# Shallow water volcanic edifices in high-resolution seismic reflection profiles: examples from the Gulf of Naples (Italy)

Volcanism
Gulf of Naples
Seismic facies
Eustatism

Volcanisme sous-marin
Golfe de Naples
Faciès sismique
Eustatisme

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ABSTRACT

The Gulf of Naples (southern Italy) is well known for active subaerial volcanism (Somma-Vesuvius and Phlegrean Fields). Several shallow submarine volcanic edifices are known to exist around the Phlegrean area, but these have never been studied in detail.

These volcanoes, located on the shelf, at a maximum depth of 150 m, are characterized by two different seismic facies in high-resolution seismic reflection profiles: 1) chaotic reflections, with variable amplitude and frequency; 2) in-phase reflections, with low frequency and high amplitude or high frequency and low amplitude.

Seismic facies (1) is interpreted as an image of massive volcanic deposits, such as lava flows, domes, pyroclastic flows or lahars; while seismic facies (2) is interpreted as reflecting layered pyroclastic deposits, such as surge and fall deposits. This seismic interpretation is confirmed by other geophysical and geological data available for the studied area.

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RÉSUMÉ

Faciès sismique haute-résolution de volcans sous-marins à faible profondeur : exemple du Golfe de Naples (Italie)

Le Golfe de Naples (Italie méridionale) est bien connu pour son volcanisme actif sub-aérien (Somma-Vésuve et Champs Phlégréens). Quelques volcans sous-marins sont connus au voisinage des Champs Phlégréens, mais ils n'ont jamais été étudiés en détail. Ces volcans sous-marins sont situés sur la plate-forme du Golfe de Naples, qui présente dans cette zone une profondeur maximale de 150 m ; ils sont caractérisés par deux faciès sismiques sur les profils sismiques haute résolution: 1) des réflexions chaotiques, avec différentes amplitudes et fréquences ; 2) des réflexions en phase, avec basse fréquence et haute amplitude ou haute fréquence et basse amplitude.

Le faciès sismique (1) est interprété comme l'image de produits volcaniques massifs, tels que coulées et dômes de lave, coulées pyroclastiques ou lahars, tandis que le faciès sismique (2) est interprété comme l'image de produits volcaniques stratifiés, tels que dépôts de déferlantes et produits de retombées.

Cette interprétation sismique est confirmée par les autres données géologiques et géophysiques, disponibles dans la zone étudiée.

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INTRODUCTION

The Gulf of Naples is a peri-Tyrrhenian basin located on the eastern margin of the Southern Tyrrhenian Sea (Fig. 1). During the Quaternary, central and southern Italy were characterized by the development of potash-rich volcanoes, which have been grouped in the Roman Comagmatic Province (Washington, 1906). This volcanic activity began about 2.0 Ma ago and has lasted until today with the historical eruptions of Vesuvius, Phlegrean Fields and Ischia. The Roman Comagmatic Province is characterized by a wide range of edifices, from large central volcanoes with summit calderas to regional calderas and monogenetic vents.

The tectonic significance of this volcanism is still an open question: it has been interpreted as a shoshonitic member of an orogenic association related to converging plates (Ninkovich and Hays, 1972) or as the alkaline product of the initial stages of a continental rifting (Cundari and Le Maitre, 1970). Most probably these Quaternary volcanoes are related to the extensional tectonics caused by the opening of the Tyrrhenian Sea since Tortonian times (Scandone, 1978); in this scheme the Quaternary volcanoes would be located in areas of thinned continental crust. The Gulf of Naples is famous for its active volcanism. The most recent period of Mount Vesuvius's history, between 1631 and 1944, is characterized by semi-persistent lava flow activity interrupted by short quiet periods (Santacroce, 1987). Explosive activity occurred twice at Mount Vesuvius in historical times: the major A.D. 79 plinian eruption, which destroyed the Roman cities of Pompei and Ercolano, and the A. D. 472 "Pollena" eruption, with fall and pyroclastic flow deposits (Santacroce, 1987). On the island of Ischia the latest volcanic eruption is the A.D. 1302 Arso lava flow (Vezzoli, 1988), but other volcanic eruptions occurred in historical times; in particular the eruption of the"Porto d'Ischia" volcanic centre and the formation of the "Lago del Bagno" lacustrine basin were described by Pliny (Naturalis Historia, II. 88. 203). On Phlegrean Fields, several centres were active from 4,500 yrs B.P. up to historical time; the latest eruption in this area occurred at Monte Nuovo in A.D. 1538 (Rosi and Sbrana, 1987).

In the vicinity of Naples, fumaroles are still active at Solfatara (Pozzuoli) and on the western side of the Mount Epomeo (island of Ischia); hot water springs are common throughout the island of Ischia.

Although the volcanic products of the historical period are chiefly effusive, the area of the Gulf of Naples is mainly characterized by explosive products. The most famous catastrophic event is the eruption of the Campanian Ignimbrite (35,000 yrs),which caused the formation of the Phlegrean Caldera (Barberi *et al.*, 1978); this event is thought to be the biggest volcanic eruption ever to have occurred in the Mediterranean Sea.

The Somma-Vesuvius Mount is the only polygenetic volcano in this area, while monogenetic pyroclastic centres, built up by phreato-magmatic eruptions, such as tuff rings and tuff cones, are widespread on Phlegrean Fields (Rosi and Sbrana, 1987), on the islands of Procida and Vivara and in the eastern part of the island of Ischia (Vezzoli, 1988).

The zone south of the Phlegrean area, is also characterized by small monogenetic centres. The submarine hyaloclastic

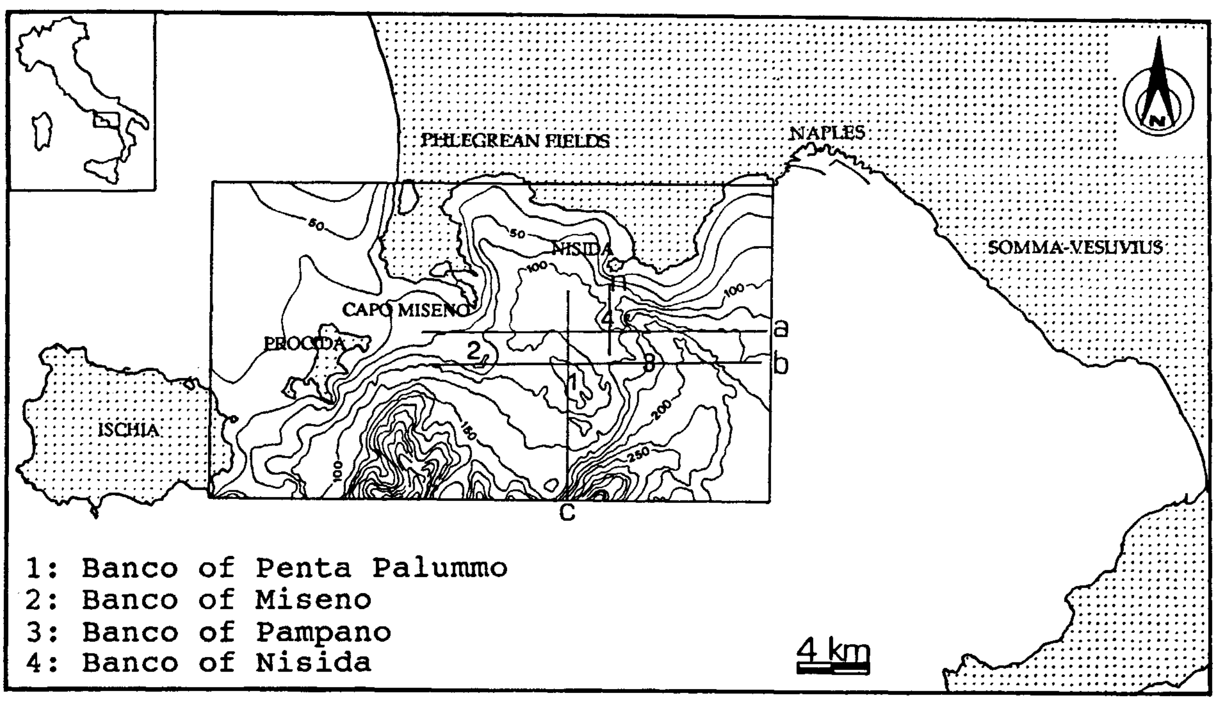


Figure 1

*Location and bathymetric map of the study area (isobaths every 25 m, after Fusi et al., 1991): 1 = Banco of Penta Palummo; 2 = Banco of Miseno; 3 = Banco of Pampano; 4 = Banco of Nisida*

Localisation et carte bathymétrique de la région étudiée (isobathes chaque 25 m, après Fusi *et al.*, 1991): 1 = Banc de Penta Palummo ; 2 = Banc de Miseno ; 3 = Banc de Pampano ; 4 = Banc de Nisida.

volcanic edifices of Formiche di Vivara and La Catena, located between the islands of Procida and Ischia, have been studied by Di Girolamo and Rolandi (1975). Many other volcanic centres are mapped on the Carta Geologica d'Italia (Fogli 183-184). All these volcanic edifices are located on the shelf, which in the Neapolitan area is not deeper than 150 m.

The present study concerns four of these submarine monogenetic volcanoes: the Banco of Penta Palummo (No. 1 on Fig. 1), the Banco of Miseno (No. 2 on Fig. 1), the Banco of Pampano (No. 3 on Fig. 1) and the Banco of Nisida (No. 4 on Fig. 1). They were initially identified from bathymetric surveys conducted by the Istituto Idrografico for the Carta Geologica d'Italia (Fogli 183-184). The Banco of Nisida was originally studied by Latmiral *et al.* (1971); the authors noticed the flat top of this submarine volcano and the inclined reflectors on its flank. Finetti and Morelli (1974) described briefly the Banco of Nisida, the Banco of Penta Palummo and the Banco of Miseno, on the basis of a multichannel seismic reflection survey. Due to the lack of seismic resolution, the structure of the submarine volcanoes was not described in detail. More recently, these submarine volcanoes have been partly investigated through a single channel survey (Pescatore *et al.*, 1984); their magnetic structure (Napoleone *et al.*, 1984) and their geomorphological characteristics (De Pippo *et al.*, 1984) have also been studied. The sediments overlying these volcanoes have been described by Pennetta *et al.* (1984).

The aim of the present study is to characterize the structure of shallow-water volcanic edifices by means of high-resolution single-channel seismic reflection profiles.

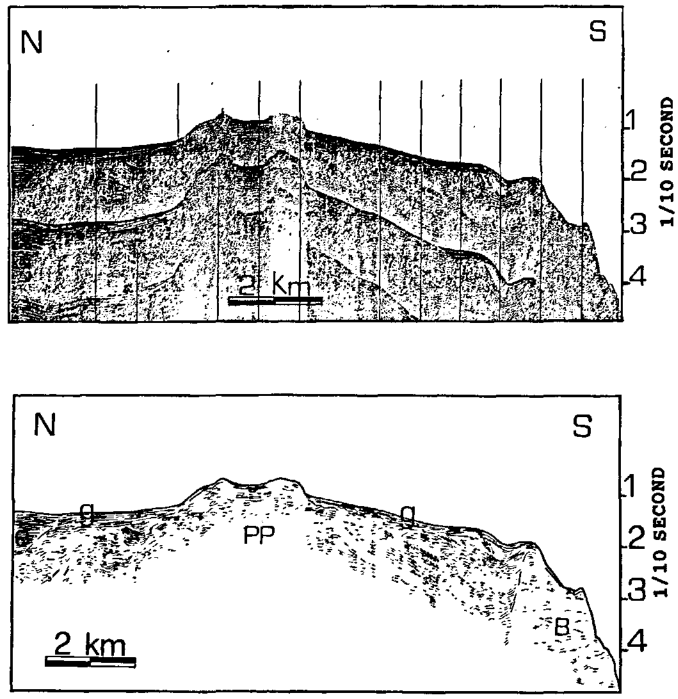


Figure 2

*Line "c": a) original seismic line; b) line-drawing and interpretation (vertical scale: 1/10 second two-way travel time): PP = Banco of Penta Palummo; e, g = sedimentary units (Fusi* et al., *1991); B = volcanic unit (Fusi* et al., *1991).*

Profil "c" : a) profil sismique original ; b) ligne et interprétation (échelle verticale: 1/10 seconde temps double) : PP = Banc de Penta Palummo ; e, g = unités sédimentaires (Fusi *et al.*, 1991) ; B = unités volcaniques (Fusi *et al.*, 1991).

## SEISMIC DATA ACQUISITION

The single-channel seismic reflection profiles presented here were collected in 1989 and 1990 with the CNR owned R/V *Bannock* for a research project covering the entire Gulf of Naples. The participants in the project were the Institute of Oceanology of the Istituto Universitario Navale (Naples) and the Departement of Earth Sciences of the University of Milan.

To collect these profiles, an unusually large sparker array (36 electrodes), designed by Institute of Oceanology of the Istituto Universitario Navale was employed. This particular kind of sparker permits the collection of seismic data in water depths ranging from 50 m to 1,000 m, with a maximum penetration of about 1 second two-way travel time. In shallow water, multiplication prevents the observation of reflections with a travel time of less than a few tenths of a second. The resolution obtained with this seismic system is of the order of 2 m.

The interpretation of unmigrated seismic profiles has been performed at the Department of Earth Sciences of the University of Milan. The identification of volcanic units was based on seismic facies and morphology. Bathymetric and magnetometric data have also been used in interpretation. Line drawings were made by tracing enough of the major real events to produce faithful schematic representations of the actual sections.

## SEISMIC FACIES OF THE SUBMARINE VOLCANOES

Four submarine volcanic bodies have been investigated by high-resolution seismic reflection profiles: the Banco of Penta Palummo, the Banco of Pampano, the Banco of Miseno and the Banco of Nisda (Fig. 1). All these volcanoes have grown on the shelf around Phlegrean Fields, in a water depth ranging around 150 m. The top of these volcanoes is generally at about 50 m below sea level.

The Banco of Penta Palummo is a submarine volcano, situated about 5 km south of the Island of Nisida (No. 1 on Fig. 1), extending in a NW-SE direction and with a flat top some 75 m below sea level (Fig. 1). Morphologically, it is characterized by a strong asymmetry of its flanks: the southern one is very steep, with a scarp about 250 m high, while the northern one is flat (Fig. 1 and 2). This volcano shows two different seismic facies. The first is represented by chaotic reflectors, with varying frequency and amplitude, characterizing the central part of the volcanic body (Fig. 2 and 3). The second is represented by in-phase reflectors, mainly with high amplitude and low frequency (Fig. 2 and 4), but sometimes with low amplitude and high frequency (Fig. 2). This seismic facies was never described in detail for volcanic bodies in previous works.

On the southern flank of the Penta Palummo volcano, the "in-phase reflectors" of the second seismic facies permit the iden-

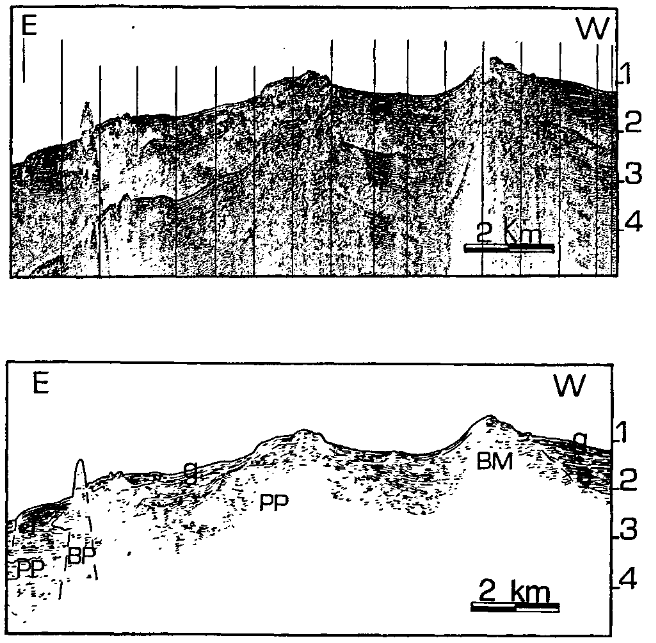


Figure 3

*Line "b": a) original seismic line; b) line-drawing and interpretation (vertical scale: 1/10 second two-way travel time): PP = Banco of Penta Palummo; BM = Banco of Miseno; BP = Banco of Pampano; e, f, g = sedimentary units (Fusi* et al., *1991).*

Profil "b" : a) profil sismique original ; b) ligne et interprétation (échelle verticale: 1/10 seconde temps double) : PP = Banc de Penta Palummo; BM = Banc de Miseno ; BP = Banc de Pampano ; e, f, g, = unités sédimentaires (Fusi *et al.*, 1991).

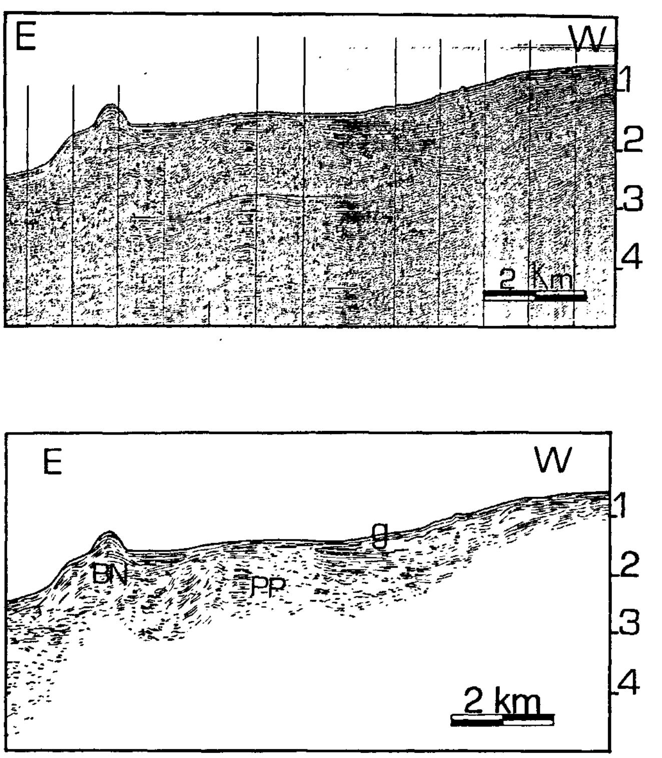


Figure 4

*Line "a": a) original seismic line; b) line-drawing and interpretation (vertical scale: 1/10 second two-way travel time): PP = Banco of Penta Palummo; BN = Banco of Nisida; g = sedimentary unit (Fusi* et al., *1991).*

Profil "a" : a) profil sismique original ; b) ligne et interprétation (échelle verticale : 1/10 seconde temps double) : PP = Banc de Penta Palummo ; BN = Banc de Nisida ; g = unité sédimentaire (Fusi *et al.*, 1991).

tification of different depositional surfaces (Fig. 2), outlining the periclinal dip of the volcano. On the northern side some gently folded reflectors are visible (Fig. 2). In some cases these in-phase reflectors present onlap and toplap complex relationships (Fig. 4). These reflectors are always sharply cut by a flat erosional surface at about 1.5 second two-way travel time (Fig. 2 and 4), which is suturated by recent sub-horizontal marine sediments (unit "g" of Fusi *et al.*, 1991).

The Banco of Miseno is a round-shaped submarine volcanic edifice located 2 km south of Capo Miseno (No. 2 on Fig. 1). It has a flat top at about 50 m below sea level, with a diameter of about 1 km, and symmetrical flanks (Fig. 1). It is characterized mainly by chaotic seismic reflectors, with high amplitude and low frequency. On the eastern flank, some in-phase reflectors, lying in continuity with those of the Banco of Penta Palummo and charac-

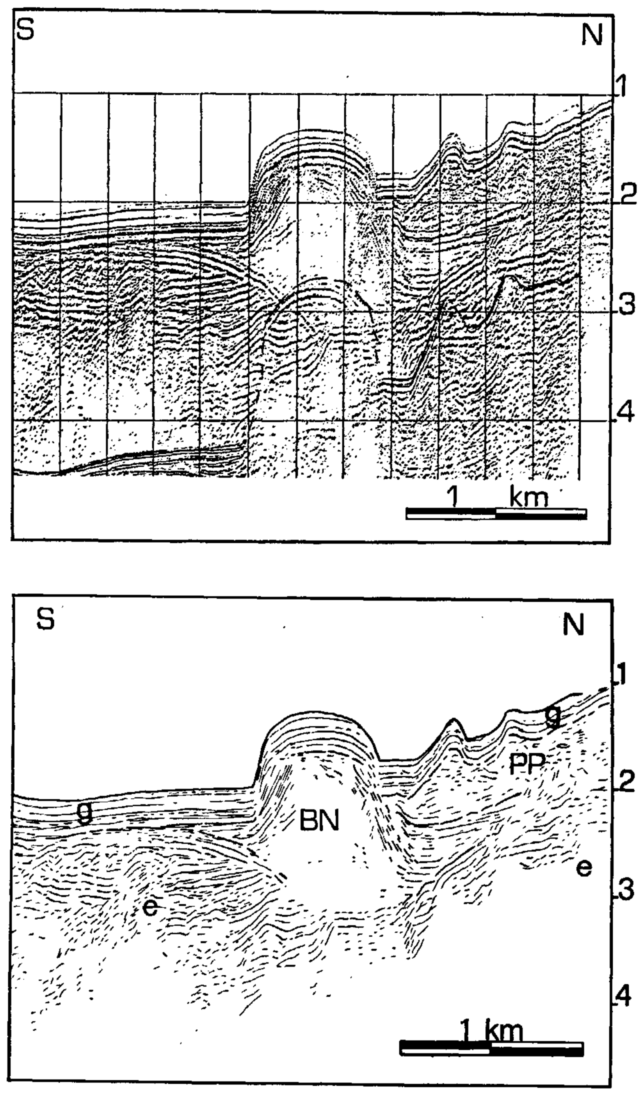


Figure 5

*Line "n": a) original seismic line; b) line-drawing and interpretation (vertical scale: 1/10 second two-way travel time): BN = Banco of Nisida; PP = Banco of Penta Palummo; e, g = sedimentary units (Fusi* et al., *1991).*

Profil "n" : a) profil sismique original ; b) ligne et interprétation (échelle verticale : 1/10 seconde temps double) : BN = Banc de Nisida ; PP = Banc de Penta Palummo ; e, g = unités sédimentaires (Fusi *et al.*, 1991).

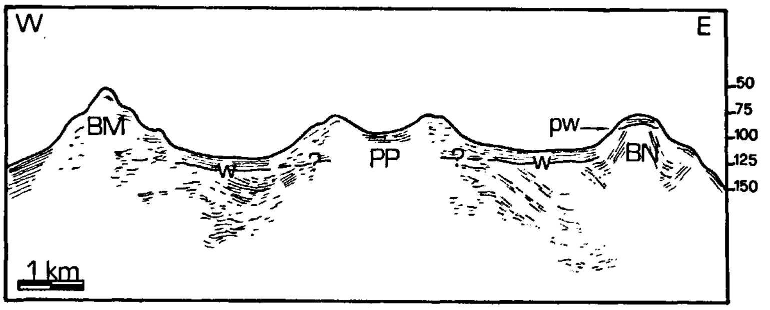


Figure 6

*Schematic cross-section of the studied area (vertical scale: m below sea level): BM = Banco of Miseno; PP = Banco of Penta Palummo; BN = Banco of Nisida; w = Wurm unconformity (18,000-14,000 yrs B.P.); pw = post-Wurm unconformity.*

Croquis de la zone étudiée (échelle verticale : m au-dessus du niveau de la mer) : BM = Banc de Miseno ; PP = Banc de Penta Palummo ; Bn = Banc de Nisida ; w = non-conformité wurmienne (18,000-14,000 yrs B.P.) ; pw = non-conformité post-wurmienne.

terized by low frequency and high amplitude, are visible (Fig. 3). On the western flank some in-phase reflectors interfinger with the recent sedimentary coverage (unit "e" of Fusi *et al.*, 1991).

The Banco of Pampano is a small volcanic body, located about 4 km southeast of the island of Nisida. It has a diameter of about 500 m and a high morphological relief, its top being at a depth of 105 m below sea level (No. 3 on Fig. 1). This volcanic body is characterized by the lack of reflectors (Fig. 3). This structure cuts vertically the volcano-sedimentary sequence.

The Banco of Nisida is a small volcanic edifice, located about 2 km south of the island of Nisida. This submarine volcano has a basal diameter of about 1.5 km and a flat top at about 75 m below sea level, with a diameter of about 600-700 m (No. 4 on Fig. 1). Morphologically, its flanks are strongly asymmetrical, the eastern one being steeper than the western one (Fig. 4). This volcanic edifice is characterized by in-phase, low amplitude and high frequency reflectors, delineating the periclinal dip of the flanks of the volcano (Fig. 4 and 5). A central zone, completely lacking reflectors, characterizes this volcano (Fig. 5). The in-phase reflectors are clearly truncated by an erosional surface, which is sealed by recent sub-horizontal marine sediments. This volcanic building is underlined by other sediments (unit "e" of Fusi *et al.*, 1991), which show an inflection of about 0.1 second under the volcanic body (Fig. 5).

## DISCUSSION

The Phlegrean submarine volcanoes grow on a shelf at a depth of approximately 150 m. For intermediate composition volcanoes, such as those of the Roman Province, this water depth is considered sufficiently shallow for explosive activity to occur. In fact explosions can take place at about 100 m below sea level for basaltic volcanoes (Moore and Fiske, 1969; Jones, 1970). In tholeiitic islands, explosive activity seems to begin about 200 m below water level (Moore and Schilling, 1973), while for alkalic magmas the critical depth of explosive volcanism is greater (700-800 m below sea level; Staudigel and Schmincke, 1984). Volcanic sequences produced under shallow subaqueous conditions are complex. They generally consist of localized lava flows, interfingering with pyroclastic deposits and resedimented volcanic debris (Fisher and Schmincke, 1984).

The Banco of Penta Palummo was supposed by De Pippo *et al.* (1984) to consist of two different craters. The seismic line, which crosses the area of the expected two craters, indicates the presence of only one crater, with a diameter of about 2 km (Fig. 2). This crater is filled by what can be interpreted as layered shallow-water marine or volcaniclastic sediments. The central part of the volcano, which lacks reflectors, is supposed to be made of massive rocks, such as lava flows or massive pyroclastites. The presence of lavas is more likely, as supposed by Napoleone *et al.* (1984), because a magnetic anomaly (220 gamma, Napoleone *et al.*, 1984; 150 gamma, Fusi *et al.*, 1991) is associated to the Banco of Penta Palummo.

The layered sediments on the southern flank of the volcano (Fig. 2: 2-3 second two-way travel time interval; Fig. 6) are here interpreted as layered surge-like or thin bedded flow-like pyroclastic rocks. The reasons for this are: 1) the layers disposed simulating the periclinal dip, typical of proximal pyroclastic deposits; 2) the thin transparent zones alternating with strong reflectors and outlining different eruptive events. The whole Phlegrean area is characterized by the presence of pyroclastic monogenetic centres; this kind of volcanism most probably also characterizes the submerged area south of Phlegrean Fields. Furthermore, the gently folded reflectors on the northern flank of the volcano (Fig. 2 and 6) can be interpreted as primary meso-folds in surge deposits.

A chaotic lenticular body is present on the eastern side of the Banco of Penta Palummo (Fig. 3); because of its external shape and of the chaotic reflections, this is interpreted as a volcanic debris-flow, due to a gravity event on the flank of the volcano. The pyroclastic deposits of the Banco of Penta Palummo are cut by a flat unconformity at about 1.5 second two-way travel time (Fig. 2 and 4), which is covered by subhorizontal in-phase reflectors, interpreted as Holocene sediments (unit "g"; Fusi *et al.*, 1991). This unconformity is considered as the erosional surface of the last glacial minimum (18,000-14,000 yrs. B.P.; De Pippo *et al.*, 1984), dating in this way the main activity of the Banco of Penta Palummo before 18,000-14,000 yrs B.P. Recurrence of volcanic activity after the last glacial minimum can not be excluded, because this unconformity seems to continue under the present crater (Fig. 2 and 6).

The Banco of Miseno is presumed to be a tuff cone, for several reasons: in-phase reflectors, alternating with chaotic reflectors, suggest the presence of surge-like layered deposits, alternating with massive deposits; the nearby Capo Miseno subaerial volcanic edifice is composed of massive and cross bedded layers, due to the emplacement of alternating pyroclastic flows and wet surges (Rosi and Sbrana, 1987). The magnetic anomaly (220 gamma, Napoleone *et al.*, 1984; 150 gamma, Fusi *et al.*, 1991) suggests the presence of massive lava under the pyroclastic deposits. The Banco of Pampano, which is characterized by the lack of reflectors, is interpreted as a dome structure; the presence of lava is supported by a strong local magnetic anomaly (140 gamma, Napoleone *et al.*, 1984).

The Banco of Nisida is interpreted as a tuff cone for several reasons: it is characterized by in phase reflectors, interpretable as layered pyroclastites, with periclinal dip; no magnetic anomaly is associated to this submarine volcano (Napoleone *et al.*, 1984); it is likely that this submarine monogenetic centre is similar to the subaerial monogenetic centre of Nisida, which is a tuff cone, entirely composed of stratified yellow tuffs, formed by highly lithified beds of ashes and pumices (Rosi and Sbrana, 1987). Differences in reflectivity of the ashes and pumices beds can give the reflectors observed in seismic profiles. The zone lacking reflectors at the centre of this tuff cone is interpreted as the volcanic pipe, filled up with massive volcanic products.

Latmiral *et al.* (1971) interpret the reflectors of the Banco of Nisida as layered beach sediments. I do not agree with this interpretation, because these reflectors form the flank of the volcano and are continuous under the recent sedimentary coverage (Fig. 5). No evidence of the "buried volcano of Nisida" (Finetti and Morelli, 1974) can be seen on the high resolution seismic reflection profiles. The flat top of the Banco of Nisida, lying 75 m below sea level, is related to some regressive events. Being shallower than the unconformity at about 1.5 second two-way travel time (Fig. 6), which is related to the last glacial minimum (18,000-14,000 yrs. B.P., Pennetta *et al.*, 1984), it is probably related to a post 18,000-14,000 yrs. B.P. regressive event. This flat top of the Banco of Nisida is interpreted as an ancient beach, because some round cobbles have been dredged (Pescatore *et al.*, 1984). On the basis of these geomorphological observations, the activity of the Banco of Nisida can be considered post 18,000-14,000 yrs. B.P.; no other volcanic activity took place after the formation of the ancient beach at 75 m below sea level.

It is inferred that the inflection of reflectors of unit "e" (Fusi *et al.*, 1991) under the Banco of Nisida is due to the weight of this tuff cone. Pyroclastic rocks have generally a low specific weight (about 1 g/cm$^3$; Fisher and Schmincke, 1984). This low specific weight and the small size of the Banco of Nisida should be insufficient to cause inflection in consolidated sediments. As described before, this volcano is characterized by a massive central part, probably with a higher density. Furthermore the Gulf of Naples is characterized by very high rates of sedimentation in Plio-Pleistocene (about 3,000 m of sediments; AGIP Trecase 1 and Mina 1 wells) so part of these sediments remain unconsolidated. The weight of the tuff cone of Banco of Nisida and of its massive central zone on an unconsolidated substratum can explain the inflexion of the sediments of unit "e", observed in Figure 5.

## CONCLUSIONS

Shallow-water volcanic edifices of the Gulf of Naples show two kinds of seismic facies on high-resolution seismic reflection profiles: 1) a chaotic seismic facies, often completely lacking reflectors; and 2) a seismic facies, characterized by in-phase reflectors, with variable amplitude and frequency, often outlining the periclinal dip of the volcanic edifice. The first seismic facies is generally described as typical of volcanic bodies, while the second, although described for submarine volcanoes, has never been explained in detail.

Magnetic anomalies and geological data from the mainland demonstrate that the first seismic facies corresponds to massive volcanic deposits (lava flows, domes, pyroclastic flows, lahars), while the second seismic facies corresponds to layered pyroclastic rocks (surge and thin bedded pyroclastic flows deposits).

The activity of two volcanoes has been dated on the basis of high-resolution seismic data. The layered pyroclastic products which form the flanks of the Banco of Penta Palummo are cut by a sharp unconformity, which can be referred to the last glacial minimum (Wurm; 18,000-14,000 yrs. B.P.), so the main activity of this volcano can be dated as pre-18,000-14,000 yrs. B.P. The Banco of Nisida is characterized by a flat top, shallower than the previous unconformity, connected to a post-Wurm minor regressive event. The activity of Banco of Nisida is thus younger than 18,000-14,000 yrs. B.P. but older than a post-Wurm minor regressive event.

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