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The Phlegrean fields beneath the sea: the underwater volcanic district of Naples, Italy

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Abstract. Following the bradyseimic crises of 1970 and 1984, the Institute of Oceanology of the Istituto Universitario Navale (IUN) of Naples held, all around the Pozzuoli area, high-resolution reflection seismic surveys, occasionally multichannel but generally single channel. In this paper an interpretation of seismic data is presented, integrated with magnetic information (where available), which aims to better outline the underwater volcanic district.
The tectonic features and the main faults which gave origin to the Phlegrean volcanism were identified and the existence of a basement fault zone, 1.5 km wide and more than 6 km long, inside the Pozzuoli Gulf, has been documented. An overall uplift of 500 m of the Pozzuoli shoreline, after the development of the underwater caldera, was also recognised. Fluid traps were depicted and a fluid circulation inside the basement (at more than 4000 m depth) is hypothesised. These may justify the large amount of vapours and gases in the sedimentary column.

1. Introduction

The geographical location of the Campi Flegrei is indicated in Fig. 1. Although this area has been studied by many authors and a massive bibliography is available concerning volcanologic, petrologic and seismologic aspects and models (Barberi et al., 1991; Rosi and Sbrana, 1987 and references therein), the only geophysical, seismic, low-resolution data in that area, came back from the work done by Finetti and Morelli (1974), with the technological tools of that period. It was therefore imperative to survey the region and the adjacent Tyrrhenian margins with a narrower sampling grid and an higher vertical resolution with respect to that obtained by the Flexotir (T.M.) source. The purpose of the work was to achieve a better knowledge of the tectonic and subbottom structures of the area and to better locate the top of the Cenozoic-Mesozoic

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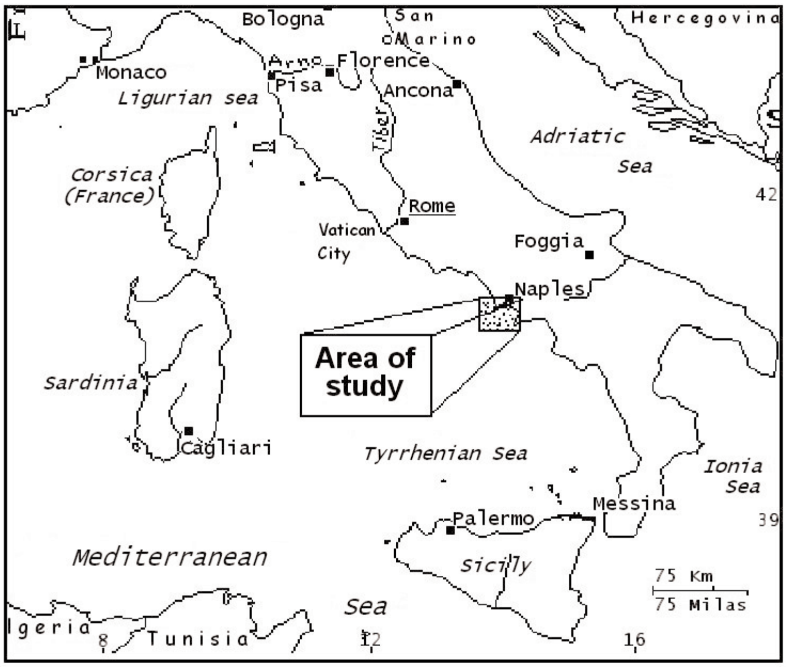

Fig. 1 - The geographical frame of study.

carbonatic platform and the overlying Cenozoic sediments or volcanic filling up. Special attention is steered toward the underwater deposits of the Campanian Ignimbrite and of the Neapolitan Yellow Tuff.

To rationalise the work, the geophysical analysis was carried out splitting the studied territory into four sectors shown in Fig. 3b (the satellite image comes courtesy of Chevron Ltd.). Each sub-area has been chosen based on an homogenous as possible data coverage and with similar subbottom structures:

- the Tyrrhenian margin, south of the Gulf of Naples, characterised by submerged volcanoes and the rise of the Dohrn and Magnaghi canyons;
- the Naples' Gulf, where the sedimentation shows wide spread Campanian Ignimbrite (CI) and Neapolitan Yellow Tuff (NYT);
- the north-western Tyrrhenian margin, where magnetic, gravimetric and seismic data are available and where a good correlation exists between onshore and offshore structures;
- the Gulf of Pozzuoli, characterised by submerged volcanic banks and by the carbonatic block recognisable between the Magnaghi and Dohrn canyons.

2. The high resolution seismic area coverage

The surveys were conducted by means of a 15 kJ MEAS (Multiple-electrodes Extended Array Sparker; Fig. 2). It consists of a 4 x 4 meter metallic cage which holds a planar array of 36 equally

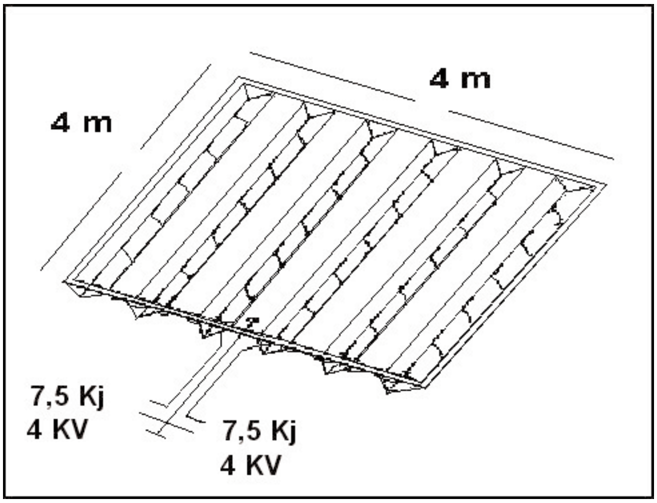

Fig. 2 - MEAS (Multiple electrodes Extended Array Sparker).

spaced electrodes, divided into two banks of 18, each powered with 7.5 kJ. The penetration reaches a depth of 2 seconds (two-way travel time) in soft sediments. The intrinsic resolution of the seismic source is 6 meters, but the ghost generated by the ship's hull in some situations may degrade the vertical resolution down to 25 meters. The firing rate was 6 seconds, which at a ship's speed of 4 knots allowed a shot every 12 meters. For the high resolution and high penetration, a water gun source with 2 x 400 cubic inches, firing every 8 seconds, was adopted. The streamer was equipped with 24 channels, divided into sections, each 25 meters long, for a total length of 600 meters, this was the maximum length compatible with ship's manoeuvrability in relation to the width of the Gulf of Pozzuoli.

3. Seismic facies and stratigraphic constraints

Within the area of interest, various seismic facies are recognised, usually well correlated to onshore geology (see Table 1). They are commonly also identified with the aid of seismic images of the different geoacoustic features of the subbottom.

The stratigraphic constraints are related to the nature of materials (sudden impedance change, absorption, lateral homogeneity), the acoustic source spectrum, hydrophones sensitivity and frequency response, and to the signal-to-noise ratio of the recording system.

4. The Tyrrhenian margin, south of the Gulf of Naples

This area roughly fits the one spanned by the lines 1 to 6 drawn in Fig. 3a. During the survey of those lines the radiolocation was done by Loran C, on the lines external to the Gulf, with fix accuracy of +/- 250 m, while Microfix (T.M.) was used inside the Gulf, achieving an accuracy

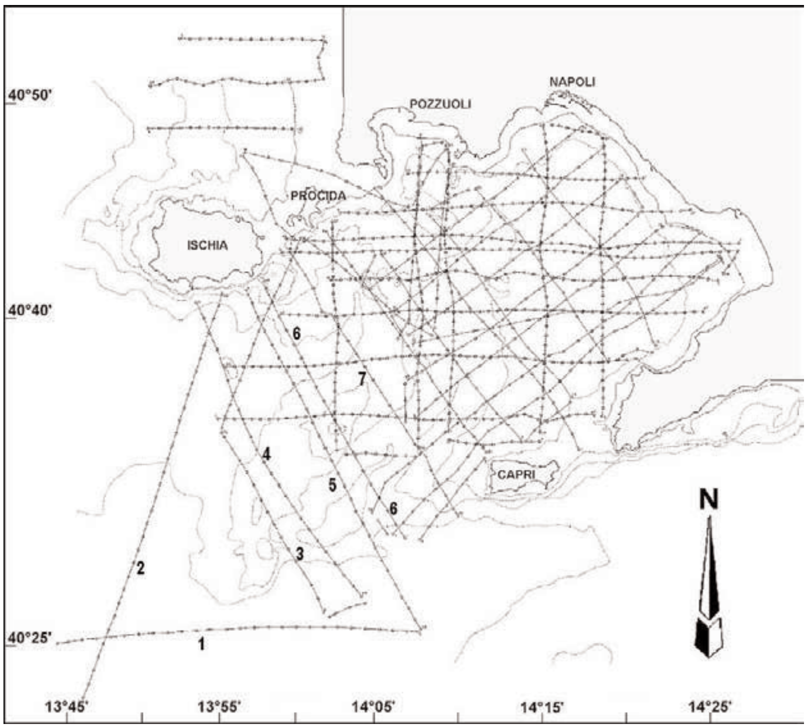

Fig. 3a - Sparker lines (MEAS) surveyed in 1989-1990.

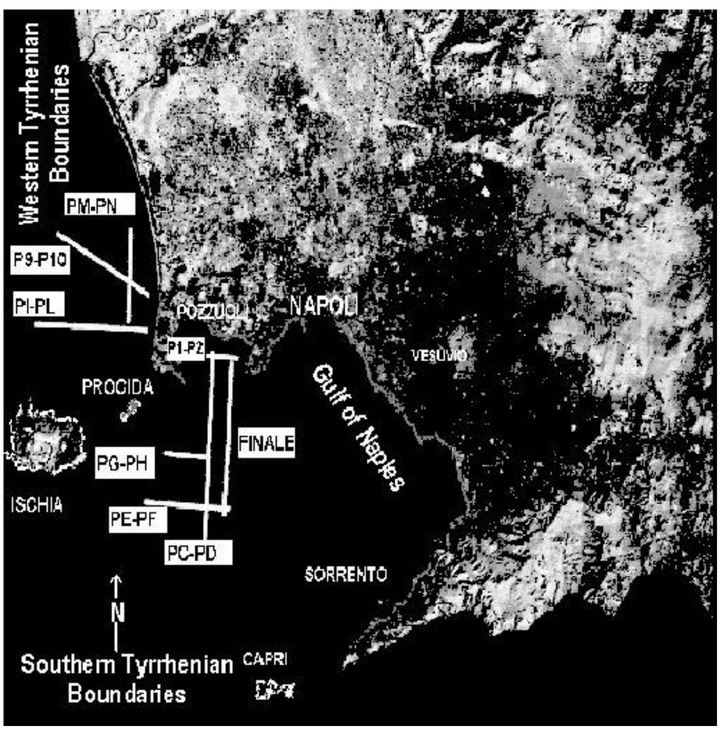

Fig. 3b - High resolution (50m) and high penetration water gun lines.

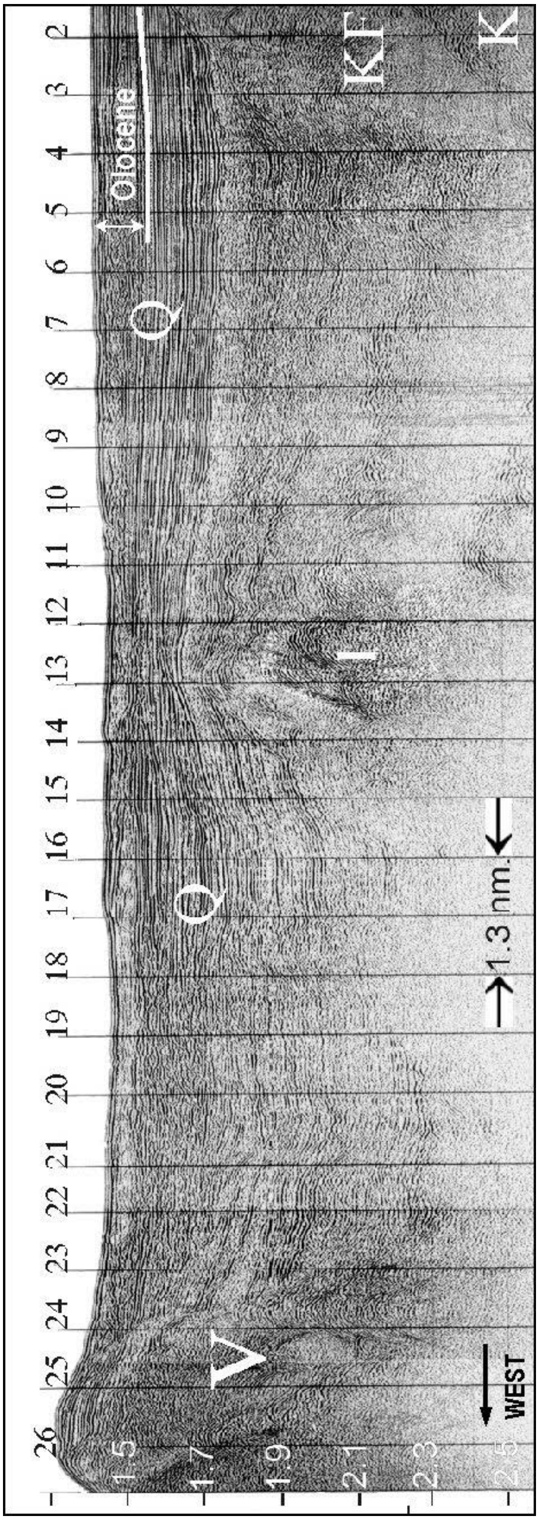

Fig. 4 - Seismic line 1 of Fig. 3a.

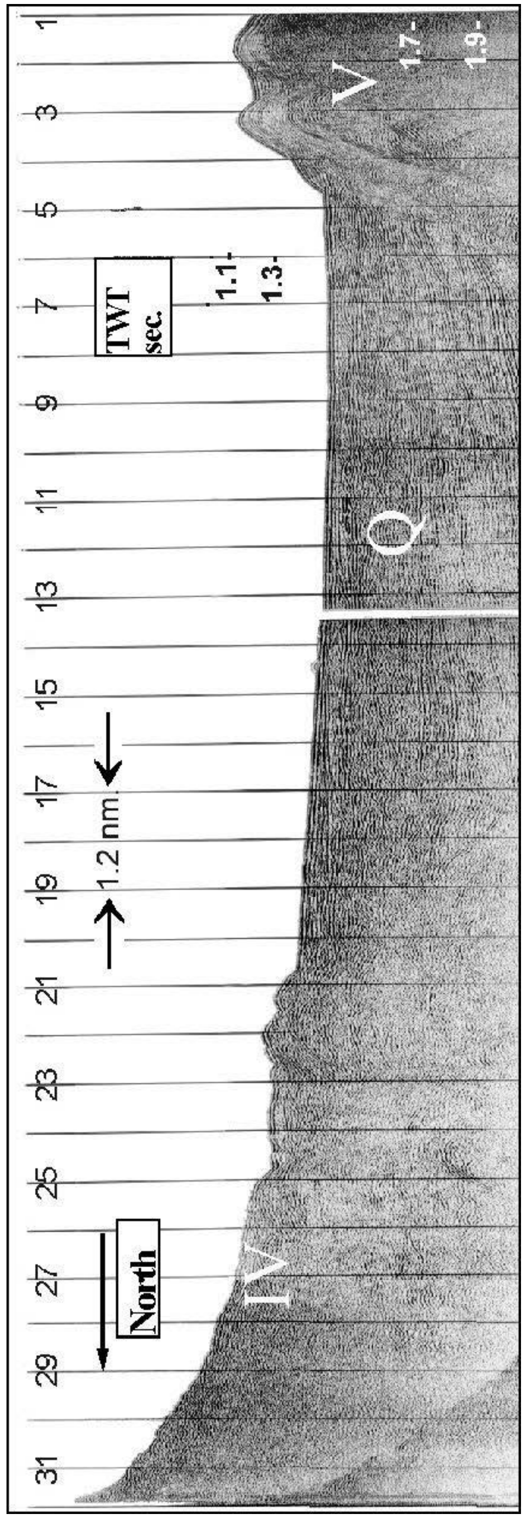

Fig. 5 - Seismic line 2 of Fig. 3a.

Tab. 1. Main ashore geological units and used acronyms.

K	Limestone
KF	Flysch
V	Volcanic intrusion
IV	Ischia VOlcanic
Q	Quaternary sediments
T	Tuff
F	Fumaroles/Fractures
L	Lava
S	Slumps
CI	Campanian Ignimbrite
NYT	Neapolitan Yellow Tuff
SL	Plioquaternary sedimentary layers
PQS	Plio-pleistocene sediments
OVM	Old Volcanic Marker
ES	Erosional Surface
IVP	Incoherent Volcanic Products

of +/- 2 meters. The small circles in Fig. 3a are fix markers posed every 6 or 6.5 nm (depending on the line) and progressively numbered on the profiles. A detailed magnetic map overlapping the inward part of this area (corresponding to lines from 3 to 6) has been done by IUN (Istituto Universitario Navale), contracting the Lamont Doherty Observatory. On the other hand, no magnetic map is available for the outward part (corresponding to lines 1 and 2); therefore, the analysis in this second area was carried out with the only aid of the seismic stratigraphy.

Lines 1 and 2 are given in Figs. 4 and 5 (see Table 1 for nomenclature). It is worth noting

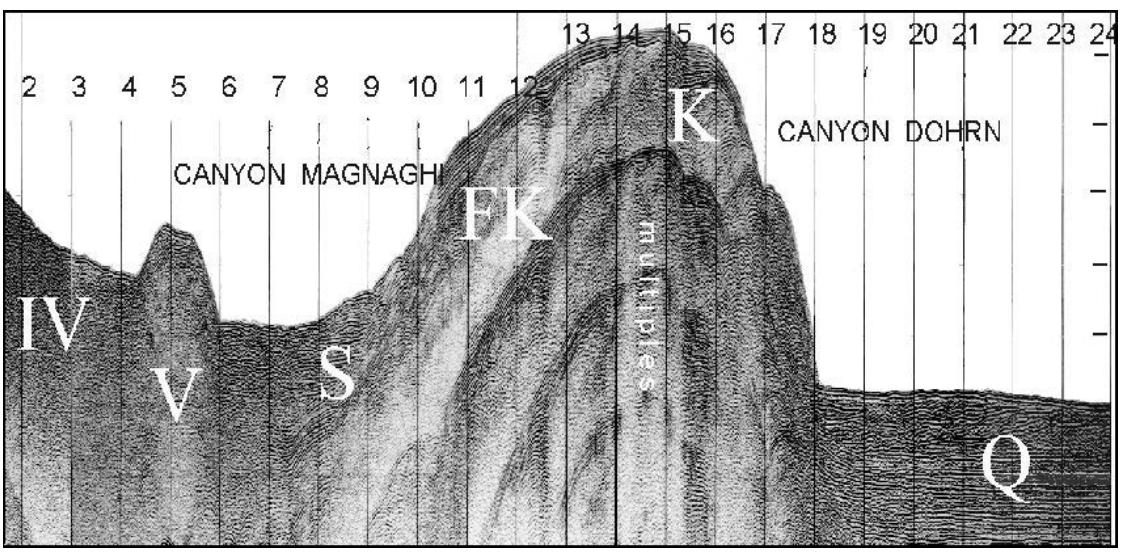

Fig. 6 - Seismic line 4 of Fig. 3: the tertiary sedimentary block originating Magnaghi and Dohrn Canyons.

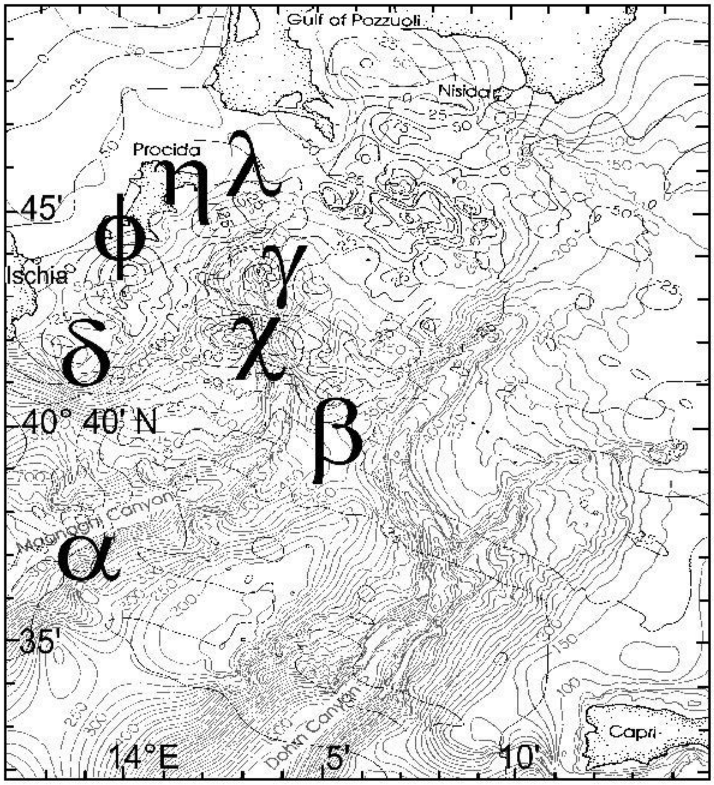

Fig. 7 - Sea beam bathymetry (gray lines) and magnetic anomalies (black). Greek letters indicate underwater volcanoes previously not identified.

that, thanks to the intrinsic high-resolution feature of MEAS, it is unnecessary to manually superimpose any line drawing on the seismic section.

In Fig. 4, we can recognise, on the eastern corner, the Mesozoic limestone tilted blocks (K) correlated with those outcropping at the Sorrento peninsula. The Mesozoic is covered here by thick flysches (KF) with a conformable tilting, limited upward by the Upper Miocene unconformity. More recent, and nearly sub-horizontal onlapping sediments, dated from Pliocene to Holocene, cover the unconformity. A significant intrusion characterised by an important fault, presenting a throw of nearly 700 meters, is evident in the middle of the line. This intrusion onset the overlying sediments, whose bending demonstrates that the action was active till the end of the Pleistocene, while the Holocene sediments appear undisturbed. The lack of magnetometric data does not allow us to define the nature of the intrusion whose magmatic origin is only inferred by the acoustic facies.

The rising of an important, underwater volcano, elevated 300 m over the surrounding sediments, can be seen at the western end of line 1. This volcano is better defined in Fig. 5 (line 2). The geographical coordinates are: lat 40°24' N, long 13°47'35" E. The Ischia Volcano rise can be noticed on the northern side of line 2: its underwater roots are documented 7 miles off the emerged Ischia island. The upper cone, about 1 km wide, is filled with undisturbed sediments meaning that there isn't recent activity. The width at the bottom level is of about 7000 meters and

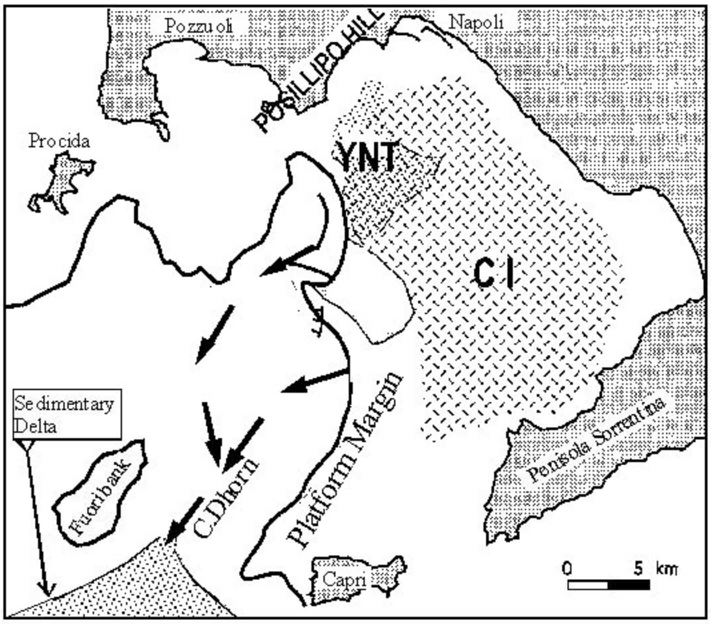

Fig. 8 - Underwater geographical distribution of Campanian Ignimbrite (CI) and Neapolitan Yellow Tuff (NYT). Example deducted from sparker survey (Milia, 1996).

a slump is clearly visible on its flank. Quaternary sediments regularly fill the flanks of the volcanic dome, suggesting an age of mid-Quaternary time. According to onshore studies (Rosi and Sbrana, 1987) the volcano was active until 150 ky ago.

Lines 3, 4 and 5 (in Fig. 6, line 4) show a tilted limestone block, oriented NNE-SSW that is bounded by the two most important canyons of the Naples' Gulf: Dohrn canyon, eastward, and Magnaghi canyon on the side of Ischia (Fig. 7). Towards Ischia the block presents a monocline dipping SSW which is covered by a flysch layer. The two Canyons are undoubtedly of tectonic origin, linked to the Miocene structures of the carbonatic blocks and are finally filled by Plio-

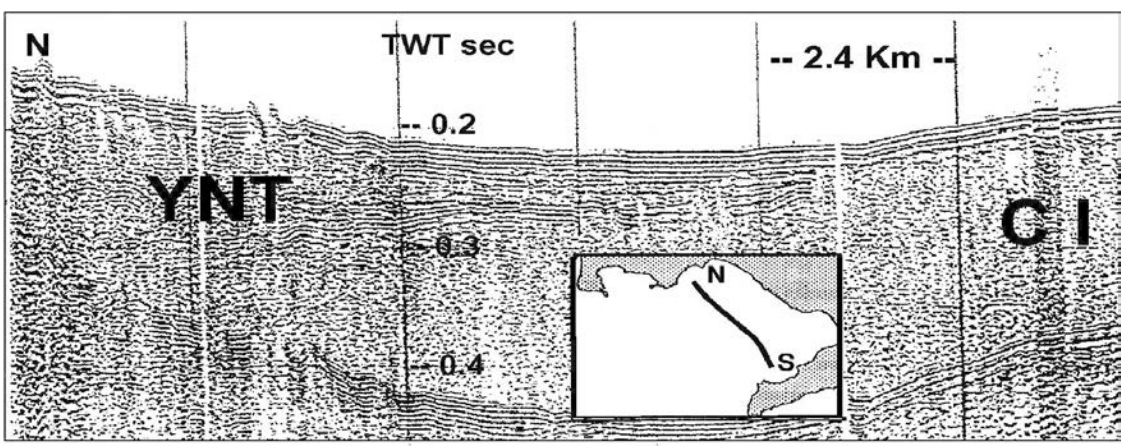

Fig. 9 - Seismic evidence of C I and NYT are shown. The sparker seismic section is oriented SE-NW. CI Campanian Ignimbrite; K carbonatic mesozoic rocks; PQS plio-pleistocene sediments; RFT refraction signals due to K hard rocks.

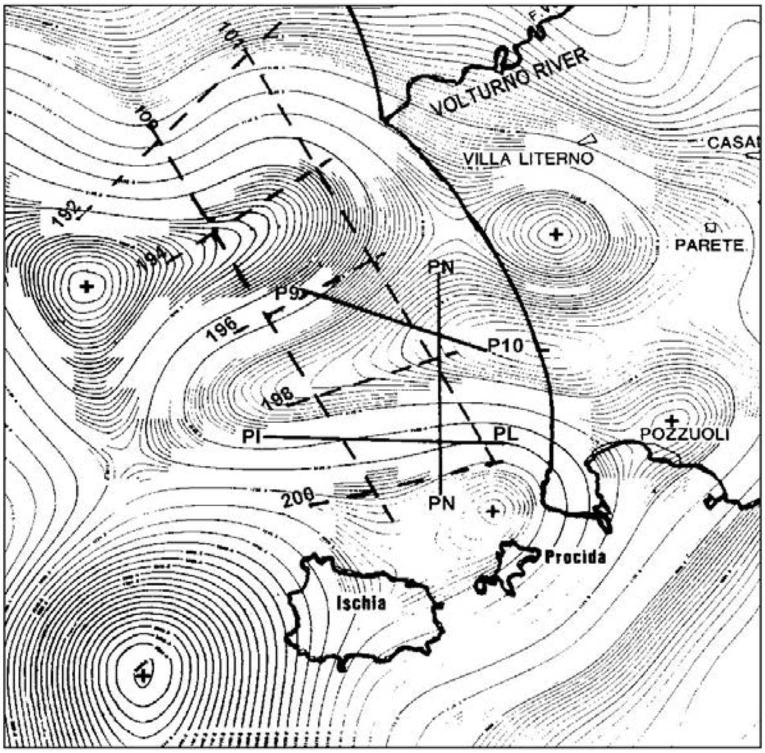

Fig. 10 - Location map of the seismic lines Aquapulse (dashed) and Water-Gun (continuous) superimposed to magnetic anomalies reduced to the Pole (Cassano and La Torre, 1987).

Quaternary clastics whose distribution is described by Milia (1996). A magnetic map for this area is available, from the Lamont Doherty Observatory. Although a topographical distortion is present between magnetic and bathymetry maps, it is possible to overlap the two and to recognise the small volcanoes indicated by Greek letters in Fig. 7. These volcanoes have light phreato-magmatic eruption origins. Their magnetic anomalies fall in the range of 50 ÷ 170 nT, alike to those of inland volcanoes of the Pozzuoli Gulf.

5. The Gulf of Naples

The study of the sedimentation in the Gulf of Naples disclosed a lot of information on the Campanian Ignimbrite (CI), well recognisable in the high-resolution sparker lines collected between 1986 and 1990.

The analysis done by Milia (1996) allowed us to draw, with a high degree of confidence, the platform margin as it was 33 ky ago (Fig. 8). The paleogulf was a continental or, at the most, a very shallow water environment, in which the pyroclastic flows were propagating upward a very shallow water surface. It is presently lying as deep as 150 m under the sea level (Fig. 9).

Looking at figure 9, we can consider that:

- The regressing and prograding wedge shaped unit that lies below the CI and above the PQS implies a sedimentary by-pass and erosion on top of it. This wedge shaped surface has been formed upward with respect to the old sea level (Milia, 1996).

- Assuming a mean subsidence of 2 mm/y (Brancaccio et al., 1991) from the Tyrrhenian age to the present, the CI (33 Ky) subsided about 60 to 70 meters.
- The old absolute sea level (Bard et al., 1990a, 1990b) was about 85 meters shallower than the present one.
- Without adding the subsidence due to the sedimentary load, all the aforesaid suggests that the emplacement of the CI flow occurred either above the sea level or in very shallow water.

6. The Northwestern Tyrrhenian margin

Fig. 10 shows the north-western extension of the area under discussion where geophysical data are available: maps of magnetic anomalies reduced to the pole and Bouguer residual gravity anomaly (Cassano and La Torre, 1987); some multichannel reflection seismic lines, acquired by the Italian Ministry of Industry in 1968; high resolution Water-Gun multichannel reflection seismic lines (Mirabile et al., 1989); stratigraphic data from "Mofete", "San Vito", "Villa Literno" and "Parete" wells.

The interpretation of all these seismic lines (Aquapulse source: 101, 109, 192, 194, 196, 198, 200; Water-Gun source: PM-PN, P9-P10, PI-PL) is not trivial (Frattini 1992), but the main results are worth reporting here, avoiding the lengthy analytical analysis, less significant within the frame of the present work.

- The underwater continuation of the Mt. Massico (not reported in the figures) Meso-Cenozoic carbonatic horst and its offshore prolungation in the south-westward direction;
- the migration of Volturno riverbanks to the north;
- the presence of volcanic products, of the two east-west oriented volcanic sources: at sea and at Villa Literno-Parete, overlying and masking the carbonatic platforms.

We have drawn the interval velocity contours versus depth as a supplementary aid to interpretation of the high-resolution Water-Gun lines (Figs. 11 and 13).

Line PM-PN is 13 km long and it develops along shore. The correlation with onshore geology indicates that Ischia and the Phlegrean Fields volcanism is present in the southern part of the line, whereas the northern part lies within the Parete-Villa Literno volcanic area.

The two volcanisms are different in age being the southern one of Pleistocene-Holocene age and the northern one of the Miocene-Pleistocene (Barberi et al., 1991).

Looking at Figs. 11 and 12 (between shot point 300 and 469) we can identify a high velocity unit, about 5 km in extension that can be reported as the Procida volcanic acoustic basement. This unit dips NW, from 1800 to 2500 m, and its high velocity and density justify the weakness of the signal below it, because the volcanic intrusions reflect or scatter almost all the energy (Fig. 12). In Fig. 12 this unit is marked as B. It breaks the sedimentary horizon A, that may represent the transition from Miocene to Pliocene. The upper horizon B is bent and almost cancelled by the active volcanic centre.

The central part of line PM-PN (SP 300-180, Fig. 12) shows a basin like structure with a

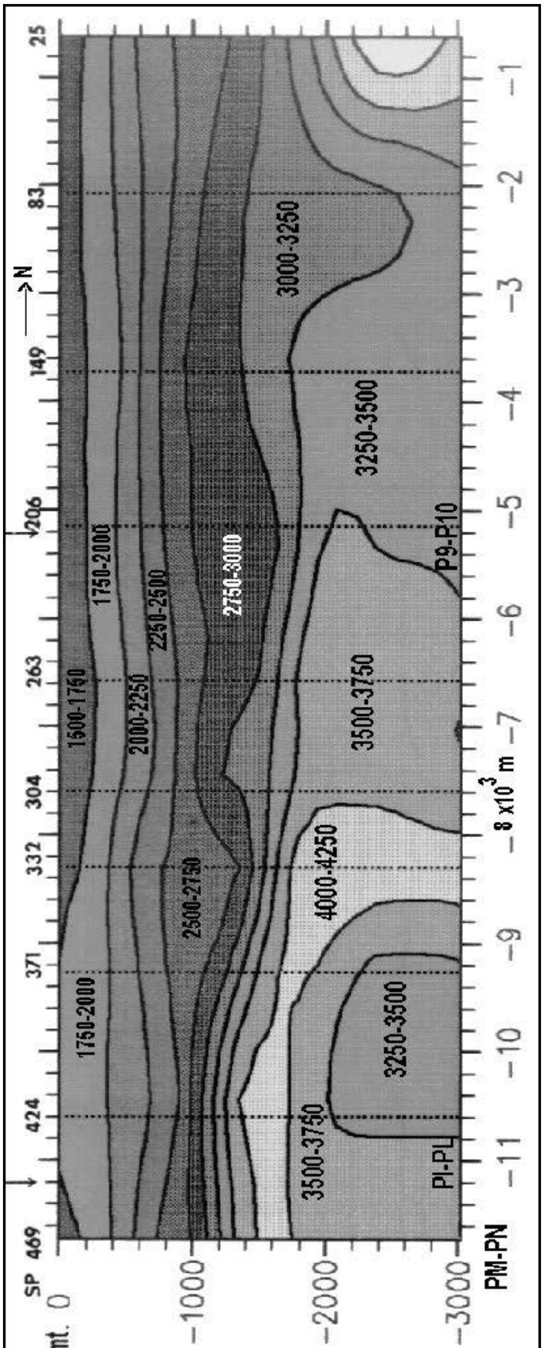

Fig. 11 - *Interval velocity* contours for the PM_PN line drawn in Fig. 10.

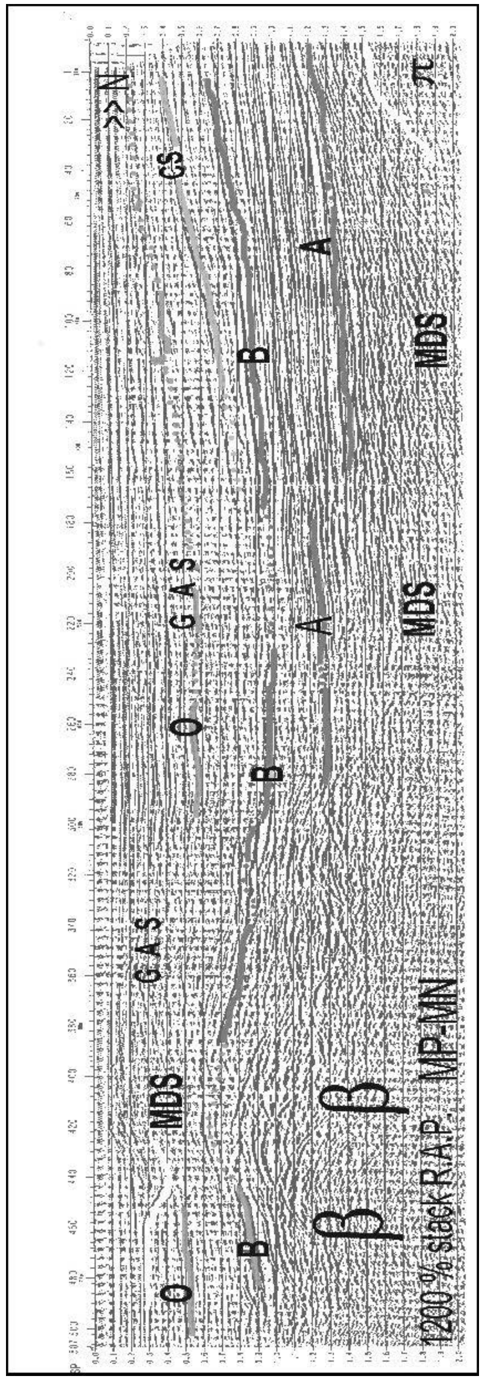

Fig. 12 - Seismic PM-PN line drawn in Fig. 10. Multitrace 1200%Stack. Real amplitude preservation. A: top of Miocene; B: top of Pliocene; O: Olocene seismic horizon; β: Volcanism correlated with magnetic maximum of Procida; π: Volcanism correlated with Villa Literno Magmas; MDS: Mechanically disturbed sediments; CS: Wedgeshaped surface (pyroclastic?).

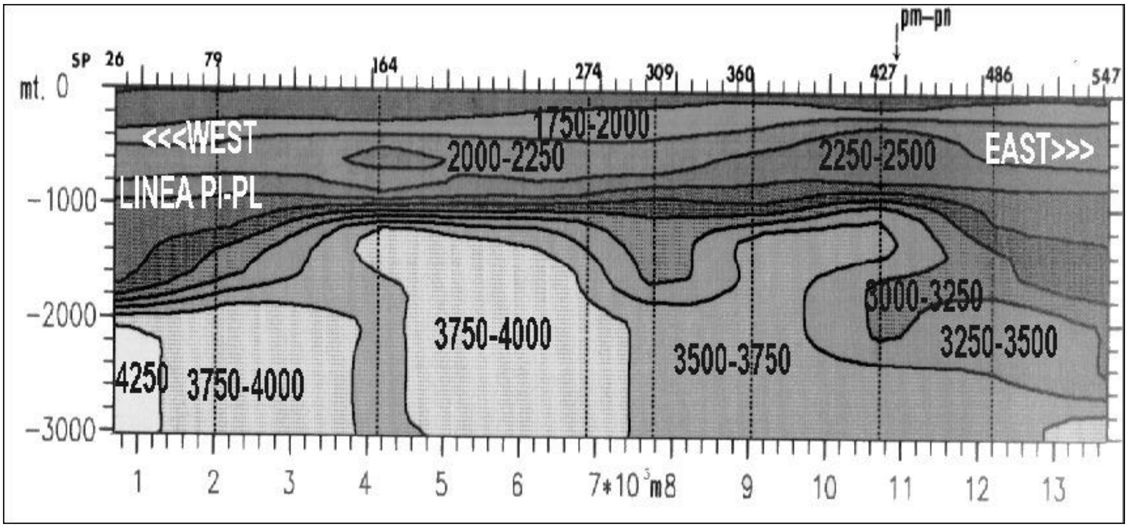

Fig. 13 - Line PI-PL: interval velocity contours.

regular sedimentation extending till the northern end of the line. Between SP 270-150 the sedimentary pack presents a diffused upcoming of gases, from a depth of about 2000 m down to the sea bottom. On the northern side, this seismic line shows a high velocity block at a depth of about 1500 m. The correlation with magnetometry indicates the presence of a volcanic rock associated with Villa Literno-Parete lavas (Agip, 1977; Ortolani and Aprile, 1978).

We do not find any bright spot associated with shallow accumulations of fluids in the PM-PN line, however, the considerable presence of vapours and gases in the sedimentary pack allow us to suppose the existence of such fluids at depth.

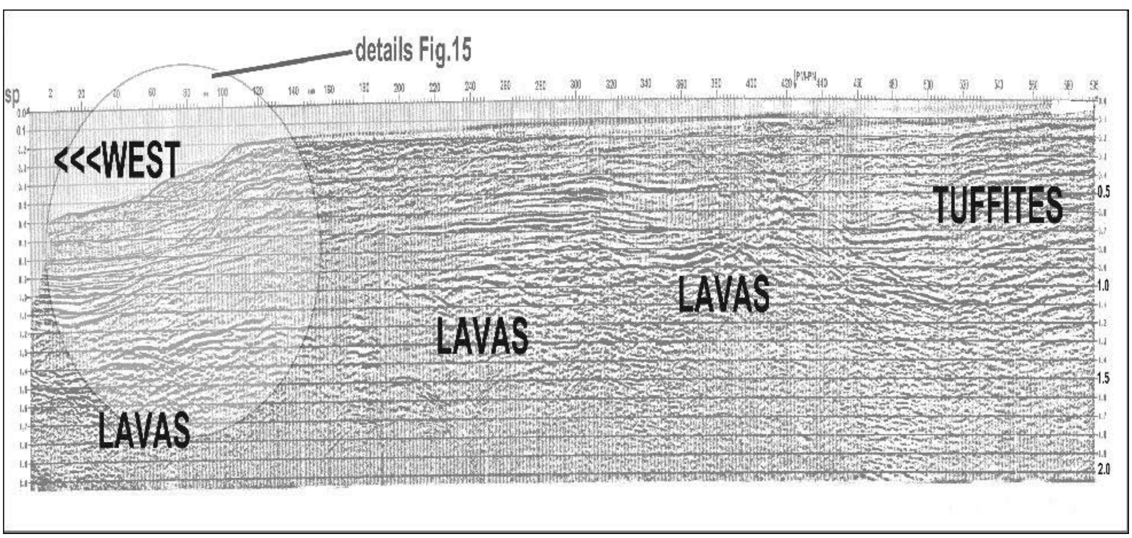

Fig. 14 - Seismic section (Water Gun) PI-PL.

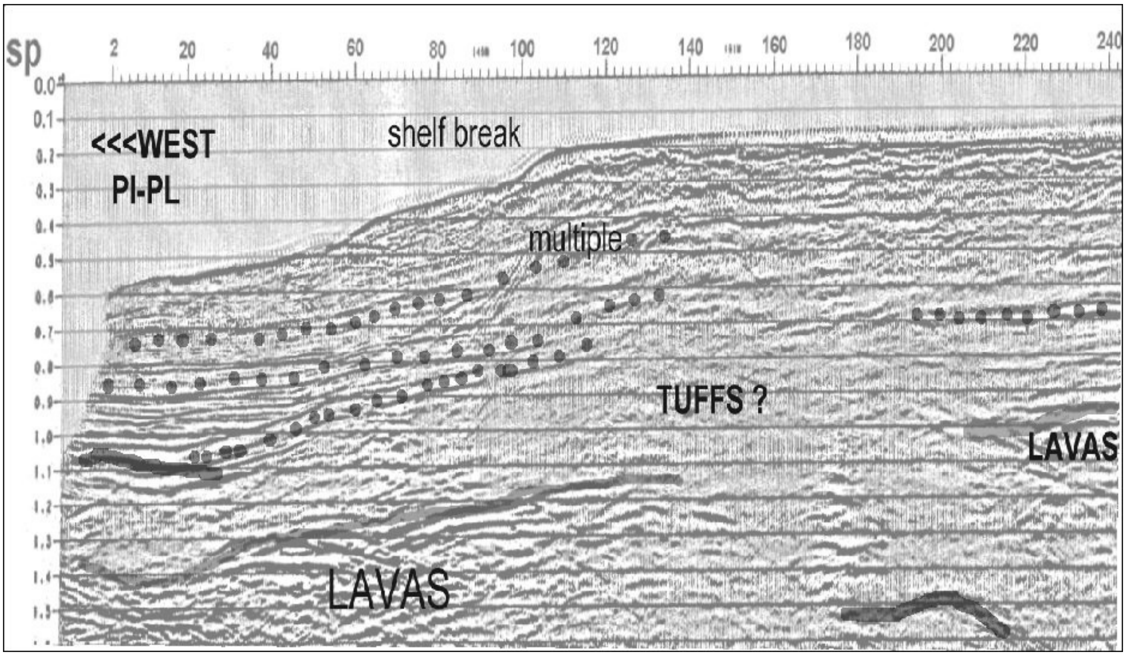

Fig. 15 - Particular of the West end of the line PI-PL drawn in Fig. 10. A small sedimentary basin probably filled by volcanic products is evident on the left side. A bank of tuff is assumed as a consequence of the seismic facies that presents no internal stratification. The stronger flat horizons may be due to changes in volcanic-sedimentary facies.

Line PI-PL (Figs. 13 and 14) can be interpreted with the aid of data coming from the geothermal well Mofete 1 (Fig. 16; Cassano and La Torre, 1987; Rosi and Sbrana, 1987). A good correspondence exists between the post caldera products of Mofete 1 well and the volcanic - sedimentary sequence identified in the seismic profiles as tuffites (Fig. 14). In this section,

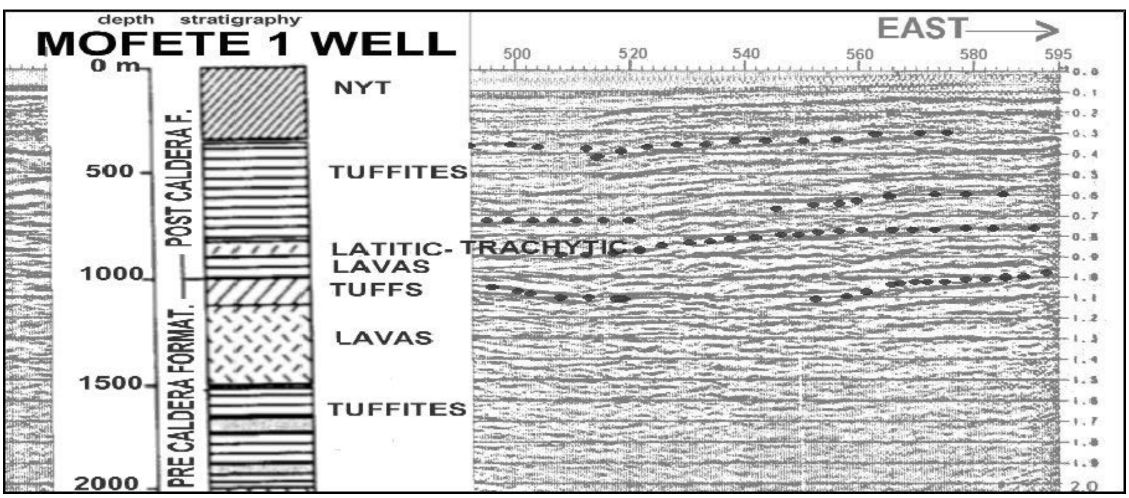

Fig. 16 - Correlation between Mofete 1 well stratigraphy and seismic stratigraphy PI-PL Line. Below the lava at 1.0 sec. the signal becomes too weak to identify some other horizon. No marks of fluid reservoir are evident. Mofete 1 well data from Cassano and La Torre, Rosi and Sbrana.

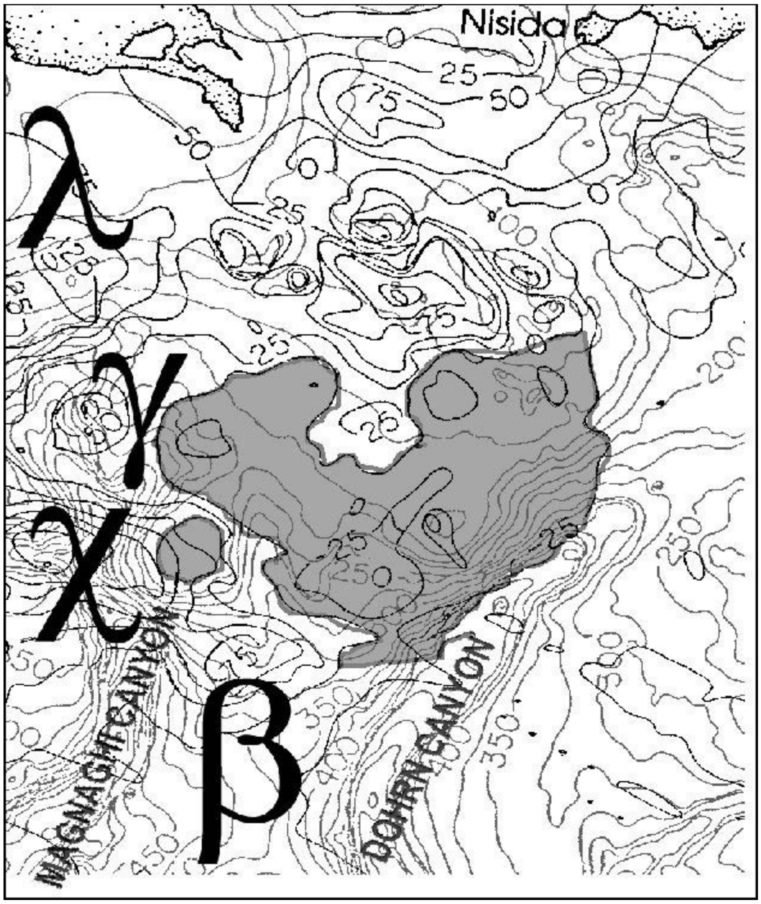

Fig. 17 - Carbonatic block, bounding the volcanic area south of the Gulf of Pozzuoli. The magnetic anomalies are zero or negative as in the carbonatic area of the Gulf of Naples.

between SP 520 and SP 595, the stratigraphic sequence is made of subparallel reflectors.

Looking at the interval velocity (Fig. 13) calculated for this seismic profile and comparing it with the data of the Mofete 1 well (Fig. 16), drilled 5 km apart, it results a high degree of correlation between the two exists. The seismic velocity of the sequence of tuffites and that from the well, both show a range between 2200 and 2400 m/s. Information on its lateral extension can be obtained from profiles PM-PN, 101 and 200 and, turned out to be 3 km in the E-W direction and 2 km in S-N direction.

7. The Gulf of Pozzuoli

The caldera rim of Pozzuoli is bounded to the south by a carbonatic tilted block confined between the Magnaghi and Dohrn canyons (Fig. 17). This block is aligned in a NNE-SSW direction with the carbonatic bank named Fuori bank (Figs. 6 and 8).

We called the northern part of this bank, well recognisable in the Sea Beam bathymetry, Aloha bank (whose seismic image is shown in Fig. 18). At the top of the bank thin strata,

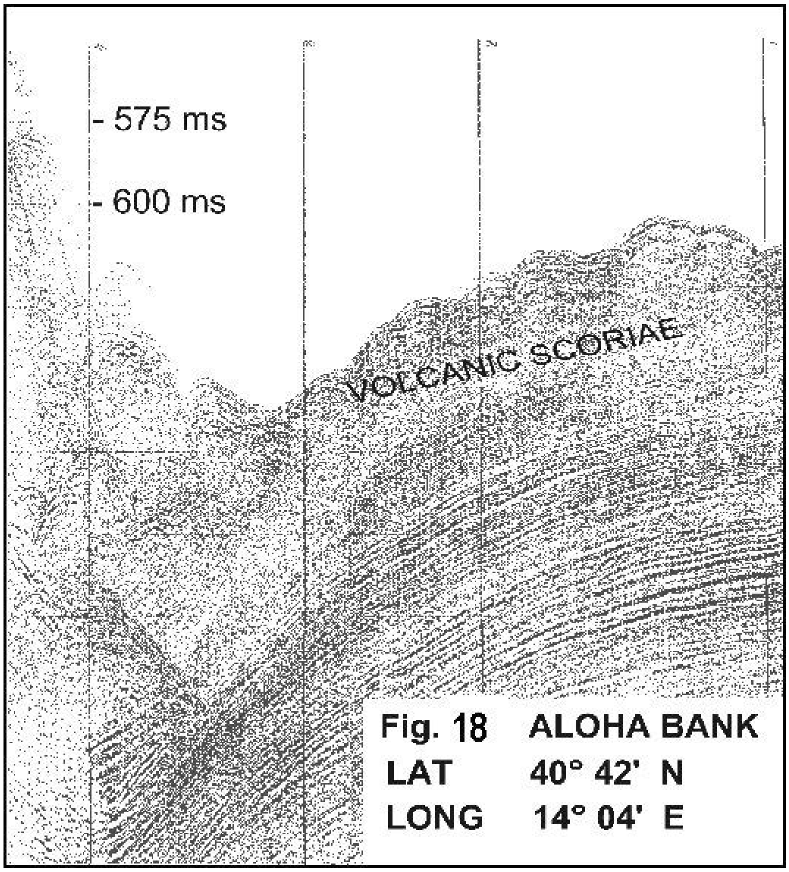

Fig. 18 - Seismic image of Aloha Bank.

probably of Pliocene age, are present, underlain by volcanic scoriae of high transparency and probably of low density.

Just at the western side of the carbonatic Aloha bank, a small volcano is present (marked as γ in Fig. 17).

In Fig. 19, the SSS image of the Miseno Bank corresponds to a magnetic positive anomaly of +125 nT. The shape and NNE-SSW orientation of its cone suggests the presence of a fault bounding the carbonatic block and along this fault the volcanoes γ, χ and Miseno are aligned (Fig. 21).

The seismic image of the Miseno Bank is shown in Fig. 20 where, starting from the north to the south, the Miseno tuffaceous cap that overlays an Old Volcanic Marker (OVM) can be recognised. The volcanic intrusion still pushing upward and deforming the sea bottom line is visible at the centre of the line as well. This Miseno dome is composed of a tuffaceous staff over a sliding surface that dislocates the tuff with respect to the lava extruded during the volcano's eruption.

An important fault seems to exist on the northern side, between the Miseno Cap and the Miseno Bank. Presumably, it is the same fault along which the underwater volcanoes η, ι, ϕ

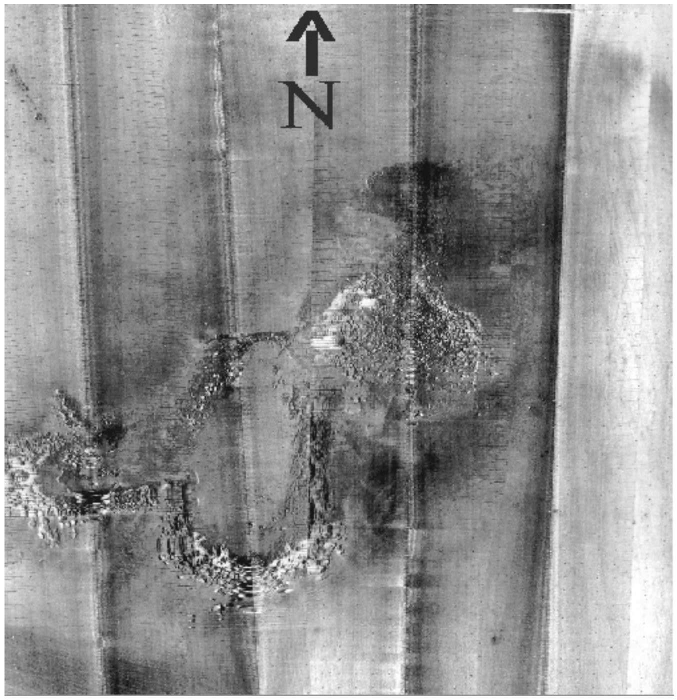

Fig. 19 - Side Scan Sonar view of the Miseno bank. Observe the major axis NNE-SSW orientation.

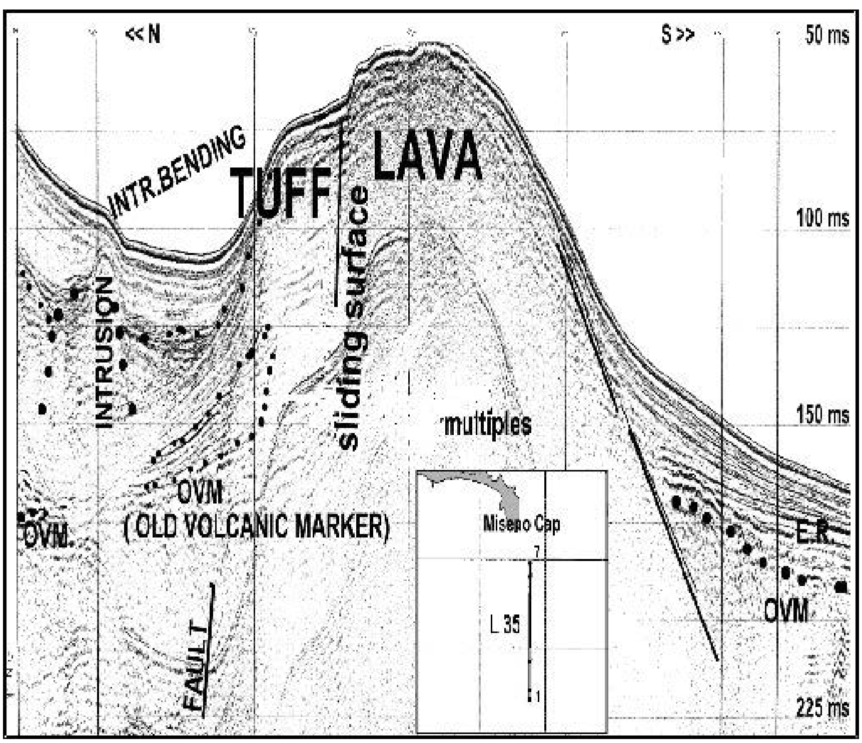

Fig. 20 - High resolution seismic image of the Miseno Bank. OVM: Old Volcano Marker.

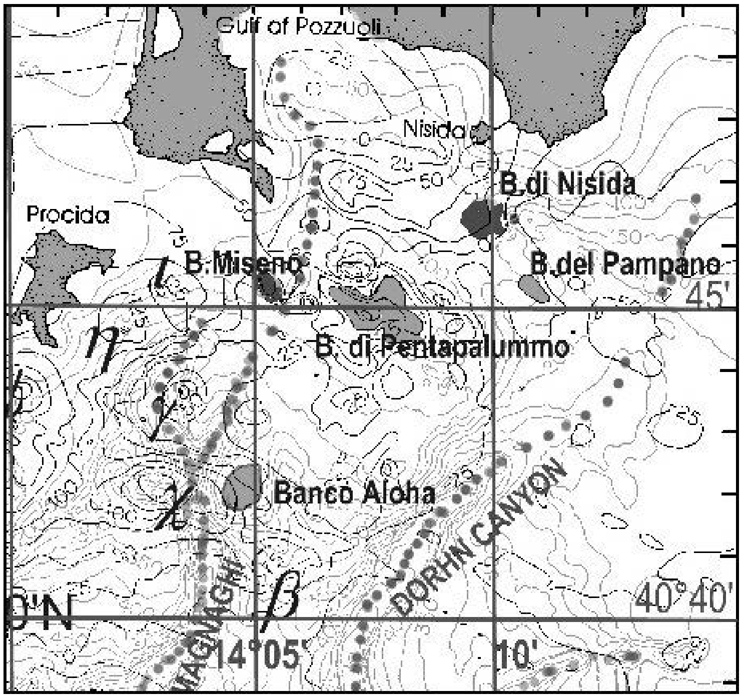

Fig. 21 - Distribution of the banks on the caldera rim. With the exception of the Aloha Bank, that is sedimentary, they are all volcanic.

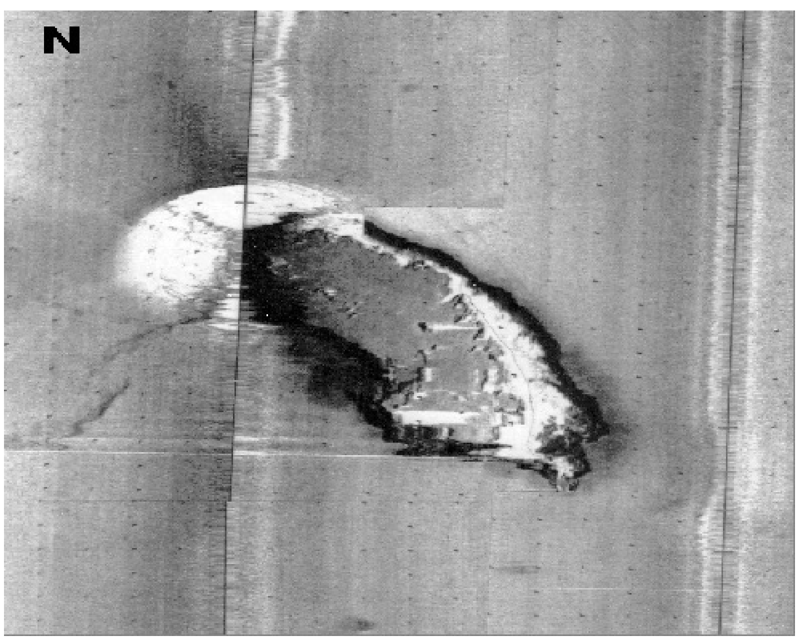

Fig. 22 - SSS view of the Pampano Bank.

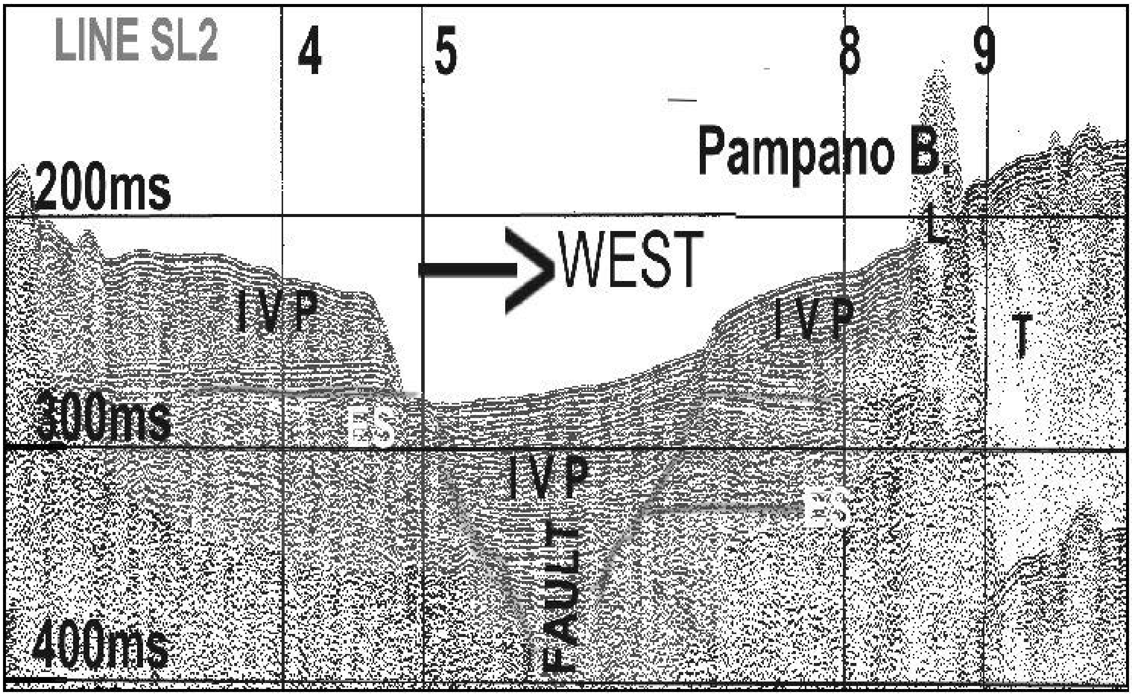

Fig. 23 - Sparker stratigraphy of the Pampano Bank and its east-west surroundings. L: Lava; T: Tuff; IVP: Incoherent Volcanic Products; ES: Erosional horizontal Surface (probably Wurm traces).

(Figs. 21 and 7, being the ι volcano marked as λ in Fig. 7) are aligned. This may be a radial fault converging towards the big volcano conduct (Figs. 32 e 33) found in the Gulf of Pozzuoli and presented in the following paragraph.

Fig. 20 also suggests the presence of an erosional surface on the southern flank of the Miseno Bank, probably representing the Wurmian marker as inferred by its depth (175 ms, corresponding to about 132 m).

The southern flank of the Miseno volcano is a lava surface that comes from the Magnaghi canyon prolongation in its northeastern branch (Fig. 33), where the actual Baia canyon can represent a northwestern derivation.

The Fig. 21 reports the distribution of the volcanic banks in the Gulf of Pozzuoli; the figure also shows the most important faults that can be seen from bathymetry and are well confirmed by the Sparker profiles. The northwestern branch of the Magnaghi canyon disappears, buried by the younger volcano-sediments, in the Procida channel.

At the western part of the Pozzuoli Gulf, in front of the Gulf of Naples, we can find a very sharp bank, the Pampano Bank. Fig. 22, shows the side scan (SSS) view of this extruded lava slab and Fig. 23, its seismic image (line SL2 of Fig. 3a).

An important feature of the Pampano Bank is the existence of a significant fault that separates its western side from its eastern one. The fault zone is filled, in its deeper part, by regular sedimentation, while in the uppermost section the sedimentation is more chaotic and surely coming from the disruption of the volcanic scoriae cone of the Pampano.

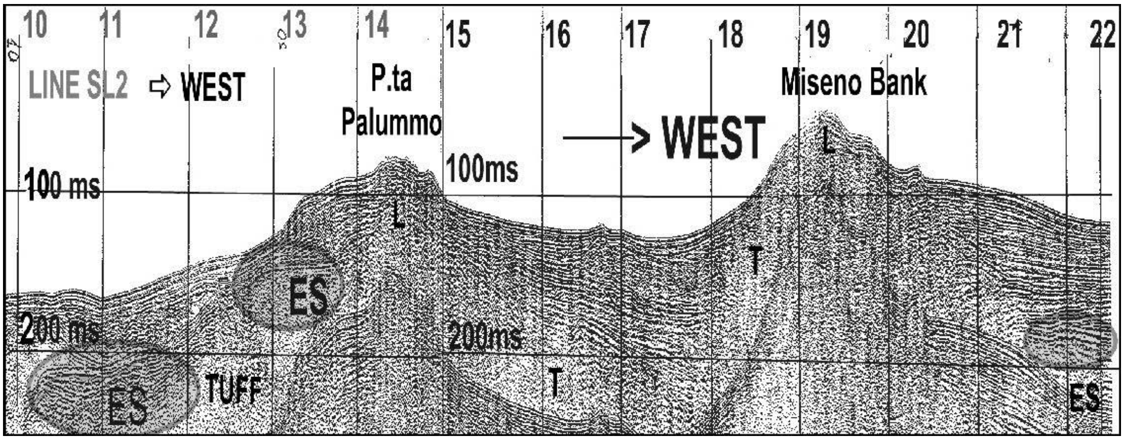

Fig. 24 - Sparker line crossing Pampano (Fig. 23), Penta Palummo and Miseno Banks.

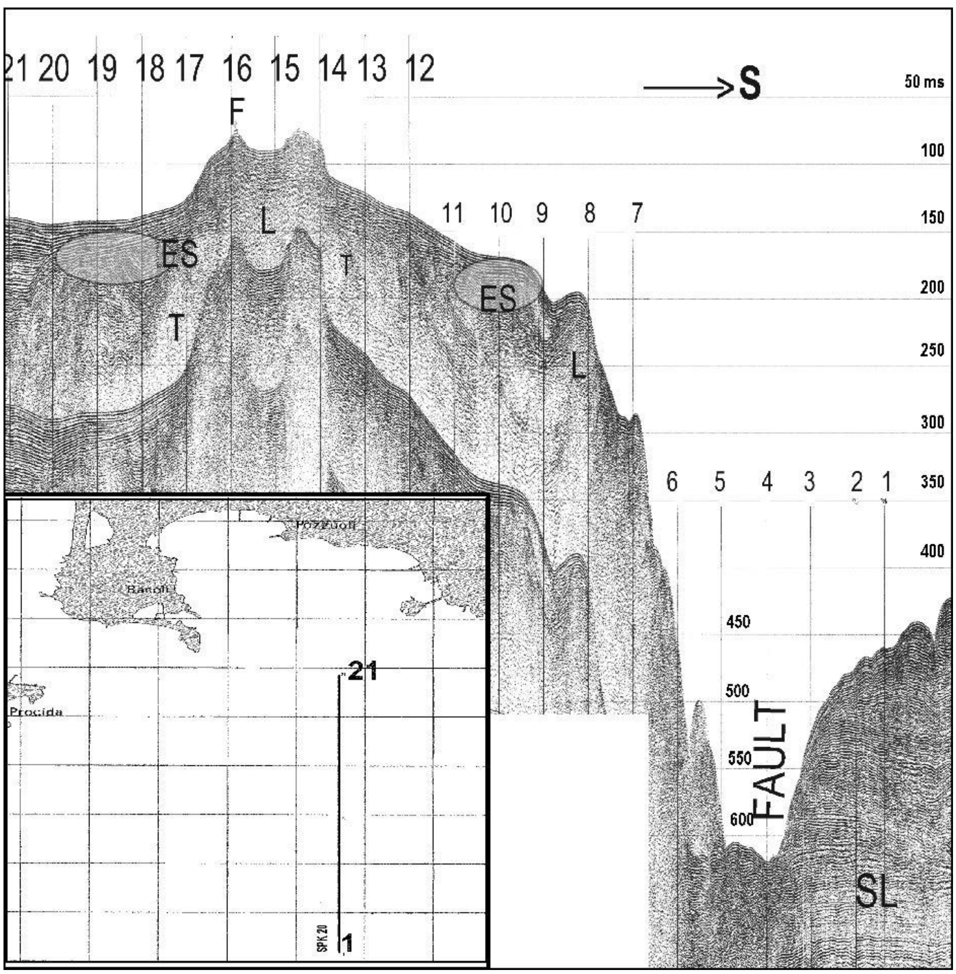

Fig. 25 - High resolution Sparker seismic profile crossing the top of the Penta Palummo Bank. The volcano is well depicted in its internal structure. L: Lava; T: Tuff; F: Fumaroles; SL: Plioquaternary sedimentary layers covering the carbonatic Mesozoic block.

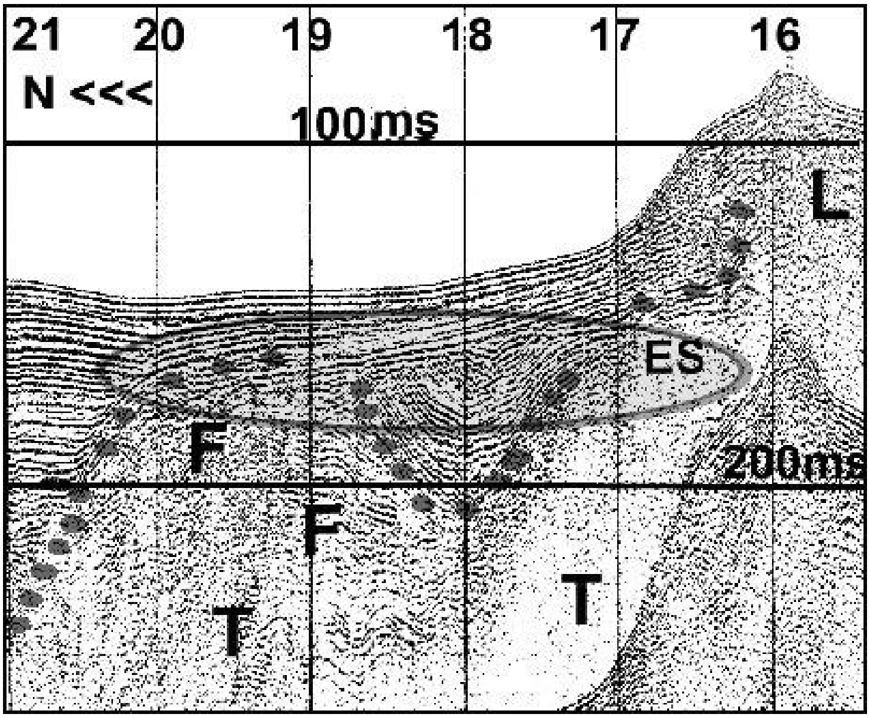

Fig. 26 - Northern flank of the Penta Palummo Bank.

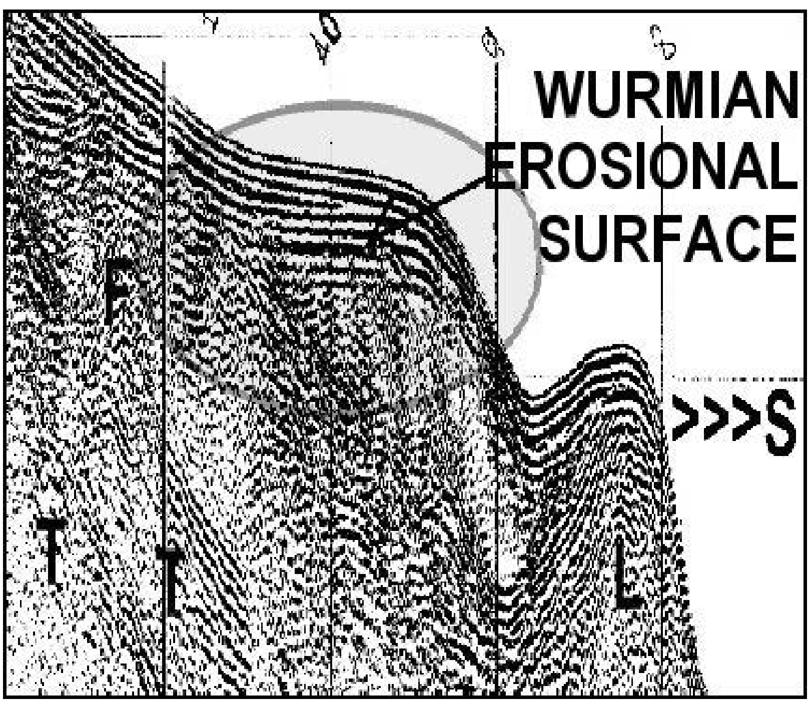

Fig. 27 - Detail of the southern flank of Penta Palummo. L: Lava; T: Tuff; F: Fractures. Northern and Southern Wurm erosional surfaces are both at a depth of -135 meters.

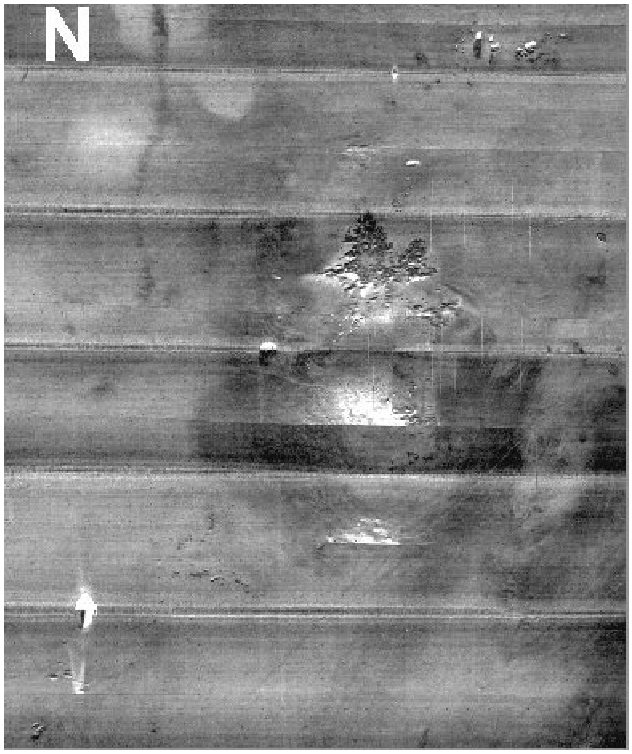

Fig. 28 - Mosaic of SSS view of the Penta Palummo Bank. The brighter targets are high reflectivity spots corresponding to lava.

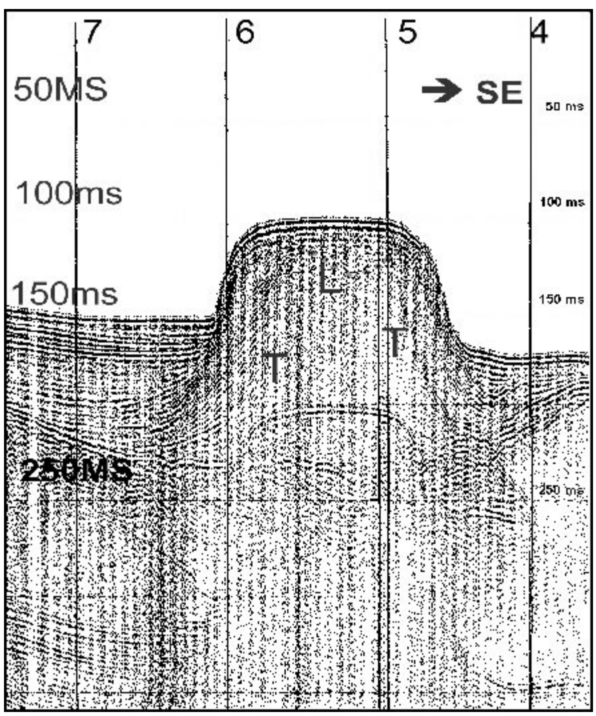

Fig. 29 - Sparker section of the Nisida Bank (1972).

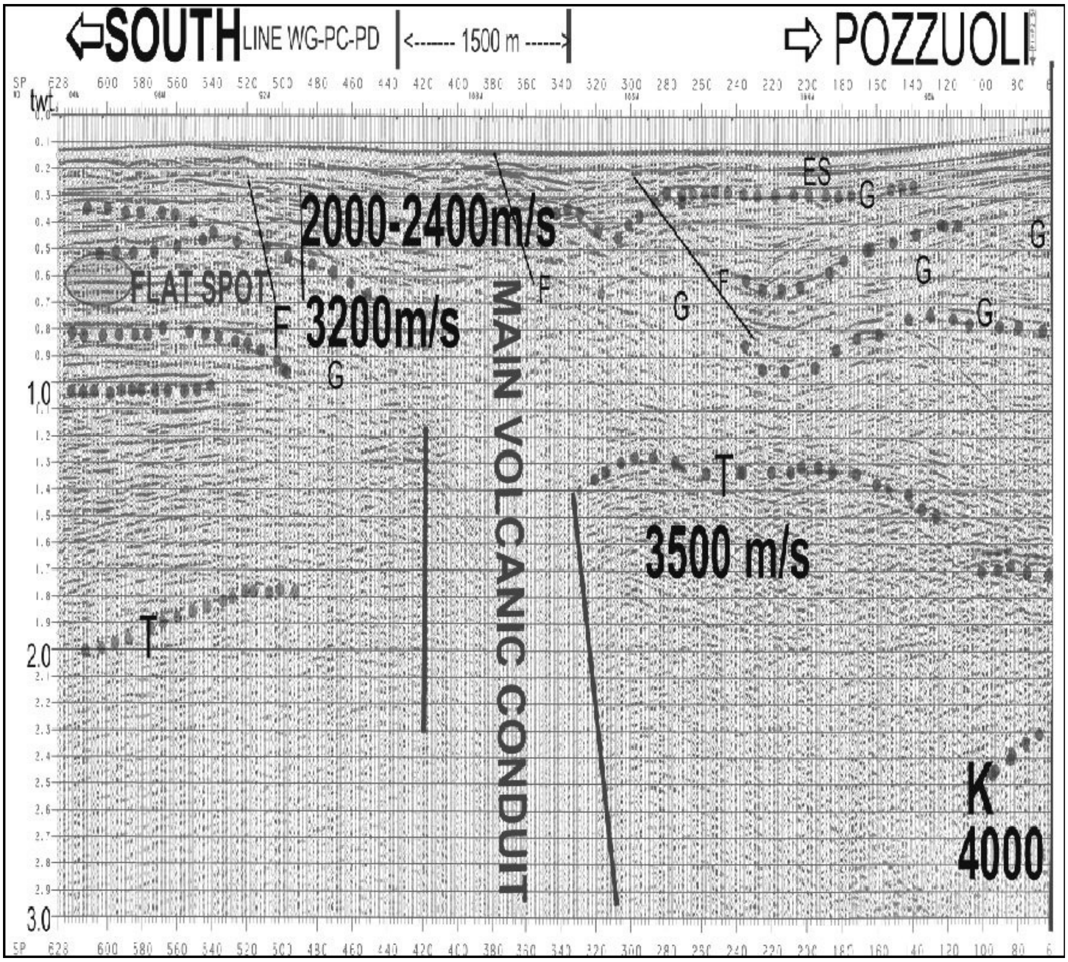

Fig. 30 - The north-south Water-Gun PC-PD Line inside the Pozzuoli Gulf. MVC is the Main Volcanic Conduit clearly visible in the seismic profile. T is, probably, a thermo-metamorphosed layer. K is the carbonatic basement. Compare with section P1-P2 in which it is clearly recognisable. F are fractures identified by joining the vertices of diffraction hyperbolas. G indicates diffused gas; Flat Spots are fluid accumulations. ES is a flat, horizontal, erosional surface a little deeper (300 ms) than Wurm (200 ms).

In Fig. 23, the two erosional, flat, surfaces, indicated by ES, are displaced by about 40 ms, indicating that the western side subsided about 30 meters in the last 18 Ky.

Another major feature, within the area of study, is the Penta Palummo Bank, roughly shown in Fig. 24, but enhanced in the high-resolution seismic image of Fig. 25. As can be seen, the volcano is well depicted in its internal structure and, on the Southern flank, a secondary lava slab can be recognised (Fig. 8). The volcano arises from the fault limiting the northern side of the Aloha bank. This fault follows (Fig. 17) the east to west deepening of the carbonatic block.

In Fig. 25, on the southern and northern sides of the volcano, erosional Wurmian surfaces are well evidenced (the shadowed ellipses): they indicate that Penta Palummo had subaerial activity (details in Figs. 26 and 27). On the northern flank (Fig. 26), the ES unconformity truncates a possible tuff block that is tilted and vertically fractured and whose northern boundary coincides with the cone of the big central volcanic conduct in the bay of Pozzuoli. The dotted line in Fig.26

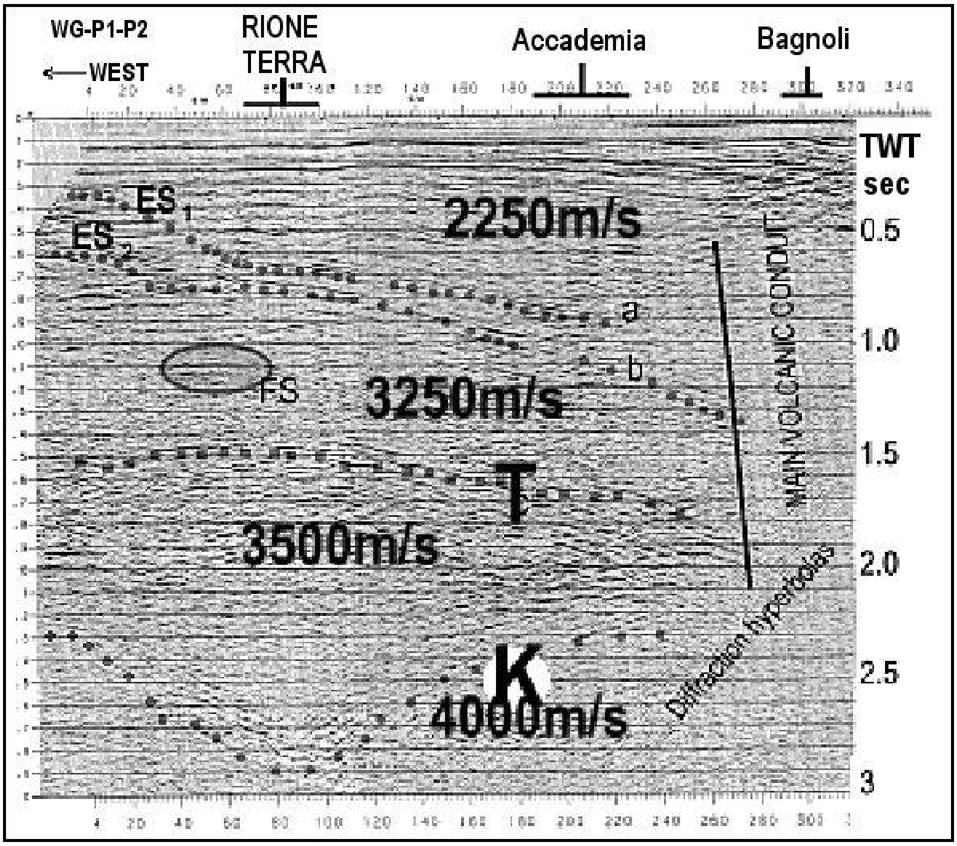

Fig. 31 - West-East WG line parallel to the Pozzuoli coast line.

indicates the tuff block, probably, eroded by the sea action during Wurm. The tuff block intrudes into the main volcano cone, as will be seen later comparing to the water gun PC-PD line of Fig. 30.

Further information about the structure and the nature of the Pozzuoli Gulf area can be achieved looking at Fig. 31, where a water gun profile (P1-P2 drawn in Fig. 3b) parallel to the Pozzuoli coast line is presented. In Fig. 31 the interval velocities (Ranieri, 1990) are indicated; "a" and "b" dotted lines, are two seismic horizons that give rise to two different erosional terraces ES1 (-310 m) and ES2 (-600 m). Admitting that ES1 is the Wurm erosional surface, there was a subsidence of more than 170 m in the last 18 Ky. ES1 was found in the same position (TWT - 300 ms) on profile PC-PD (image in Fig. 30 and plan in Fig. 3b). In Fig. 31, considering ES2, we must add 290 m to the excursion of the coast line, taking also into account the height of the "La Starza" (a well studied inshore terrace), the whole vertical displacement in the Pozzuoli offshore area becomes of the order of 500 m.

In Fig. 31, FS indicates a Flat Spot caused by accumulation of fluids (a liquid phase) extending for about 600 m; T indicates a quite regular sequence on the western side, disappearing upon contact with the main volcanic conduit. This sequence is probably thermo-metamorphosed. K is the carbonatic basement, highly tectonised, with fractures responsible for the magma

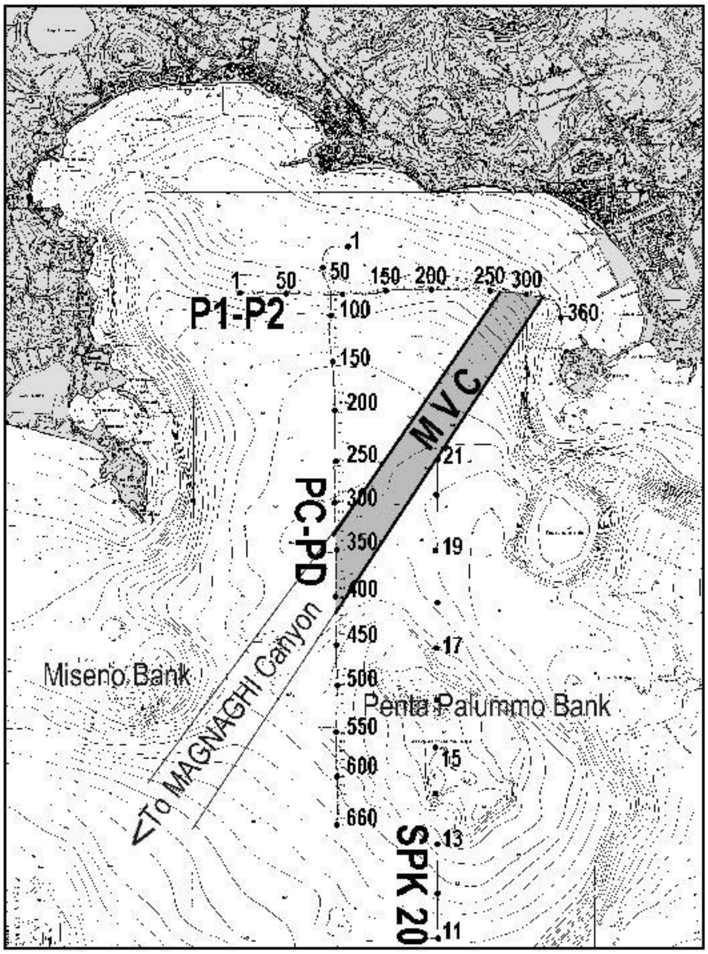

Fig. 32 - Position of the Shot point of the WG lines PC-PD and P1-P2, and Position Markers of the Sparker Line SPK 20. The isolines are bathymetric.

infiltration and for the volcanic activity. The top of the carbonatic basement near the fracture is supposed to be at a depth of more than 3000 m, reaching about 4000 m at the syncline bottom valley. The horizon K was also found in the profile PC-PD (Fig. 3b and Fig. 30).

The main fault distribution is summarised in Fig. 33.

8. Conclusions

8.1. The Tyrrhenian margin, south of the Gulf of Naples.

In this area, the Ischia volcano, with a radius of about 20 km at the sea-bottom, is the biggest volcano.

Further multichannel seismic data and specific magnetic surveys are necessary to detail the

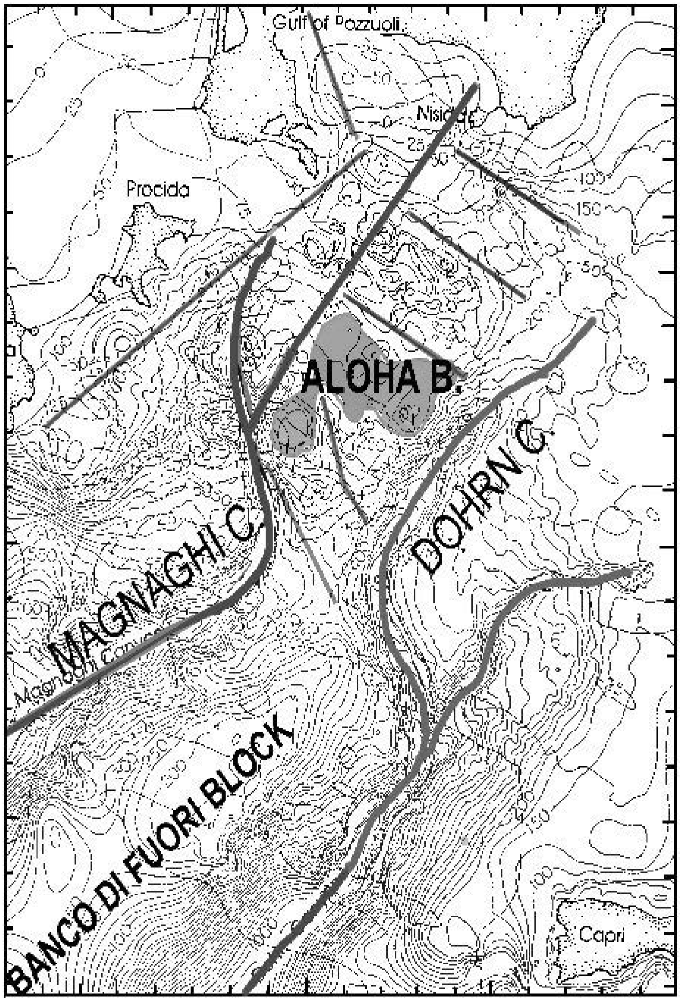

Fig. 33 - System of Faults and Fractures in the limestone basement. Isolines are related to magnetometry.

tectonic trends and the location of the basement faults, and to explain the origin and nature of the volcanic intrusions.

8.2. The north-western Tyrrhenian margin

The seismic profile along shore, in the southern part, suggests the presence of a lava layer at 1.5 s T.W.T. deeping abruptly to more than 3 s, WNW of the Procida Pozzuoli magnetic maximum (Fig. 10).

The sharpness of the transition to sediments and volcano-sediments depression (shot point 304, in Figs. 13 and 14) may suggest the presence of faults in the limestone basement. This, however, was not imaged in the seismic sections; neither beneath the lava layer nor under the softer materials filling the depression, which can be deeper than 4000 meters. At the northern end, the PM-PN profile (Fig. 12) again shows lava deposits between 2 and 3 s that can be associated to less recent Villa Literno-Parete volcanism, related to the tectonic activity of the 41st parallel strike-slip (Spadini and Wezel, 1995).

8.3. Western Naples Gulf and Phlegrean Fields.

The limestone basement, outcropping at the Island of Capri and Sorrento promontory, reveals a series of structural highs from tilted blocks at increased depths, from south to north. The first from the south is the Fuori bank that lies by Magnaghi and Dorhn canyons, drawn in Fig. 33. It was displaced to the east by a relative left lateral movement from the corresponding Aloha bank. The displacement is of approximately 4 km, along a NW-SE fault, linked to the Southern Tyrrhenian tectonic evolution, and nearly parallel to the WNW-ESE strike slip separating the southern from the northern Tyrrhenian domains at the 41st parallel latitude (Spadini and Wezel, 1995). The dramatic depression of the Phlegrean Fields area is confirmed by the seismic markers referred to the top of the Miocene unconformity and the top of the carbonate platforms, on the northwestern margin, north of Procida, and on the southeastern margin of the Gulf of Naples. The volcanic area corresponds to the higher tectonic deformation along the direction from Ischia to Procida and to the Phlegrean Fields.

The Phlegrean volcanism originates from the prolongation of the Magnaghi Canyon (Fig. 32). The two (Maniaghi and Dohrn) canyons bound the carbonatic blocks that are displaced to the left by a NW-SE directed sequence of fractures. The Aloha block bounds the eastern branch of the Magnaghi fault, near its fork. This fault zone continues inside the Gulf of Pozzuoli (Fig. 32) becoming a very important source of volcanic products. The fracture is 1.5 km wide and 6 km long and probably reaches ashore, the Pozzuoli's magnetic maximum, some kilometres northwards from the shoreline. In Fig. 32, the grey dashed corridor is obtained from the images of the Main Volcanic Conduit recognised on seismic lines and indicates the prosecution of the Magnaghi Canyon (Fig.21) inside the Gulf of Pozzuoli and on the Bagnoli plane.

There is no evidence of any eventual caldera and all the Phlegrean volcanism may be explained by the presence of crustal faults actually recognised and mapped utilising the seismic profiling.

8.4. Geothermal sources.

We have found several small flat spots that indicate the presence of accumulated fluids in the upper sequences of the volcanic filling up in the Pozzuoli Gulf. The most important fluid trap is indicated by FP in the line P1-P2 at 1.1 s (Fig. 31). It seems that the superficial reservoirs do not justify the intense and deeper presence of vapours and gases in the volcanic sediments. The reservoirs are not so extended as to justify industrial exploitation of the geothermal energy. We must admit, on the other hand, to the existence of a deeper intracarbonatic water circulation, more promising from the industrial point of view.

The erosional surface (ES) found in the seismic profiles indicate a differential uplift in distinct zones of the bay. Concerning the Pozzuoli's shoreline, the difference from the deeper position of ES and the onshore La Starza terrace (not mapped here) is of about 500 meters.

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