M-A inter-Plinian, between “Mercato Pumice” and “Avellino Pumice”;
(iii) A-P inter-Plinian, between “Avellino Pumice” and “Pompeii Pumice”; and
(iv) P-XX inter-Plinian, between the “Pompeii Pumice” and the last erupted products of the XXth century (Figure 5B) [73].

Moreover, a new geological map of the Somma-Vesuvius volcano at the 1:20,000 scale was recently constructed (Figure 5C) [75]. In this map, an interpretation of the volcanological evolution is shown, based on four main phases, including (Figure 5A): phase 1: the building of the Somma stratovolcano (39 ky–22 ky); phase 2: the caldera formation (22 ky–AD 79); phase 3: the post-caldera activity (AD 472–AD 1631); and phase 4: the growth of the Vesuvius cone (post-1631–1944). During the second phase, a multiphase caldera formation took place, following the emplacement of at least four Plinian eruptions (Pomici di Base, Mercato, Avellino, and Pompeii). During the third phase, the post-caldera activity took place, which was dominated by the deposits of two sub-Plinian eruptions: AD 472 Pollena (PPL) and AD 1631 (PMX). During the fourth phase, the Vesuvius cone grew (post-1631–1944), with the effusion of lavas and volcanic eruptions of a strombolian-type. The corresponding volcanic deposits are represented by wide lava flows, overlying the southwestern slopes of Vesuvius [75].

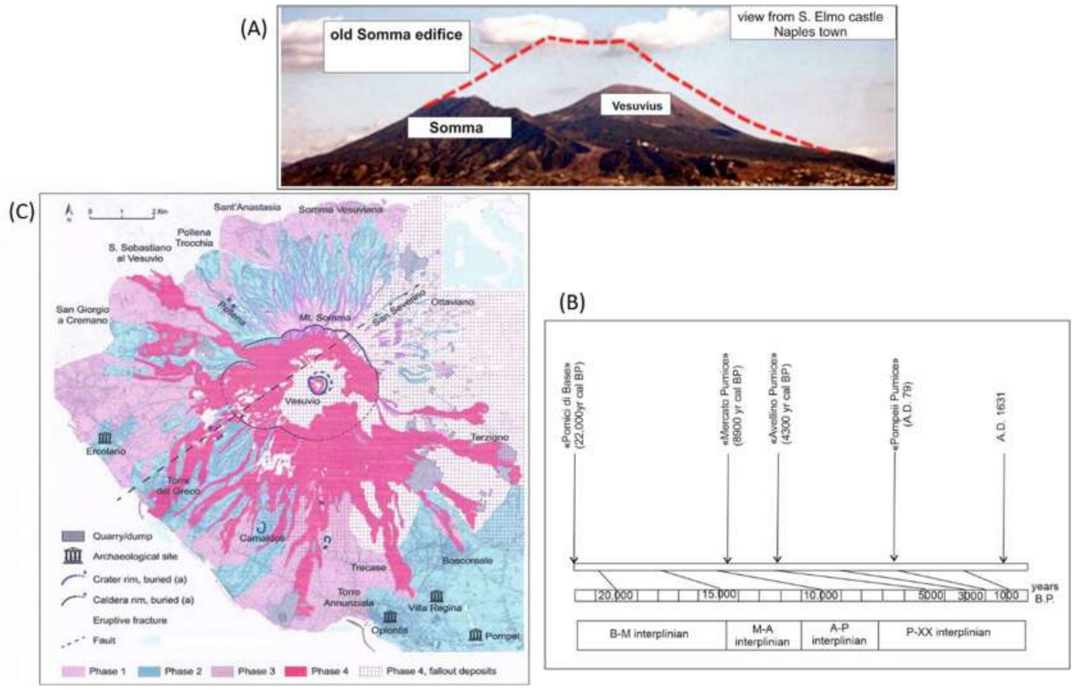

Figure 5. (**A**) Sketch reconstruction of the original profile of the old Somma volcano (modified after [74]); (**B**) Sketch diagram showing the eruptive history of the Somma-Vesuvius (calibrated ages; modified after [73]). (**C**) Geologic map of the Somma-Vesuvius (modified after [75]).

4. Results

4.1. Description of the Seismic Units

Seven seismic units (A, B, C, D, E, F, G) are identified on the seismic profiles of the eastern Bay of Naples based on the seismic stratigraphic and volcano-stratigraphic interpretation (Table 1, Figures 6–10). The G unit is recognized on the seismic profiles GRNA01 and GRNA03 (Figure 6). Its seismic facies is characterized by discontinuous, undulated, and wavy seismic reflectors. Moreover, the seismic unit shows thickness variations. The F unit is identified on the seismic profiles GRNA11, GRNA15, GRNA17, and GRNA21 (Figures 7–10). Its seismic facies is distinguished by parallel and continuous seismic reflectors, while the unit shows a wedge-shaped external geometry. The E unit is identified on the seismic sections GRNA11, GRNA15, and GRNA21 (Figures 7, 8 and 10). It is characterized by discontinuous and parallel seismic reflectors and shows thickness variations. The D unit is recognized on the seismic profiles GRNA17 and GRNA21 (Figures 9 and 10). Its seismic facies is acoustically-transparent and it is characterized by a wedge-shaped geometry. The C unit is identified on the seismic sections GRNA01, GRNA03, GRNA11, GRNA17, and GRNA21 (Figures 6, 7, 9 and 10). Its seismic facies shows two subfacies, the first one with parallel and continuous seismic reflectors and the second one with progradational reflectors. The B unit is an important volcanic seismic unit and is recognized in all the studied sections (Figures 6–10). Its seismic facies is acoustically transparent and the geometry is mounded-shaped. The A unit is another important volcanic seismic unit and is identified in all the studied sections (Figures 6–10). Its seismic facies is acoustically-transparent, while its shape is tabular (Table 1).

The 6 km long Grna01 seismic profile (Figure 6) is located offshore the Vesuvius volcano and crosses the easternmost sector of Naples Bay with an NW-SE trend (Figure 1). Four seismic units are recognized based on seismic facies and strata patterns: (G, C, B, A units; Figure 6). Based on the time-to-depth conversion of the seismic reflector corresponding to the top of the A seismic unit, this seismic reflector is located at a depth of about 412 m, which is in overall agreement with the depth of the Campanian Ignimbrite at the "Trecase 1" borehole (400 m; Figure 2). One mounded-shaped structure, composed of the B unit, is recognized. Proceeding from northwest to southeast, a significant thickness variation of the G seismic unit is observed, since the G unit increases in thickness (Figure 6).

The Grna03 seismic profile (Figure 6) has a length of about 8 km and crosses the eastern sector of Naples Bay with a NW-SE trend (Figure 1). The top of the A unit occurs at depths of 363 m (Figure 6), being in agreement with the depth of the top of the Campanian Ignimbrite unit at the "Trecase 1" borehole (400 m; Figure 2). Three mounded-shaped seismic structures, composed of the B unit, are recognized (Figure 8). The C unit drapes two of these three structures, while it onlaps the flank of the southeastward one (Figure 6). Proceeding from southeast to northwest, a thickness variation of the G unit is observed (Figure 6).

The Grna11 seismic profile (Figure 7) has a length of about 20 km and crosses the eastern Bay of Naples with a SE-NW trend (Figure 1).

Five seismic units are identified (A, B, C, E, F; Table 1; Figure 7). The E unit is located in depressions located between the seismic structures composed of the B unit or alternatively, at the top of the A unit (Figure 7).

The top of the A unit occurs at depths ranging between 330 m and 400 m (Figure 7), showing a good correlation with the top of the Campanian Ignimbrite (400 m; Figure 2).

Three broad seismic structures are recognized, composed of the B unit, respectively, having three mounds northwestwards, one mound at the center, and one mound southeastwards (Figure 7).

The C seismic unit has a progradational seismic facies and overlies the flanks of the mounded-shaped seismic structure composed of the B unit.

The E unit is extensive and in the northwest sector covers the volcanic edifices of the B unit, while in the southeast, it overlies the top of the A unit (Figure 7).

A part GRNA01 and GRNA03 (Figure 6), the F seismic unit is tabular in shape and was detected in all the seismic lines (Figure 7).

The Grna15 seismic profile (Figure 8) has a length of about 20 km and extends from Naples to the Sorrento offshore (Figure 1).

Five seismic units (A, B, C, E, F; are recognized) (Table 1; Figure 8).

The E unit is located in a depression between two seismic structures of the B unit, and on the top of the A unit (Figure 8).

The C unit is located in a depression on the B unit and on the top of the CI unit. Time-to-depth conversion yields a value of 462 m for the depth to the top of the A unit. This value is in agreement with the depth of the top of the Campanian Ignimbrite at the "Trecase 1" well (400 m; Figure 2).

The Grna17 profile (Figure 9) has a NW-SE orientation and a length of about 22 km, extending from the Naples offshore (Posillipo hill) to the Sorrento Peninsula offshore (Figure 1).

Table 1. Seismic units of the eastern Bay of Naples.

Seismic Profiles	Seismic Units	Seismic Facies External Geometry
GRNA01, GRNA03	G	Undulated and wavy seismic reflectors, discontinuous.
GRNA11, GRNA15, GRNA17, GRNA21	F	Parallel and continuous seismic reflectors and wedge-shaped external geometry
GRNA11, GRNA15, GRNA21	E	Discontinuous and sub-parallel seismic reflectors
GRNA17, GRNA21	D	Acoustically-transparent seismic facies, wedge-shaped unit
GRNA01, GRNA03, GRNA11, GRNA17, GRNA21	C	Parallel and continuous seismic reflectors. Prograding reflectors onlapping the top of a seismic structure composed of the B unit.
GRNA01, GRNA03, GRNA11, GRNA15, GRNA17, GRNA21	B	Acoustically-transparent seismic facies and mounded-shaped external geometry
GRNA01, GRNA03, GRNA11, GRNA15, GRNA17, GRNA21	A	Acoustically transparent seismic facies and tabular external geometry

Five seismic units are identified based on seismic interpretation (A, B, C, D, F).

The D unit is recognized offshore the city of Naples, unconformably overlying both the B and the C seismic units (Figure 9).

The C unit is deposited in a depression located at the top of the A unit, which is laterally bounded by the D and B seismic units.

The B unit includes a small seismic structure below the D unit and two wider seismic structures inter-layered in the A unit (Figure 9).

The Grna21 profile (Figure 10) crosses the Naples offshore from Posillipo to the Sorrento Peninsula (Figure 1). Six seismic units are recognized based on seismic interpretation (A, B, C, D, E, F; Table 1; Figure 10). D unit is deformed in the "Banco della Montagna" feature, a wide volcaniclastic field previously described in the Naples offshore [6,59,76,77]. The C unit is located in a depression, located at the top of the A unit and is laterally bounded by a seismic structure of the B unit. The E unit forms small deposits located at the top of B unit. The B unit includes three seismic structures (Figure 10). The A unit is wide and thick in this seismic line (Figure 10).

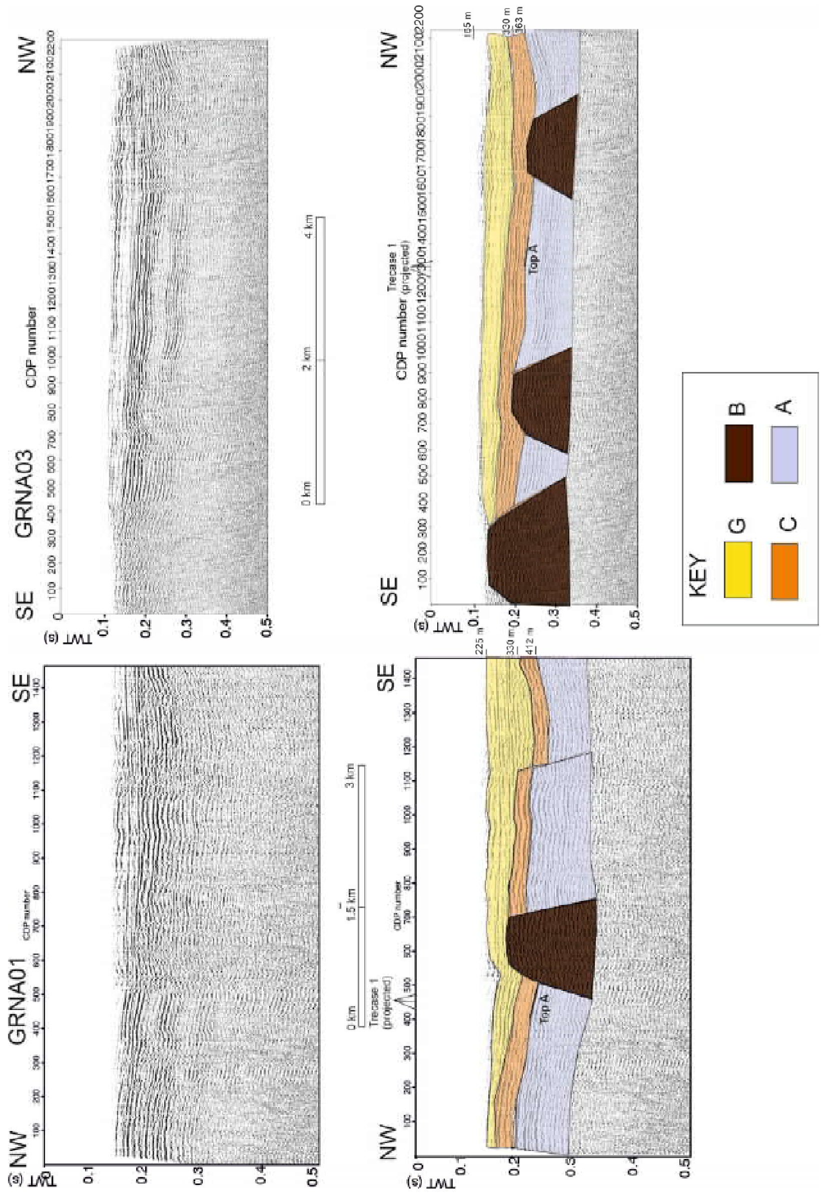

Figure 6. Seismic profile Grna01 (left side) and seismic profile Grna03 (right side), and corresponding geologic interpretation calibrated with the "Trecase 1" well (Figure 2).

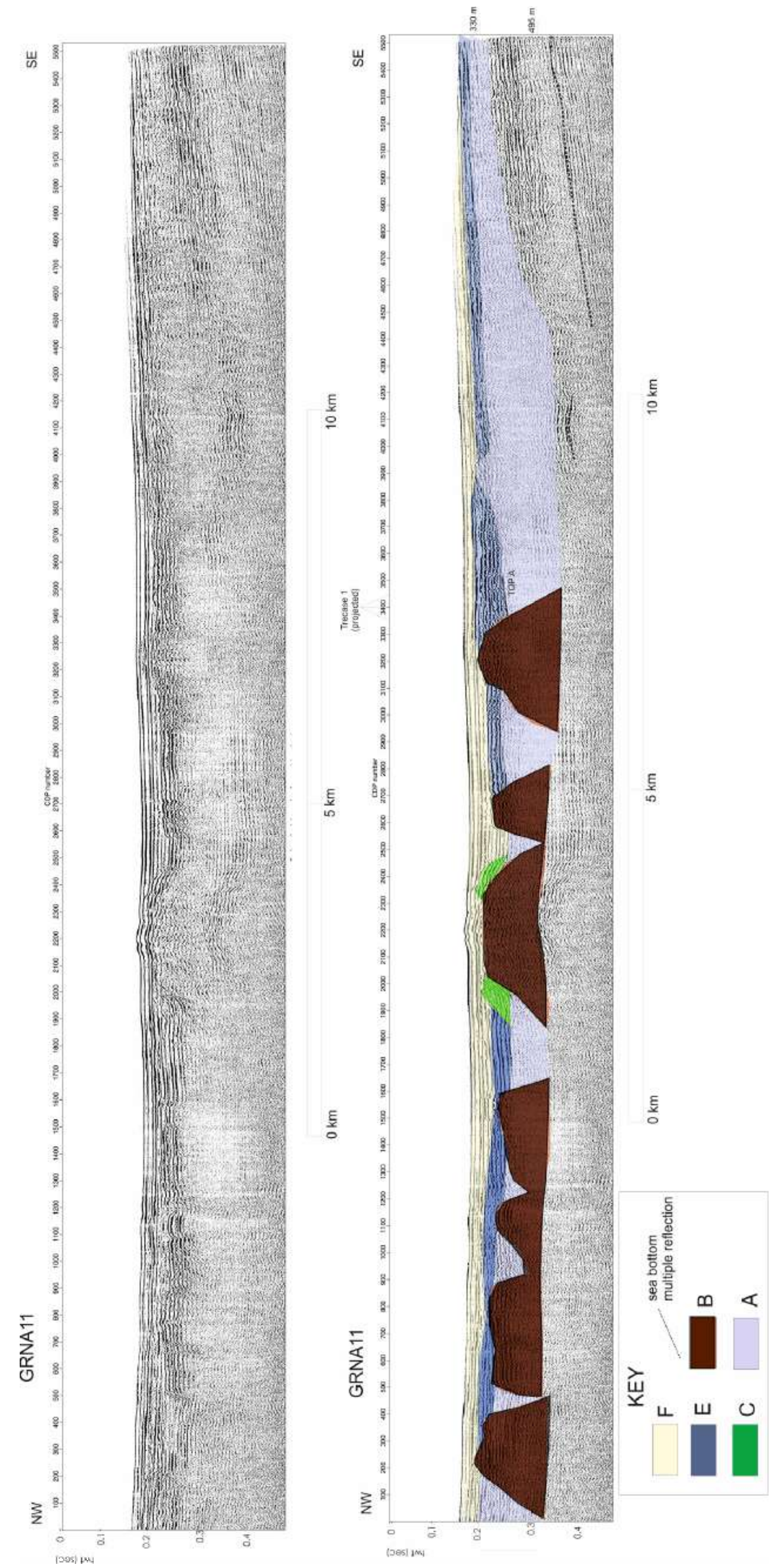

Figure 7. Seismic profile Grna11 and corresponding geologic interpretation, calibrated with the "Trecase 1" well; (Figure 2).

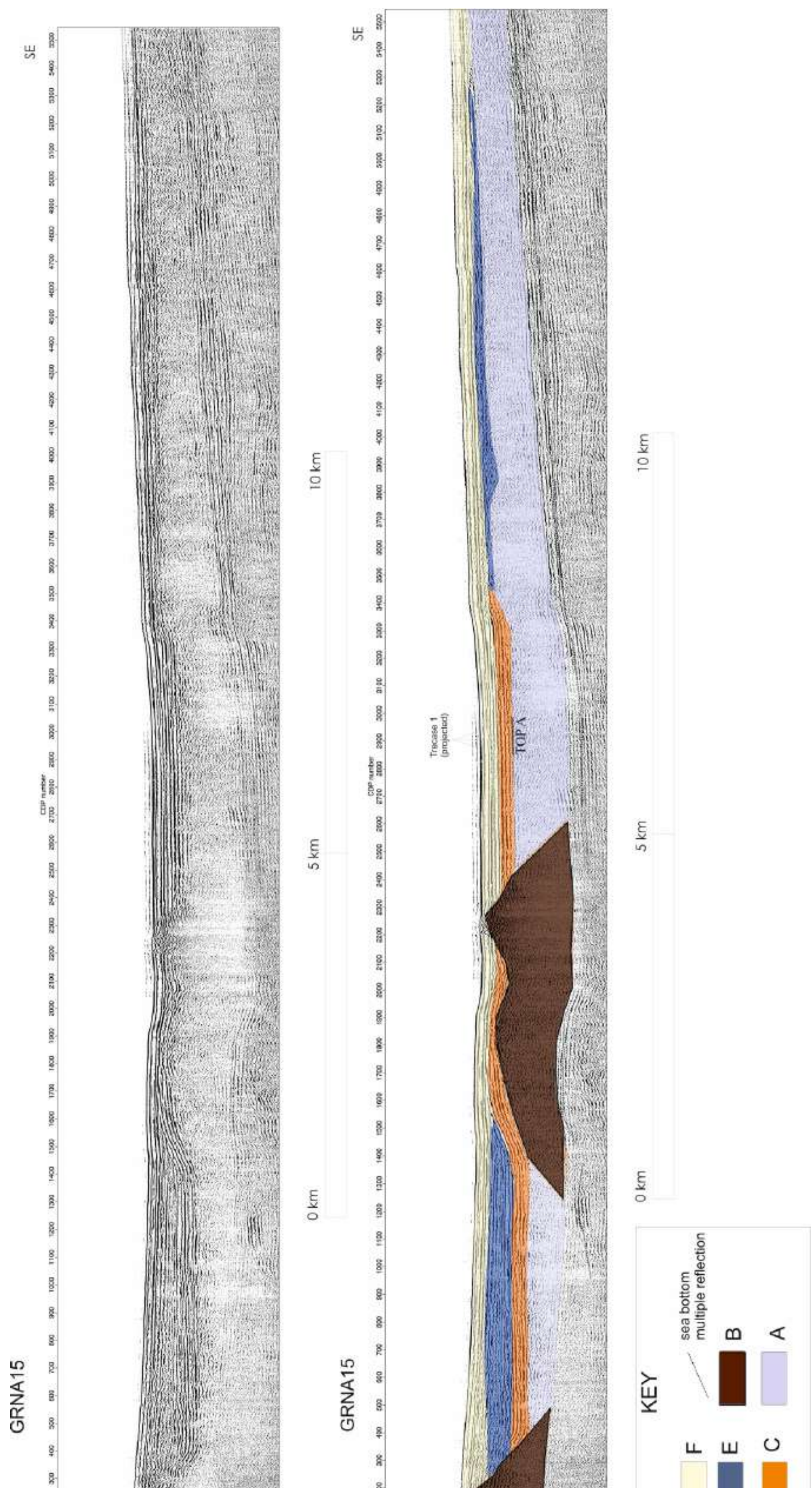

Figure 8. Seismic profile Grna15 and corresponding geologic interpretation, calibrated with the "Trecase 1" well (Figure 2).

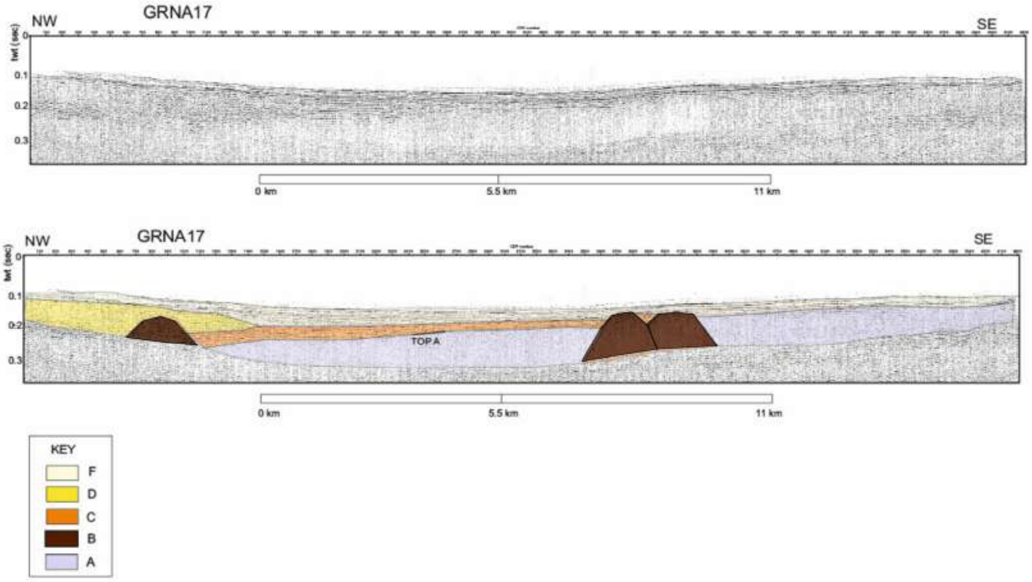

Figure 9. Seismic profile Grna17 and corresponding geologic interpretation.

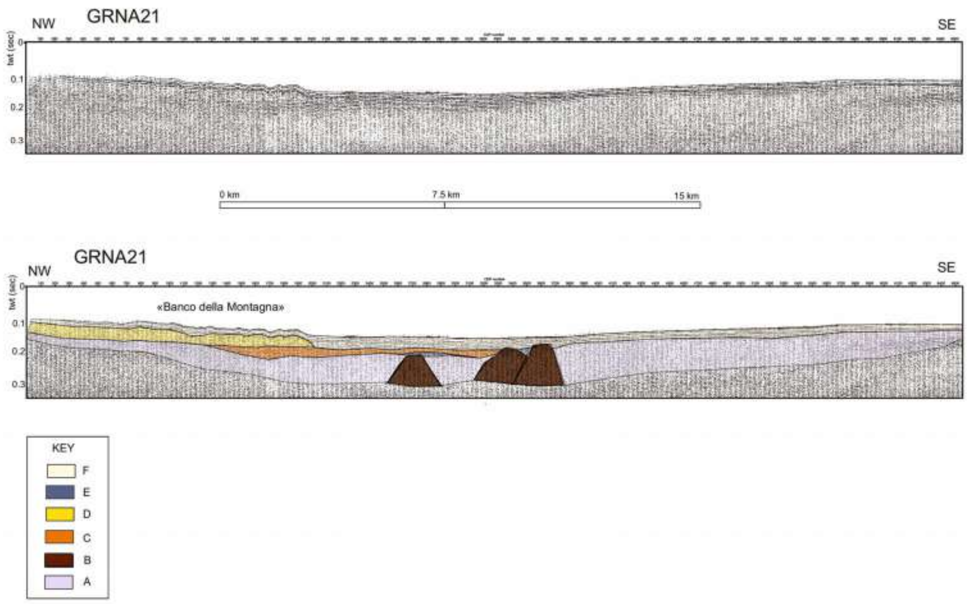

Figure 10. Seismic profile Grna21 and corresponding geologic interpretation.

4.2. Geological Interpretation of the Seismic Units

The G unit is identified on both the Grna01 and Grna03 seismic lines (Figure 6). The G unit could comprise volcanic deposits older than AD 79 and apparently capped by eruption deposits dated at their base.

The G unit probably represents pyroclastic flow deposits from Vesuvius, based on its location only offshore of Somma-Vesuvius and by the discontinuous and undulated character of the seismic reflectors. This interpretation is supported by the qualitative correlation with previous core sampling in the area, which have cored the fallout deposits of the AD 79 in the upper meters of the seismic unit [4], but the thickness of the seismic unit is much larger than the thickness of the AD 79 deposits.

Thus, the G unit is interpreted to mainly consist of PDCs of pre-AD 79 Plinian eruptions. Figure 11 shows the isopach maps of "Pomici di Avellino", "Pomici di Pompei", and "Pomici di Mercato" eruptions [25].

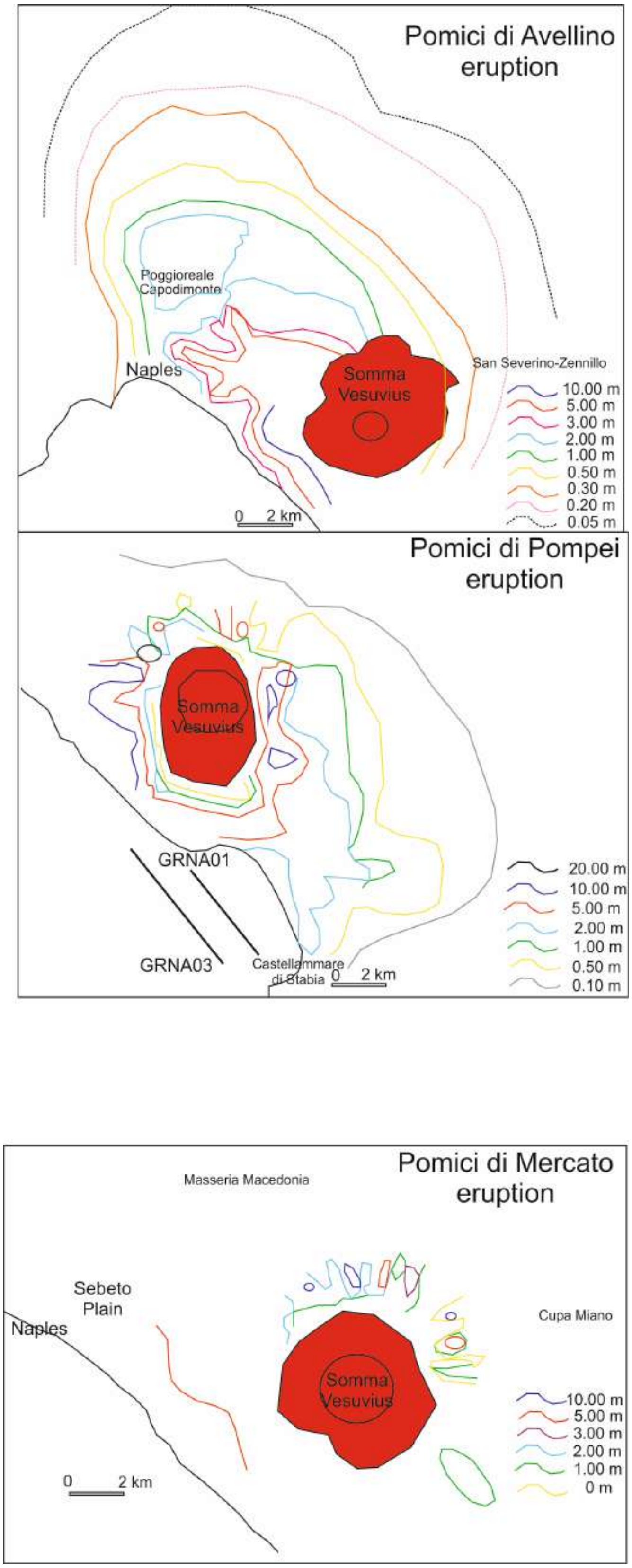

Figure 11. Isopach maps of the "Pomici di Avellino", "Pompei Pumice", and "Pomici di Mercato" eruptions (after [25]). These maps were used as geological constraints in order to support the interpretation of the G seismic unit as the PDCs older than the AD 79 eruption. The location of the GRNA01 and GRNA03 seismic profiles (Figure 6) is also shown.

In that paper, the authors discussed the dispersal, thickness, and extent of the PDC deposits, which were generated during seven plinian and sub-plinian eruptions (Pomici di Base, Greenish Pumice, Pomici di Mercato, Pomici di Avellino, Pompeii Pumice, AD 472 Pollena, and AD 1631 eruptions).

The isopach maps and the facies character reveal that the dispersal of the PDCs from Vesuvius was mainly controlled by the intensity of the eruption, by the location of the vent with respect to the Mt. Somma caldera and by the inherited topography. The most widely dispersed volcanic deposits are those of the Pomici di Avellino and Pomici di Pompei. In these maps, the isopachs of the volcanic deposits, reported in meters, indicate that they projected eastwards, not toward the Bay of Naples (Figure 11).

Based on the data of Gurioli et al. [25], the volcanic deposits of the Pomici di Mercato eruption are mainly located on the northern slopes of Mt. Somma, highlighting that the vent location was similar to that one of the present-day Vesuvius (Figure 11).

The Pomici di Avellino deposits reach their maximum thickness in the western sector of Vesuvius and are characterized by a strong facies variability. They are recognized as far as 25 km from the inferred vent, which was probably eccentric with respect to the volcano. Based on these data, the G unit is likely correlated with the volcanic deposits derived from the oldest plinian eruptions (Avellino, Mercato, and Pomici di Base).

The F and C units are recognized in the whole study area (Table 1; Figures 6–10) and are interpreted as highstand (HST) and lowstand (LST) system tract deposits from the Late Quaternary. The highstand deposits (HST) are younger than the phase of maximum marine ingression (about 4–5 ky B.P.) and were described in previous papers on the Bay of Naples [4]. The C unit, which is composed of lowstand deposits, was alsofound both in depressions between the buried tuff rings of the B unit and at the top of the A unit (Figures 6–10). The lowstand deposits (LST) were formed during the sea level lowstand during the last Quaternary glacial episode (isotopic stage 2) [54].

The D unit is identified on the seismic profiles Grna17 and Grna21 (Table 1; Figures 9 and 10). This unit is interpreted as the submarine extent of the Neapolitan Yellow Tuff (NYT) deposits, which underlie Naples and cropping out widely in the adjacent Posillipo hill. The NYT was emplaced during the second phreato-magmatic eruption from the Phlegraean caldera and crops out over an area of 1000 km^2 [8–11,16,18,67,68,70].

The NYT deposits were identified in the Gulf of Pozzuoli and in the northern Phlegraean Fields offshore [12,14,20,58,78–80]. Pyroclastic deposits represent main stratigraphic markers in the marine sedimentary record [81–83] and were documented on the Campania continental margin [84–88]. A continuous seismic reflector mapped in the northern Phlegraean offshore was correlated with the NYT deposits [21]. This horizon is inter-layered in transgressive deposits, which are thicker than those detected in other Campania outer shelf settings, as a consequence of a high input of pyroclastic and volcaniclastic deposits, related to the eruptive activity of the Campania Plain during the Late Pleistocene-Holocene.

The E unit (Table 1; Figures 7, 8 and 10) is found in depressions located between the buried tuff rings composed of the B unit or at the top of the A unit. Based on its location and on the seismic facies, characterized by discontinuous, sub-parallel seismic reflectors, the E unit is interpreted as a widely distributed debris flow unit, whose deposition is possibly related to eruptive processes in the Somma-Vesuvius offshore. Sulpizio et al. [89] have shown onshore stratigraphic data contrasting the occurrence of a large debris avalanche, which occurred just before the Avellino eruption of the Somma-Vesuvius volcano [90]. Indeed, volcaniclastic mass flows often occurred during the geological past and are characterized by rain-triggered debris flows and hyperconcentrated flows. These volcaniclastic deposits crop out widely along the cliffs of the western coastline and are separated by paleosols or erosional surfaces [89]. The volcaniclastic deposits ascribed to debris flows are coarse-grained and rich in lithic blocks, and are correlated with the pyroclastics with lava blocks of the Herculaneum log [90]. Based on these data, the E unit could represent a volcaniclastic mass flow, which occurred in the geological past, possibly after the eruption of the Campanian Ignimbrite (A unit) or after the emplacement of the B unit, interpreted as buried tuff rings [11,72].

The B seismic unit (Table 1; Figures 6–10) was previously interpreted as buried volcanic mounds [5] or cryptodomes [1] genetically related to Somma-Vesuvius eruptive activity. However, this interpretation needs be re-examined. For example, the height-to-width ratio of these bodies is very low (possibly 1:15–1:20), which seems more consistent with an interpreted of them as tuff rings, although they do not show any crater-related depressions, which should be evident in these edifices. This geological interpretation is supported by the width of the volcanic edifices (up to several km) and by comparison with similar volcanic edifices recognized in the Neapolitan area [11,72]. Figure 12 compares the structures of the B unit in seismic profiles GRNA11 and GRNA15 with the general types of volcanic edifices (lava dome, crater row, fissure vent, pyroclastic cone, tuff cone, tuff ring, maar). On the seismic profile GRNA11, two volcanic edifices, interpreted as tuff rings, are identified; both with a width of 6 km (tuff rings 1 and 2). On the seismic profile GRNA15, tuff ring 3 has a width of 5.6 km (Figure 12). The dimensions of the volcanic edifices, as measured on the seismic sections, are compatible with those of tuff rings recognized in the Neapolitan area and described in previous geological literature (Figure 12).

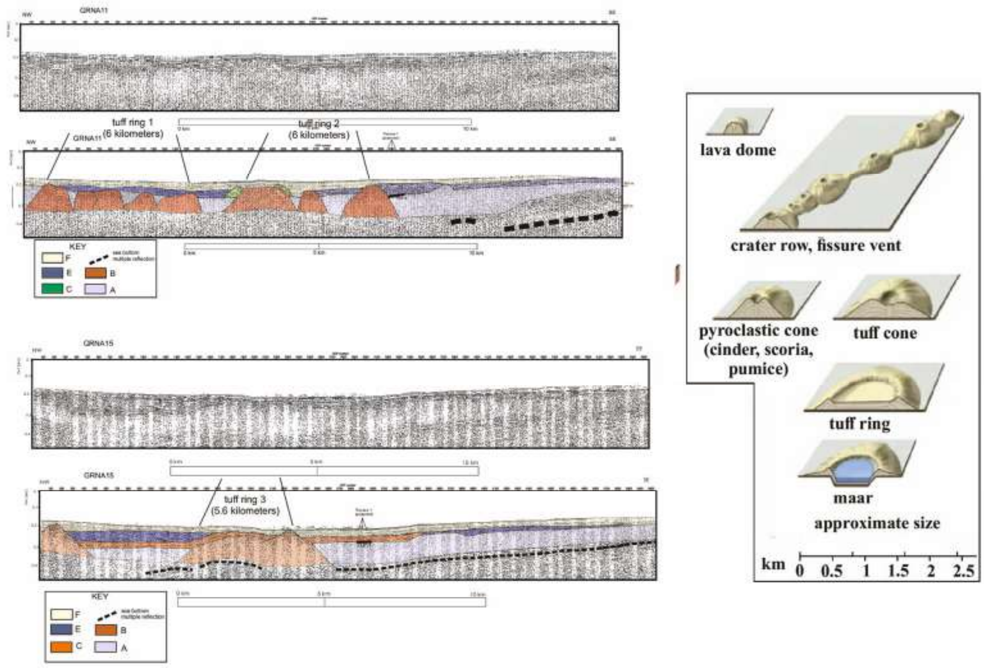

Figure 12. Sketch showing the geological constraints used for the interpretation of the B seismic unit. On the right side of the figure, several types of volcanic edifices were represented, based on the volcanological literature in order to show the shape and the approximate size of the tuff rings. On the left side of the figure, the GRNA11 and GRNA15 seismic profiles were reported (Figures 7 and 8), showing the interpretation of the volcanic edifices interpreted as tuff rings in the eastern sector of the Bay of Naples. Note that the dimensions of the volcanic edifices, measured on the seismic sections and ranging between 5.6 and 6 km, are compatible with those of the tuff rings recognized in literature in the Neapolitan area [11,72].

The A seismic unit (Table 1; Figures 6–10) is an important seismic unit in the stratigraphic architecture of the Bay of Naples. Due to its stratigraphic location and based on previous geological literature [7,59,91,92], it can be correlated with the Campanian Ignimbrite pyroclastic flow deposits. Based on literature data, this unit is important because it was identified in the whole subsurface of the eastern Bay of Naples [7,59,91,92]. The Campanian Ignimbrite is composed of thick pyroclastic deposits, trachytic and phonolitic in composition, and genetically related to a collapsed caldera [8–11,13,47,50,66–70,93,94].

5. Discussion and Conclusions

Seven seismic units were identified on the multichannel seismic lines presented in this paper (Figures 6–10), namely the G (pyroclastic flows of Vesuvius), F (highstand deposits), E (debris flows of Vesuvius), D (Neapolitan Yellow Tuff), C (lowstand deposits), B (buried tuff rings), and A (Campanian Ignimbrite) seismic units.

The seismo-stratigraphic data analyzed in this paper (Figures 6–10) can be interpreted as a succession of events for the eastern sector of the Naples Bay, referring, in particular, to the Somma-Vesuvius offshore area. The seismic profiles show a low seismic unit with an acoustically transparent seismic facies (A), corresponding to the 39 ky-old Campanian Ignimbrite and another acoustically-transparent seismic unit (B), located seawards that underlies the C unit (lowstand deposits) and is overlain by the F unit (highstand deposits; Figures 6–10).

The seismic unit B is interpreted as buried tuff rings. This interpretation is supported by the fact that tuff rings are abundant in the Neapolitan area [11,72]. For example, after the eruption of the Neapolitan Yellow Tuff (15 ky B.P.), the volcanic activity of Campi Flegrei volcanic complex was characterized by hydromagmatic phenomena, and by minor effusive activity forming lava domes. In the caldera of the Neapolitan Yellow Tuff, volcanism created numerous monogenetic vents, including tuff rings, tuff cones, cinder and spatter cones [11,72,95–98]. Among them, the tuff ring of Averno (3700 years BP) is interpreted as a maar-type, lake-filled volcano, formed during an explosive eruption of Campi Flegrei [72]. The Averno tuff ring is circular, with a rim diameter of 1.5 km, overlying an irregular topography composed of relicts of the earlier Archiaverno tuff ring [11]. Other significant tuff rings of the Neapolitan area were described by Di Vito et al. [11], discussing the characteristics of the main volcanic units of the Campi Flegrei caldera, younger than 12 ky B.P.

In proximal domains, the C unit is overlain by a chaotic seismic unit interpreted as formed by the volcanic deposits older than the AD 79 pyroclastic flow deposits (G; the pyroclastic deposits representing the base of this eruption; Figure 11) [25]. The G unit is an important seismic unit in the stratigraphic architecture of the eastern Naples Bay (Figure 6). The G unit is composed of some of the PDCs older than the AD 79 volcanic deposits. Previous studies on the geological setting of the Bay of Naples offshore the Sarno prodelta have documented the stratigraphic signature of the tephra deposit erupted by the Vesuvius volcano during the AD 79 volcanic event [4]. Moreover, the isopach maps of the PDCs constructed by Gurioli et al. [25] were used to check the correlation of this seismic unit with some of the PDCs older than AD 79 volcanic deposits (Figure 11) and have confirmed this interpretation. Figure 11 reports the isopach maps of Pomici di Avellino, Pompei, and Pomici di Mercato eruptions [25]. Based on the data of Gurioli et al. [25], five of the seven Vesuvius plinian and sub-plinian eruptions (Pomici di Base, Greenish Pumice, Pomici di Mercato, Pomici di Avellino, Pompeii Pumice, AD 472 Pollena, and AD 1631 eruptions) have dispersed PDCs radially and their dispersion was controlled by the location of the vent and by the palaeo-topography. The most dispersed deposits are those of the Pomici di Avellino and Pompeii Pumice, extending more than 20 km from the inferred vent [25]. The maximum thickness of Pomici di Mercato is 18 m (measured to the north), while the maximum thickness of Pomici di Avellino is 22 m (measured to the west). The isopach map of the Pomici di Mercato eruption has shown that these deposits are mainly located along the northern slopes of Mt. Somma, and that the corresponding vent was located in a location similar to that one of the Vesuvius. The isopach map of the Pomici di Avellino eruption has shown that they have their maximum thickness in the western sector of the volcano and are characterized by important lateral variations in lithofacies and thickness [99]. Sulpizio et al. [99] studied the sedimentology and the physical volcanology of the Pomici di Avellino eruption through field and laboratory studies, establishing five eruptive units (EUs), which emplaced during an opening, Plinian and final phreatomagmatic phase of this eruption. The PDCs of the Avellino eruption were erupted during EU1, EU2, EU3, EU4, and EU5 with different eruptive mechanisms.

Due to its seismic facies and to the stratigraphic relationships, the C unit is interpreted as the lowstand system tract (LST) deposits, i.e., the sediments that were deposited during the falling and lowstand of sea level. These deposits were disturbed by the eruption of the D unit, interpreted as the Neapolitan Yellow Tuff deposits (15 ky B.P.).

The seismo-stratigraphic analysis of multichannel profiles calibrated with gravity cores offshore the Vesuvius volcano and Posillipo hill has highlighted new implications for the Quaternary volcanism of the Campania continental margin. Multichannel seismic lines are interpreted to study the stratigraphic relationships between the Quaternary marine deposits deposited in this area and the volcanic acoustic substratum (A and D units). The volcano structure is controlled by NE-SW trending seismic structures, suggesting a volcano–structural correlation with the regional faults occurring in this area [100,101]. These structures correspond with tuff rings composed of the B unit, which underlie the lowstand deposits and seem to be younger than the A unit. The tuff rings seem to be younger than 37 ky B.P. (A unit) and older than 18 ky B.P. (approximate lower boundary of the lowstand deposits of the C unit).

The total magnetic field offshore the Somma-Vesuvius volcanic complex (Figure 13) shows that the shape of the anomaly is dipolar. There is no apparent effect caused by the occurrence of remnant magnetization with respect to that of the present-day main field. NE-SW trending seismic structures identified based on seismic data represent a preferential pathway of magma uprising for Vesuvius volcano. These structures mainly occur offshore of the Torre del Greco and the Torre Annunziata towns and are evident on the sketch magnetic map of Figure 13, which includes the tuff rings shown in this paper and the A and D seismic units. The geological structures identified through seismic interpretation are located in a complex magnetic anomaly area (Figure 13), which is made up of several anomalies, reaching a maximum intensity of 400 nT. This area represents the offshore prolongation of the Vesuvius volcano. The seismo-stratigraphic data suggest a close relationship between the seismic structures offshore the volcano and in the eastern sector of the gulf, and the structural setting of the Naples Bay, controlled by NE-SW trending (counter-Apenninic) regional faults (Figure 13).

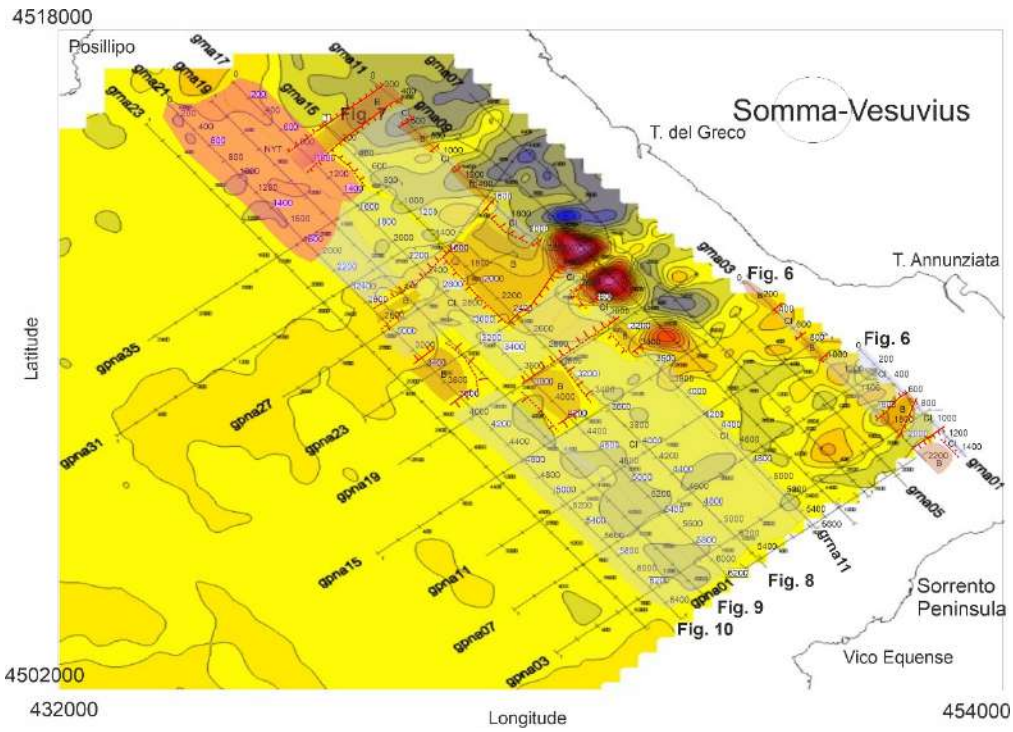

Figure 13. Magnetic map of the eastern Naples Bay and location of the seismic lines with superimposed A, B, and D seismic and volcanic structures based on this paper.

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