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ACTIVE DEFORMATION AND VOLCANISM OFFSHORE CAMPI FLEGREI: NEW DATA FROM SEISMIC REFLECTION PROFILES.

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1. Introduction

In south-western Italy, the Bay of Naples encompasses two volcanic regions which were highly active for the past 400 kyrs. The large stratovolcano Monte Somma-Vesuivius dominates the area to the east of the bay whereas the Campi Flegrei ('Burning Fields') shape the north-western part of Naples Bay.

Both volcanic provinces are characterised by numerous eruptions in the more recent geologic past. In the Northwest, two severe eruptions at 39 and 15 ka B.P. within Campi Flegrei lead to caldera collapses, the formation of Pozzuoli Bay and thick deposits of tuff and other volcanoclastic all over the northern part of Naples Bay. Within the last 15 kyrs, numerous small scale eruption centres scattered all over Campi Flegrei and within Pozzuoli Bay. Strong subsidence and a pronounced sea level rise since the Last Glacial Maximum lead to an intercalation of the volcanic deposits with marine sediments. Towards the East of Naples Bay, the substratum offshore Herculaneum is made of an alternating succession of pyroclastic density currents and marine sediments mainly originating from three to four large plinian (i.e. highly explosive) eruptions of Vesuvius within the last 18 kyrs. Large collapse calderas represent an exceptional explosive type of volcanism, not only dangerous to local population but with potential global impact. One of these structures can be found at the west coast of Italy near the city of Naples, within the 200 km^2 Campi Flegrei area. Campi Flegrei is centered around the Bay of Pozzuoli and not only covers a large area of the shelf, it also includes outskirts of Naples and is overall inhabited by more than 1.5 million people.

Volcanic activity at Campi Flegrei ranges from 300 ka B.P. to 1538 A.D. with most severe eruptions from 60 ka B.P. onward (Rosi & Sbrana, 1987; Pappalardo et al., 1999). Today, the onshore part of Campi Flegrei is structurally dominated by a quasi circular caldera-like shape some 12 km in diameter, which includes about 30 small volcanic edifices such as tuff cones, cinder cones, maars and domes (Rosi & Sbrana, 1987; Scarpati et al., 1993; Orsi et al., 1996; Di Vito et al., 1999; Deino et al., 1994, 2004; Piochi et al., 2004). These mostly effusively erupted magma volumes of less than 0.1 km³ dense rock equivalent (DRE) in monogenetic manner (Di Vito et al., 1987; Rosi & Sbrana, 1987; Di Vito et al., 1999; Mastrolorenzo, 1994; Lirer et al., 2001; Orsi et al., 2009). However, three severe explosive eruptions shaped the Campi Flegrei Volcanic District: the Monte Epomeo Green Tuff of Ischia Island at 55 ka B.P. and 45 km³ DRE (Vezzoli, 1988), the Campanian Ignimbrite at 39 ka B.P. and 150 km³ DRE (Civetta et al., 1997; De Vivo et al., 2001; Orsi et al., 1996; Rosi et al., 1996; Rosi and Sbrana, 1987; Fisher et al., 1993), the Neapolitan Yellow Tuff at 15 ka B.P. and 40 km³ DRE (De Vivo et al., 2001; Deino et al., 2004). The last two events are believed to have caused large caldera collapses, vast pyroclastic deposits over the Campanian Plain and in the offshore area of the Bay of Naples. The Yellow Tuff products nowadays still dominates the landscape around Pozzuoli Bay.

Seismic reflection represents one of the geophysical techniques that better allow the reconstruction of the subsurface geologic structures. Such technique in the last few years, has achieved a remarkable improvement, in the wake of oil search, both for the technological development of the equipment in the acquisition phase, and for the progress of computers that have allowed the application of more complicated techniques.

In this thesis, from these considerations, I will discuss of four main subjects:

1) Interpretation of seismic reflection profiles offshore Campi Flegrei (CF) area permitted the identification of several geologic features in the inner shelf offshore Campi Flegrei and Bay of Naples. The seismic dataset used for my work was collected by OGS (Osservatorio Geofisico Sperimentale – Trieste) during 1973 and recently reprocessed by Bruno et al., 2002 and 2003. The overall quality of seismic data is high, although the data suffer of technological limits of 35 years ago. A reprocessing of the data (Bruno et al., 2000, 2002, 2003) reduced most

of the limiting effects of the acquisition phase. The more recent seismic data collected in this area are, in most cases, high resolution – single channel sparker and uniboom profiles, which allow the shallow Quaternary cover to be studied in detail (Fusi et al., 1991; Milia, 1996, 1998, 2000; Milia et al., 1998; Aiello, 2005), but do not penetrate deep; therefore, very little can be said about the deeper morphostructural features of the area, especially in CF area. For that reason, full fault geometry and kinematics, and in some cases the tectonic involvement of the deep geological units are hypothetical. For all these reasons the sea environment geology in the Ischia area and in the Gulf of Naples is less known than the onshore areas. Reprocessing (Bruno et al., 2000) permitted to gain more information on the deep part of Bay of Naples and CF, and to obtain new information at low cost.

The interpretation of seismic profiles allowed the identification of four seismo-stratigraphic units. However, I was interested mainly to structural analysis, also because a detailed seismic stratigraphy is beyond the resolution of the data.

The main goal was, in fact, to build the stratigraphic framework through the identification of depositional units and to delineate a broad geo-volcanological and structural framework of the CF with the aim of exploring the connection between volcanism and tectonics. Individual units were delineated on the basis of contact relation and internal layering characteristics as revealed by seismic reflectivity. Seismic facies analysis permits, in fact, to delineate the environmental setting of the studied area. The identification on seismic section of important faults allows to perform a structural analysis of the investigated area. The fault pattern was obtained by spatial interpolation of fault traces along single profiles. The study stresses also on the recognition of the fault systems responsible for the formation of Ischia Island and the Bay of Naples and finding their relationship with the sedimentary and volcanic units of the area.

2) Reprocessing and interpretation of seismic lines Na-306-78 and Na-307-78 (ENI-AGIP) localized at the passage from northern zone of the

Campi Flegrei to the southern sector of Volturno Plain. A reprocessing of this seismic lines permitted to increment signal/noise ratio and to improve vertical and horizontal resolution. The aim was to improve the data quality from the elaboration of 1978. In parallel with the processing of the seismic data, Licola1 well log has been digitalized and processed. Sonic log (Bhc), radioactive log (Gamma-ray) and electrical log (Dual laterolog) were elaborated. Objectives of this study has been to gain geologic ties on which founding the interpretation of the seismic lines.

3) Interpretation of first arrivals by means of seismic tomography of all Eni-Agip seismic lines belonging to the Naples permit. Seismic reflection data processing benefit of tomographic inversion of first arrivals to improve the performance of the static corrections and the imaging of the shallow structure (0-300 m deep). The shallow seismic imaging is very poor due to the superficial geology (volcanic sequences), strong lateral Vp changes, acquisition gaps and to an overall low CMP folding. Consequently, the shallow-intermediate structures are poorly imaged. Seismic tomography is used to extend the seismic imaging not sampled by the deep multichannel seismics.

This deep seismic dataset available permitted the reconstruction of the structure and the morphology of the submerged carbonate basement and to describe the characteristics of the fault systems responsible for the formation of Ischia and Bay of Naples. The seismic interpretation moreover led important considerations about the mechanics of resurgence of Ischia Island, outlines the structural setting of the bay and the tectonic relationships between Campi Flegrei and the island of Ischia. The greater tectonic complexity of Campi Flegrei area with respect Vesuvius district is also shown. A general view of the seismic line permitted also the reconstruction of the Quaternary tectono-stratigraphic evolution of this sector of the Eastern peri-Tyrrhenian margin.

Despite this study done at this sector of CF, there is a considerable lag of knowledge about the stratigraphic-structural setting of the Pozzuoli Bay area. For example caldera-diagnostic evidence like buried volcanic features (e.g. rim structure) and the reconstruction of the volcano/sedimentary evolution are not well defined or questionable.

4) In this thesis, I will discuss the processing and interpretation of high resolution multi-channel seismic profiles acquired during the oceanographic cruise CAFE_07 – Leg 3, conducted in Naples and Pozzuoli Bay in January 2008 by IAMC-CNR in collaboration with Bremen University. Within the scope of this thesis, the processing and the interpretation of these reflection seismic profiles allow to reconstruct the young depositional history in Campi Flegrei offshore area (Pozzuoli Bay). The re-processed old multichannel seismics (OGS, 1973), in fact, permit the reconstruction of fault geometry and kinetic and to gain new hints about the tectonic involvement of the deep units, but nevertheless these outcomes did not at all yield high-resolution images on meter-scale.

In contrast, seismic dataset acquired in the recent past (Fusi et al., 1991; Milia, 1998; Milia et al., 1998, 2000) are sparker and boomer surveys which are highly limited in their vertical and horizontal resolution and severely suffer from analogue recording and very shallow penetration depth (absolute best would be 0.3 s TWT).

CAFE seismic lines close the gap between very shallow and the available deep seismic data.

The area of interest for this thesis is the north-western part of Naples Bay, particularly the Gulf of Pozzuoli. The multichannel reflection seismics shots during January 2008 in this region’s shallow waters (max. depth ~150 m) allow for high vertical and lateral resolution of volcanic features and the sedimentary interplay with an acceptable penetration depth. The digital recording of the survey allows for all modern processing steps to make use of the full potential of such unconventional data set. The already established stratigraphy for the last 15 kyrs from the submerged part of Campi Flegrei could be validated in the new seismic data, primarily by means of seismic reflector terminations. Moreover, the high vertical and lateral resolution in the range of one meter contributed to improve the resolution of the published acoustic data in terms of a more detailed classification of single seismic units.

Nevertheless, the newly acquired seismic data allowed for a clear definition of the seismic facies parameters. On this basis, deposits of pyroclastic density currents could be well defined and thus distinguished from marine units.

CHAPTER 1

1.1 Regional and local geological setting

The Campi Flegrei Volcanic District (CFVD) is situated on the western continental margin of the Campanian Plain in a Pliocene-Quaternary extensional basin (fig. 2). The area is dominated by NE-SW and NW-SE trending normal faults and the Apennine thrust belt to the east (Oldow et al., 1993; Ferranti et al., 1996; Milia & Torrente, 1999).
For the past 30 to 35 Myrs, the Mediterranean tectonics were controlled by retreating subduction within the Africa–European convergence zone (Malinverno and Ryan, 1986; Royden, 1993; Wortel and Spakman, 2000; Faccenna et al., 2001; Jolivet et al., 2008). Because of this slab roll-back and accompanying back-arc extension, the Tyrrhenian Sea started opening by rifting between the Corsica–Sardinia block and the Italian peninsula during early Oligocene (Oldow et al., 1993) (fig. 1).

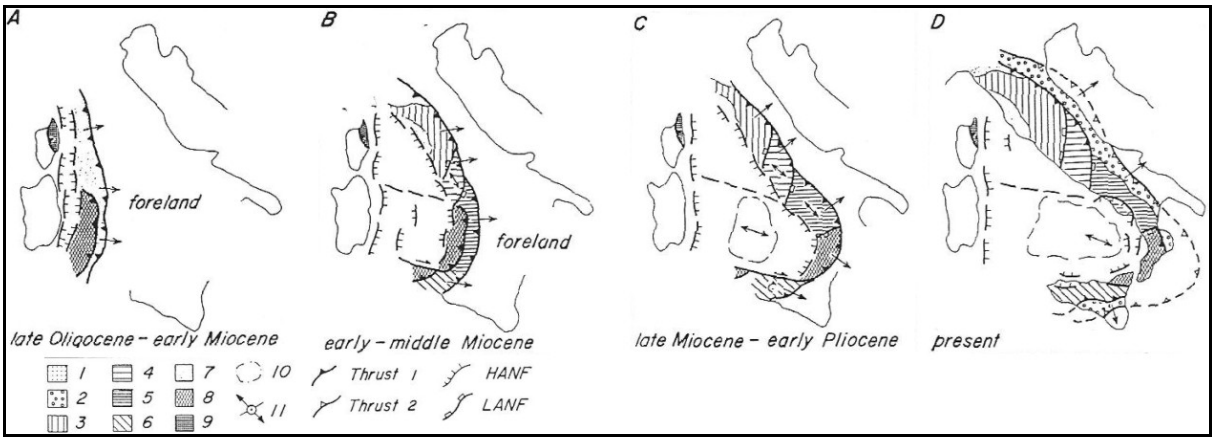


Fig. 1: Evolution of the peri-Tyrrhenian Sea and orogenic belt. 1: undeformed foreland deposits; 2: deformed foredeep deposits; Allochtones of: 3: N-Appenines, 4: Abruzzi, 5: Campania-Lucania & S-Apennines, 6: W-Sicily; 7: undifferentiated basal units; 8: Calabrian arc & associated rocks in N-Africa; 9: Alpine Thrust Belt; 10: oceanic crust of late Miocene-Pliocene/ Pliocene-Pleistocene age; HANF: high angle normal faults; LANF: low angle normal faults. (Oldow et al., 1993)

Generally large scale block rotations occurred in the Miocene and Pliocene, transport direction was towards the East and changed to NE for the Apennines segment during Pliocene (Oldow et al. 1993). The southern Tyrrhenian Sea is underlain by oceanic crust formed during the rifting with its formation centre shifting from the basins' central part (late Miocene - early Pliocene) to south-eastern part (Pliocene - Pleistocene) (Oldow et al., 1993), fig. 1. As a consequence, the Tyrrhenian margin was affected by tensile tectonics, characterized by N–S and NNW–SSE normal faults, and then by NW–SE and NE–SW normal faults and W–E strike-slip faults (Doglioni, 1991) (fig. 2). Moreover, a large horst and graben structure split into several smaller asymmetric horst-graben structures and hosting the Campanian Plain (which incorporates CF) (Milia, 1999a; Milia&Torrente, 1999). The graben basement is made of Mesozoic carbonates which crop out at the Sorrento peninsula, the southern limiting horst of Naples Bay (Finetti-Morelli, 1974, Milia, 1999). The half-grabens are tilted to the NW and filled with Late Pliocene to Quaternary siliciclastic sediments (up to 3 - 5 km) and volcanoclastic material (Orsi et al., 1996 and references therein).

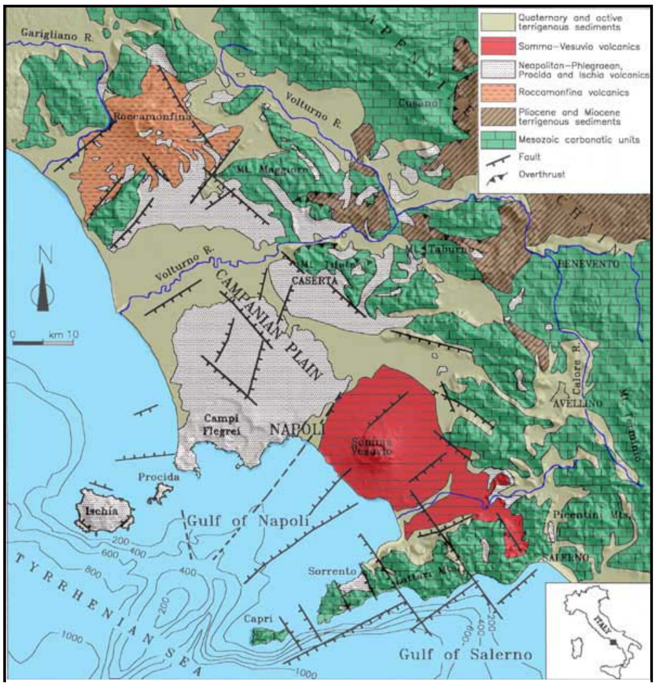


Fig. 2: The Neapolitan volcanic district is located on the Tyrrhenian margin of the Campanian Plain. This plain is a NW-SE Plio-Quaternary basin filled up by more than 3000 m of Quaternary clastics and volcanic rocks overlying a Mesozoic carbonate substratum. During the Late Quaternary, because of intense volcanic activity, thick volcanic units were interlayered within marine sediments in the Campi Flegrei region (modified after Orsi et al., 2003).

Beside the main NE-SW and NW-SE normal faults, minor E-W trending ones also occur in Naples Bay (Milia & Torrente, 1999). These faults generally had a large control on accommodation space, thus on depositional environment, especially in Naples Bay (Milia, 1999). Strong continuous subsidence and sudden uplift events occurred (still ongoing to this day) in Pozzuoli Bay and regulate the accommodation space; this happens in conjunction with sea level changes during Holocene times (Milia et al., 2000; A. D'Argenio et al., 2004). Fault arrangement is more complex than in southern Naples Bay and numerous small fractures characterize the offshore part of Campi Flegrei (Milia et al., 2000; Bruno et al., 2003).

Because the Adriatic plate is subducted under the eastern coast of Italy (compressing the Apennine chain) (Doglioni, 1991), persistent volcanism occurred in northern Campania from 1.5 Ma B.P. onward (Giannetti et al., 1979; Giannetti, 2001; Metrich et al., 1988) and at about 0.36 Ma in the Somma Vesuvius Volcano area (Brocchini et al., 2001; De Vivo et al., 2001). In the Campi Flegrei has at least been active since at least 60 ka (Rosi & Sbrana, 1987; Pappalardo et al., 1999).

About the volcanic formation and evolution of the Campi Flegrei, the majority of researches (Rosi & Sbrana, 1987; Orsi et al., 1992 & 1996; De Vivo et al., 2001, Deino et al., 2004) define the CF area to be dominated by two large subaerial explosive eruptions, which took place at ~ 39 ka B.P. and ~ 15 ka B.P. and generated large caldera structures of several kilometres in diameter. These two structures are nested into each other, the younger and smaller inside the older and

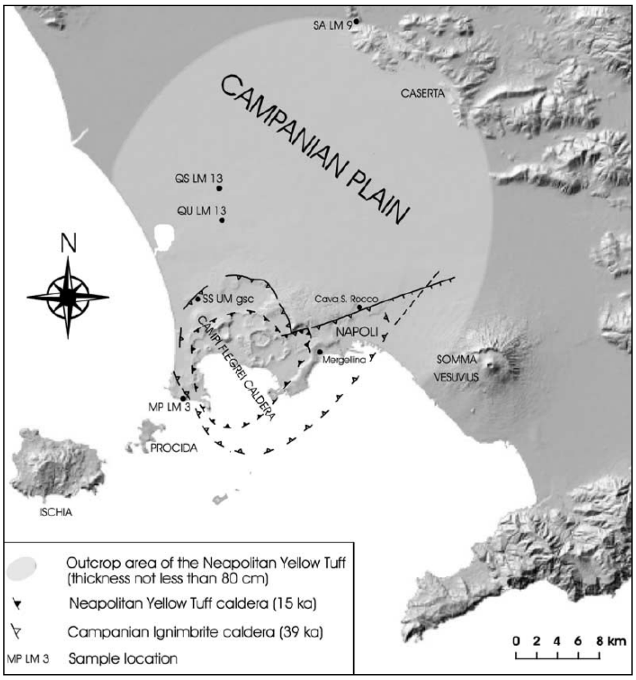


Fig. 3: Grey shading: NYT surface-spread represented by the 80 cm isopach. Note: Offshore CI and NYT caldera boundaries are just assumed by Deino et al. and yet have no fully proven evidence. (Deino et al., 2004)

larger caldera, both being typical examples of collapse caldera structures (fig. 3).

The older volcanic eruption at around 39 ka B.P. produced a grey tuff – the Campanian Ignimbrite (CI) of 150 km³ DRE (dense rock equivalent; Orsi et al., 1996, Rosi et al., 1996) – erupting from the Campi Flegrei and covering almost the whole Campanian region with vast flow deposits. The younger eruption, the Neapolitan Yellow Tuff (NYT) one, occurred about 15 ka B.P. (extruded about 40 km³ DRE), is characterised by dispersion of product over 1.000 km² in the Campanian Plain (Orsi et al., 1992, 1996; Scarpati et al., 1993; Wohlez et al., 1995) (fig. 3). The assumed NYT-associated collapse caldera spans over 90 km² (fig. 4) with a central dropdown of 600 m (Orsi et al., 1999; Deino et al., 2004). After Deino et al., 1992, the NYT is the largest known trachytic phreatoplinian eruption. Generally, large caldera structures experience episodes of so called 'unrest' which are characterized by vertical ground movements and an increase in shallow seismicity (Newhall et al., 1988). At the Campi Flegrei volcanic caldera, this phenomenon was not followed by immediate eruptions (de Natale et al., 2006, Troise et al., 2007), which it is common at stratovolcanoes. Possible explanations from various models reveal a striking likeliness of a coupled mechanical and thermodynamic effect of heatflow from a relatively shallow magma chamber (between 4 to 12 km below the

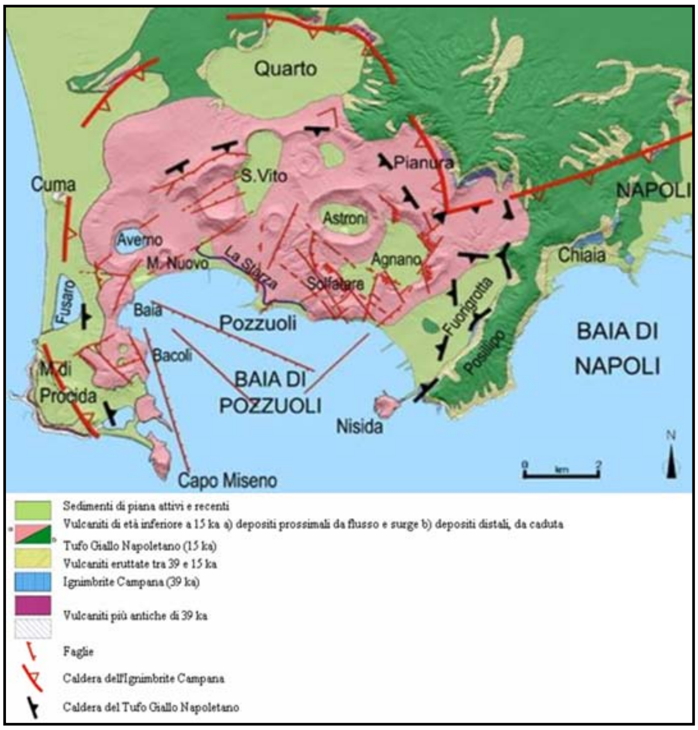


Fig. 4: Geological sketch map of CF area and main outcrops: -recent terr. sediments <15kyrs -Neapolitanian Yellow Tuff NYT, ca. 15 kyrs; -Campanian Ignimbrite, ca. 39 kyrs; - Volcanics >39 kyrs (from Orsi et al., 1996, Deino et al., 2004).

seafloor) and the uppermost aquifers. This interaction could strongly modify and amplify ground deformations at calderas (De Natale et al., 1991 & 2001; Troise et al., 2001, Battaglia et al., 2006; Bellucci et al., 2006) Gottsmann et al., 2006). Ground level changes could be reconstructed for the last 2.000 years since Romans settled in Campi Flegrei (Bellucci et al., 2006; Troise et al., 2007). Over this period, three sharp uplift events in the range of +15 m in a few years time occurred on top during a long term of continuous subsidence: (1) 80 - 230 A.D., (2) 1441 - 1538 A.D., (3) 1969 - ongoing. From 1969-'81 the net uplift was +3.5 m at the town of Pozzuoli, during 1982-'84 uplift exceeded +1 m/yr (De Natale et al., 1991).

The last event since 3.8 ka was the Monte Nuovo eruption in 1538 A.D. west of the town of Pozzuoli after 100 yrs of uplift (Bellucci et al., 2006). The interplay of long-term (eustatic sea level changes, continuous subsidence) and relatively short term (volcano-tectonic uplift) phenomena strongly influenced the evolution of Pozzuoli and Naples Bay in post-LGM (Last Glacial Maximum) times (A. D'Argenio et al., 2004; Milia & Torrente, 2007).

In the Bay of Naples a morphologic structure formed by a continental shelf, a continental slope and a basin can be singled out (Milia, 1999; Aiello et al., 2001) (fig. 5). The continental shelf has a width of about 20 km in the central area, decreasing towards SE, to 2.5 km near the island of Capri. In the Campi Flegrei offshore, the shelf is irregular, because of the presence of several banks whose morphologic characteristics suggests that they are volcanic edifices (Orsi et al., 1996). In particular, the CF sea floor is characterized by the presence of monogenic volcanoes, small calderas, tuff cones and lava extrusion (Milia, 1999). Most of them correspond to mound-shaped highs in the bathymetry. A structural high, formed by a horst of the carbonate basement (Banco di Fuori) is extended in a NE–SW direction in the central area of the bay, between Capri and Ischia Islands, with a minimum depth of 130 m (Fusi et al. 1991; Aiello et al. 2001). The maximum depth of the bay is about 1300 m, to the west of the island of Capri. The Naples Bay is dominated

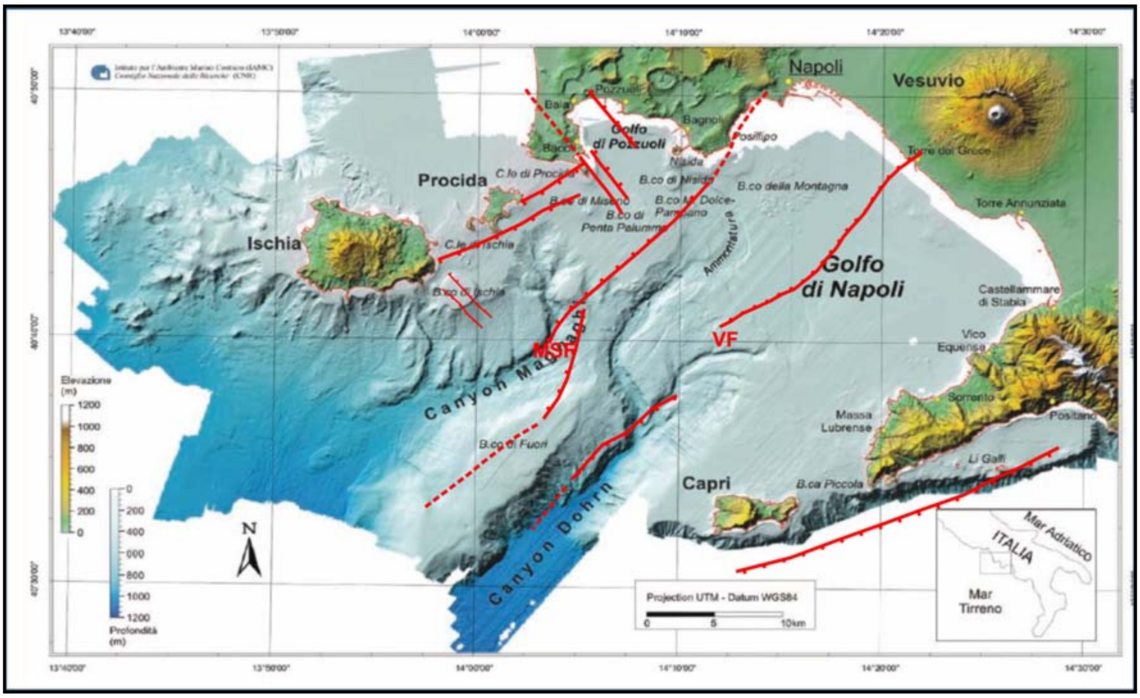


Fig. 5: Digital terrain model of the Naples Bay and adjacent areas (from D'Argenio et al., 2004). The map reported the main tectonic lineaments (taken from Bruno et al., 2003). VF: Vesuvius Fault; MSF: Magnaghi-Sebeto Fault.

by two submarine canyons: the Magnaghi and the Dohrn Canyons, both having a preferential NE–SW trend. The Magnaghi Canyon, about 15 km long and having a trilobate head, mainly drained the volcanoclastic input supplied by Ischia and Procida Islands during their eruptive activity. In contrast, Dohrn Canyon is about 25 km long and formed by two branches which merge into a main branch NW of Capri Island, draining the siliciclastic supply from the Sarno–Sebeto River plain (Dohrn south-eastern branch) and as well as volcanic material from the Campi Flegrei through the ''Ammontatura'' Channel (Dohrn north-western branch) (Secomandi et al., 2004).

Seismic reflection data from the Bay of Naples (Finetti and Morelli, 1974), recently reprocessed by Bruno et al. (2000, 2003) show faults cutting Pleistocene sediments with a prevailing NE–SW strike, except in the Neapolitan Yellow Tuff caldera, where NW–SE faults also occur (Fig. 5). In particular, a NE–SW normal fault, that seems to continue onshore (Bruno et al., 1998), was recognized in the Vesuvian area. This fault is the well-known Vesuvian Fault (fig. 5) (Finetti and Morelli, 1974; Bruno et al., 1998, 2003) and could be considered one of the preferential pathways for Vesuvian magma. Many NE-SW faults and fractures are located between Ischia and Procida Islands, some of them correlating with some well-known volcanic banks (Bruno et al., 2003). A structural pattern composed of several NE–SW trending normal faults, imaged by seismic profiles and named the ‘‘Magnaghi–Sebeto’’ line (fig. 5) (Bruno et al., 2003) divides the Bay of Naples into two areas: a western area, characterized by several volcanic banks and reliefs and an eastern one, characterized by a NE-dipping monoclinal structure made of sedimentary rocks.

The two large caldera-forming eruptions were extensively studied at outcrops and deep bore holes (e.g. AGIP, 1987; Rosi & Sbrana, 1987; Scarpati et al., 1993; Orsi et al., 1996; Di Vito et al., 1999; Deino et al., 2004). Remnants of CI volcanic edifices/deposits can only be found at the very periphery of the Campi Flegrei area since they have been partially eroded and buried under younger deposits (Orsi et al., 1996). The NYT deposits are much better preserved and, for instance, Orsi et al., 1992, defined two main members corresponding to the main eruption phases and separated by a sharp unconformity. The NYT caldera collapse occurrence is marked by this unconformity. It was possible to make seismo-stratigraphic reconstructions of several units in the NYT deposits and younger (D’Argenio et al., 2004; Milia & Torrente, 2007), but not for the CI since acoustic penetration depth was insufficient.

The time span since ~ 15 ka until today is characterised by a three some millennium-long epochs of mostly subaerial volcanic activity restricted to the rim of the inner collapse area and interrupted by times of relative quiescence (Di Vito et al., 1999; Deino et al., 2004). Epoch I: 15 - 9 kyrs, explosive eruptions; Epoch II: 8.6 - 8.2 kyrs, explosive eruptions; Epoch III: 4.8 - 3.8 kyrs, explosive & rare effusive eruptions. The epochs' typical activity locations within CF are detailed given within Di Vito et al., 1999, as well. The last event was the Monte Nuovo eruption in 1538 A.D. west of the town of Pozzuoli after 100 yrs of uplift (Rosi & Sbrana, 1987; Bellucci et al., 2006).

The interplay of long-term (eustatic sea level changes, continuous subsidence) and relatively short term (volcano-tectonic uplift) phenomena strongly influenced the evolution of Pozzuoli and Naples Bay in post-LGM times. Reconstruction of pre-LGM (Last Glacial Maximum) times is less defined because seismic resolution reached its limits at shallow depths due to strongly attenuating CI deposits (A. D'Argenio et al., 2004; Milia & Torrente, 2007). The Wurmian low sea level stand from ca. 18 to 14 ka B.P. of approx. minus 130 to 110 m (reference 0 m = today) generated level surfaces in the submerged part of the CF caldera and intense erosion along its subaerial morphologic rim (Orsi et al., 1996). During the Holocene, sea level rose rapidly by 9.5 mm/yr from 10 to 5.5 ka B.P. and approx. 1 mm/yr from 5.5 ka B.P. until today (after Fairbanks, 1989; Bard et al., 1990, in Milia & Giordano, 2002). For instance, D'Argenio et al., 2004, made a detailed seismo-stratigraphic and core data analysis of Naples Bay (similar did Milia et al. in numerous papers, 1998, 1999, 2000) and showed good correlation between the offshore intercalation of marine and reworked volcanic units and onshore volcanic deposits. Sediment supply acted as the leading force in the organization of stacking patterns of the seismo-stratigraphic units recognized in this area. Considerably but less detailed reconstruction was done in Pozzuoli Bay as very little sufficient acoustic data was or is available (e.g. Milia & Torrente, 2000). Mean sedimentation rates for the last 6 ka were 36 - 45 cm/ka in the central basin and 21 cm/ka at the outer shelf of Pozzuoli Bay (Buccheri & Di Stefano, 1984; in A. D'Argenio et al., 2004).

Zollo & Judenherc, 2003, found a buried feature resembling a quasi circular and single rim-like structure of 8 to 12 km in diameter at 0.8 to 2 km depth and with a height of 1 to 2 km just south of Pozzuoli Bay by active seismic tomography, fig. 6. The apparent rim is characterised by high p-wave velocity and high density rocks. Lithologic data from an experimental geothermal well drilled onshore by *AGIP* in 1986 (Mofete well, AGIP, 1987) pointed to consolidated lava and/or tuffs with high p-velocities of 3.5 - 4.5 km/s at the rim's depth. A positive gravity anomaly of similar shape supports these findings (Capuano & Achauer, 2003). In a recent publication, Dello Iacono et al., 2008, further defined the vertical v_p anomaly to be clearly arc-shaped and stretching from Capo Miseno to Nisida. They also correlated the arcuate high-velocity-zone to fumaroles, dikes and a NYT-formed mound reported in Milia et al. in 1998 and 2003. In the larger context of the discussion on the Campi Flegrei evolutionary mechanisms, it has to be taken into consideration that these findings are the yet only, but strong, geophysical evidence for a single submerged caldera rim.

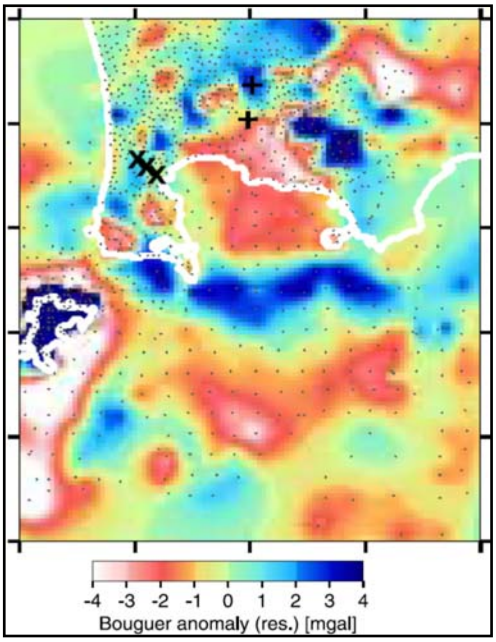


Fig. 6: Positive gravity anomaly south of Pozzuoli Bay with position of CAFE seismic lines (from Zollo & Judenherc, 2003).

Berrino et a., 2008 show 7 interpretative profiles of a Bouguer anomaly map in the Gulf of Naples and Neapoletan area which cross the circular gravity minimum centred on the Campi Flegrei. They show again that the gravity minimum can be due to a sub-circular depression and also support the hypothesis that it results from the superposition of two different and nested collapses.

1.2 Ischia Island

The island of Ischia is located on the westernmost portion of the CFVD (Orsi et al., 1996); the island is the emerged top of a large volcanic complex located along the NE–SW regional strain field (fig. 7).

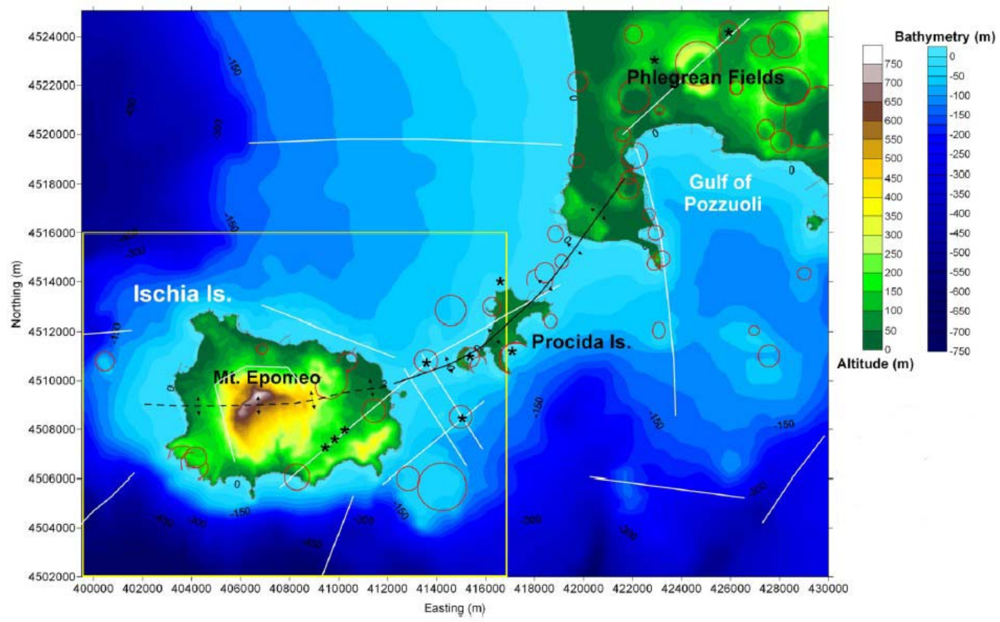


Fig. 7: Topographic and bathymetric map of the Campi Flegrei-Ischia ridge. White lines are faults, black lines are ridges, red circles are crater rims, asterisks are latitebasaltic and latite volcanoes. (taken from Paoletti et al., 2009)

Bruno et al. (2002) hypothesize that Ischia represents only the remnant of a once larger volcanic complex and points out the importance of regional tectonics on the patterns of magma uprising. Acocella and Funiciello (1999) interpret the NE–SW lineaments as transfer faults with sub-vertical fault planes which could be easily intruded by magma. The Ischia offshore area is characterized by several monogenetic edifices, with latitebasaltic-latitic composition (Di Girolamo and Rolandi, 1975), aligned along the NE–SW system of faults that connects the South-Eastern sector of Ischia to the Island of Procida and to Campi Flegrei (Di Girolamo and Stanzione, 1973; de Alteris and Toscano, 2003). Part of the island was invaded by marine waters prior and after the emplacement of the Green Tuff (GT), a major ignimbritic eruption dated at 55 ka (Gillot et al., 1982) that produced caldera collapse (Orsi et al., 1991; Tibaldi and Vezzoli, 1998).

After the GT eruption, the volcano-tectonic activity appeared to be mainly driven in the past 33 ka by the quasi-rigid uplift of Mt. Epomeo, interpreted as a resurgent block inside the caldera depression (Orsi et al., 1991). The island is characterized by a resurgent dome uplifted by at least 800 m (Gillot et al., 1982), displaying one of the largest resurgence cases ever reported. Two main models have been proposed to define the structure of the resurgent dome: 1) the volcanotectonic horst model, where the resurgent block is bordered by outward-dipping faults (Rittmann, 1944; Capaldi et al., 1976; Rittmann and Gottini, 1980; Vezzoli, 1988; Fusi et al., 1990; Luongo et al.,1995); 2) the simple-shear model, where the resurgent block, tilted around a N–S-trending horizontal axis, is bordered by high-angle inward-dipping faults (Orsi et al., 1991).

Fusi et al. (1990) and Tibaldi & Vezzoli (1998) proposed that the resurgent process of Ischia was produced by volumetric variations in the subsurface magma body. Orsi et al. (1991) suggest that the source mechanism is an increase in magmatic pressure in the upper part of a shallow magma chamber. Luongo et al. (1995) and Cubellis & Luongo (1998) used a punched laccolith mechanism to model the uplift of Mount Epomeo. Acocella et al. (1997, 1999) and Molin et al. (2003), according to similar experimental models, proposed that the resurgent doming of Mt. Epomeo is due to a trapdoor uplift mechanism, with a hinge in the south-eastern part of the island. More recently, Carlino et al. (2006) proposed that the uplift, the volcanic and seismic activity and the ground deformation of the past 2000 years are connected to the existence of a laccolith with a hypothesized diameter of 10 km and a depth of up to 1 km in the centre of the island.

As regards this resurgent mechanism, the present seismic interpretation has allowed to propose a structural model of Ischia and its resurgent dome.

The present activity of Ischia is characterized by low-intensity and shallow seismicity, bradyseismic events and by hydrothermal activity (Maino and Tribalto, 1971; Rittman and Gottini, 1980; Buchner, 1986; Cubellis, 1985; Alessio et al., 1996).

CHAPTER 2

Seismic Stratigraphy Scheme

2.1 Methodology

During the seismic interpretation, the first step in building the stratigraphic framework is the identification of depositional units. Individual units were delineated on the basis of contact relations and internal layering characteristics as revealed by seismic reflectivity. The definition of packages into seismic sequences is obtained by means of reflector terminations and unit-internal feature classification. Seismic facies analysis allows to outline the environmental setting and to describe the lithofacies from seismic data. Seismic facies units are groups of seismic reflections whose parameters (configuration, amplitude, continuity, and frequency) differ from those of adjacent groups (Mitchum et al., 1977). Classical interpretative schemes (Emery and Myers 1996, Badley, 1985) were used to reconstruct faults kinematics; the shallow geological structures have been investigated taking into account the techniques of seismic stratigraphy, whose basic concepts are reported by Vail et al. (1991).

2.2 Seismo-stratigraphic features

CF region shows an extremely variable seismic response. Volcanic areas are often strongly heterogeneous. They present large vertical velocity variations due to their physical characteristics and to their peculiar sedimentation mechanism and to sin-depositional and post-depositional chemical processes. In volcanic areas, stratigraphy is frequently complex because morphology, facies and elastic properties vary due to deposition and transport processes and paleotopography (Cas and Wright, 1987). Unlike for the well-known regularly widespread ‘‘pyroclastic fall’’ deposits, the above statement is particularly true for ‘‘pyroclastic density current deposits’’. These deposits are extremely variable sedimentological characteristics, and in both welding and zeolitization degree and therefore show extremely variable diagenetic facies. Welding variations primarily reflect variation of the emplacement temperature, whereas lithification due to zeolitization reflects post-depositional chemical alteration processes (Cole and Scarpati, 1993). A lateral transition between extreme facies occurs over distance as small as a few tens of metres (Bais et al., 2003). This complexity, reflected in the seismic sections, lead to an intrinsic difficulty in the interpretation of seismic data.

Seismic data acquired in the Campi Flegrei area (fig. 8) (Campi Flegeri-Ischia volcanic system) are characterized by low Signal/Noise ratio. The main reason of the signal decay is due to the massive presence of volcanic rocks and structures that produce a strong scattering of the seismic energy. While the western sector of CF is characterized by abundance of volcanic units, the eastern sector of CF is characterized by a NW-dipping monoclinal structure made of sedimentary rocks (high Signal/Noise ratio).

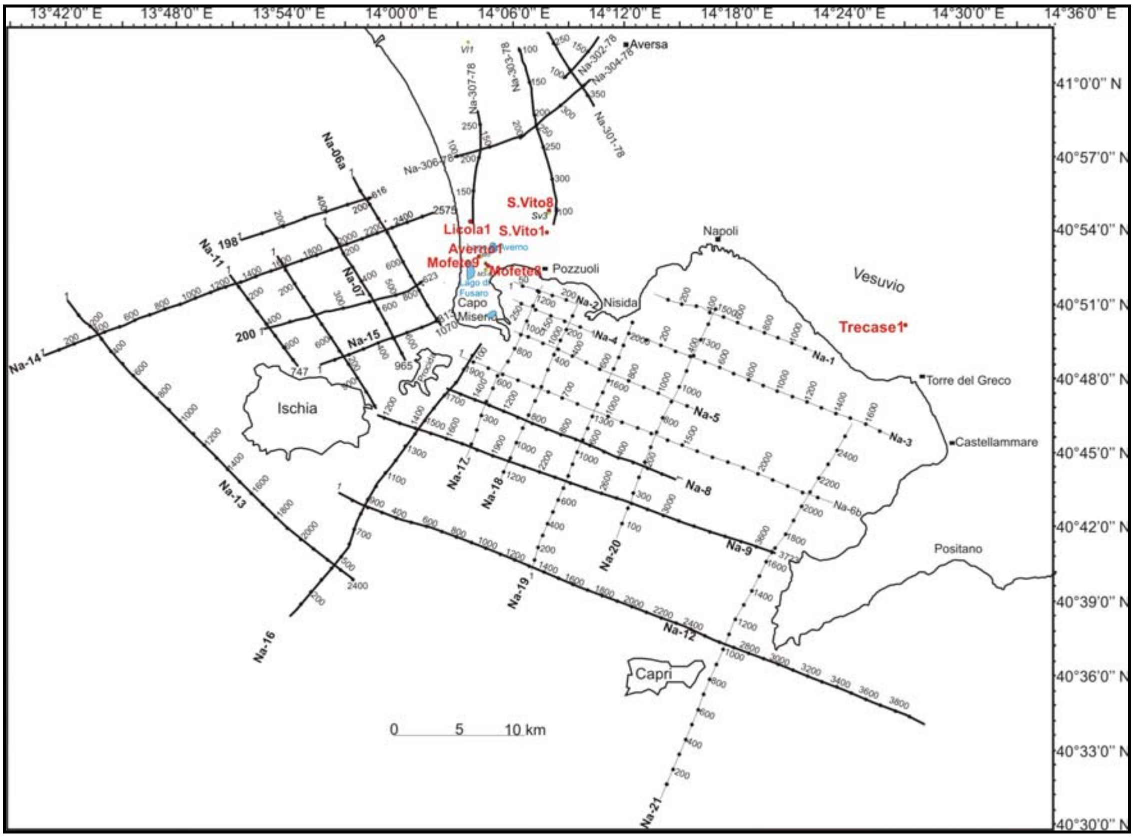


Fig. 8: Seismic data acquired in the Campi Flegrei area

2.2.1 Log data analysis

The geothermal wells "Trecase1", drilled in the Somma-Vesuvius area, and "Licola1", located in the southern zone of the shoreline Domitio (fig. 9) are used in order to carry out an indirect calibration of the age of the seismic sequences and in order to obtain geologic ties for constraining the interpretation of the seismic lines. Comparison between seismic sections and well log data, in fact, allows the association of lithotypes to variations in physical property of rocks and to relate each seismic sequences to a geologic unit.

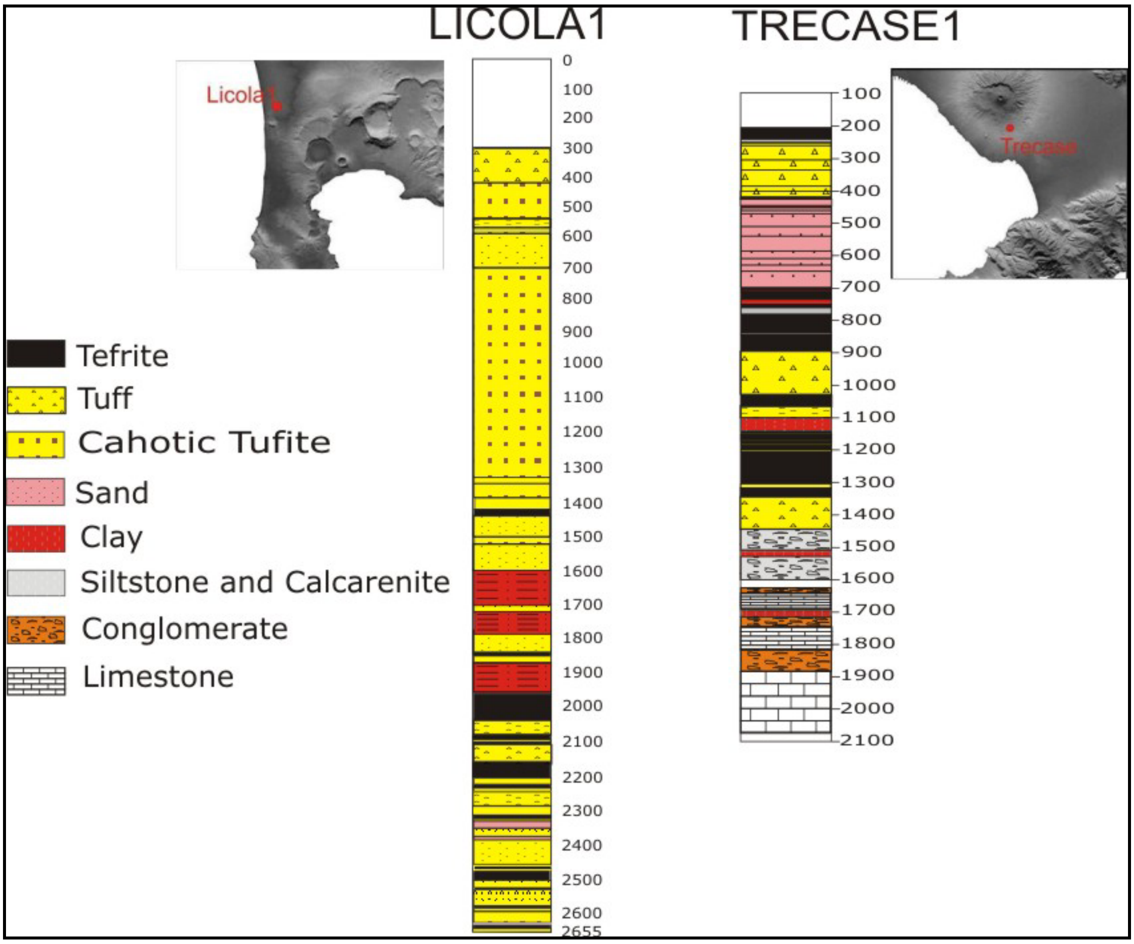


Fig. 9: Stratigraphic columns of geothermal wells "Licola1" e "Trecase1"

The geothermal well "Trecase1" (fig. 9), located on land in the Somma-Vesuvius area (Balducci et al., 1985), is drilled for a total depth of 2068 m. Mesozoic-Cenozoic carbonate rocks were drilled at depths between 1670 and 1852 m b.s.l.. These carbonate rocks are overlain by conglomerates deposited in a subaerial environment (Milia et al., 2003) during a period of emersion of the area that is also witnessed by the absence of Pliocene marine sediments on- and off-shore (Brancaccio et al., 1991; Milia, 1999b). The subaerial conglomerates are overlain by 0.98–1.24 Ma-old marine siltstones and calcarenites (Milia et al., 2003). The Lower Pleistocene siltstones and calcarenites are overlain by deep marine clays deposited when Naples Bay reached the maximum water depth. The deep marine clays are overlain by 400 ka-old lavas followed by a succession of marine to subaerial sandstones and siltstones with interbedded lavas and tuffites and stratified sands. The latter unit was deposited between 400 and 100 ka in Naples Bay (Milia, 1999a), during tectonic stability and fills the central part of the basin. The latest products (0-252 m), late Quaternary in age, are made up mainly of pyroclastic deposits of the Campanian Ignimbrite (39 ka-old; De Vivo et al., 2001).

"Licola 1" well, located outside CF caldera, is deep 2653 m. Log recording starts at 235 m depth: the stratigraphy is characterized for the first 1500 m by tuffs of different nature erupted from Campi Flegri Volcanic District and Somma-Vesuvius; the interval comprised between 1550 m and 2000 m is characterized by a level of silt and clay. Below 1900 m and down to the bottom of the well, the contemporary presence of levels of lava, tuffs and sandstone may indicate the early stage of CF volcanism, with prevailing submarine activity (Bruno, 2004).

2.2.2 Seismic data analysis

The lack of deep geothermal wells in the CF offshore area makes the reconstruction of the age of basin formation and the chronological calibration of seismic sequences filling more complex. The interpretation of the seismic profiles permitted to identify four main seismic units (ages are inferred by well Trecase 1) (Table 1).

From top to bottom, the defined seismic sequences are delimited by three seismic horizons, representing geological unconformities, which may be correlated with the structural stratigraphic units of the southern Apennines:

Unconformity C: top of seismic unit U3. It may represent a marine flooding surface.

Unconformity B: top of seismic unit U2. It is characterized by high amplitude and complex morphology. It represents a clear angular unconformity.

Unconformity A: Top of the tilted Meso-Cenozoic carbonates (seismic unit U1), cropping out in the Sorrento Peninsula and Capri Island.

Legend	Seismic facies	Description	Origin	Age
U4	Transparent; continuous, high amplitude, parallel reflections.	Highest unit, widely present at bottom of all the Gulf of Naples. The unit *onlap* onto seismic reflector "C".	Marine deposits that coexist with volcanic and volcanoclastic sequences erupted from CF and Somma-Vesuvius.	Late Quaternary
U3	Variable energy; clinoform continuous and with high amplitude; transparent facies.	Sedimentary unit (prograding wedge).	Siliciclastic marine successions and volcanoclastic sequences	Middle Pleistocene
U2	Oblique-parallel reflections with high amplitude and continuity	First sedimentary unit in the basin; prograding wedge dipping to the NW.	Siliciclastic marine successions (cyclic depositional consisting of alterning sands and clay), involved in tectonic tilting with carbonates	Lower Pleistocene
U1	Chaotic	Seismic basement of sedimentary basins; monoclinal reflectors dipping to the NW	Carbonates, cropping out in the Sorrento Peninsula and in the Capri Island.	Meso-Cenozoic

Tab. 1: Unit of Campi Flegrei offshore area

In figure 10, the correlation between Trecase well litostratigraphy and the seismic units recognized, is reported.

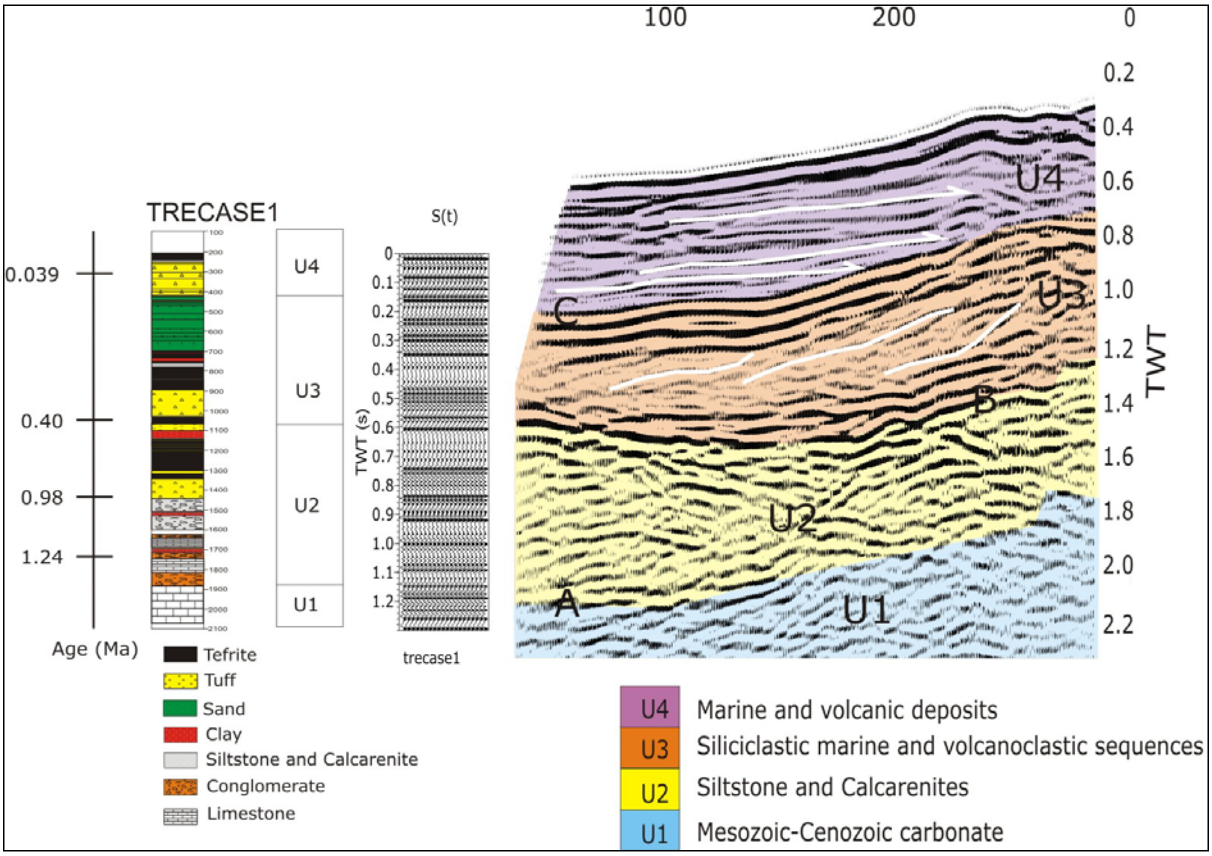


Fig. 10: Carbonate rocks (unit U1) form the substrate of the basin fill. Unit U2 correspond to the oldest marine sediments overlying the substratum. It probably was deposited during an early event of tectonic subsidence, controlled by the activity of NW-SE extensional faults, responsible for the change from subaerial to marine environment. Unit U3 was deposited during tectonic stability and fills the central part of the basin. The latest depositional sequence, Unit U4, consists of pyroclastic deposits which coexist with marine sediments deposited during a period of low sea level.

In figure 11 part of the seismic line Na-11 and Na-12 are reported. These lines represent an example of how the previously described depositional units were identified. The three main unconformities (labelled A, B, C) are clearly recognized. Seismic unit U4 is the highest unit with parallel and narrow spaced reflectors (marine deposits) (fig 11-A), onlapping above unconformity C. The unit U3 constitutes a sequence of variable seismic facies energy, mostly continuous and with sub-parallel reflectors (fig 11-B); this facies is characterized also by prograding clinoforms (fig. 11-A). The seismic unit U2 is characterized by reflections with high amplitude and continuity (fig 11-A). In the Bay of Naples unit U2 constitutes a prograding wedge dipping NE (fig 11-B).

Seismic unit U1 is the seismic basement cropping out in the Sorrento Peninsula (fig. 11-B). Within this unit, areas with low reflectivity alternate with strong and very discontinuous reflectors (fig. 11-A).

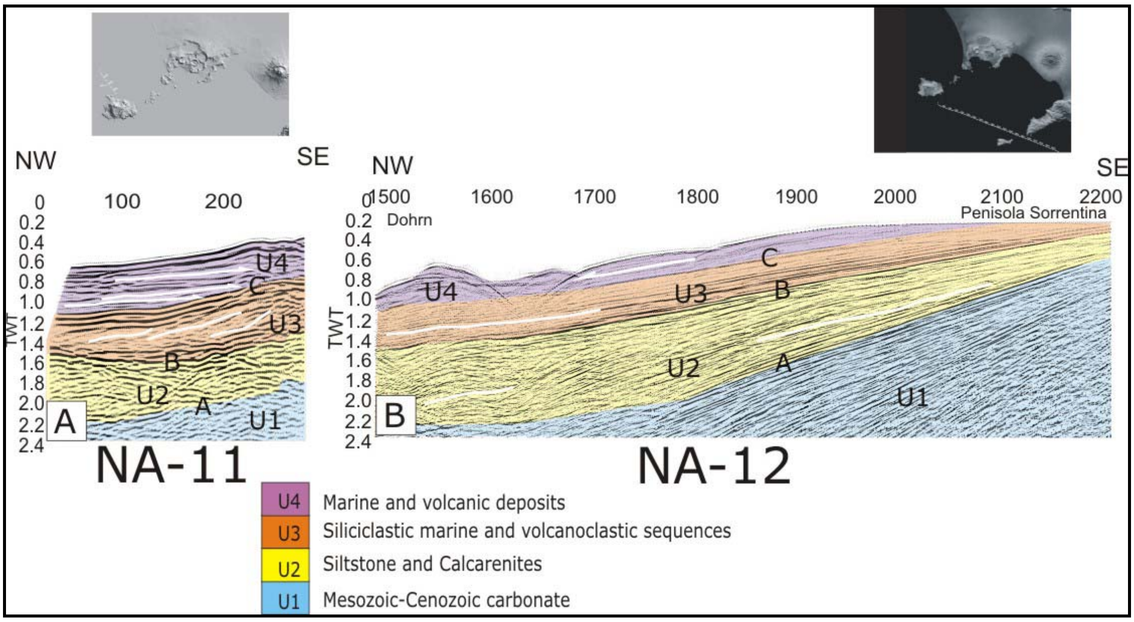


Fig. 11: Part of seismic line Na-11 (A) and Na-12 (B).

As for another example to recognize the seismic units, I show part of the seismic profile Na-14 (CDP 1140-1520) and the corresponding interpretation (fig. 12). The seismic unit U4 is onlap above C; the seismic unit U3 is characterized by clinoforms and acoustically transparent facies. Unconformity B is characterized by high amplitude reflections and complex morphology; it represents, in fact, an important tectonically-enhanced unconformity; the reflector of seismic unit U2 appears contorted and discontinuous: probably the deposition of this sequence has happened during the of the Plio-Pleistocene tectonic-volcanic activity. The seismic unit U1 is characterized by lack of stratifications.

In some seismic profile (es: Na-08, Na-09, Na-12), it was possible to make a clear distinction between the Holocene marine deposits and the volcanic and volcanoclastic sequences erupted from CF and Somma-Vesuvius.

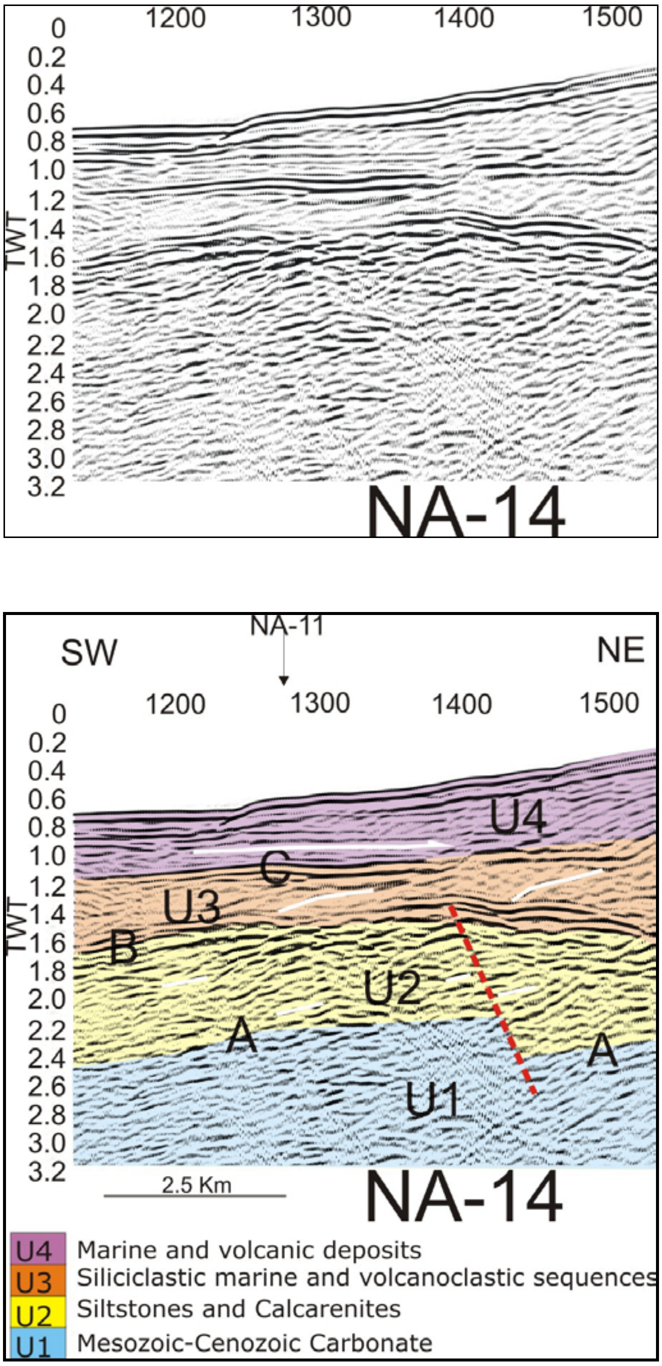


Fig. 12: Seismic profile Na-14 and corresponding interpretation. (for location of the seismic line, see fig. 8)

The high-resolution seismic profiles acquired in the offshore area south of the Campi Flegrei (i.e. Pozzuoli Bay) (fig. 13) permitted to perform a detailed seismo-stratigraphic analysis of Pozzuoli Bay.

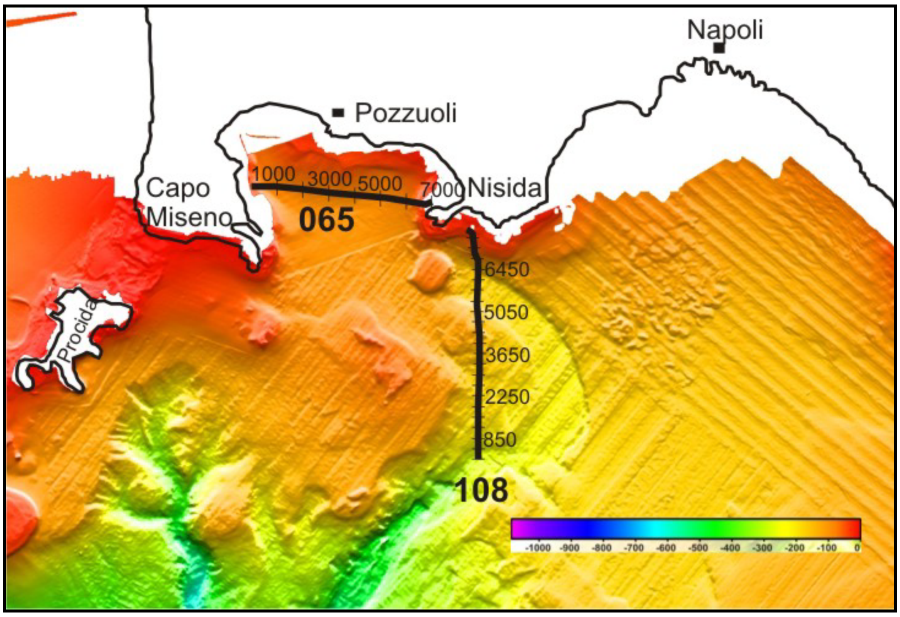


Fig. 13: High-resolution seismic profiles acquired in the offshore area south of the Campi Flegrei (Pozzuoli Bay)

Four major seismic units (fig. 14) are defined by picking their top reflections. In particular seismic profile GeoB08-065 (fig. 48)

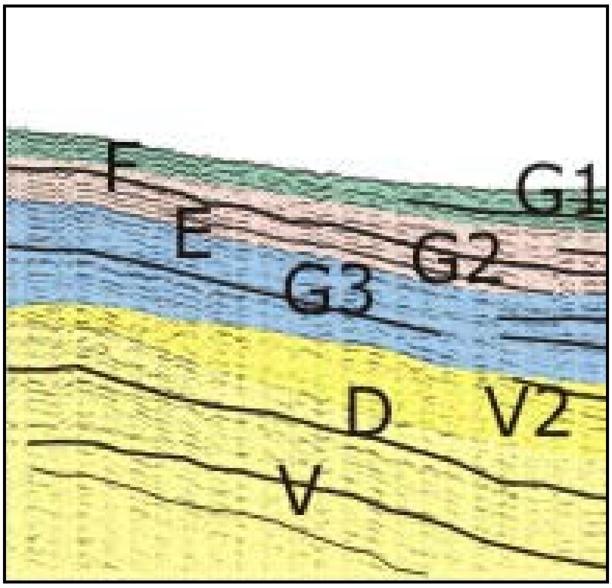


Fig. 14: Multichannel seismic profile in Pozzuoli bay showing units: G1, G2, G3 and V.

permitted to define the seismic units. These four seismic seismo-stratigraphic units are delimited by three principal seismic horizons (labelled D, E, F).

Unit G1 (< 4 ka B.P): From a descriptive point of view, unit G1 is assumed to start with the first reflection below the seafloor: highest unit, widely present at bottom of all the Gulf of Pozzuoli. The top and internal reflections are wavy to hummocky and subparallel with a medium to high amplitude and good lateral continuity. The thickness of the unit generally increase with distance to the coast. Unit G1 is presumably bounded by a seismic unconformity at its base as sporadic onlap reflections indicate (line 065, CDP 1000).
According to Milia et al., 2002, the uppermost unit (unit G1) is made up of three subunits.

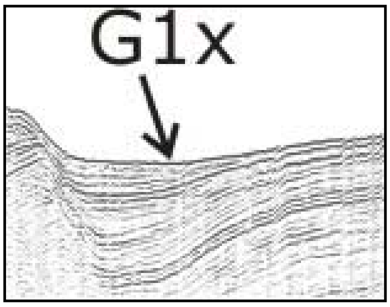


Fig. 15: seismic profile GeoB08-065 showing unit G1*x*

- Unit G1*x* characterized by undisturbed high amplitude and good continuity reflectors which onlap above horizon F (fig. 15).
- Unit G1*y*: the bending of horizon F may be caused by an emplacement of a magmatic intrusion. The clear onlap terminations of unit G1*y* above horizon F suggest a very recent deformation (fig. 16).

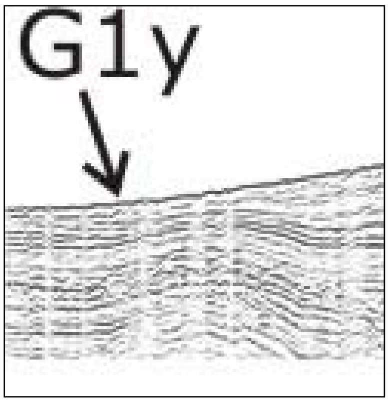


Fig. 16: seismic profile GeoB08-065 showing unit G1y

- Unit G1*z* (CDP 6000-7000) constitutes a complex prograding unit (fig. 17). The seismic facies is characterized by low-amplitude and good moderate continuity of the reflectors. The stratigraphic position of unit G1z suggest that it represents the highstand record of the sea level

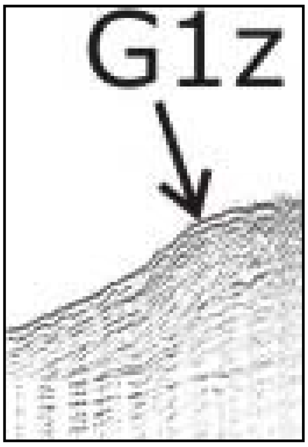


Fig. 17: seismic profile GeoB08-065 showing unit G1z

Unit G2 (8.2 - 4 ka BP)**:** This unit can be split into two parts:

G2*x*) has very weak amplitudes (partly transparent) throughout its traceability along all profiles (partly transparent);

G2*y*) internal reflections of this unit are of very high amplitude, parallel and continuous and good lateral continuity.

This unit is constituted by marine sediments, concordantly overlying each other

Unit G3 (11-8.6 ka BP): Unit G3 is characterised by a wavy top reflection, which is highly disrupted, covering a band of reflections of high to mid amplitude with parallel to subparallel and, at some parts, disturbed reflection patterns. It is, in general, build up by disturbed to chaotic reflections of mid to predominantly low amplitude. The zone's reflection amplitude is very high in the upper but decreases rapidly to transparency with depth.

Unit G3 is related to thick marine units due to first strong subsidence, creating large accomodation space at inner N of Pozzuoli Bay

Unit V: The top of unit V is wavy continuous and of low amplitude. The base of Unit V could not be traced thus no thickness was derived for it. The deeper parts of unit V are always masked by multiple reflections or by transparency. At the top, Unit V is limited by a rough erosional surface that exhibits subaerial character. This unit is related to the Neapolitan Yellow Tuff erupted from Campi Flegrei 12000 years ago (Milia et al., 1998). Unit NYT is the offshore continuation of that unit cropping out in Bagnoli and Posillipo.

The wedge-shaped **Unit V2** could be interpreted as a distinct depositional unit of the Neapolitan Yellow Tuff (NYT) (Cole et al., 1993).

The stratigraphic analysis of deep boreholes, which are located in the city of Naples, in fact, indicates that the NYT pyroclastic deposits are characterised by the superposition of two distinct units (Scarpati et al., 1993): the lower subunit is a phreato-plinian ashfall follwed by pyroclastic surges, representing the initial eruptive phase. The upper subunit is made of numerous pyrocalstic flows which show up as thick and massive units with internal layering (Perrotta & Scarpati, 2002).

In general, the acoustic substrate in the Pozzuoli bay central plain comprises a chaotic seismic facies attributed to the Neapolitan Yellow Tuff (12.0 ka B.P.) and which is overlain by three sedimentary units: G1, G2, and G3 (Milia-Giordano, 2002). Unit G1 and Unit G2 are marine Holocene sediment that drapes all pre-existing morphology; unit G3 should be a thick marine units due to strong subsidence, creating large accomodation space at inner N of Pozzuoli Bay. Units G2 and G3 correspond to the marine succession outcropping at La Starza (12.0–4.0 ka B.P.), whereas unit G1 has been dated to less than 4.0 ka B.P (Cinque et al., 1985).

CHAPTER 3

Interpretation of seismic reflection profiles offshore Campi Flegrei

3.1 Introduction

Campi Flegrei (CF) region is one of the most hazardous volcanic and seismic areas in the world, therefore the geophysical study of its marine environment (where little direct information are available) is a key to better understand this area. The data used in this chapter are recently reprocessed by Bruno et al. (2002, 2003). The main goal was to build the stratigraphic framework through the identification of depositional units and to delineate a broad geo-volcanological and structural framework of the CF with the aim of exploring the connection between volcanism and tectonics. Individual units were delineated on the basis of contact relation and internal layering characteristics as revealed by seismic reflectivity. Seismic facies analysis permits to delineate the environmental setting of the studied area. The identification on seismic section of important faults allows to perform a structural analysis of the CF area. The study stresses also on the recognition of the fault systems responsible for the formation of Ischia Island and the Bay of Naples and finding their relationship with the sedimentary and volcanic units of the area. The original seismic dataset was characterized by low redundancy and low bandwidth; reprocessing yielded an improvement of the seismic dataset quality by means the most recent techniques aimed to the enhancement of signal to noise ratio. A comparison between the new and old data (Bruno, 2002) shows that the new sections are characterized by a much higher S/N ratio; this permitted to gain new constrain on the structural setting of CF offshore area. Because of the structural complexity of the studied area, all the available geological and geophysical data were utilized to aid interpretation such as exploratory wells located few kilometres off the seismic profiles and the high resolution magnetic anomaly map of the gulf (Siniscalchi et al., 2002; Aiello et al., 2004). The previous seismic studies at the same scale in adjacent areas (Bruno et al., 1998; Bruno et al., 2000; Bruno et al., 2003; Bruno 2004) was a fundamental tool for interpretation. The identification on seismic section of important faults allows to perform a structural analysis of the CF offshore area and to estimate their kinematics.

3.2 Interpretation of the seismic lines

The interpretation concerns 13 seismic lines (fig. 19), covering an area of about 2000 Km² which extends from the northern coast of Ischia and Procida Island up Sorrento Peninsula. These seismic lines have a NW-SE and NE-SW prevalent direction but the structural style of the area is best underlined on NW-SE lines (lines Na-08, Na-09, Na-12, Na-13).

We will proceed the description beginning from the oldest southern-eastern portion of the area. Lines Na-09, Na-08 and Na-12 permitted, in fact, to delineate the geological setting of the eastern sector of the Bay of Naples.

Seismic line Na-09 (fig. 20) best outlines the tectonic relationships between Bay of Naples and Campi Flegrei-Ischia Ridge.

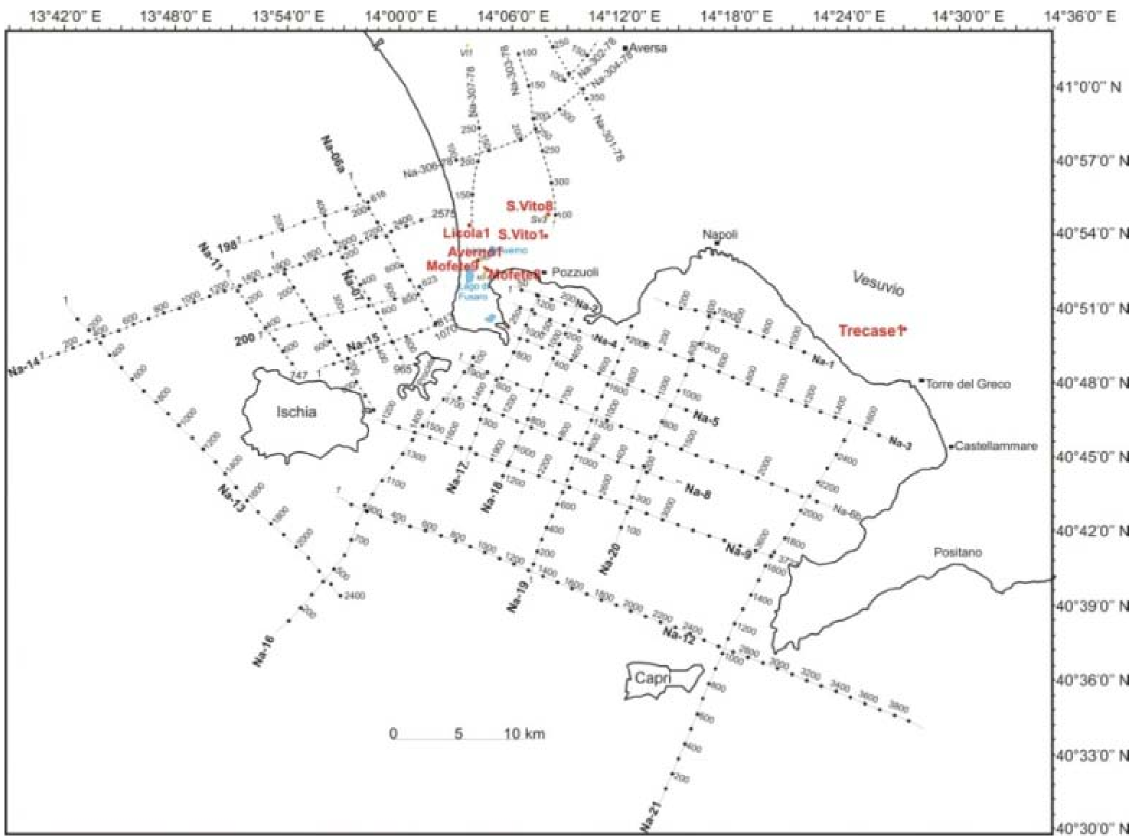


Fig. 19: Map with position of OGS seismic lines

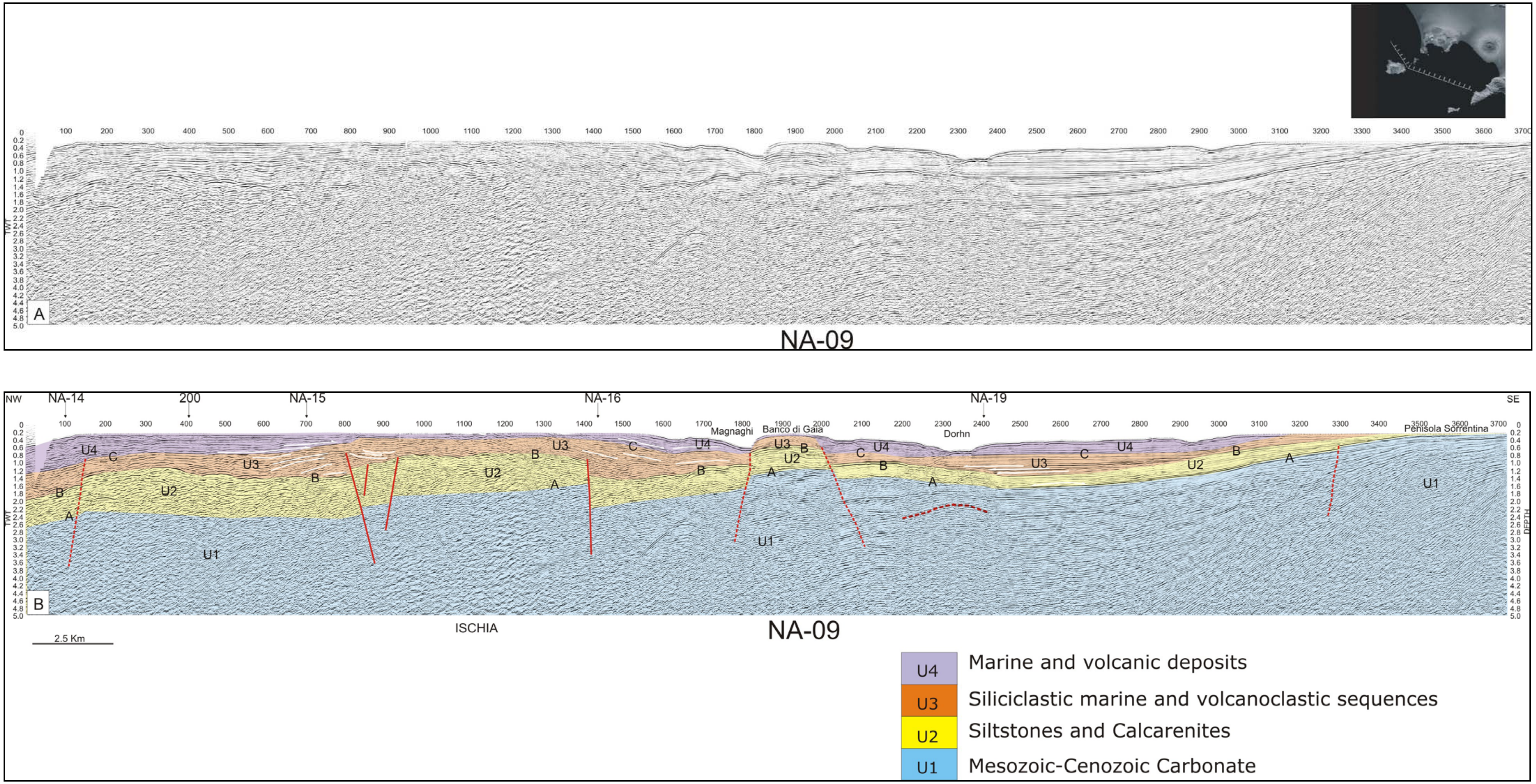


Fig. 20: Seismic line Na-09 (A) and interpretation (B). The greater tectonic complexity of Campi Flegrei area with respect Vesuvius district (Bruno et al., 2000; Piochi et al., 2005) is visible. In correspondence of CDP 1830-2030, in the median zone between canyons Dohrn and Magnaghi, the line crosses a structural high (Banco di Gaia).

The seismic line (fig. 20) shows a seismic response extremely varied. In the left part (to the NW of Canyon Magnaghi) an area with a low Signal/Noise ratio is present, then the line runs in an area characterized by good reflectivity (Gulf of Naples). The line, in fact, crosses in its first part (CDP 0-1700) the area characterized by the maximum deformation rate related to the opening the Tyrrhenian Sea. Seismic line Na-09 (CDP 2300-3700) (fig. 21), shows that in the Bay of Naples, the horizons A and B assume a NW-dipping monoclinal trend. As already identified by Finetti and Morelli (1974) and Fusi (1991), the tilted Mesozoic carbonates crop out in the Sorrento Peninsula. The eastern area of the bay is made, in fact, of sedimentary rocks; the reflectors that characterize this part of the section do not show particularly interpretation problems; all the reflectors are characterized by good energy. Units 2 in this area exhibits features typical of a basin fill sequence, with onlap on both sides of unconformity A. Units U3 and U4 (CDP 2400-3500) (fig. 21) permit also to distinguish a proximal to distal seismic facies variability. The facies succession of these seismic units consists of basal convergent onlapping packages overlain by chaotic zones. Onlap and draping facies are best developed in the distal portion of the basin and are frequently removed in the proximal portion of the basin. The seismic section moreover shows (CDP 2300-2400 – TWT 1.3-1.6 s) that the monoclinal trend of the unconformity A and B is abruptly interrupted beneath the Dhorn Canyon. The monoclinal trend that characterizes the unconformities (CDP 2500-3000) (fig. 21) is, in fact, interrupted by a dome-like structure (CDP 2300-2400); the seismic units U2 and U3 passes from a seismic facies characterized by continuous and parallel reflectors to a chaotic and contorted configuration. Such deformation could be caused by the presence of a magmatic intrusion. The onlap terminations of the reflectors of the seismic unit U3 above B (CDP 2400 – TWT 1.2), permit to date as late-Pleistocene the onset of the deformation.

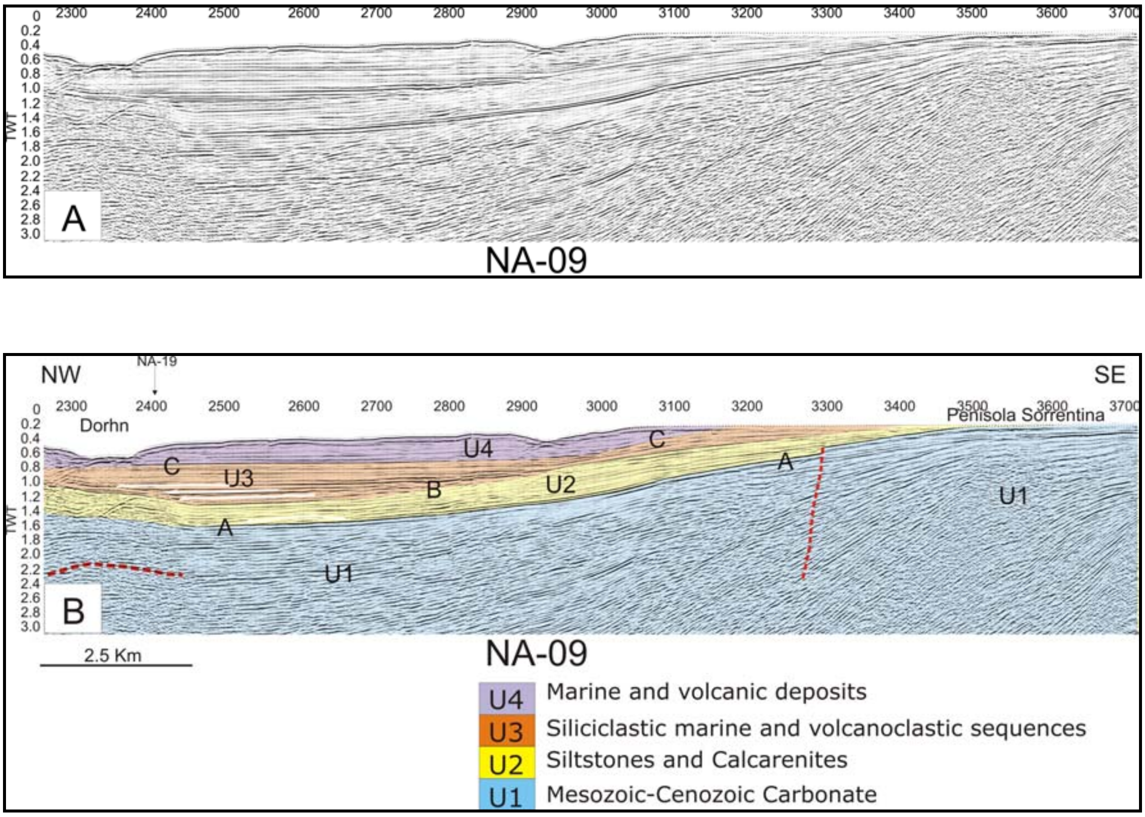


Fig. 21: Part of the seismic line Na-09 (A) (CDP 2300-3700) and corresponding interpretation (B). The monoclinal trend is interrupted by a dome-like structure.

Line Na-09 in correspondence of CDP 1830-2030 (fig. 22), in the median zone between the Dohrn and Magnaghi canyons, crosses a structural high. The line probably crosses a volcanic bank which represents a relic morphology, characterized from the outcrop to the deep sea of erosional surfaces. In correspondence of CDP 1500-1700 (fig. 22), the reflectors of the units U3 and U4 evidence the passage from an oblique configuration to a sub-parallel ones. In this sector (CDP 1400-1800), in fact, the line crosses the continental slope of the Ischia Island. The sigmoidal-oblique progradation pattern configuration, showing a package of sediments characterized by a high-frequency seismic facies, probably is originated from the dismantling of Ischia volcano slopes.

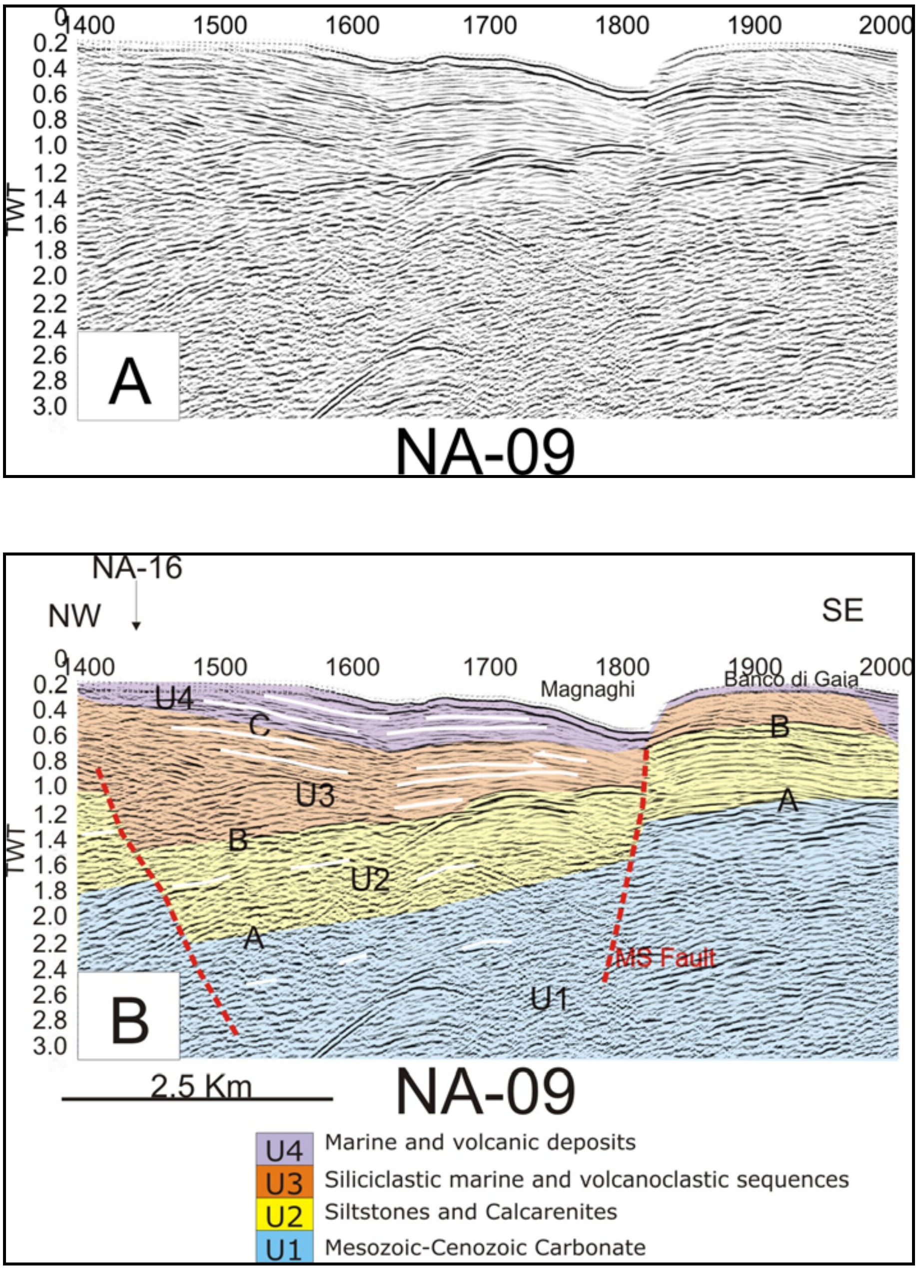


Fig. 22: Part of the seismic line Na-09 (A) (CDP 1400-2000) and interpretation (B). In correspondence of CDP 1600, reflectors of U2 and U3 passes from an oblique configuration to a sub-parallel ones.

In the western sector of the Bay of Naples, seismic line Na-09 shows that the monocline structure of the carbonate basement in the Gulf of Naples, is interrupted by a fault system, with large throw, which isolate a horst-like structure beneath Ischia (fig. 23 - CDP 900-1400). Two inverse faults (CDP 800 and CDP 1440) are recognized in the seismic section. The line between CDP 800-1800 (fig. 23), near Ischia Island eastern cost, exhibits, within seismic units U3 and U4, lateral outward progradation (CDP 1500 – 1800). The prevailing structure revealed by downlapping geometry is accompanied by an outward thickening of these seismic units. Seismic unit U4 also shows similar, although reduced, pattern of outward progradation.

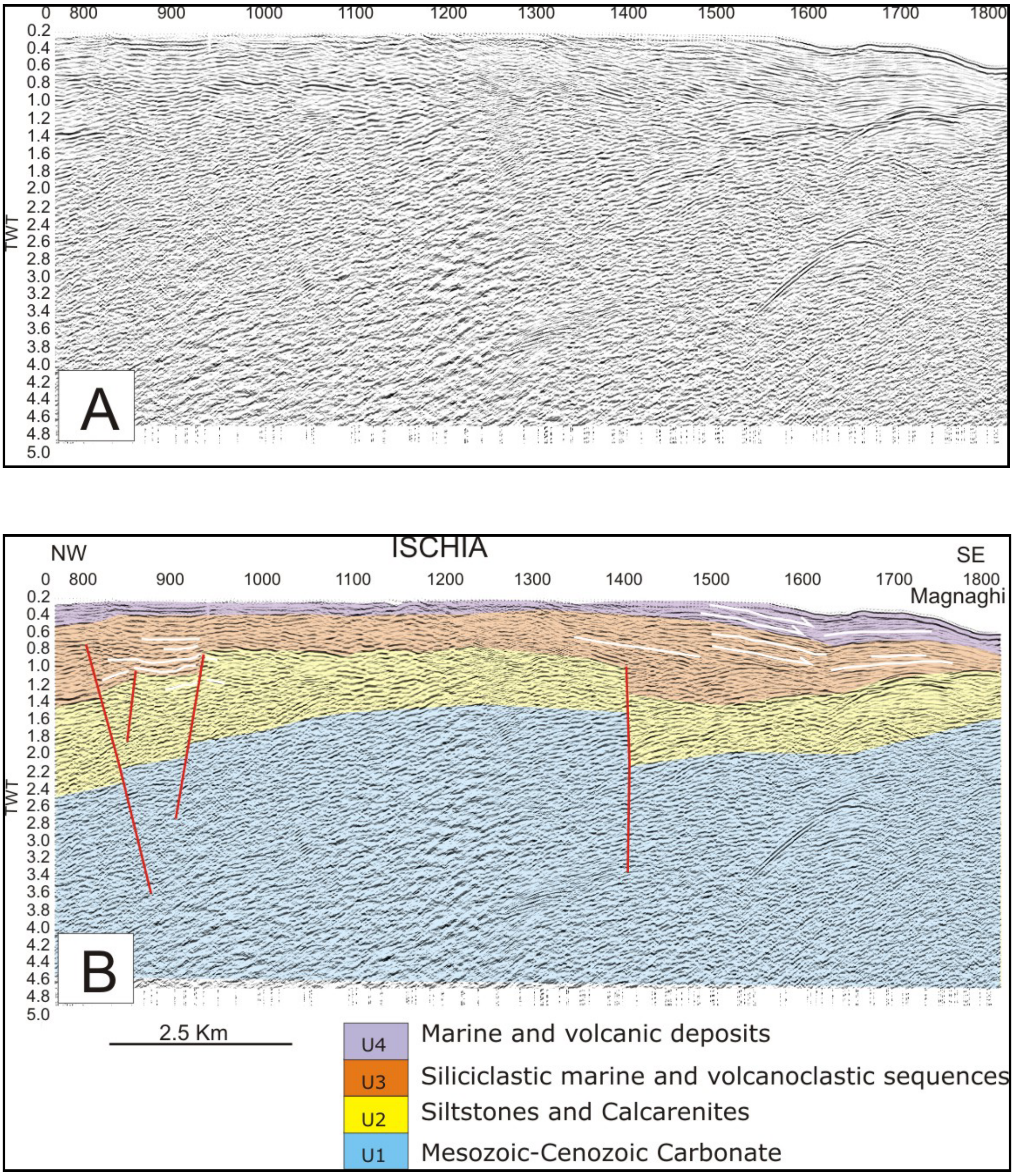


Fig. 23: Part of the seismic line Na-09 (A) (CDP 800-1800) and interpretation (B).

Seismic line Na-12 (fig. 24) runs between the Gulfs of Naples and Salerno, between the Island of Capri and the Sorrentina Peninsula. The seismic unit U2 (CDP 1500-2100) is characterized by reflectors tilted towards NW with oblique-parallels configurations and in paraconcordance over of the meso-cenozoic acoustic basement (seismic unit U1). Unit U2 could be interpreted like a prograding wedge of lower Pleistocene age (see tab. 1 – chapter 2 – para. 2.2.2), formed by clastic sediments (cyclic depositional consisting of alterning sands and clay). In the Bay of Naples the basement (seismic unit U1) shows a regular dip towards NW with the exception of the presence of the structural high of "Banco di Fuori" (CDP 1000-1450) that interrupts the monoclinal trend of the structures (Fusi 1991, Aiello 2005). This morphostructural high, situated between Dohrn and Magnaghi canyons, and elongated in NE-SW direction, with the south-eastern flank steeper than the north-western one, presumably is formed by a tilted block of Mesozoic carbonates (Aiello et al., 2005). Moreover, seismic line Na-12 shows that the monocline trend is dissected by normal faults (CDP 2800-3100). These structures, with a regional relevance, causes the abrupt sinking of the carbonatic basement south of Sorrento Peninsula and separate the Gulf of Naples from the Gulf of Salerno, which completely lack of volcanism.

Line Na-08 (fig. 25), which runs from the western branch of Dohrn canyon up to the eastern offshore of Ischia Island, puts well in evidence that in the uppermost seismic unit (U4), the reflectors appear contorted and discontinuous (CPD 800-1600), with diffuse presence of dome-like structures; the same seismic unit between CDP 0-800 is characterized by parallel reflectors with high amplitude and continuity. The profile in correspondence of CDP 700, TWT 1.6 sec, shows that the monoclinal trend of unconformity A is interrupted. Line Na-08 allows, in fact, to detect the deformed basement (seismic unit U1): the U1 reflectors appear chaotic between CDP 800-1600 whereas show good continuity between CDP 0-800.

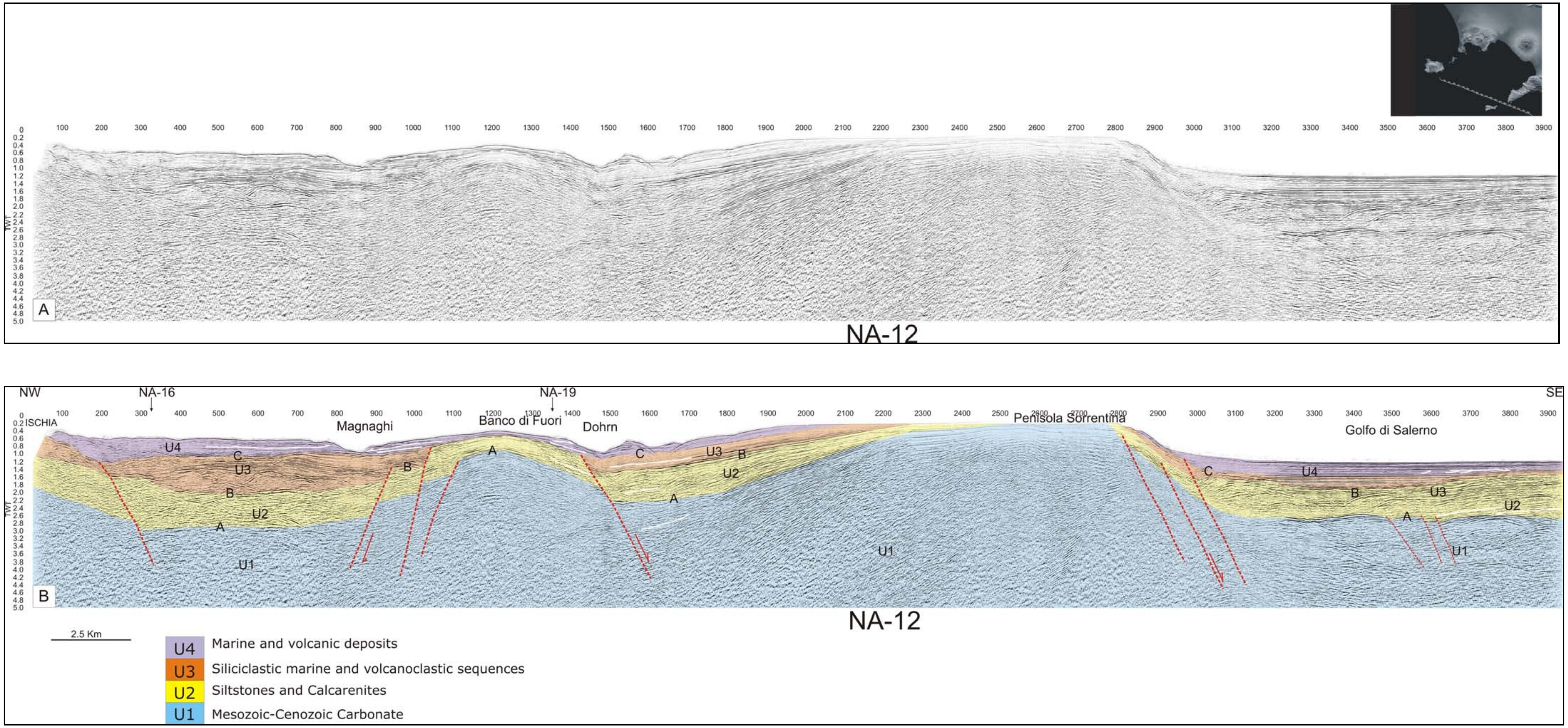


Fig. 24: Seismic profile Na-12 (A) and corresponding interpretation (B).

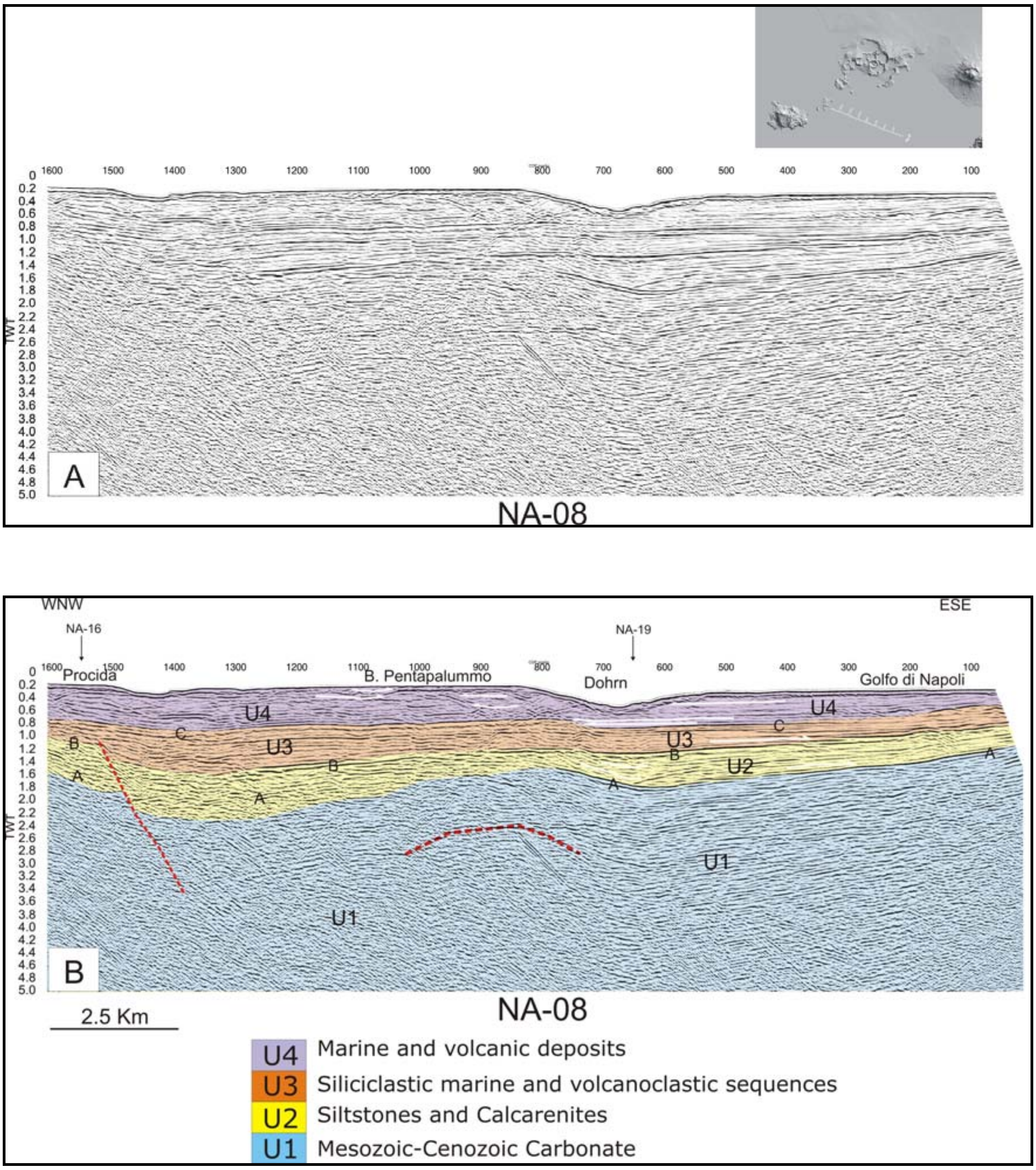


Fig. 25: Seismic profile Na-08 (A) and corresponding interpretation (B).

Moving in the north-west sector of the study area, a number of lens-shaped structure and morphological depression with an aspect caldera-like, are recognized. The first structures, well evident on the lines Na-06 (fig. 26) and on the Na-11 (fig. 27), showing a complex internal morphology and limited by significant contrast in acoustic properties (velocity and density), are interpretated as related to shallow, sill-like magmatic structures on the base of their geometry, seismic signal and structural relationship with the sedimentary host-rock. The morphological depressions, recognized on line Na-15 (fig. 28), are interpreted as related to caldera collapses with thick accumulation of proximal pyroclastic deposits.

Seismic line Na-06 (fig. 26) with NW-SE trend, localized to N of Ischia, puts in evidence (CDP 280-400; TWT 1.4 s) the presence of a lens-shaped structure delimited at the top and at the base by strong seismic reflections. It is interpreted as a magmatic sill, which intruded into the seismic unit U3.

Seismic profile Na-11 (fig. 27), located in the northern offshore of Ischia Island, with a NW-SE trending, shows unit U4 in onlap above C; seismic unit U3 is characterized by clinoform with eroded topset and sub-parallels reflectors (probably placed at the end of the subsidence phase that interested carbonatic platform), unconformity B appears deformed. Within seismic unit U2, reflectors, generally undisturbed outside this area, appear discontinuous, even within the most recent units. These configurations may indicate diffuse presence of volcanic features. Chaotic to contorted reflectors within unit U1 can be interpreted as expression of the deformed carbonate basement. In the centre of profile Na-11 (fig. 27) (CDP 300-400 - TWT 1.4 sec.) the existence of a lens-shaped feature within seismic unit U2, easily distinguished from surrounding stratal reflections, could be tied to the presence of another magmatic sill. On the right side of section Na-11 (fig. 27) (CDP 450-700), the seismic unit U3 consists of a sequence of continuous and sub-parallels reflectors characterized by a progradational configuration.

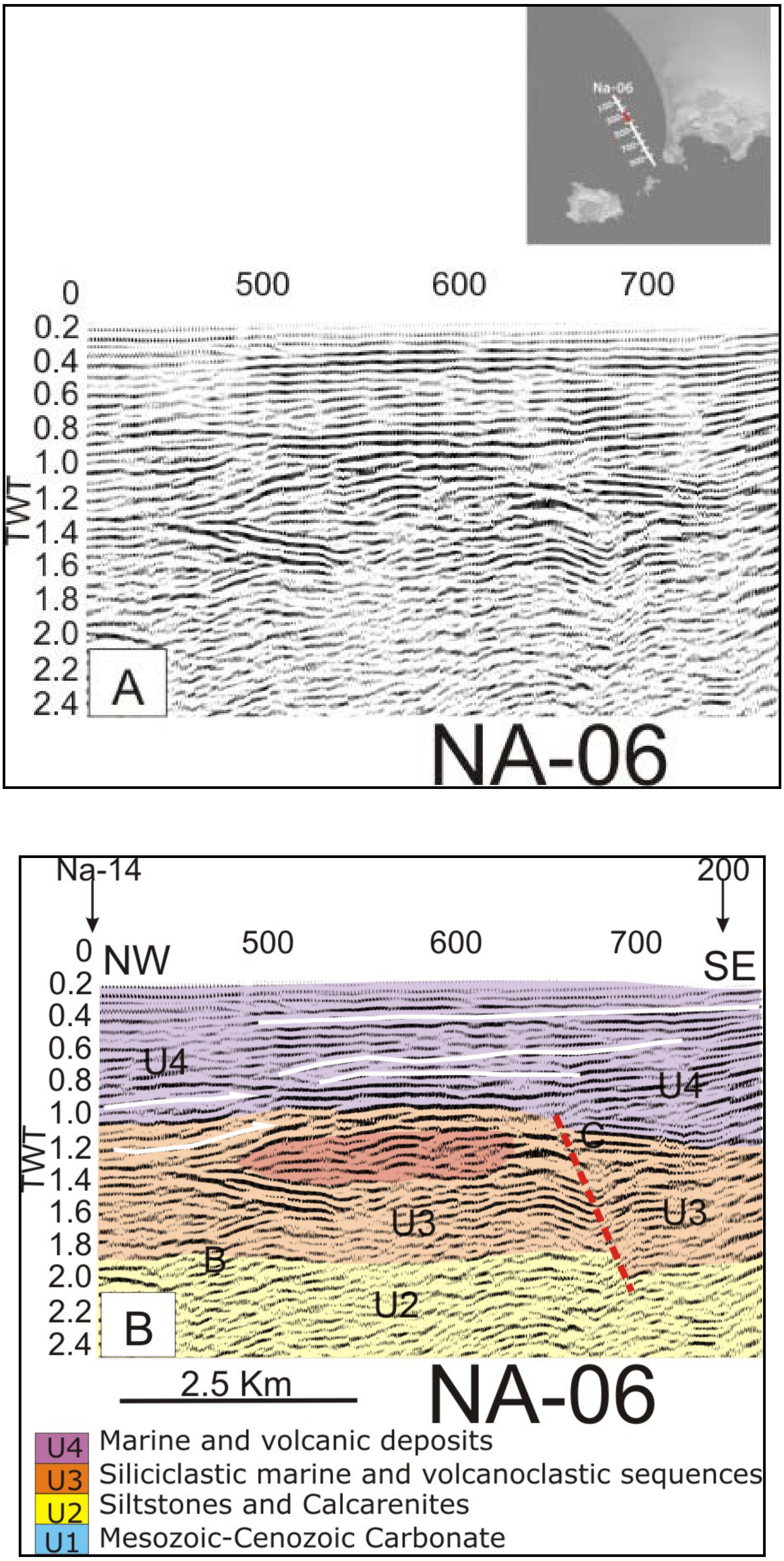


Fig. 26: Na-06 seismic line (A) and interpretation (B). The profile, with NW-SE trending, localized to N of Ischia shows the presence of a magmatic sill.

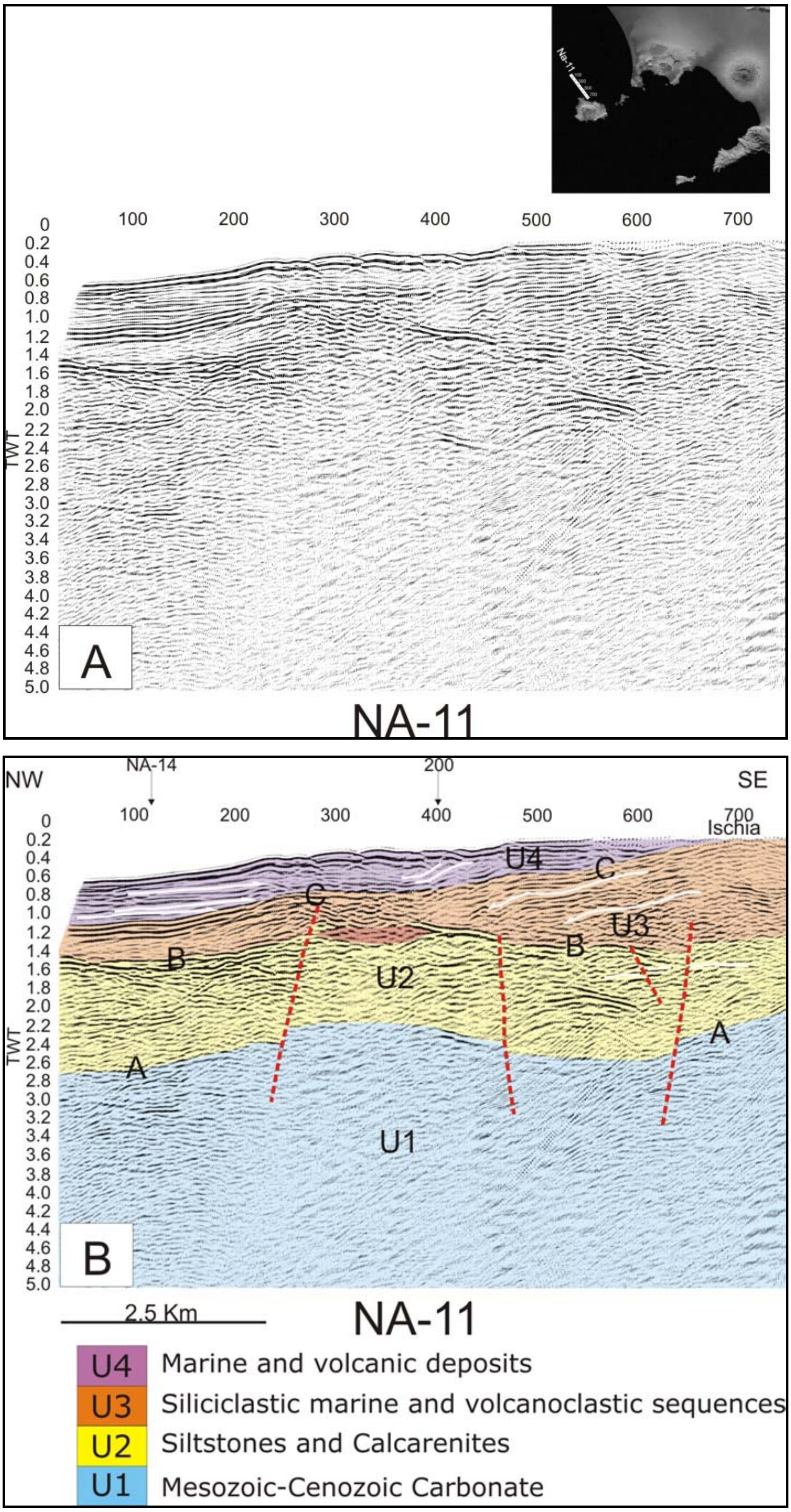


Fig. 27: Seismic profile Na-11 (A) and interpretation (B).

Seismic profile Na-15 (fig. 28) runs from Ischia to the Campi Flegrei. On the right side (CDP 500-800), reflectors of seismic unit U4 show a progradational configuration onlapping above C. The sedimentary supply comes from northeast and could be directly connected to the volcanic activity of the Campi Flegrei. The reflectors indicate a high rate of accommodation during the emplacement of the volcano-clastic deposits. In the north-east sector of Ischia Island, where the seismic unit U3 reaches the maximum thickness (1,3 s TWT, approximately 2000 m), seismic line Na-15 evidences a morphological depression. This last structure, with an aspect caldera-like, situated less than two kilometres from the coastline, could be genetically connected to eruption of Campanian Ignimbrite.

The western sector of the Ischia Island offshore is shown by seismic line Na-13 (fig. 29). The line, between CDP 1000-1350, shows that seismic units U1, U2, U3 and U4 were involved in an uplift process. It is possible to differentiate (CDP 900-1400) an external block, delimited1 by high angle reverse faults, and an inner block, delimited by normal faults. The source mechanism may be a magmatic intrusion (as a laccolith) located at a depth of approximately 3 Km. The small thickness of the seismic unit U3 (CDP 1100-1300) in this zone is probably caused by erosion processes. The highest unit (U4) is characterized by parallel reflector with good continuity and high amplitude. Between CDP 700-1000, seismic unit U3, to the NW of Ischia resurgence, shows a progradational configuration. Between CDP 1800-2400 a dome-like structure is present; the faults associated to such structure cut also the uppermost Late Quaternary reflectors. This structure could be tied to an other volcanic block reviving to SE of Ischia. The geometry of the folded strata, characterized by constant thickness, suggests a post-depositional and very recent folding. In CF offshore area, in fact, are common (Milia and Torrente, 2000) magmatic intrusion which rose upward and caused the warping of the overlying horizontal layers.

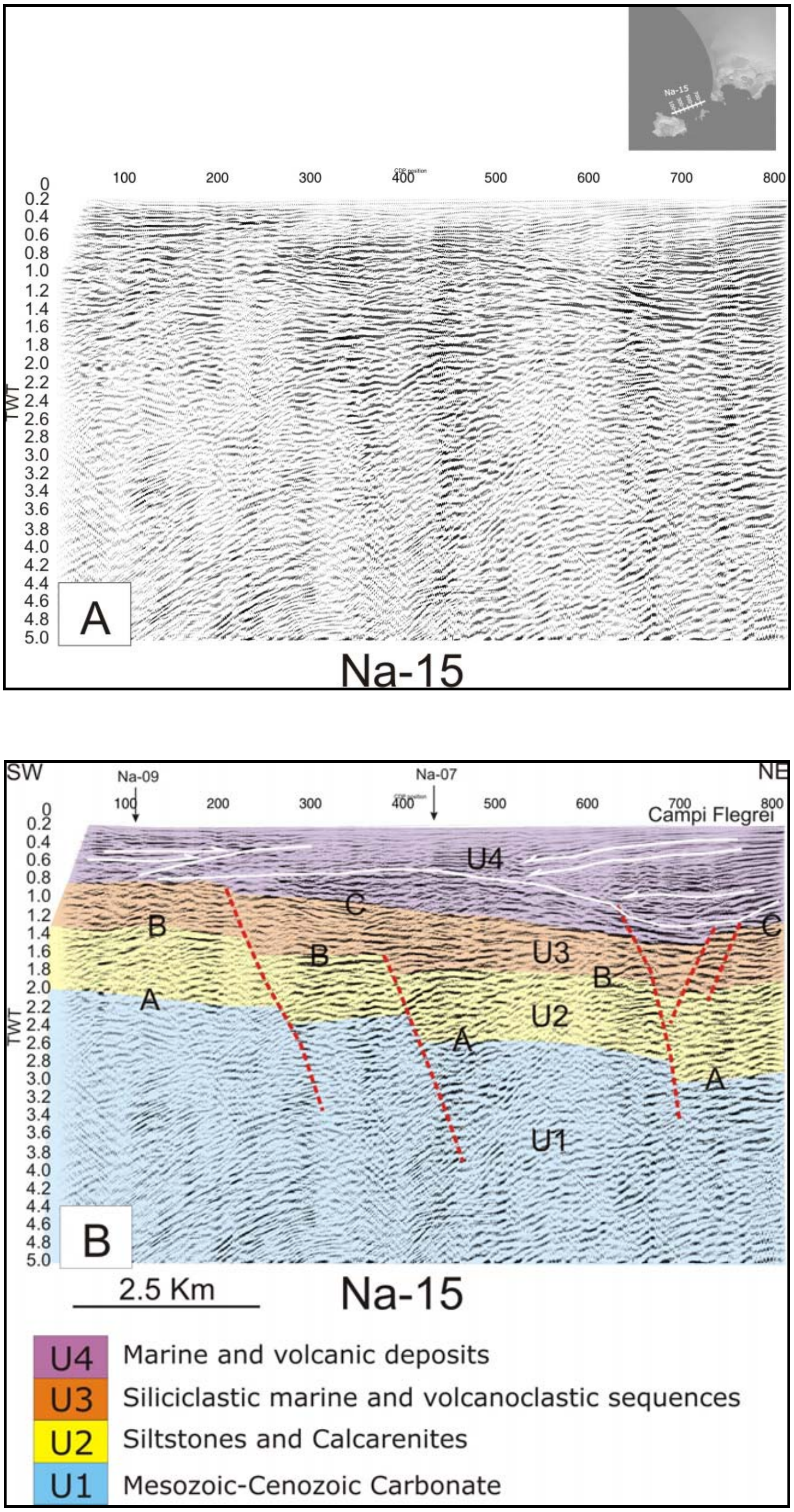


Fig. 28: Seismic profile Na-15 (A) and interpretation (B). It is possible to note a volcanic related sinking (CDP 600-800). The U4 reflectors show a progradational configuration: sediment supply may be related to the volcanic activity.

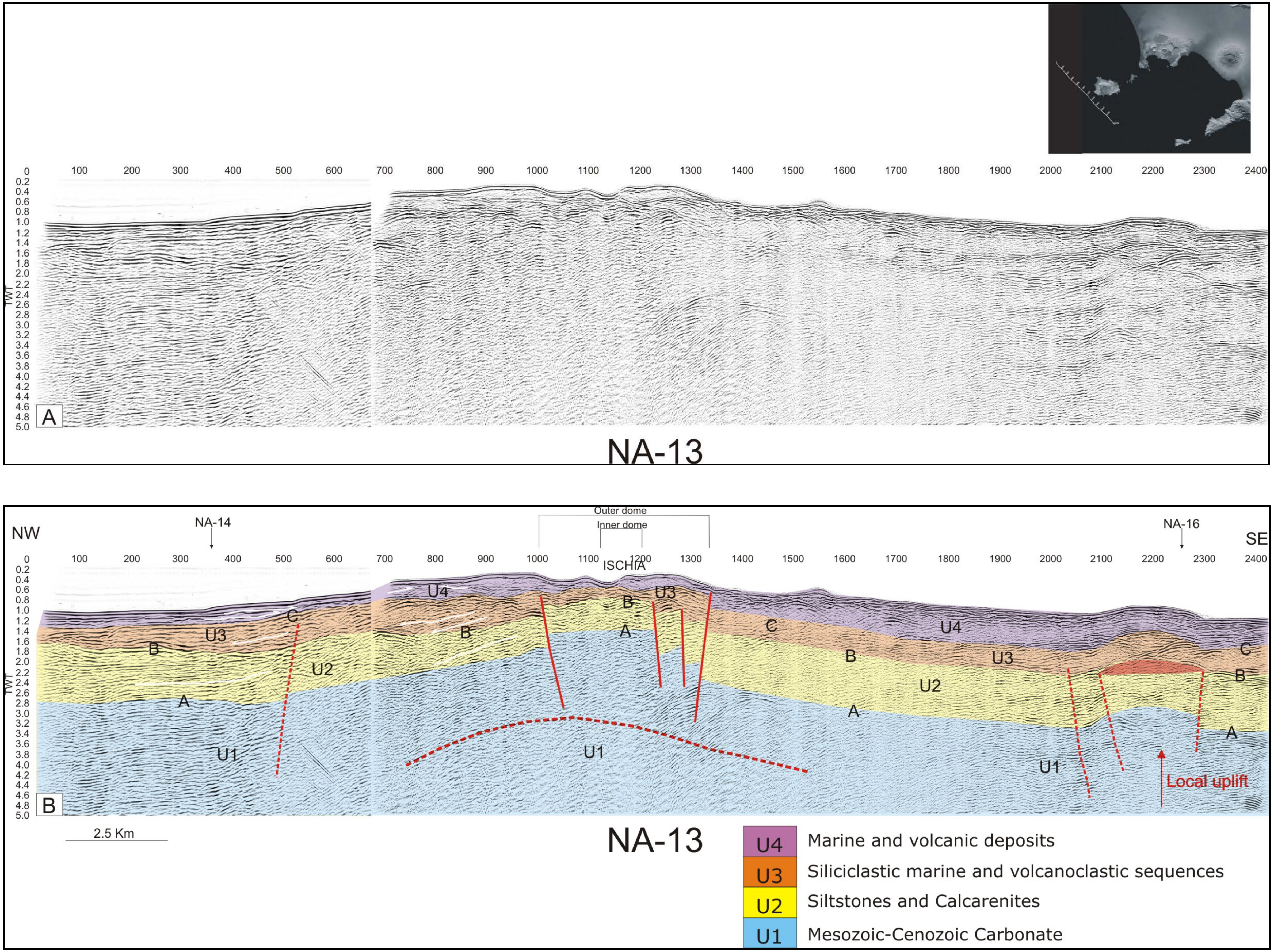


Fig. 29: Seismic profile Na-13 (A) and interpretation (B). The line runs to the west of Ischia Island. Between CDP 1800-2400 a dome-like structure is present.

Line Na-13 (fig. 29), in correspondence of CDP 2200 – TWT 2.2 s., shows the presence of a reflection free zone interpreted a magmatic sill, whose presence is also visible on seismic line Na-16 (fig. 30) that crosses Na-13 in correspondence of CDP 2250.

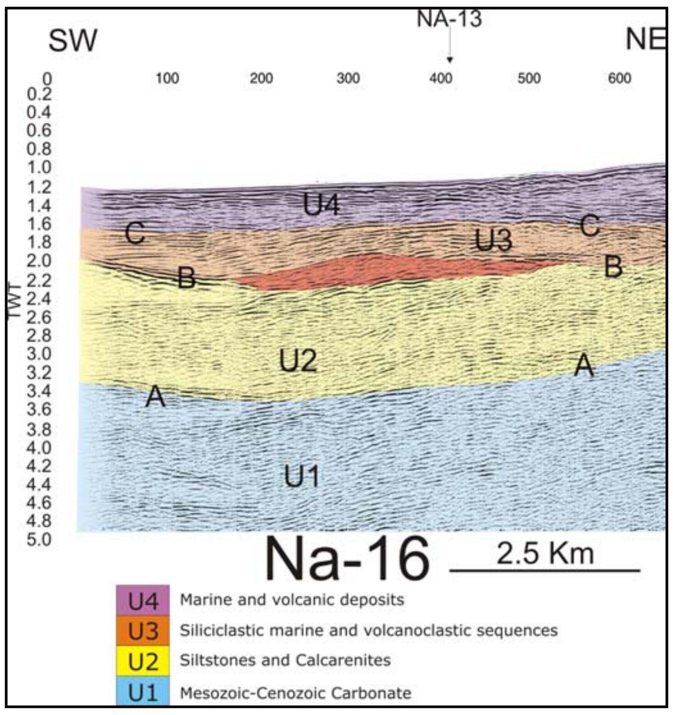


Fig. 30: Seismic profile Na-16 shows a magmatic sill (CDP 150-500 - TWT 2 sec).

Interpretation of transverse seismic reflection profile - seismic line 198 (fig. 31) - from North to Ischia to the Campi Flegrei, puts in evidence a system of normal faults that underline the substantial deepening of the Mesozoic carbonatic acoustic basement towards north-east (Campi Flegrei); the carbonate sinking (seismic unit U1) in CF area is evidenced also by the geothermal wells Licola1 and Trecase 1 (fig. 9). Licola1, located outside the CF caldera, on the shoreline, not drilled the limestone until the bottom of the well (2655 m); instead Trecase1 recovered the acoustic basement to the depth of 1885 m. Seismic Unit U1 was affected by strong continuous subsidence as a consequence of extensional tectonic which affected the inner part of the Apenninic chain, after the end of the Mio-Pliocene piling-up of Apenninic chain. The litostratigrafic data of Licola1 and Trecase1 well indicate a high subsidence rate of the Campanian Plain in the last 1 Ma.

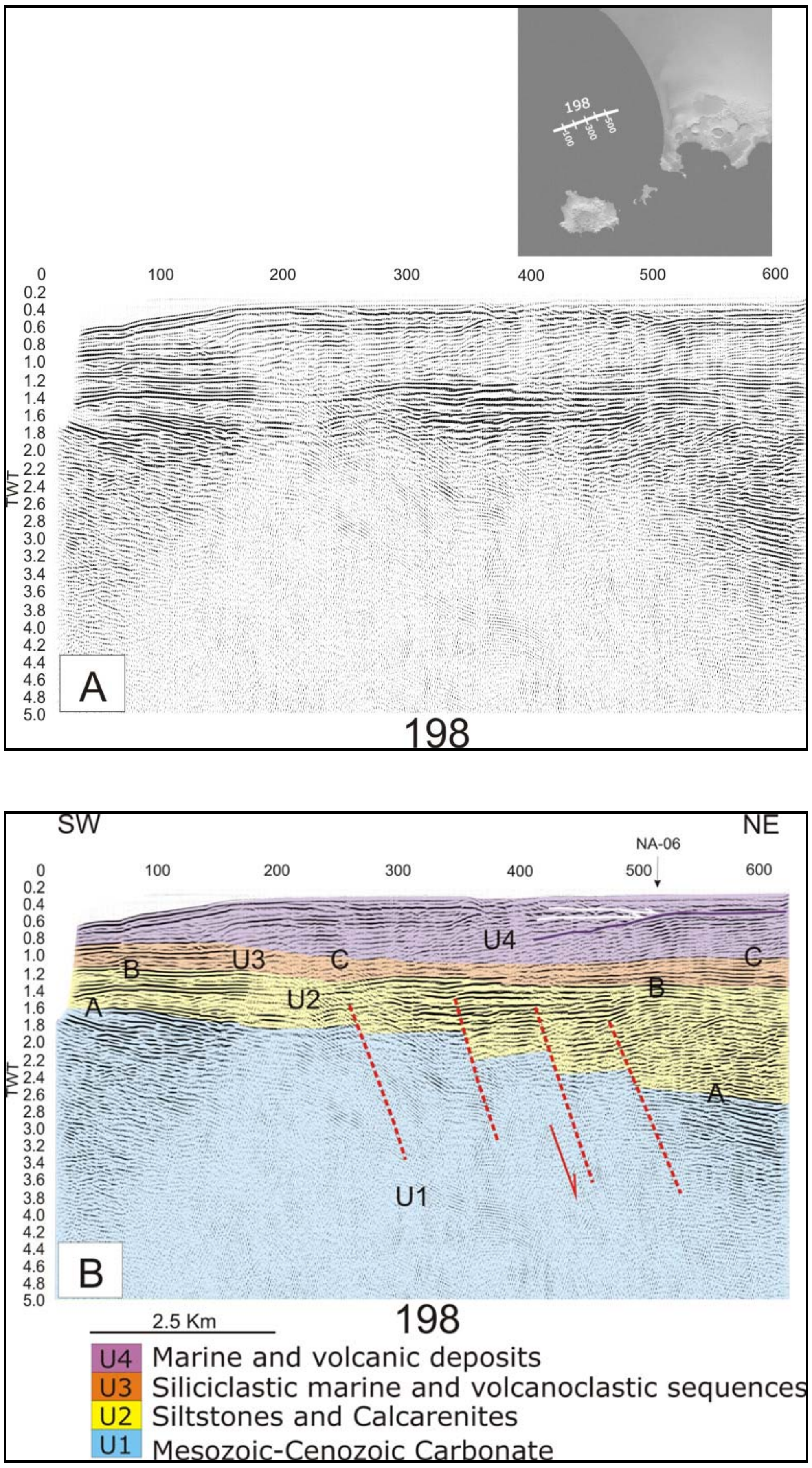


Fig. 31: Seismic profile 198 (A) and interpretation (B).

3.3 Discussion

Seismic line Na-09 provides an overview of the structural setting of the Bay of Naples. Seismic reflection data permitted to split the whole territory of the study into three different sub-areas. Starting from Bay of Naples eastern sector and running in NW direction, it is possible to differentiate (fig. 32):

1) The eastern sector characterized by the NW-dipping Meso-Cenozoic substrate cropping out in the Sorrento Peninsula and in the Capri Island.
2) The northern area of the bay, the Campi Flegrei offshore, characterized by the presence of volcanic banks and dominated by two submarine canyons;
3) The uplift observable around the Island of Ischia.

3.3.1 Evolution of the Bay of Naples

The geological evolution of the Campania continental margin, following the geodynamic evolution of the Neogene Southern Apennines–Tyrrhenian Sea system, included two orthogonal extensional phases: an older one, linked to NW–SE faults that produced horst and graben structures parallel to the Apenninic chain, was followed by the main extensional event that gave rise to asymmetric extensional structures controlling the physiography of the region. The Bay of Naples is one of these NE-trending half grabens with its depocenter located in the north-west. Two NE–SW trending ridges bound the Bay of Naples: to the north, the Campi Flegrei consists of about 50-km-long active NE–SW volcanic ridge; another ENE–WSW trending ridge, the Sorrento Peninsula, bounds the Bay of Naples to the S. As a result, the basin fill architecture of the Bay of Naples is characterised by a NW-dipping Meso-Cenozoic substrate (seismic Unit U1 – see tab. 1, chapter 2, para. 2.2.2), overlain by an angular unconformity attributed to the Pliocene–

Pleistocene emersion of the area (Milia and Torrente, 1999; 1997), and covered by a Quaternary succession of stratified sediments. The Quaternary deposits have been previously reported (tab.1; chapter 2; para. 2.2.2). The first products of volcanism were emplaced 400 ka ago, at the end of the main extensional phase, when the crustal thinning of the Campania continental margin made the lower crust more susceptible to melting and flow (e.g. Hendrie et al., 1994; Hay et al., 1996).

The shelf bordering the NW coast is instead part of an extensive system of volcanic banks formed before the last Wurmian regression (18–14 ka; Pescatore et al., 1984). A structural high formed by a horst of the carbonate basement (Banco di Fuori) is extended in a NE-SW direction in the central area of the bay, between the Capri and Ischia Islands, with a minimum depth of 130 m (Milia, 1999; Aiello et al., 2001). Two canyons engrave the continental slope: the Magnaghi Canyon, located between Ischia and Bocca Grande bank, and the Dohrn Canyon, positioned between Banco di Fuori and Capri (Aiello et al., 2001).

Reflection profiles have shown a structural pattern of normal faults cutting Pleistocene sediments with a prevailing NE-SW strike. This trend is named the Magnaghi-Sebeto line (Bruno et al., 2003) and divides the Bay of Naples into two areas: a western area, characterized by several volcanic banks, and an eastern one, characterized by a NW-dipping monoclinal structure made of sedimentary rocks.

This work is mainly focus on the Ischia structure as detailed description of the eastern part of the Bay of Naples have been done by previous authors (Finetti et al., 1974, Bartole et al., 1984; Bruno et al., 2000; Bruno et al., 2003; Bruno 2004, Aiello et al., 2004; Milia and Torrente, 1997; 1999).

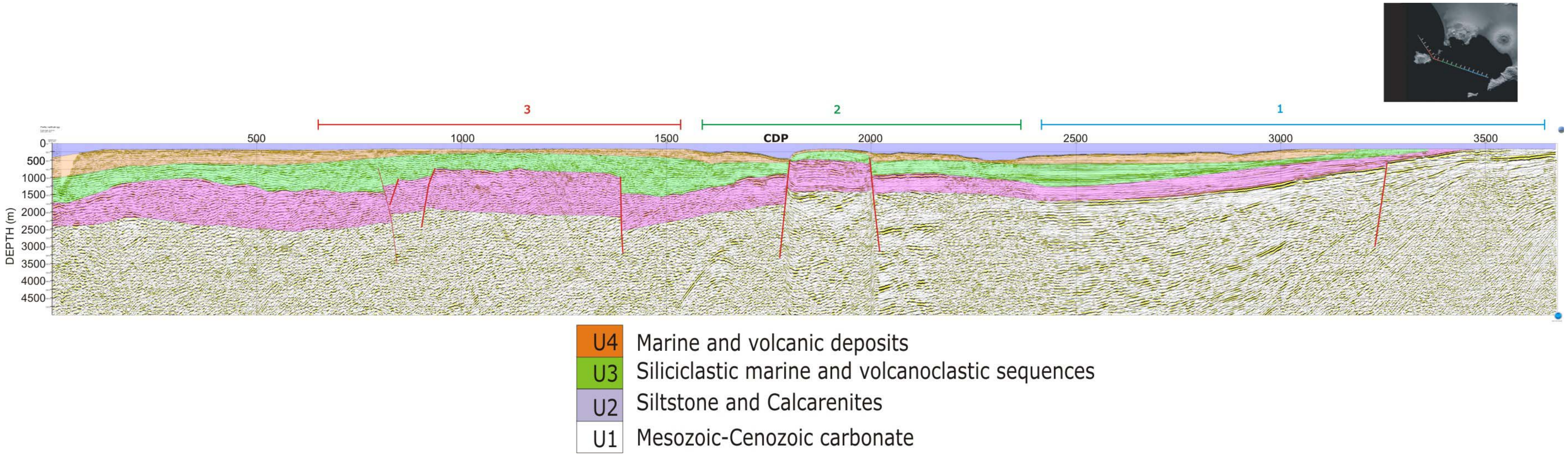


Fig. 32: Seismic line Na-09. Depth conversion of seismic reflectors was made using *GeoSuite* software.

3.3.2 The uplift of Ischia

The interpretation of seismic lines (i.e. Na-13 (fig. 33) - CDP 700-1300 fig. 34) can be used to unravel the mechanics of uplift of Ischia Island. Uplift and resurgence, are phenomenology common in volcanic systems, caused by inflation-deflation processes inside magma chambers (Smith and Bailey, 1968; Lipman, 1984; Newhall and Dzurisin, 1988; Lipman, 1997). The precise modalities under which resurgence structures form are still debated.

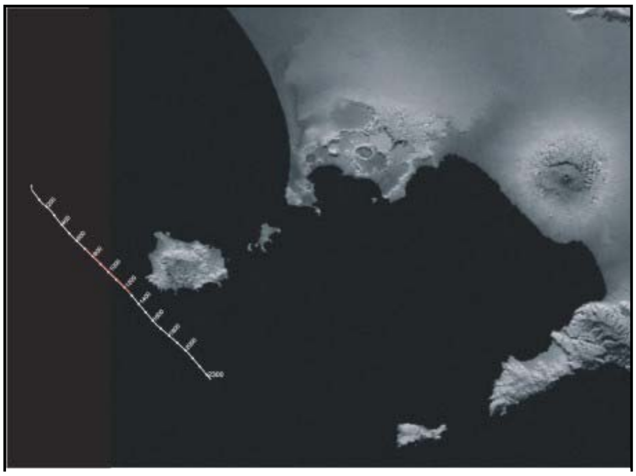


Fig. 33: Seismic line Na-13

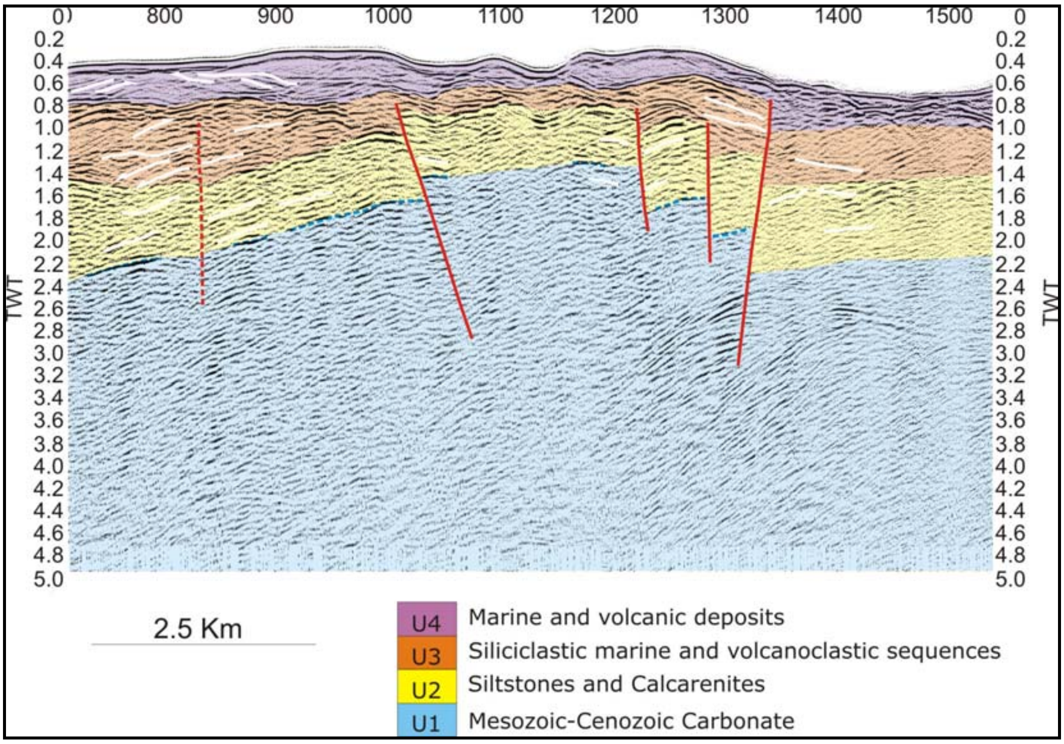


Fig. 34: Part of seismic line Na-13 (CDP 700-1500).

The geometry of resurgence, in fact, is a three-dimensional problem which has long been overlooked because well exposed resurgent structures are rare. Ischia, representing only a part of a larger volcanic field, could be used as a key example of a young, rapid and ongoing caldera resurgence.

The rising of Ischia block could be associated to an intrusion of a laccolith as already hypothesized by Nunziata and Rapolla (1987) and Carlino et al. (2006) and as well as by Rittmann (1930) only on the basis of volcanological data. The active resurgent block of Ischia shows an uplift of about 1000 m in the last ~30 ka (according to Gillot et al., 1982); the volcanic and seismic activity and the ground deformation of the past 2000 years are likely connected to the existence of a laccolith (Carlino et al., 2006). This body, with a hypothesized diameter of 10 km and a depth of up to 1,5 km in the centre of the island, is thought to have triggered the caldera resurgence after the Mount Epomeo Green Tuff eruption (55 ka years ago) and to have controlled the dynamic of the island afterwards (Carlino et al., 2006).

Our study is focused on a broader time and spatial scale, revealing a longer and larger volcano-tectonic history. In particular seismic unit U3 (fig. 35 – CDP 1200-1600) thicken laterally from 500 m on top of the resurgent dome to about 1000 m on the side of the dome. This indicates that uplift of about 7-9 Km dome was occurring during sedimentation and outward progradation of the seismic unit U3. This feature probably indicates local rapid sedimentation coeval with Ischia island uplift. The assumption of a local tectonic isolation of Ischia from Campi Flegrei is hypothesized also by Nunziata and Rapolla, 1987 and Berrino et al., 1991. The uprising of the basement to about 1 km beneath the island of Ischia is showed by Berrino et al., 2008 on the basis of quantitative interpretation of the Bouguer anomaly. Nunziata and Rapolla (1987) suggest that the basement is probably igneous, in accordance with previous gravity and magnetic interpretations (Carrara et al., 1972, 1973); instead it is also suggested (Berrino et al., 2008) that the uprising of a carbonate basement induces most of the gravity signal.

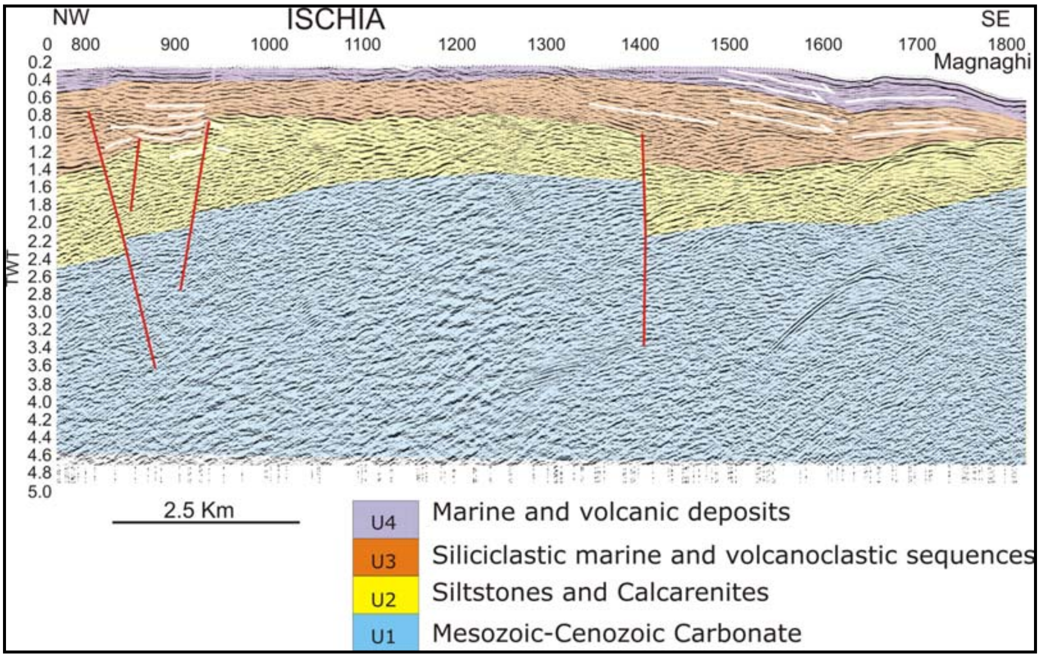


Fig. 35: Part of seismic line Na-09 (CDP 800-1800)

Unconformity C between seismic unit U3 and U4 (fig. 35) show that uplift produced two sub-areal erosion on top of the dome. The unconformity could results either from a low-stand of the sea level or a quiescent/subsidence phase. The uplift geometry is accommodate by two concurring mechanisms. The first produces a broad scale (~ 10 Km) wide doming. The second uplifting mechanism, more localized in the inner portion of the dome, is related to faulting. An isochrone two-way time map (fig. 36) relative to the seismic Horizon B, traceable over a large area, has been produced in order to reconstruct the

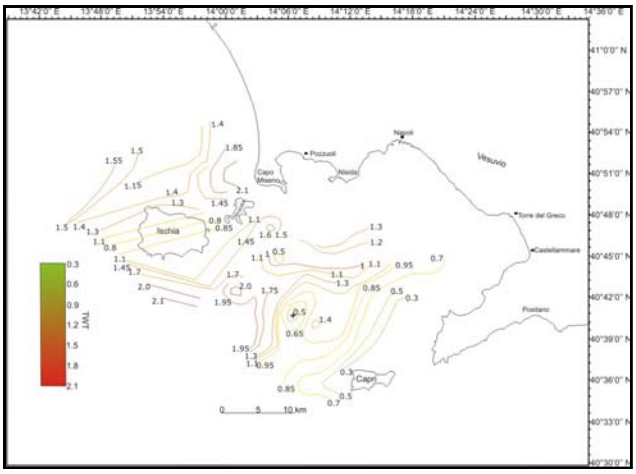


Fig. 36: Time isopach contour map of seismic horizon B

tectonic framework of the Bay of Naples and to evaluate the uplift of

Ischia. The contour lines, obtained by the interpolation of the information along all the seismic lines, show:

- Near the Sorrento Peninsula an almost regular dip;
- A more complex trend near the Campi Flegrei volcanic Ridge;
- NW of Procida Island, the isolines assume a sub-circolar shape evidencing the presence of a depression with a caldera-like feature;
- Near Ischia Island, the isochrones vary from 1.4 s (TWT) in the northwestern sector to c. 0.8 s (TWT) in the Ischia island central area, down to less than 2.1 s (TWT) in the southeastern sector. The amount of the uplift of Ischia (a velocity of about 2000 m/s was considered representative for the Late Quaternary seismic units) is about 1200 m.

High-angle, inward dipping, reverse faults bounds the inner portion of the uplifting dome (fig. 34). These faults upthrow the U2 pre uplift unit in the inner block of about 500 m (fig.35). Locally, outward dipping normal faults, are also observed. This style of deformation is commonly observed both in the experiments and in nature. In experiments, reverse faults were obtained simulating resurgence (Sanford, 1959; Davison et al., 1993; Schultz-Ela et al., 1993; Marti et al., 1994; Merle and Vendeville, 1995; Acocella et al., 2000, 2001) (fig. 37); in nature, reverse faults border calderas (Mori and Mckee, 1987) and resurgent domes (Skilling, 1993; Orsi et al., 1996; Acocella and Funiciello, 1999; Schirnick et al., 1999). Outward-dipping normal faults subsequently develop in the innermost part of the block. Their formation is probably due to a gravitational sliding of the periphery of the volumes bordered by the reverse faults (Molin et. al, 2003). Faulting thus partly

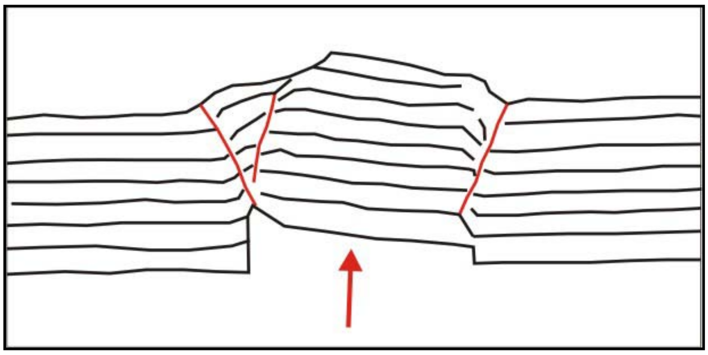


Fig. 37: Cross-section view of the final state of deformation of an experimental resurgent block (taken from Acocella et al., 2003).

accommodate uplift of the block, to balance the space problem created by resurgence.

The seismic line Na-13 (CDP 800-1500) (fig. 34) has been restored as sketched in the four-stage scenario below (fig. 38):

Stage A (Late Miocene - Lower Pleistocene): Unit U2 deposits overly the Meso-Cenozoic substrate (unit U1).

Stage B (Middle Pleistocene): initial deposition of seismic unit U3 probably related to an initial stage of magma emplacement and uplift

Stage C (Upper Pleistocene): uplift and doming of Ischia island is connected to the emplacement of a magmatic intrusion: progradational structures within seismic Unit U3 are developed.

Stage D (Late Quaternary): After a period of a low-stand of the sea level or a quiescent/subsidence phase a new gravitational disequilibrium, induced by vertical movements, generated the prograding unit U4 downlapping above reflector C. The uplift is controlled by the activity of the high-angle inward-dipping reverse faults; outward-dipping normal faults in the innermost part of the block are developed.

The interpretative model shows:

- Total uplift is about 1200 m;
- The rate of uplift is about 0.2 cm/y;
- Resurgence was probably discontinuous and took place through intermittent uplifting (with intense erosion and redeposition) and tectonic quietness phases.
- The ellipsoidal laccolith hypothesized beneath Ischia Island, with an approximately diameter of 10 km and 3 km thickness, was emplaced at a depth of about 3500 m.

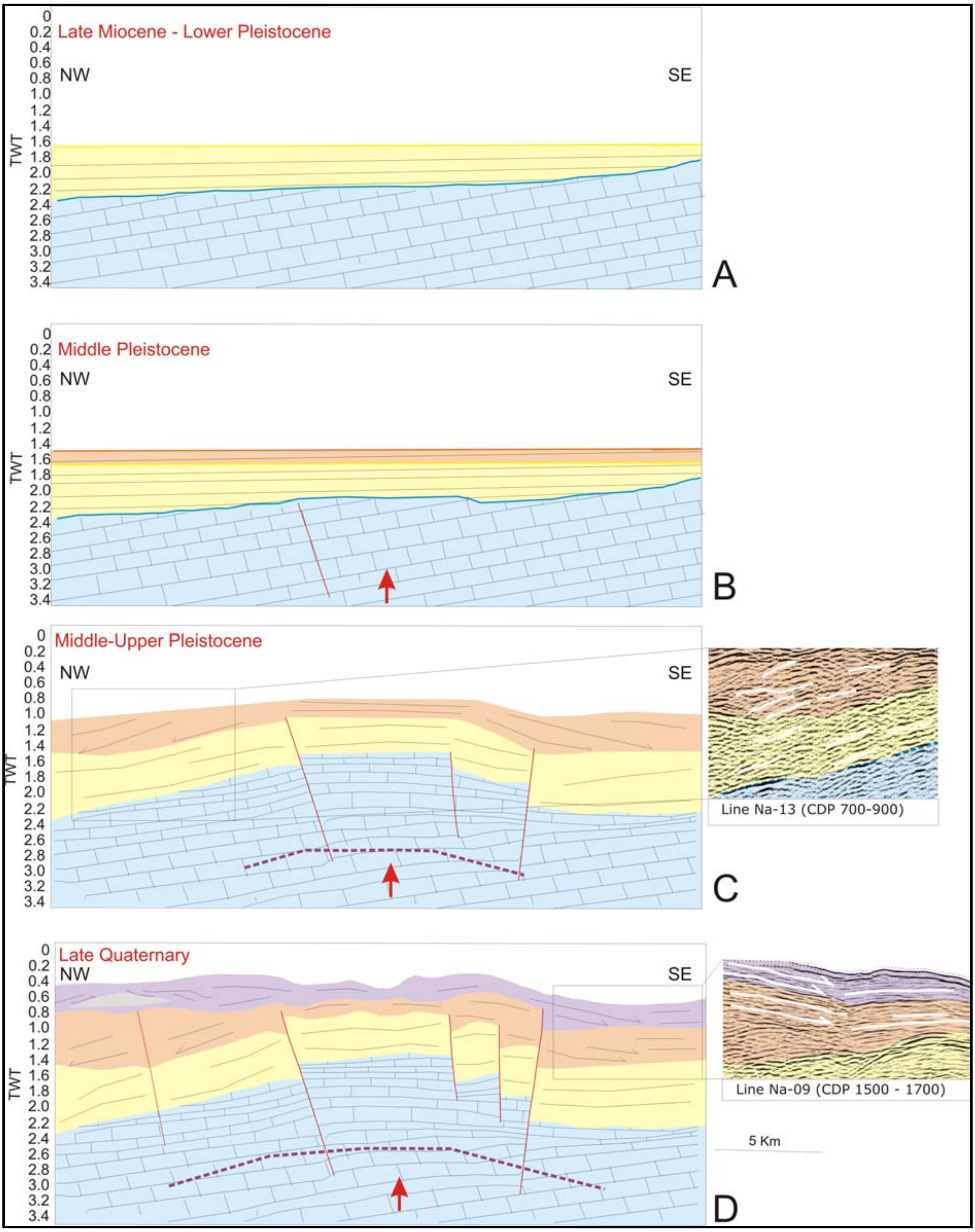


Fig: 38: Evolution scheme of Ischia Island.

3.3.3 Data analysis

Seismic lines permitted to found evidence of other small volcanic intrusion at different levels within the crust in Campi Flegrei Volcanic District (fig. 39). Those sills mainly emplace between Unit 2 and unit 3; therefore their age is younger than Lower Pleistocene and Middle Pleistocene, respectively.

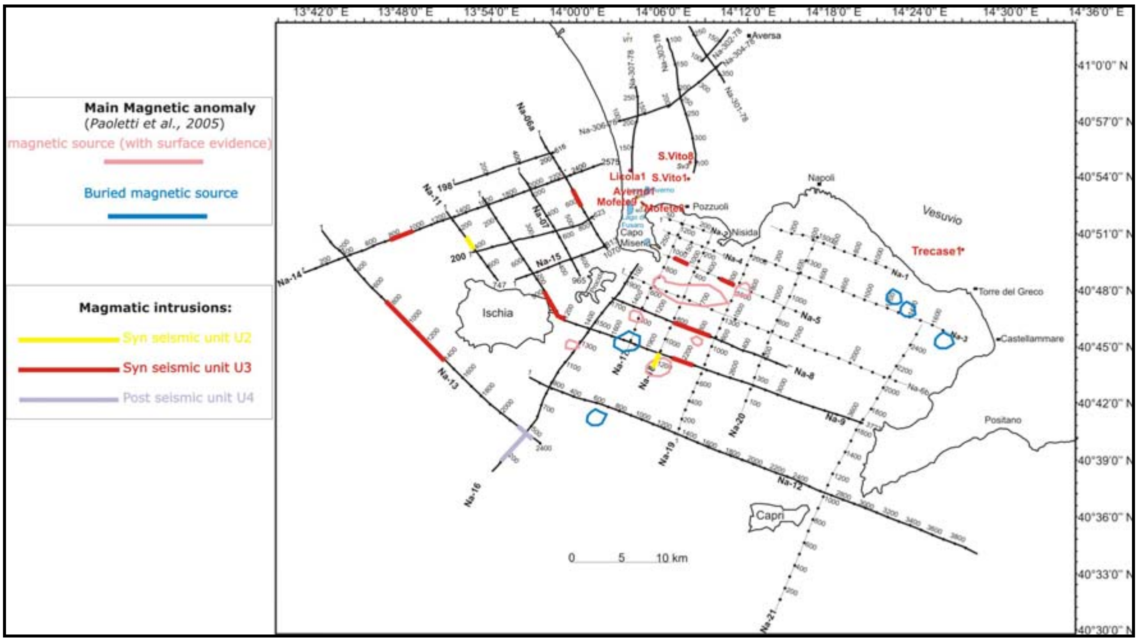


Fig. 39: The map, as recognized in the seismic lines, puts in evidence the emplacement of magmatic intrusions age-differentiated, according to the seismic units interested by the intrusion. Main structures (taken from Paoletti et al., 2005) are reported: the buried magnetic sources of volcanic origin are in blue, the magnetic sources of volcanic origin characterized by surface evidence are in pink.

In the northern area of the bay, the Campi Flegrei offshore, the shelf is irregular, because of the presence of several banks whose morphologic characteristics suggests that they are volcanic edifices (Orsi et al., 1996). Line Na-09, in correspondence of CDP 1830-2030 (fig. 22), in the median zone between the Dohrn and Magnaghi canyons, crosses one of these structural high. A qualitative correlation with the magnetic field puts in evidence a high magnetic susceptibility of this last structure;

there is a good correlation, moreover, between the anomaly shape and the geomorphology of the deep sea (fig. 40). Recent studies (Aiello, 2004) associate this field of anomaly to the submarine volcanic bank called "Gaia".

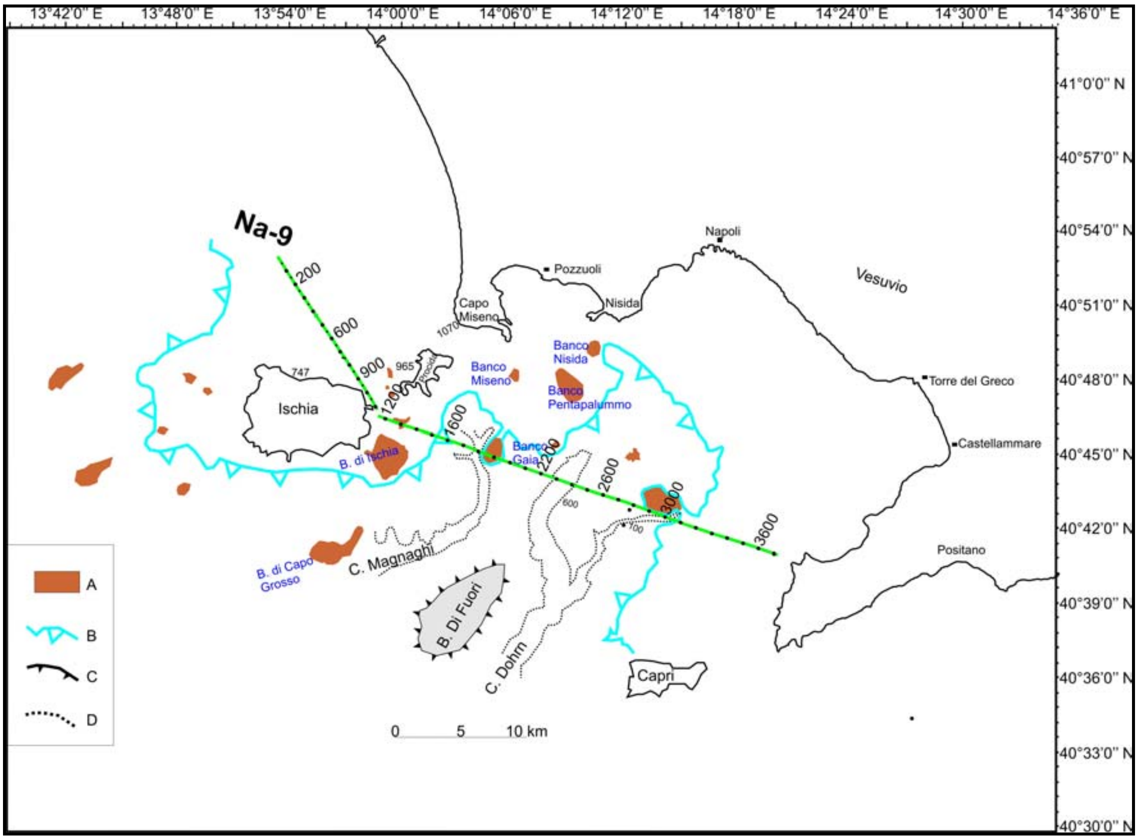


Fig.40: Geomorphology sketch map of the studied area (modified from Aiello et al., 2004; Bruno et al., 2003). A) Volcanic bank; B) Shelf Break; C) Slope of the "Banco di Fuori" structural high; D) Canyon wall. Na-09 seismic profile in correspondence of CDP 1900 crosses the volcanic bank called "Gaia"

Volcanological, geochemical, structural and geophysical data suggest that the CF and the Vesuvius plumbing systems are different (fig. 41) (Piochi et al., 2005). In particular a widespread fissure-type system fed by multiple dikes appears to be active beneath the CF (De Astis et al., 2004). Such a magma supply system (Figure 41, right side) is most consistent with the main geological features of the CF: (1) a widespread distribution of thermal springs (Caliro et al., 1999; Chiodini et al., 2003; Inguaggiato et al., 2000; Panichi et al., 1992; Panichi and Volpi, 1999) and fumaroles (Chiodini et al., 2001b; Rosi and Sbrana, 1987); (2) the highly fractured nature of the upper crust as revealed by seismic reflection data (Bruno et al., 2003); (3) a generally high heat flow; (4) the highly magnetized nature of the crust as inferred from aeromagnetic data (Agip, 1981). All these features suggest pervasive distribution of magma bodies within the crust. By contrast, a long-lived central magma supply system is hypothesized for the Vesuvius (Fig 41, left side) (Piochi et al., 2005). This kind of system is also supported by the existence of a highly rigid (De Natale et al., 2001; Vilardo et al., 1999) and magnetized (Fedi et al., 1998) crustal volume representing the volcanic conduit that extends from the crater down to about 5 km of depth. Therefore, sills emplacement could be related to the CF tectonic-volcanic system and associated to the stress produced by the magma intrusion. In areas characterized by high deformation rates (such as CF), in fact, is favoured the formation of a high number of monogenetic centers (Takada, 1994a). In this interpretation, intrusive processes could be ultimately accounted for the rapid uplift of Ischia resurgent structure.

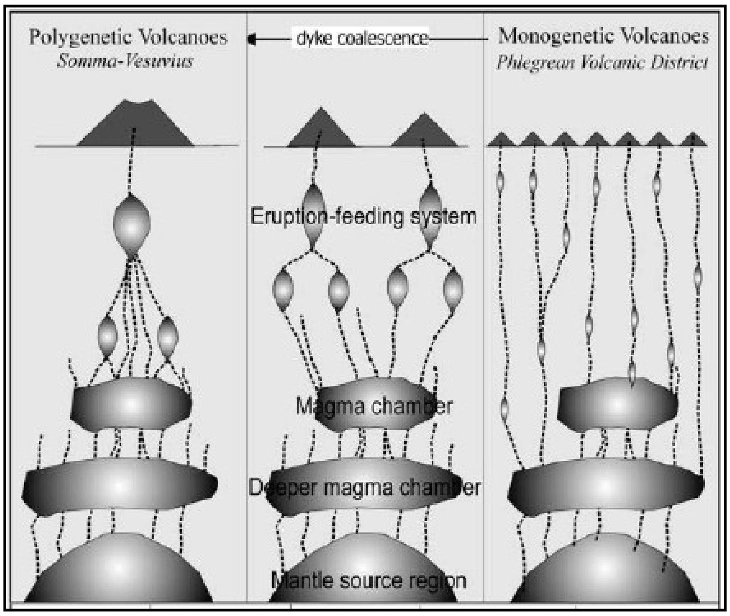


Fig. 41: Sketch of magmatic system. The different tectonic regime at CF and Vesuvius controls the magma supply systems and volcanic styles. Polygenetic volcanoes develop in areas characterized by low deformation rates; by contrast, high deformation rates prevent dike coalescence and favour monogenetic centers. This latter condition generally occurs in rift regions. (taken from Piochi et al., 2005)

Seismic line Na-09 (fig. 20) shows that the western sector of the Bay of Naples is characterized by the prevalence of seismic units of volcanic nature, while the eastern zone is characterized by sedimentary successions. The transition between the sedimentary infilling and the volcanic deposits is evidenced in seismic sections Na-12 (fig. 24), Na-08 (fig. 25) and Na-09 (fig. 20). In these seismic sections, the seismic unit U4 shows a heteropic passage between marine sediments, characterized by parallels and continuous reflectors and volcanic related sediments. A limit can be roughly place in correspondence of CDP 800 of Na-08, CDP 2300 in the Na-09 and CDP 1500 of Na-12 (fig. 42).

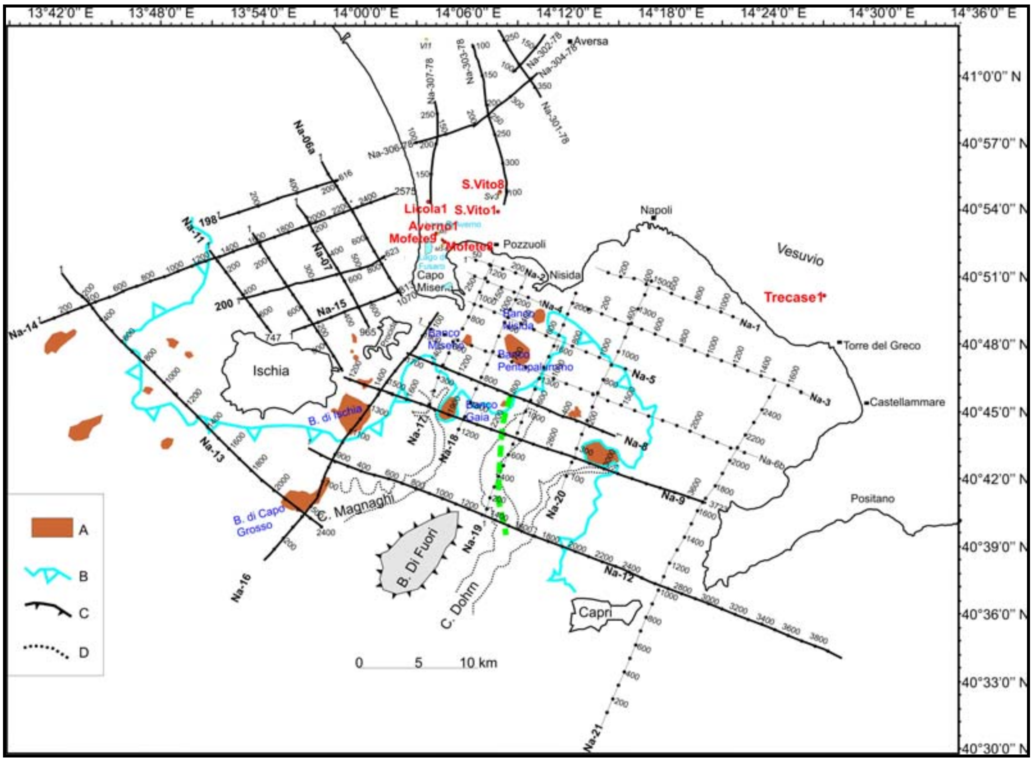


Fig. 42: Geomorphology sketch map of the studied area (modified from Aiello et al., 2004; Bruno et al., 2003). A) Volcanic bank; B) Shelf Break; C) Slope of the "Banco di Fuori" structural high; D) Canyon wall. The dashed green line represents the passage between volcanic/marine sediments.

The above limit follows the western branch of the Canyon Dhorn. In such context, the "Banco di Fuori" could have been an obstacle to the propagation of the volcanic deposits coming from CF volcanic district (Aiello et al., 2005).

The late Pleistocene volcanic activity of the Neapolitan volcanoes (Campi Flegrei, Ischia and Procida islands) experienced caldera collapses with thick accumulation of proximal pyroclastic deposits. Line Na-15 allows to delineate a structure with caldera-like aspect (fig. 28). This structure, situated less than two kilometres from the coastline, could be genetically connected to eruption of Campanian Ignimbrite. Seismic unit U4 (CDP 500-800), in fact, can be related to fallout deposits that comprise alternating ash and lapilli beds emplaced during Plinian/sub-Plinian eruptions (Di Vito et al., 2008). Probably these deposits were emplaced between Pomici di Base (18 ka) and CI (39 ka) eruptions, a period characterized by six large explosive events. Pyroclastic deposits, in fact, in this time span are known for Procida Island (activity of the Solchiaro volcano; 19,620±270 ky BP; Alessio et al., 1976; Pescatore and Rolandi, 1981; Rosi et al., 1988) and Torregaveta volcano (fig. 43) (eastern part of Campi Flegrei caldera; Pescatore and Rolandi, 1981; Rosi and Sbrana 1987; Lirer et al., 1991; Orsi et al., 1996; Pappalardo et al., 1999), where eruptive activity is older than 18–19 ky BP (De Astis et al., 2004).

Fig. 43: Location map of the seismic line NA-15, showing Procida Island and Torregaveta volcanic sources. (modified from di Vito et al., 2008)

Fig. 44, shows the fault pattern obtained by spatial interpolation of fault traces along single profiles. The faults evidence a prevailing strike NE-SW and ENE-WNW. In the Bay of Pozzuoli NW-SE faults also occur and N-S striking faults are evidenced in NNE sector of Ischia.

The NE-SW trending faults which border the Campi Flegrei area can be interpreted as structures of the strike-slip 41° PL fault (Bruno, 2000). 41 PL fault, formed in response to the different rates of opening of various sectors of the Tyrrhenian Sea (Serri, 1990), has a predominant left lateral movement. NE-striking faults of CF can be interpreted as subordinate structures related to the 41° parallel master fault (Piochi et al., 2005). The NE-SW trending faults can alternatively be interpreted (Acocella 1999, Hippolyte, 1994) also as transfer faults connected NW-striking faults developed during the Appennines orogenic phase. These faults demonstrate a dynamics of extension oblique-type. In agreement with Bruno (2003) and McClay (1995), such fault systems is connected with a transtensive tectonic which well justifies an extensional dynamics oblique-type that is characterized by segmented faults with disposition "en echelon" with respect the main structure.

The study area presents also N-S striking faults evidenced in NNE sector of Ischia. These faults, as shown in the seismic profile Na-15 (fig 28; CDP 600-800) are connected to structures with caldera-like aspect. Therefore, N-S striking faults, situated less about five kilometres from the coastline, close to the western boundary of the Campi Flegrei caldera, may be interpreted as structure related to caldera formation.

A NW-SE strike fault, localized to the north of Ischia, is also recognizable. Such system may be directly connected to the resurgence of Ischia. Acocella-Funiciello, 1999 proposed, in fact, that NE-SW regional faults have been reactivated during resurgence.

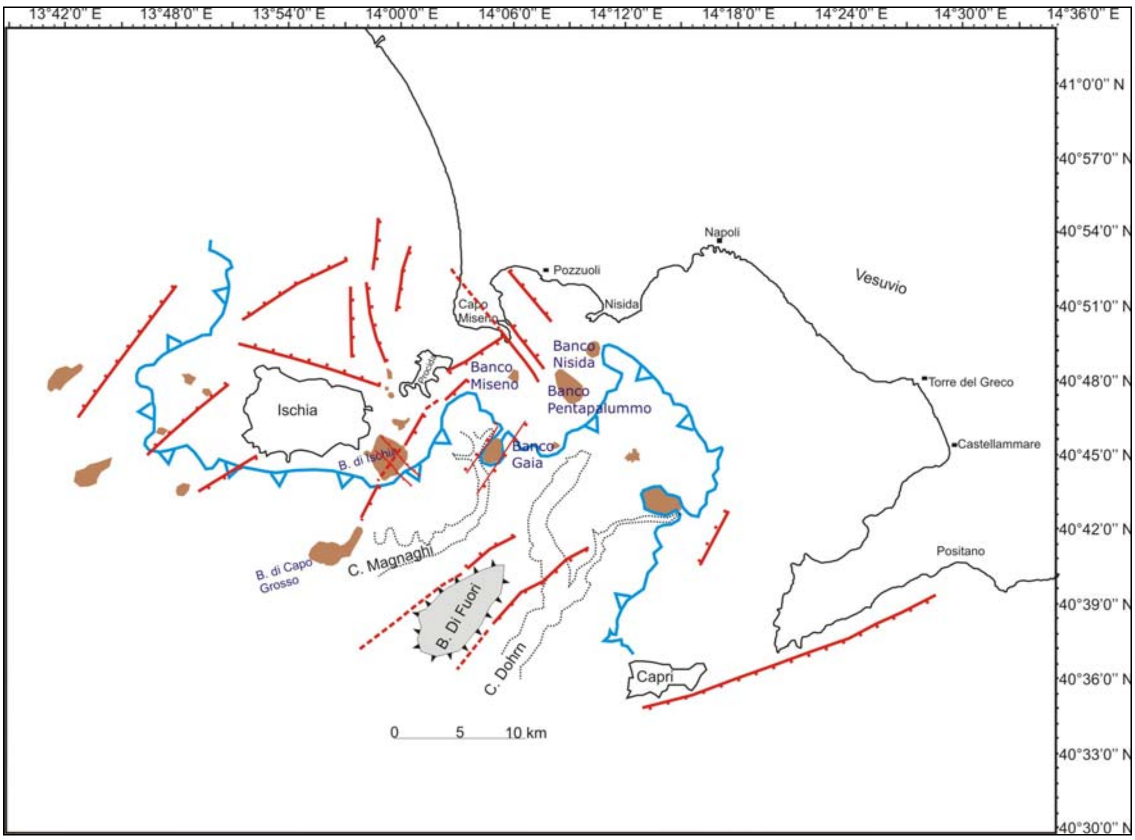


Fig. 44: Structural scheme of the study area.

The volcanic bank detected in the seismic sections like the Bank of Pentapalummo, situated inside of the inner continental shelf, on Na-08 (fig. 25 - CDP 900-1100) or the Bank of Ischia, localized between the islands of Procida and Ischia, on the Na-16 line and the Bank of Gaia, situated near the continental slope, on Na-09 (fig. 20 - CDP 1830-2030), are aligned approximately along NW-SE direction, as evidenced also in the geomorphologic map (fig. 42). Taking into account that: - the western sector of Ischia is characterized by NE-SW and E-W volcanic morphologies (Bruno et al., 2000); - several monogenetic volcanic edifices along NE-SW lineaments are present to SW of Ischia (Vezzoli, 1998); - the magnetic anomaly field (Aiello, 2004) (fig. 45) offshore Campi Flegrei shows a NE-SW trending: it results that the volcanism and the tectonic develop along a fault system oriented NW-SE and that NE-SW strike faults could be a preferential pathway of magma rising.

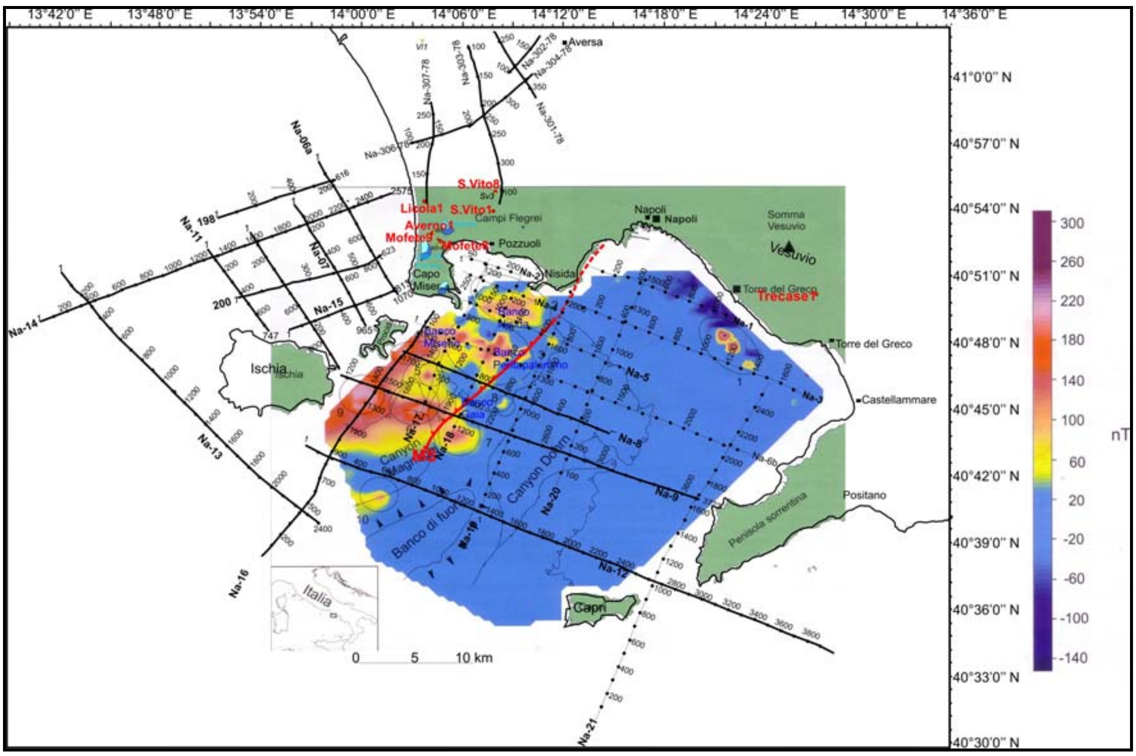


Fig. 45: Anomaly map of the total magnetic field of the Gulf of Naples (modified after Aiello et al., 2004). In correspondence MS fault, the area is characterized by high values of magnetic anomaly while to the east of such tectonic lineament there are magnetic source only near the Somma-Vesuvius coast.

Using the seismic information, it is possible to reconstruct, at a broad scale, the Quaternary tectonic and stratigraphic evolution in the Campi Flegrei Volcanic District (fig. 46). In particular, five fundamental stages are distinguished:

Stage A (Plio-Pleistocene): Unit U2 deposits overly the Meso-Cenozoic substrate (unit U1). U2 marks the beginning of a period of subsidence that is associated with the incipient transtensive tectonic activity which gave rise to the accomodation space in the bay of Naples.

Stage B (lower Pleistocene): the rapid variation in the physiographic configuration of the bay is related to the rotation of the fault block and the production of two deep hangingwall basins. The Bay of Salerno basin, associated with the Sorrento Peninsula fault, is separated from the bay of Naples by the emergent crest of the block. Unit U2 was involved in tectonic tilting with the carbonates.

Stage C (middle Pleistocene): As shown on seismic line Na-11 (fig. 27) and Na-13 (fig. 29), the first episodes of magma intrusion (within seismic unit U2) on the footwall of normal faults are developed.

Stage D (upper Pleistocene): progradation of sequence U3 from NE to SW led to formation of a wide shelf in the central Bay of Naples. This stage was characterized by tectonic stability. In the western CF offshore area, the interpretative model outlines the uplift of Campi Flegrei-Ischia ridge: the monocline structure of the carbonate basement developed in the Gulf of Naples is abruptly interrupted by a fault system with large throws which isolate a horst-like structure beneath Ischia. Seismic lines Na-14 and Na-06 (fig. 26) show a second episode of magmatic intrusion.

Stage E (present day): After the deposition of sequence set U4, the physiography of the Bay was similar to the present day. A lateral transition between the sedimentary infilling (eastern sector) and the volcanic deposits (western sector) occurs.

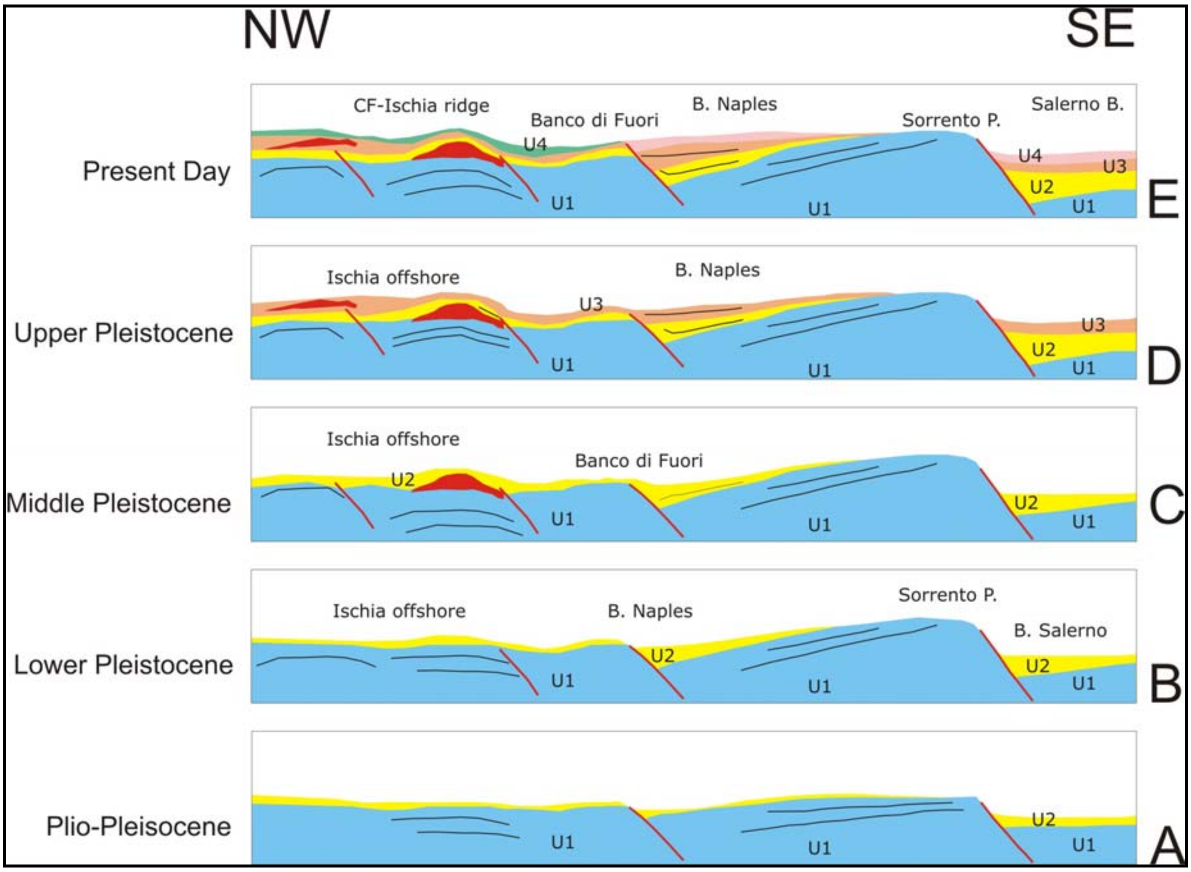


Fig. 46: Evolution scheme of the study area

Moreover, restoration of seismic line Na-09 suggests a two-dimensional cartoon representing the complex volcanic-tectonic evolution of the Bay of Naples (fig. 47):

Stage A (Mid-Pliocene – Early Pleistocene): Extension took place in the Campania region, giving rise to the Bay of Naples. Deposition of seismic unit U2 occurs.

Stage B (Middle Pleistocene): onset of magmatic activity (CDP 2000-2500) which induced vertical movements; initial deposition of seismic unit U3 onlapping above unconformity C.

Stage C (Upper Pleistocene): uplift and doming of Ischia Island;

Stage D (Late Quaternary): the northern sector of the continental shelf developed a system of banks of volcanic origin (e.g. Banco di Gaia). Seismic unit U4 (Volcanic units interlayered with marine sediments) formed. The submarine topography is dominated by two canyons which cut the continental slope of the Bay of Naples: the Magnaghi Canyon and the Dohrn Canyon.

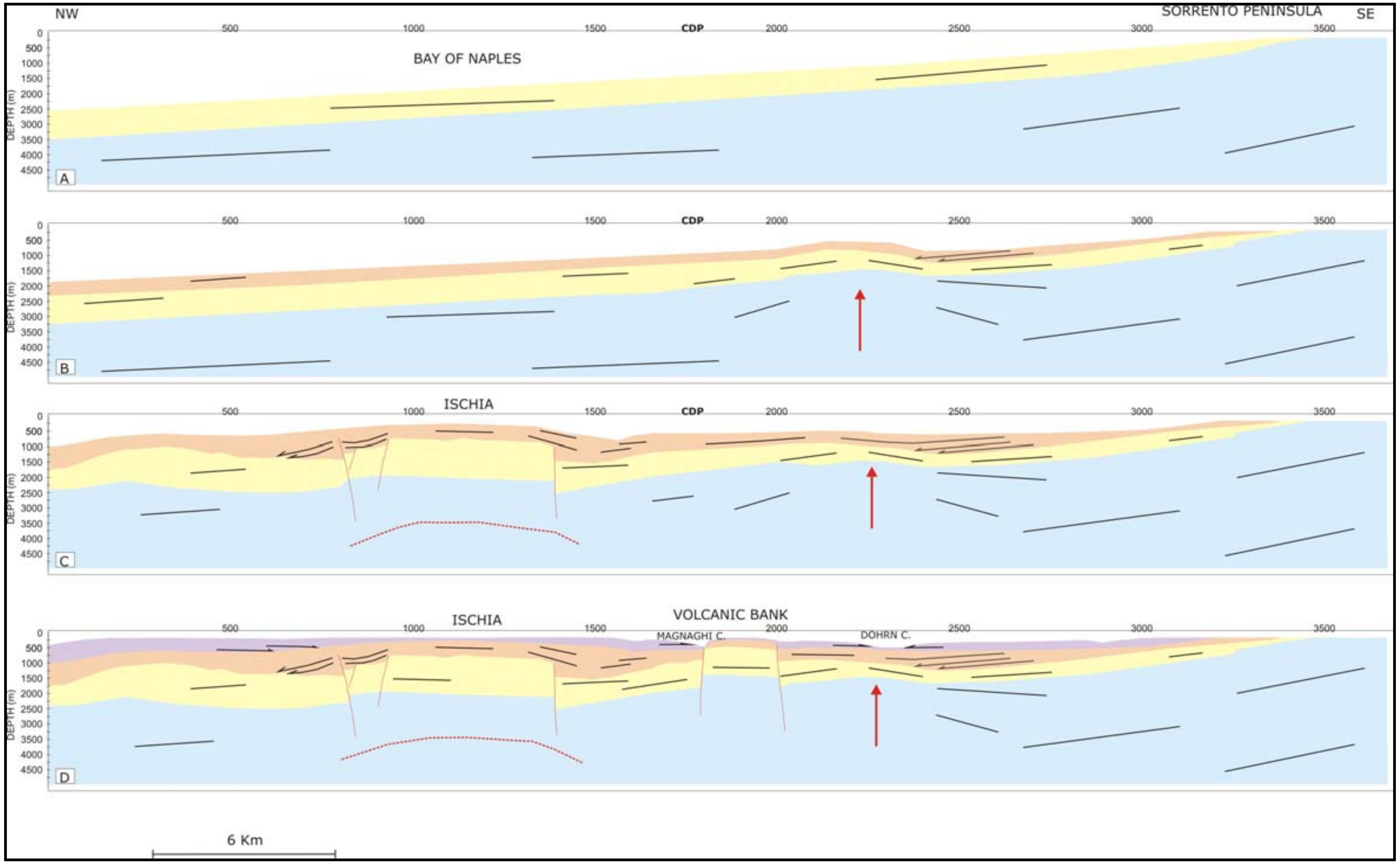


Fig. 47: Four-stage scenario of the Bay of Naples

CHAPTER 4

Reprocessing and interpretation of seismic lines onshore Campi Flegrei

4.1 Introduction

During 1978, AGIP geothermal research branch carried out a seismic survey in Campi Flegrei (CF) onshore area. The network of 7 lines was concentrated in the NW area of the volcanic complex. An explosive source (5 Kg of dynamite, in a well of 20-30 m deep) was used for the lines. The trace record length was 6 s. with a sampling interval of 2 ms. A total of 14 Hz vertical geophones, were arranged in groups (or patterns) of 24 units. A total of 48 geophone groups, deployed as a split spreading in the field, were utilised during the acquisition phases.
The selected seismic lines, Na-306-78 and Na-307-78 (fig. 48), are localized at the passage from northern zone of the Campi Flegrei to the southern sector of Volturno Plain.
A reprocessing of these seismic lines permitted to increment signal/noise ratio and to improve vertical and horizontal resolution. The aim was to improve the data quality from the elaboration of 1978. In parallel with the processing of the seismic data, Licola1 well log has been digitalized and processed. I elaborated sonic log (Bhc), radioactive log (Gamma-ray) and electrical log (Dual laterolog) to gain geologic ties on which founding the interpretation of the seismic lines. Interpretation of first arrivals by means of seismic tomography of all Eni-Agip seismic lines belonging to the "Naples" permit, is carried out. Seismic reflection data processing benefit of tomographic inversion of first arrivals to improve the performance of the static corrections and the imaging of the shallow structure (0-300 m deep).

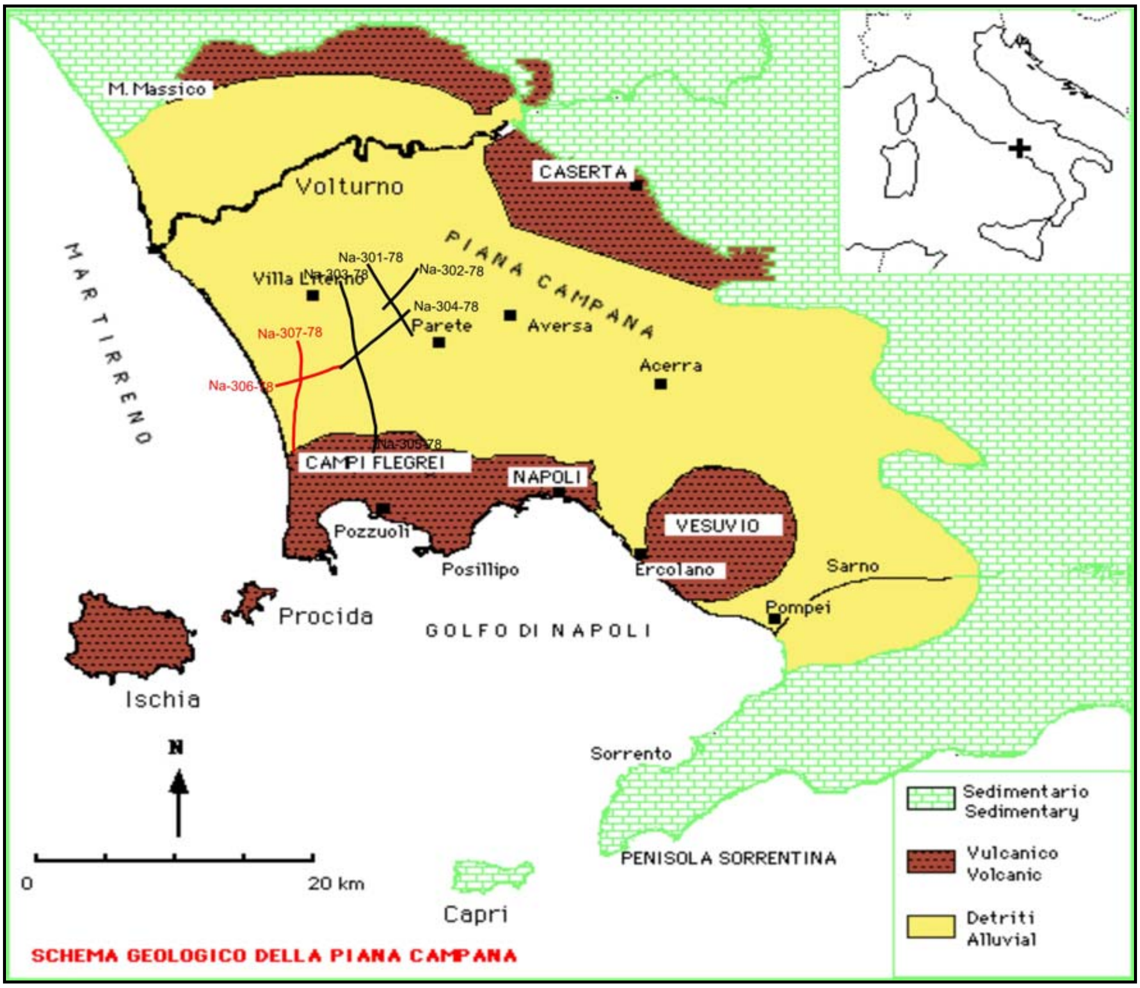


Fig. 48: Geologic sketch map of Campanian Plain (taken from Berrino et al., 2008) with position of AGIP seismic lines.

The shallow seismic imaging is very poor due to the superficial geology (volcanic sequences), strong lateral Vp changes, acquisition gaps and to an overall low CMP folding. Consequently, the shallow-intermediate structures are poorly imaged. Seismic tomography are used to extend the seismic imaging not sampled by the deep multichannel seismics.

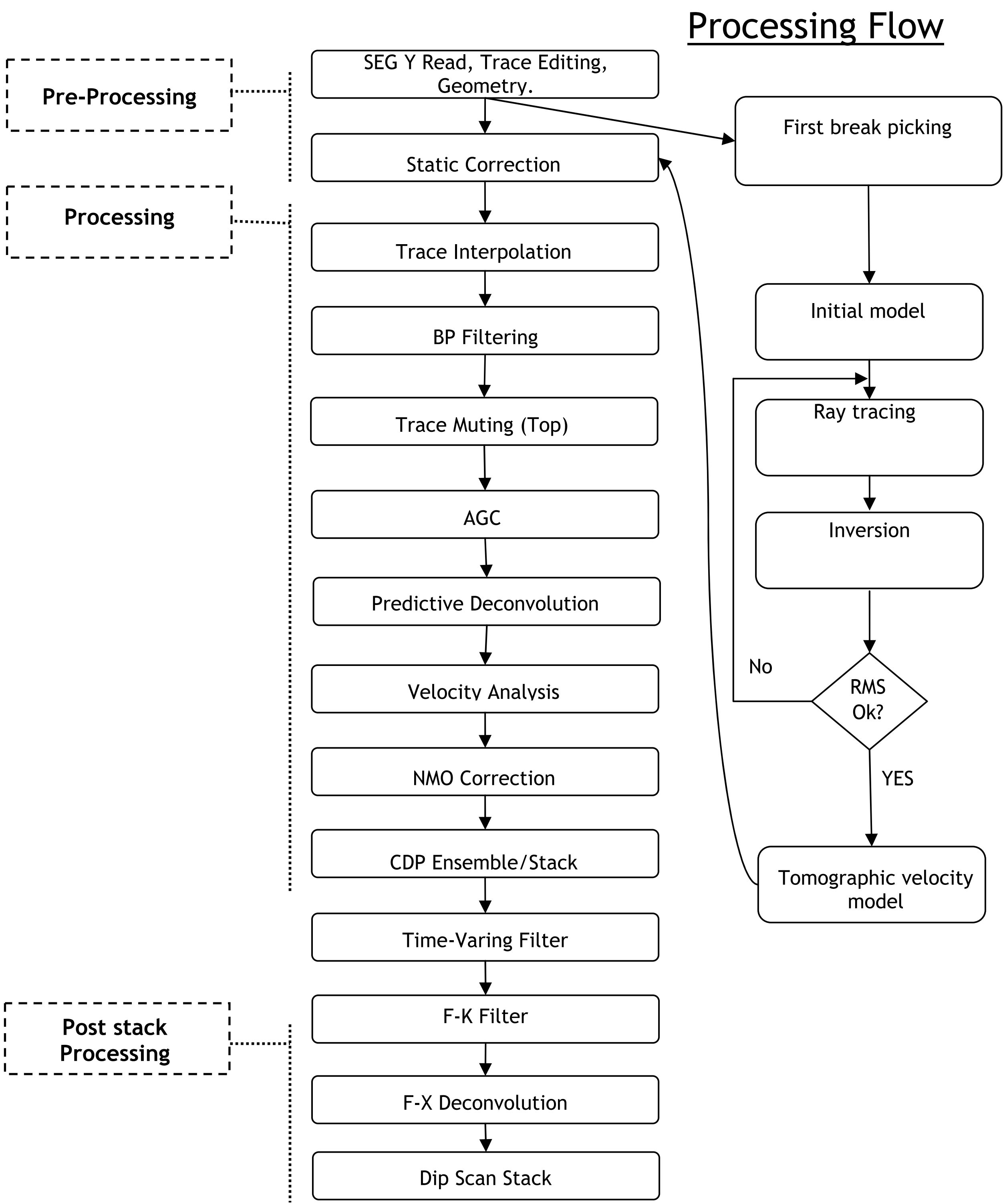
The processing of the seismic lines Na-307-78 and Na-306-78, followed the same processing-flow applied by oil industry for the processing of land seismic data. In table 2 some of the acquisition parameters of the two lines are reported. The reprocessing of seismic data, by means of most recent techniques aiming to the enhancement of signal to noise (S/N) ratio, yielded an improvement of data quality. However, it must be emphasized that the low redundancy and low bandwidth (due also to the application of analogical filers during the acquisition) of the seismic dataset, reduced the reprocessing performance.

The processing sequence (Table 3) was aimed 1) to reduction of random noise in the data; 2) to removal of unwanted coherent events and 3) to reduction of spatial aliasing by means of trace interpolation on Common Shot Point (CSP) gathers. Pre-stack predictive deconvolution weakened multiple reflections. The last process applied to the post-stacked data was the Frequency-Space (FX) deconvolution. FX deconvolution, a reliable multi-channel noise-reduction filter, preserved the most dominant dipping energy while removing random noise or dips with very low energy (Cary and Upham, 1993).

The achieved improvement has been considerable even although it was limited by the way the data were acquired in the field.

LINE	**Na-307-78**	**Na-306-78**
Lenght	9350 m	6750 m
N. of shots	37	21
Geophone spacing	50 m	50 m
Source spacing	50 m *Average*	50 m *Average*
Source	Esplosive	Esplosive
Depth source	20 m / 30 m	20 m / 30 m
N. of CDP	349	223
Maximum folding	7	7
Sampling Rate	2 ms	2 ms
Record lenght	6000 ms	6000 ms

Tab. 2: Acquisition parameters of Na-306-78 and Na-307-78 seismic lines


Processing Flow
Pre-Processing
Processing
Post stack Processing
SEG Y Read, Trace Editing, Geometry.
Static Correction
Trace Interpolation
BP Filtering
Trace Muting (Top)
AGC
Predictive Deconvolution
Velocity Analysis
NMO Correction
CDP Ensemble/Stack
Time-Varing Filter
F-K Filter
F-X Deconvolution
Dip Scan Stack
First break picking
Initial model
Ray tracing
Inversion
RMS Ok?
No
YES
Tomographic velocity model

4.2 Interpretation of the seismic lines

The Licola1 well log (fig. 49), located at CDP 355 of line Na-307-78, constrained the interpretation of the seismic reflection data. Data logs, in fact, are fundamental for correlation in geophysical exploration. Comparison between seismic sections and well log data allows the associations of litotype to variations in physical property. Licola 1 well log include the dual laterolog (DLL), resistivity and gamma-ray log. DLL resistivity permitted a good characterization of highly resistive rocks; gamma ray spectrometry was, moreover, a very useful tool to determining lithology. To compare the log data with seismic sections the pseudo-velocity and the pseudo-density log were derived from the DLL resistivity. Log recording in Licola 1 starts at 235 m of depth (fig. 49-A). Volcanic tuffs (with relatively homogeneous values of gamma ray emission and resistivity) are found down to a depth of 1400 m from the surface. Three lava beds are present at about 1400 (L3 - fig. 49), 2000 m (L1 - fig. 49) and 2500 (L2 - fig. 49). Very good correlation exists between these lithological changes and the well logs which exhibit strong positive peaks in correspondence to lava layers. On the synthetic seismograms (fig. 49-E) the main reflections originate in correspondence to the lava/tuff interfaces. In particular at Licola 1, lava layers are characterized by much higher resistivity and pseudo-velocity with respect to tuffs. Differences among tuffs and between tuffs and lavas can also be roughly picked because of their gamma-ray emission. In the Licola1 well, a very-thick layer of sandstones with frequent intercalations of tuffs and lavas extends from 1565 down to 1960 m (fig. 49-A). Sandstones are peculiarly characterized by lower values of gamma ray with respect to volcanic rocks (fig. 49-B). Below 1960 m, volcanites (mainly tuff layers) prevail with respect to sedimentary rocks down to the bottom of the well (2662 m). Contemporaneous presence of lava, tuffs and sandstones at these depths may indicate the early stage of CFVD volcanism, with mainly submarine activity. (Bruno, 2004).

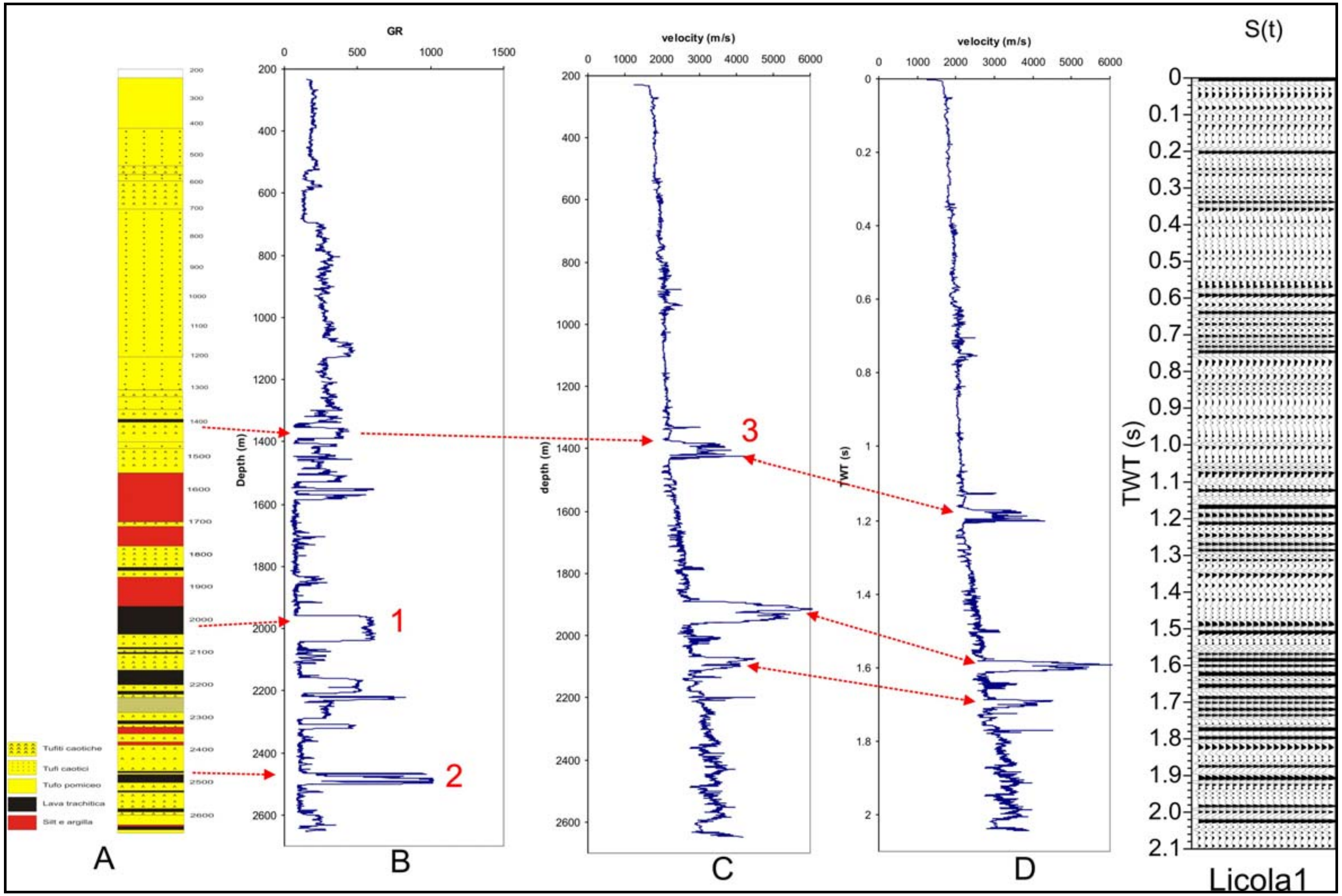


Fig. 49: A, stratigrafic column; B, Gamma ray; C, Sonic log; D, Sonic (TWT). Note that on the Gamma Ray, lava levels, in black, show high radioactivity values (they are immediately recognizable).

The reprocessing of lines Na-307-78 and Na-306-78 (fig. 51 and fig. 52), produced seismic stack sections characterized by much higher signal/noise ratio with respect the Agip sections; this allowed to follow reflectors with more detail and with grater continuity. The achieved improvement has been considerable and reduced most of the flaws of the original acquisition phase. Both sections present a similar data quality and the signal characteristic is comparable; moreover in the southern zone of line Na-307-78 (fig. 51; CDP 200-360) a clear reduction of the signal penetration is evident. The tomogram of line Na-307-78 (fig. 50) shows that the depth of the velocity model is reduced from CDP 176 until the end of the line.

This different penetration depth can be due to:

- a great attenuation of the seismic signal due to the predominance of volcanic litotypes: from CDP 200 the line runs in the Campi Flegrei; the presence of this strongly heterogeneous material cause a very high seismic attenuation.
- the quality of the reading the first arrivals, attributable to low signal/noise ratio that characterize this area.

The seismic profile Na-307-78 shows (fig. 51):

- The seismic Unit U4, constituted by a sequence of variable energy, mostly continuous and parallel reflectors, can be associated to fluvial-marine deposits with pyroclastic intercalation (see table 1; chapter 2, para. 2.2.2). It was possible to recover a seismic reflector (horizon C2) that, according to the depth, should be linked to the seismo-strata with 2.1 km/s velocity on the tomographic section (fig. 50). This horizon, constrained also Licola 1 log information (fig. 49), should be associated to a level of consolidated tuff.
- Seismic Unit U3, a seismic sequence of variable energy, parallel reflection and continuity, may be differentiated in two under-sequence:

Seismic Unit 3a: upper depositional sequence characterized by a prograding sedimentary pattern;

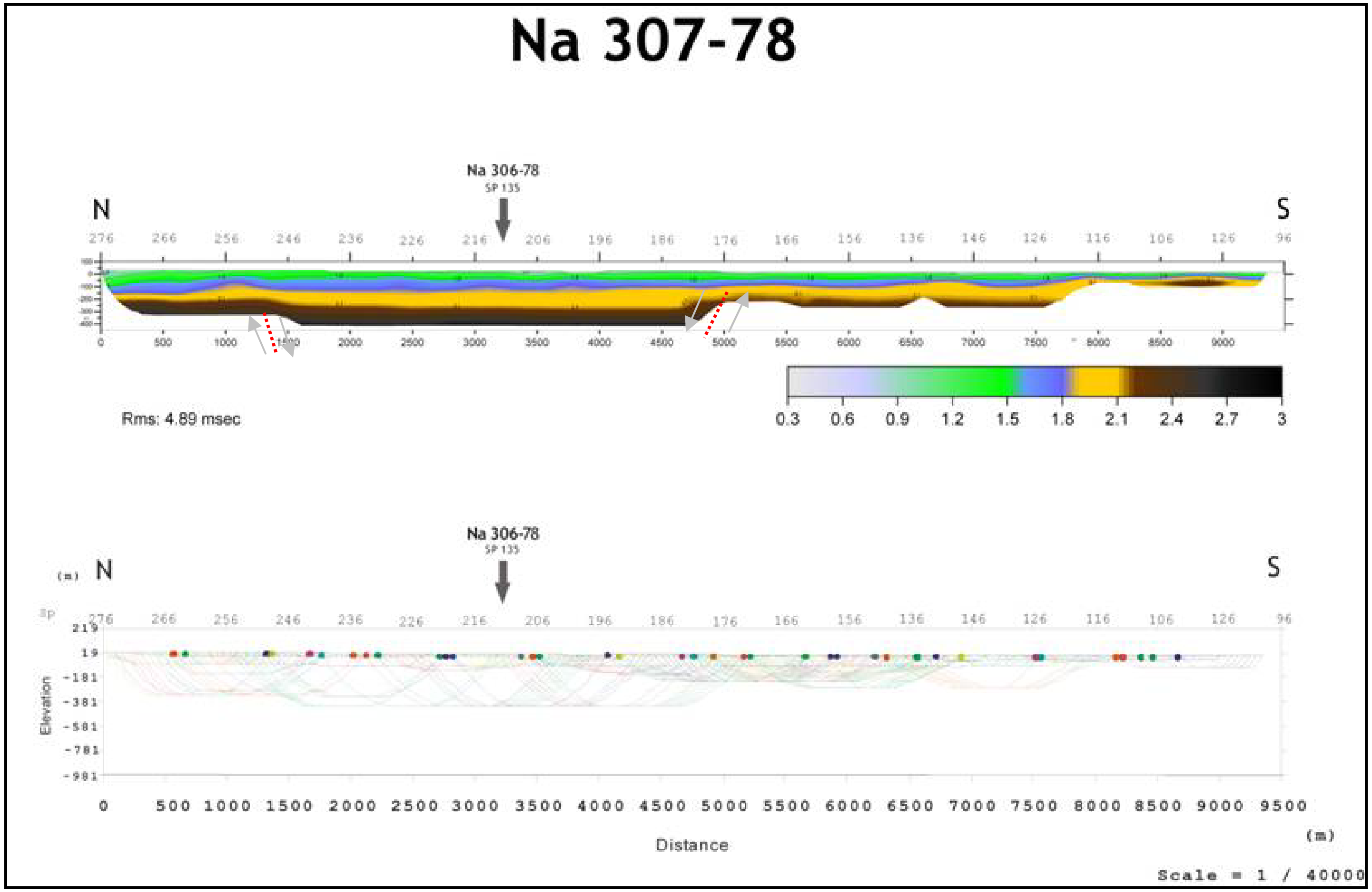


Fig. 50: Tomogram of line Na-307-78 and ray penetration. Tomographic inversion starts with an initial velocity model and iteratively traces rays through the model with the goal of minimizing the RMS error between the observed and calculated traveltimes. The final model has a RMS traveltime residual equal to 4.89 ms. The final model reveals that resolution of the velocity image rapidly deteriorates at depth, accordingly to ray penetration, moving towards south.

Horizon B2: very discontinuous, variable energy seismic horizon. Seismically it appears as few cycles of low-frequency and variable energy. It probably represents a sub-aerial erosion phase (Middle Pleistocene).

Seismic Unit 3b comprises a sequence characterized by parallel, generally sub-horizontal reflectors with poor lateral continuity. This unit is constituted by volcanic and sedimentary deposits of late Pleistocene age (Bartole, 2004; Bruno, 2000).

Seismic Unit U2, a depositional sequence (lower Pleistocene) (see table 1; chapter 2, para. 2.2.2) of high-energy, continuous, parallel and generally sub-horizontal reflectors, is also recognized

- It is possible to see (TWT 1,5) the top (Horizon A) of the carbonatic unit (U1). The sinking of this unit is also recognizable. Seismic Unit U1, a sequence of chaotic seismic events, is associated, according Bartole (1983) and Bruno (2003), to the carbonate substratum on which the previously described seismic unit rest.

- In the northern part of line (CDP 0-180), seismic unit U4, U3, U2 show a sub-horizontal trend; in southern zone (CDP 180-360) the same previously observed reflectors are followed, even if with greater difficulty. Horizon C2 surfaces at 0.2-0.3 s. According to the information from Licola1 well (fig. 49), horizon C2 may indicate a tuff level. Accounting the stratigraphy, the synthetic seismogram and the well log, it has been possible moreover to recognize some lava bodies (1,3 sec. and 1,5 sec), to a depth respectively of 1450 m and 2000 m.
- In correspondence of CDP 190 it is possible to see, in agreement with the seismic tomography (fig. 50), a normal fault that displaces mainly the horizon C2.
- At CDP 325, it is possible to recognize, on Na-307-78 tomogram (fig 50), an other normal fault.

Seismic profile Na-306-78 (fig. 52), was acquired in the Volturno Plain; therefore it is characterized by sub-horizontals reflectors. Na-306-78 intersects line Na-307-78 at CDP 137 allowing to tie the information.

Data ties correlation permitted to constrain the interpretation of the sub-superficial structure of the area.

Na-306-78 (fig. 52) led to:

- Evidence the west dipping reflections within the units U4 and U3.
- Follow in continuous way the Horizon A, top of unit U1, associated to the carbonatic platform.
- Recognize a normal fault, in correspondence of CDP 105.

Summarizing it is possible to conclude:

1. The lithological units which constitute the southern sector of Volturno Plain, show a dip to the SW;
2. The general structure of the carbonatic basement deepens towards south (CF area).
3. The passage from prevailing pyroclastic units to alluvional deposits is clearly recognizable and placed to 5 km to north of the Licola1 well.

4.3 Discussion and conclusion of tomographic sections

Seismic reflection data processing included the seismic tomography (fig. 53) of all Agip seismic lines belonging to the “Naples” permit:

- Na-301-78
- Na-302-78
- Na-303-78
- Na-304-78
- Na-305-78
- Na-306-78
- Na-307-78

The tomograms present a strong reduction of S/N ratio, approaching the CF Volcanic District, since sedimentary units are progressively substituted by volcanics. This change is cause of great dispersion of seismic signal. Decrease of S/N ratio occurs rapidly, usually within 1 km distance (i.e. line Na-307-78 in fig 51). This allowed to draw a curve roughly encircling volcanic lithotypes: the dashed blue line is the boundary between Volurno Plain and Campi Flegrei caldera (fig. 53). The analysis of the tomographic sections permit to highlight, in fact, that in CF the velocity model depth is strongly reduced because S/N ratio deteriorates on long source-receiver offsets. There is, therefore, a different surveying depth depending on lithotypes: in alluvional deposits (Volurno Plain) the seismic turning rays penetrate deeper than in volcanic deposits (Campi Flegrei caldera). Outside Campi Flegrei, the tomograms show a regular distribution of velocity with isovelocity lines mostly sub-horizontal. According to Santo et al., 1994, the first hundreds of meters, outside CF area, is constituted by marine and volcanic poorly consolidated sediments (Upper Pleistocene - Present). These sediments, with a seismic velocity comprised between 0.9 km/s and 1.8 km/s, reduce their thickness moving towards south. Na-303-78 shows that marine sediments pass from a thickness approximately of 160-180 m in the North to a thickness of 80-100 m in the south; line

Na-307-78 displays that the upper sediments reach approximately 150 m of thickness to the North till 50 m to the South. CF Caldera, in fact, is a complex volcanic area characterized by lithotypes with strong horizontal and vertical heterogeneities due to both variable sedimentology and variable emplacement mechanisms and temperature conditions. CF area, thereby, is characterized by a more complex distribution of shallow seismic velocity; consequently a clear reduction of the signal penetration is evident.

The tomogram Na-303-78 shows a normal fault, in correspondence of the northern rim of Quarto depression; this structure is evidenced by a step affecting the 2.1 km/s isoline (CDP 289). Another fault occurs in correspondence of the southern rim of Quarto depression, at the end of Na-303-78 (CDP 349). The same fault is identifiable also on Na-305-78. On line Na-305-78, a graben-like structure is visible. Normal faulting evidences are visible on lines Na-306-78 and Na-307-78 outside the CF Caldera. The analysis of Na-307-78 seismic profile, thanks also to indications obtained from Licola1 well, has permitted to link the 2,1 km/s seismic strata to the top of a tuff level.

The tomograms have permitted to identify and to localize with precision new distensive structures, to clearly distinguish the limits of the flegrea zone and of Volturno Plain, and to assign seismic velocity to volcanic litotype and to the more recent sediments.

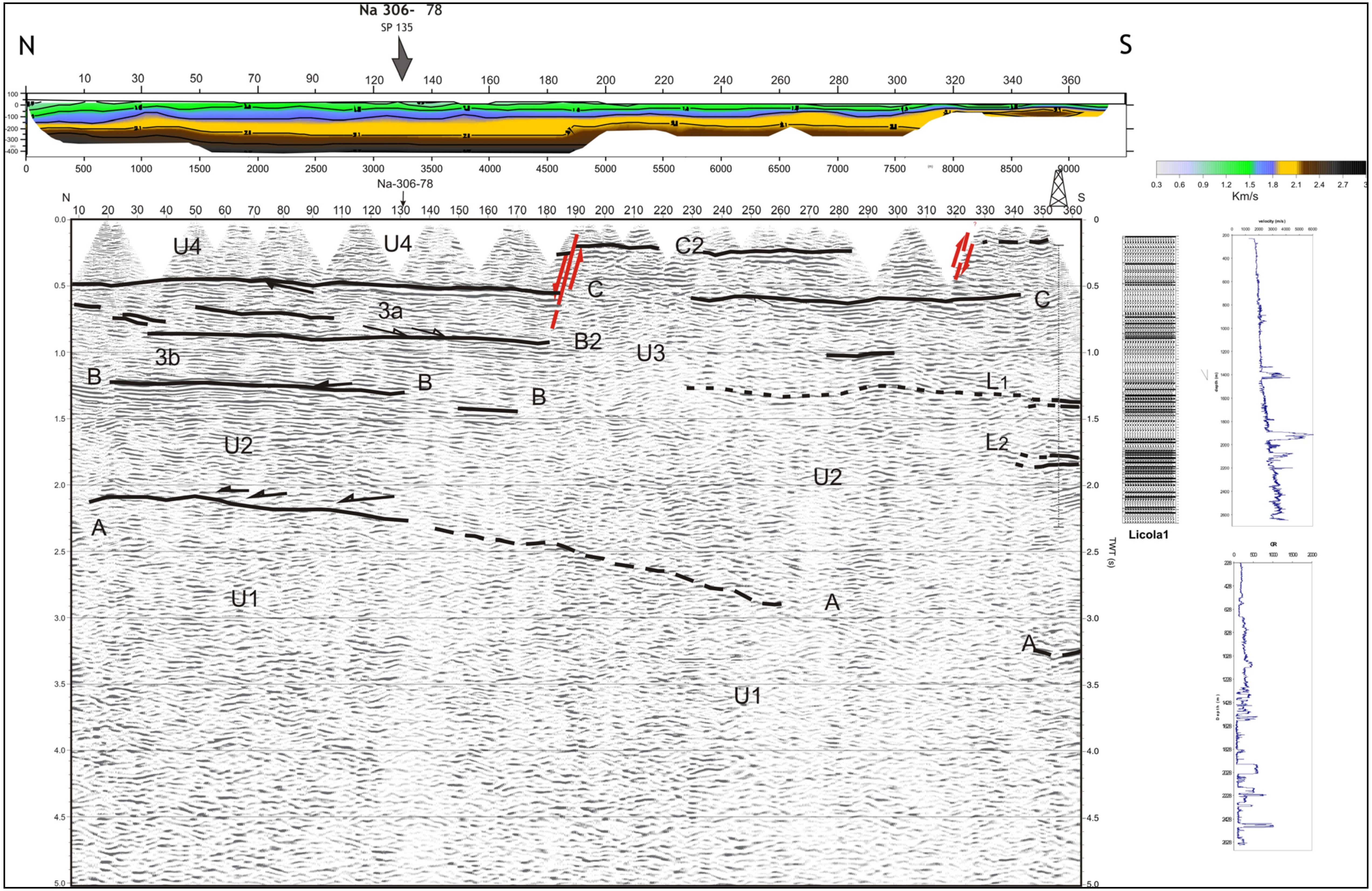


Fig. 51: Na-307-78: tomography section and interpretation of the geological structures

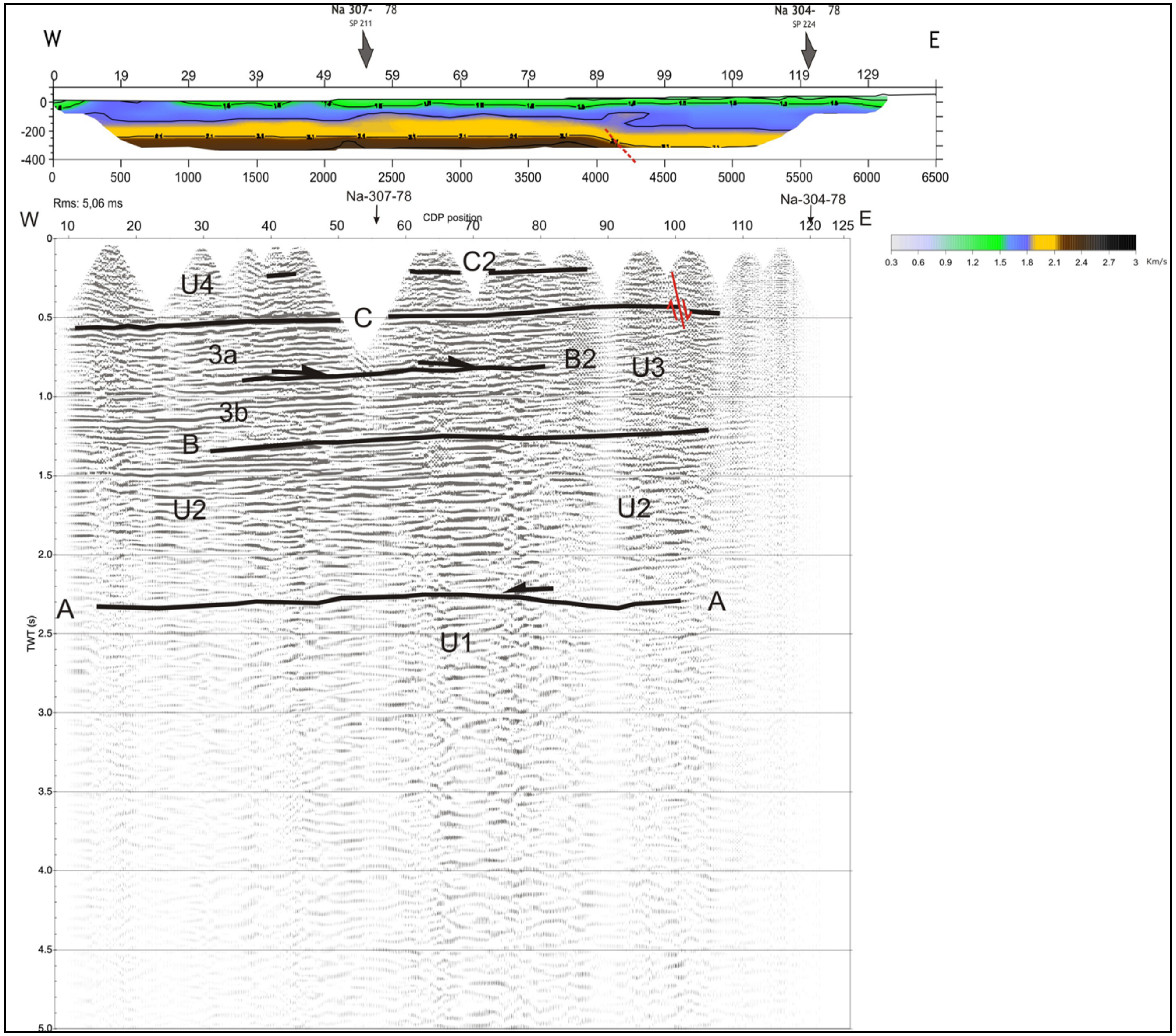


Fig. 52: Na-306-78: tomography section and interpretation of the geological structures

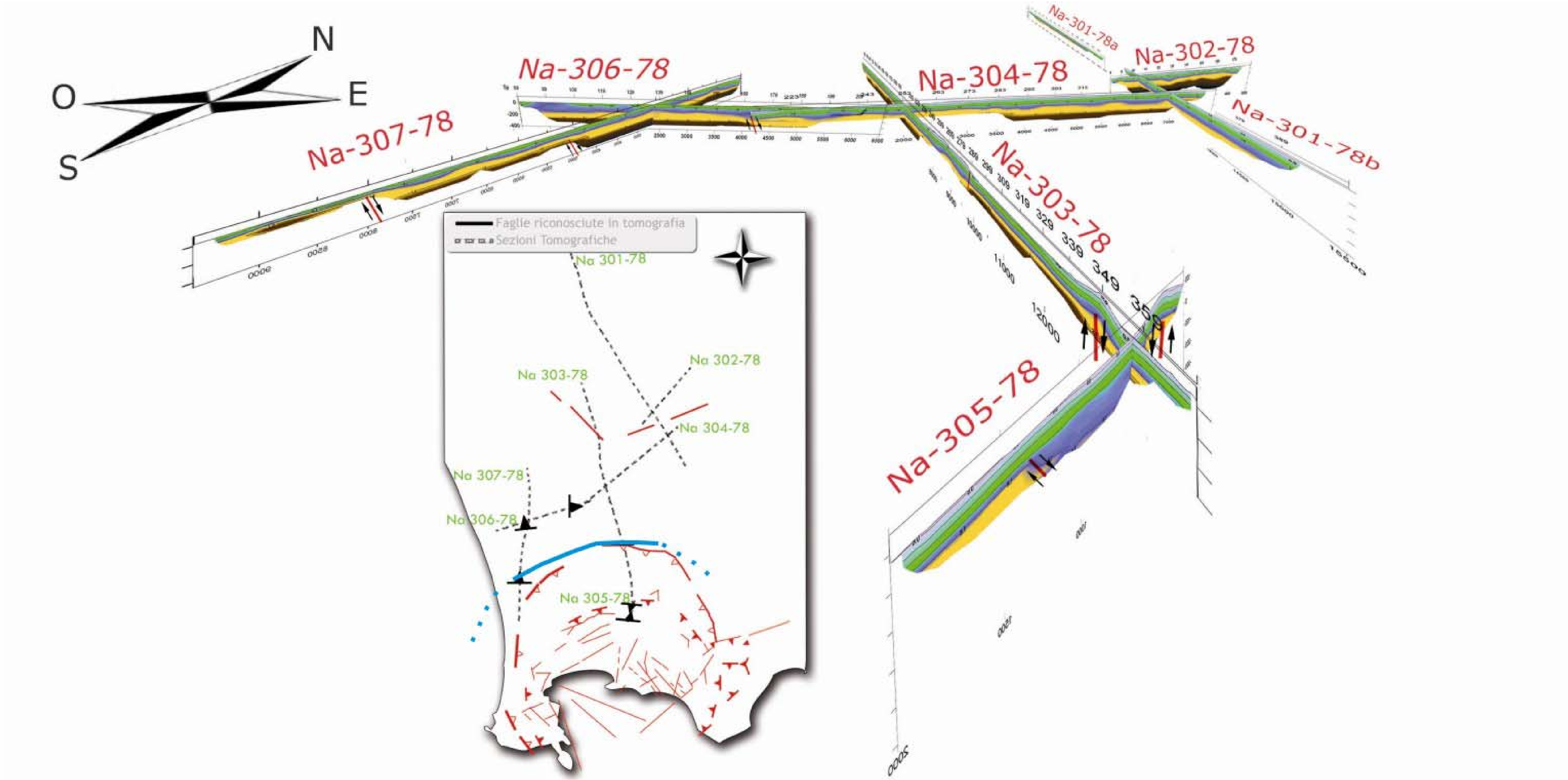


Fig. 53: Seismic tomographic sections (taken from F. Varriale, 2006)

CHAPTER 5

High resolution investigations offshore Pozzuoli Bay

5.1 Introduction

There are numerous published studies (Milia e Torrente, 1999, 2003; Milia et al., 2000, D'Argenio et al., 2004) which deal with the reconstruction of the depositional sequence at Campi Flegrei and Pozzuoli Bay and a stratigraphic scheme based on acoustic data is already developed.
The processing and interpretation of high resolution multi-channel seismic profiles acquired during the oceanographic cruise CAFE_07 – Leg 3, permit to reconstruct the younger depositional history within Pozzuoli Bay. The already established stratigraphy for the last 15 kyrs from the submerged part of Campi Flegrei (Di Vito et al., 1999) is validated in the new seismic data. The high vertical and lateral resolution in the range of one meter, contribute to improve the published acoustic data in terms of a more detailed classification of single seismic units. The processing and the interpretation of these reflection seismic profiles allow also to reconstruct the younger depositional history in the Campi Flegrei offshore area (Pozzuoli Bay). Nevertheless, the newly acquired seismic data allowed for a clear definition of the seismic facies parameters. Despite heavy research done on land around Campi Flegrei over the last 30 years, the 50 to 60 % of the assumed caldera systems are submerged; there is, therefore, a considerable lack of knowledge about the evolution of Pozzuoli Bay.

5.2 Seismic equipment and data recording

Overall, 150 profiles of high resolution multi-channel reflection seismics where acquired during a cruise with the *R/V Urania*, January 10 to 21, 2008, at Naples Bay and the Gulf of Pozzuoli. Only two lines were processed and interpreted within this thesis. Within the Gulf of Pozzuoli the average lateral profile spacing was 120 – 150 m and water depths ranged from ca. 15 to 150 m. An overview of all surveyed lines is plotted in fig. 54.

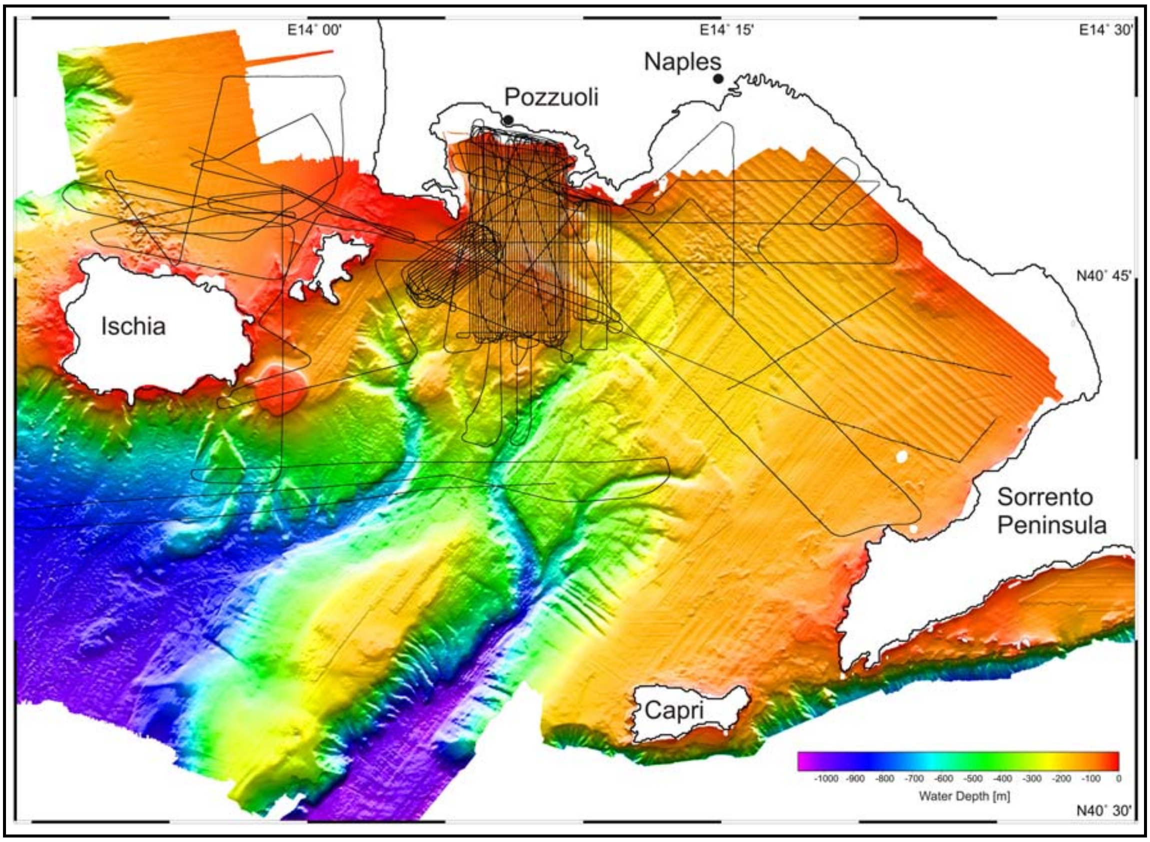


Fig. 54: All acquired profiles during R/V Urania cruise, January 2008, overlying a bathymetry mosaic of Naples Bay. Approximately 60 profiles were shot within Pozzuoli Bay, resulting in a line spacing of round 120 to 150 m. (Bathymetry by D'Argenio et al., 2004)

As seismic source a Mini GI Air Gun (Generator/Injector) was used; it can be operated with two different pairs of Generator and Injector chamber volumes; these were 2*0.12 liter in µ-mode and 2*0.24 liter in mini-mode. The main energy release in terms of frequency of the gun depends on the air chamber volumes and the towing depth. The main energy range is 60 to 850 Hz. These high frequencies naturally undergo a quite high attenuation when passing through geologic strata with various petrophysical properties and thus have a limited penetration depth. For that reason, another GI gun with larger chamber volumes, hence lower frequencies within a range of ca 30 to 500 Hz, was operated additionally on most profiles during the cruise. It was shot alternately with the μ-gun. Both guns' shot rates and consequently the shooting cycles were dependent on the limited output of the shipboard compressor unit. The provided 80 - 90 bar where just sufficient for shooting, but the generated energy was certainly reduced by operation at less than the standard 150 bar. With four buffer air bottles a stable shooting cycle, table 4, could be established for the majority of all profiles. The towing depth of both guns was approx. 1.3 m.

	→ shot time [s] →											
Large GI	0									*0 (30)*		
μ / Mini GI		6	8	12	14	18	20	24	26		*6 (36)*	...
	1. cycle									*2. cycle*		

Tab. 4: Exemplary shooting cycle, alternating release of the large-volume and the μ-GI gun.

The receiver arrays were two hydrophone streamers. A custom-build shallow water streamer with 50 m length and 48 single spherical hydrophones at a 1 m spacing, the first receiver is at 1 m from the streamer head. The average towing depth of 1.4 m was controlled by small buoys. The second streamer was a conventional deep water streamer with an active length of 100 m and 16 groups of hydrophones at 6.25 m. The towing depth of ca. 5 m was also controlled by small buoys.

The acoustic reflection data was recorded with a software written by H. Keil of the MTU working group Uni Bremen, called *MaMuCS* (Marine

Multi-Channel Seismic Acquisition System). It allows an online seismogram display of consecutive common shot gathers, digitizes up to 64 channels and demultiplexes and stores the data on hard discs in SEG-Y format. The sampling rate was set to 0.250 ms, i.e. sampling frequency of 4 kHz. On the majority of all profiles, two µ-GI gun shots were recorded in a 3000 ms long seismogram (a shot at 0 ms and at 1500 ms). The large GI gun shot was recorded in one 3000 ms long seismogram.
Vessel navigation was done via satellite positioning system: a DGPS of *R/V Urania* plus a cell phone based GPS end consumer system. The layout of the towed source – receiver array was measured for the later geometry setup, fig. 55.

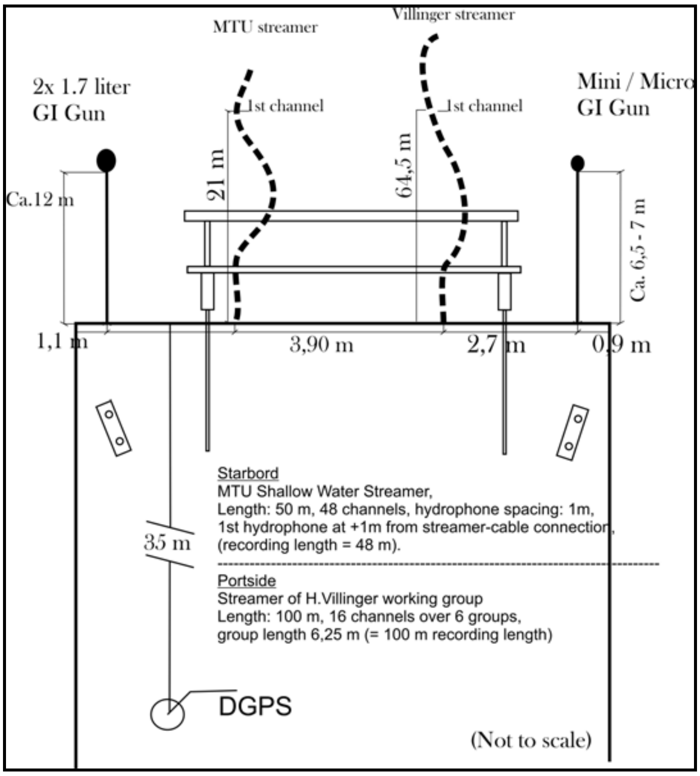


Fig. 55: Birds view on the setup of the two towed GI guns and streamers on R/V Urania (taken from Sacchi et al., 2009).

5.3 Data processing

Processing and visualization of the selected seismic data was done with the commercial software packages VISTA 2D/3D Seismic Processing, version 8.014, by Seismic Image Software (GEDCO). The geometry of the towed seismic equipment was set up and consecutive CMP-binning was done with the custom software package GeoApp, written by L. Zühlsdorff at MTU working group, Uni-Bremen. The processing can be split into two major parts (fig. 56): pre-processing, dealing with preparatory work, such as navigation data revision, and the literal processing of the raw seismic data into an interpretable image. The single steps are explained in the fig. 56.

1. **Raw Data Splittin**
 - Import Seg-y data into VISTA
 - Split data in four indipendent seismic record
 - Selected Dataset. MGI: best resolution
 - Sorting data and time correction

2. **Geometry setup**

3. **Data + geometry combination**

4. **Data cleaning**
 - reverse false channel polarities
 - sort out dead, noisy and weak channel

5. **NMO correction**
before:
- Ormsby band-pass filter
- Scaling
- Spherical Divergence (Spreading) Correction
- Static Correction
NMO correction by means of SEMBLANCE

6. **Stacking of CMP binned data**

7. **Time-Migration**
- FD algorithm

Fig. 56: Processing flow

I focus on data acquired with the μ-GI gun because this system yielded the best vertical and lateral resolution. Although the penetration depth is limited to not much more than 150 milliseconds TWT, the relatively high frequencies of the μ-GI gun offer best premises for high resolution imaging of relatively near-subsurface features. The larger gun achieved somewhat higher penetration but offers noteworthy less lateral coverage and inferior vertical resolution.

5.4 Interpretation of the GeoB seismic profiles in Pozzuoli Bay

Approximately half of the Campi Flegrei area is submerged in Pozzuoli Bay. The bay basically can be divided into (1) a shallow inner shelf with a maximum water depth of ca. 40 to 50 m, (2) a narrow and relatively steep shelf-edge slope going down to (3) a central plain at ca. 70 - 90 m water depth. To the south, two submerged volcanic banks bound the bay, Miseno Bank and Penta Palumno Bank. At the eastern boundary of the bay, Nisida Bank emerges from the seafloor. Among others, Deino et al., 2004, supposed that the buried southern rim of the NYT-eruption related caldera runs arc-shaped approximately from Capo Miseno to Miseno and Penta Palumno Bank and reaching the mainland between Nisida and Posillipo again, fig. 43.
Two profiles (fig. 57) were processed: GeoB08-065, -108. Profile GeoB08-065, WNW-ESE trending, is localized in the inner part of Pozzuoli Bay; GeoB08-108 seismic profile runs S-N direction: it starts from the Gulf of Naples and ends in the Gulf of Pozzuoli.

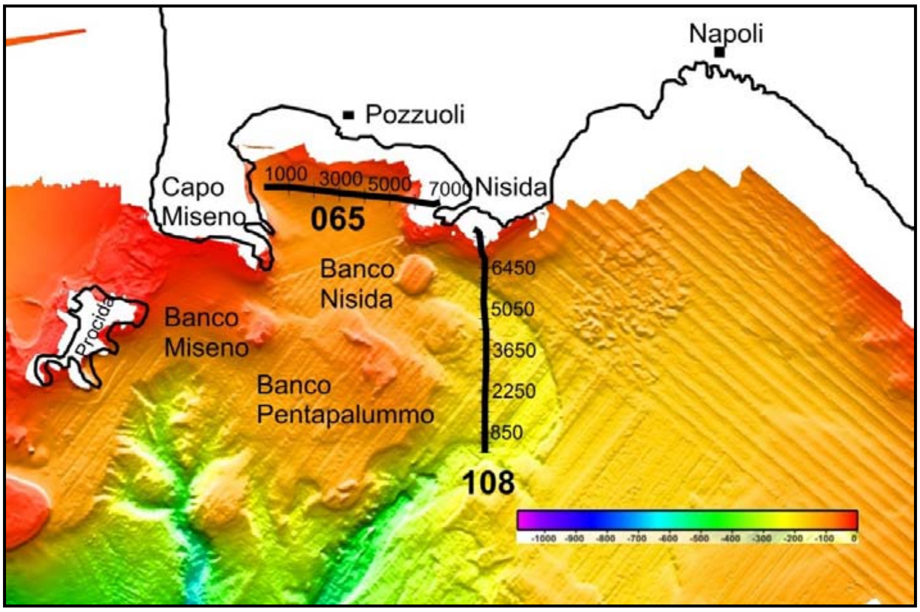


Fig. 57: Processed, described and interpreted seismic profiles GeoB08-065, -108. (Bathymetry by B. D'Argenio et al., 2004)

The original reading of the recorded seismograms' y-axes is in seconds TWT and is only converted to depth values at peculiar features or areas (by means of $depth = v * TWT/2$ with sound velocity in water v = 1500 m/s). Penetration depth is very much limited by the reflections of the first multiples with pronounced amplitudes and moreover by a generally high attenuation of the signal both almost completely masking deeper reflections. A maximum of approx. 150 ms TWT corresponding to ~110 meters below seafloor (mbsf) was recorded showing amplitude values sufficiently high enough to result in recognizable reflections. The data were processed with a one meter CMP-bin distance, so the CMP numbers on the seismograms' x-axes can be read as profile length in meters.

GeoB seismic profiles in Pozzuoli Bay

5.4.2 GeoB08-065

GeoB08-065 profile (fig. 58) runs across the inner part of Pozzuoli Bay with WNW-ESE direction; it is located in the inner continental shelf, at water depth less than -100 m; the vertical exaggeration is 8 X.

In the centre of profile, three strongly reflective horizons (horizons D, E, F respectively) are found at approximately 1,7 s, 1,15 s, 0,9 s, two-way time (TWT). The third horizon at about 1,7 s TWT has been related with the top of the NYT. It is a rough erosional surface that exhibits a subareal character. It is possible to assume that the boundary at around 1,15 s TWT (horizon E) corresponds to a slight angular unconformity that directly affected by faults, was involved in deformation produced after the emplacement of CI and NYT. The uppermost horizon (horizon F), at about 0,5 s TWT, represent a seismic discontinuity; it represents the limiting surface of seismic unit A.

The line reveals a large basin with an even seafloor. The wide "syncline" practically stretches from the upper shelf edge in the West to the eastern (from Bacoli to Bagnoli).

The most important structure individuated is a normal fault in correspondence of CDP 700. Considering that the NYT eruption produced a collapse of a caldera approximately 10 km diameter within Campi Flegrei, this fault correspond fairly well to the western caldera rim. Also the gravity map of the Campi Flegrei area has its main features in a circular gravity low in the Pozzuoli Bay and a gravity high in the northern Campi Flegrei area. The inferred positions of the caldera rims are consistent with some previous structural hypothesis (Rittmann, 1950; Di Girolamo et al., 1984; Di Vito et al., 1985; Rosi and Sbrana, 1987; Barberi et al., 1991).

Active surface-breaking faults (maximum vertical separation of 1 m) individuated in the middle of profile (CDP 3000-3500) are related to the recent deformation (< 6 ka) and uplift of the structure off Pozzuoli. The Campi Flegrei caldera is, in fact, well known for a phenomenon named "bradyseism" which is the alternating uplift and sinking of the ground within the caldera. Several dramatic episodes of uplift are known from the past 300 years, one of them has culminated in an eruption so far, in 1538, when the most recent volcanic feature of the Campi Flegrei was emplaced, Monte Nuovo. The recent seismic crisis of 1970-1972 and 1882-1984 in Campi Flegrei, though not culminating with a volcanic eruption, caused extensive damage, including the destruction of an entire district of Pozzuoli Town (Rione Terra: De Stefano et al., 1988).

The very recent volcanic activity is also demonstrated by the presence of a small laccolith off Bagnoli (CDP 5400 - 6200). The intrusion affects also seismic Unit G1 as previously evidenced (seismic unit G1*y*); the uppermost reflectors, appear distorted and then involved in deformation and uplift.

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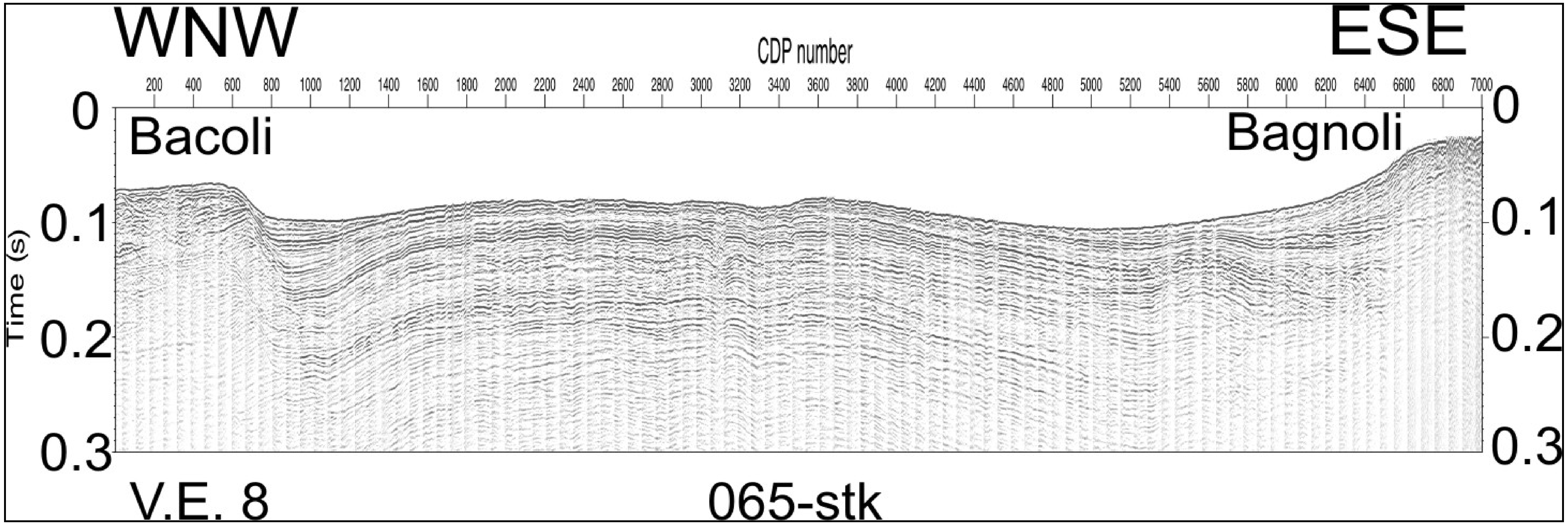
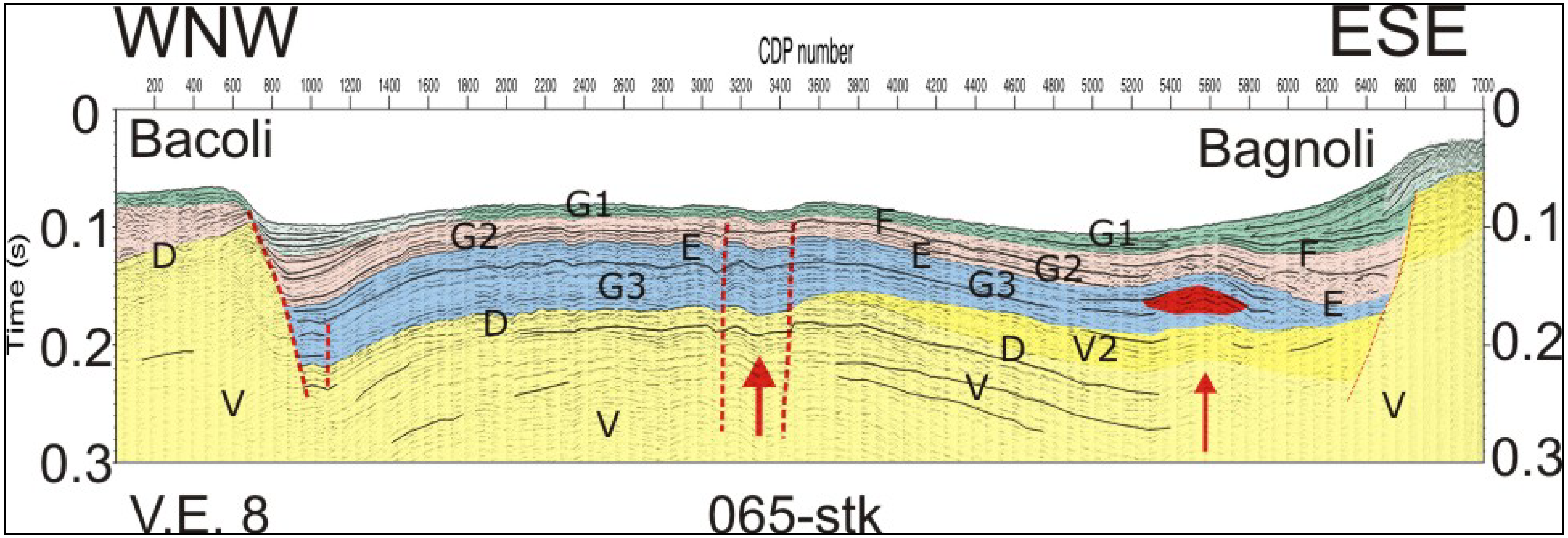
Fig. 58: Profile GeoB08-065 and corresponding interpretation.


WNW
ESE
CDP number
200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 4000 4200 4400 4600 4800 5000 5200 5400 5600 5800 6000 6200 6400 6600 6800 7000
Bacoli
Bagnoli
Time (s)
0
0.1
0.2
0.3
V.E. 8
065-stk


WNW
ESE
CDP number
200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 4000 4200 4400 4600 4800 5000 5200 5400 5600 5800 6000 6200 6400 6600 6800 7000
Bacoli
Bagnoli
Time (s)
0
0.1
0.2
0.3
G1
G2
G3
D
E
F
V
V2
V.E. 8
065-stk

5.4.3 GeoB08-108

The succession of units defined on profile 065 does not easily fit onto profile GeoB08-108 (fig. 59) which was acquired over an area with high deformation rate (the sector north of Ischia or the western part of the Gulf of Naples). The line runs in the northern part of the bay of Naples with a S-N trending; water depth ranges from around 30 m at the northern shelf edge to some 220 m in the southern part of the plane central basin; the vertical exaggeration is 8 X. The interpretation of the profile GeoB08-108 has shown the stratigraphic architecture of the external continental shelf of the Gulf of Pozzuoli area: a large irregular area because of the presence of several banks whose morphologic characteristics suggests that they are volcanic edifices (Orsi et al., 1996). In particular, the sea floor is characterized by the presence of monogenic volcanoes, small calderas, tuff cones and lava extrusion (Milia, 1999). Most of them correspond to mound-shaped highs in the bathymetry.

The acoustic substratum is limited by an irregular erosional surface. This important unconformity, that is possible to follow along all the line, could be the top of the Neapoletan Yellow Tuff: the lower limit is below the multiple reflection.

The line can roughly be divided into four major zones:

- From CDP 133 to 3200: the line displays an upper seismic units (unit G1 and G2) characterized by alternating parallel and continuous reflectors with chaotic intervals overlying an acoustically transparent volcanic unit (within unit G3) characterized by a tabular shape. The upper unit (unit G1) is interpreted as clastic marine sediments deposited during the last 4 ka; the volcanic unit could be interpreted as the external part of the Pentapalummo bank volcanic deposits.
- From CDP 3200 to 5000: the seismic line crosses a well delineated morphologic high which reaches ca. 150 ms TWT above the seafloor. This volcanic wedge-shaped body is characterized by a chaotic

seismic facies with a reflection-free configuration. According Mila&Torrente 2007, this body may be made up of Upper Pleistocene marine sands and pumice/tuff layers. The chaotic sedimentary structure may suggests diapirism (D'Argenio et al., 2004). The Holocene epiclastic marine sediments (unit G1 and G2) appear warped.

- From CDP 5000 6200: the line cross the "Ammontatura" Channel. Volcanic materials interplay with Holocene sediments deposited during Quaternary time. This sediments, also present in the GeoB08-065 seismic profile, represent, in chronostratigraphy terms, the marine sediments comprised between the beginning of the fall of the sea level after the high-stand phase (ca. 120 ka BP) and present day; the channel drained volcanic material (shales and volcanogenic sands interlayered with thick pumice levels) from Campi Flegrei: Secomandi et al., 2005 shows positive gravimetric lineaments along the Ammontatura Channel.
- From CDP 6200 to 7800: The transition from the central basin to the shelf in the northern area is obtained through a series of faults which cause the uplift of NYT. The NYT forms a thick and widespread pyroclastic unit in the area of Naples and reaches a thickness of approximately 150 m at the Hill of Posillipo. NYT originated along a system of NE-directed vents on the Posillipo hill (Milia, 2003). The line documents that offshore Naples, the NYT has forms a wedge that thickens in the direction of the Hill of Posillipo (Milia and Torrente, 2003; Milia et al., 1998; Milia, 1998).

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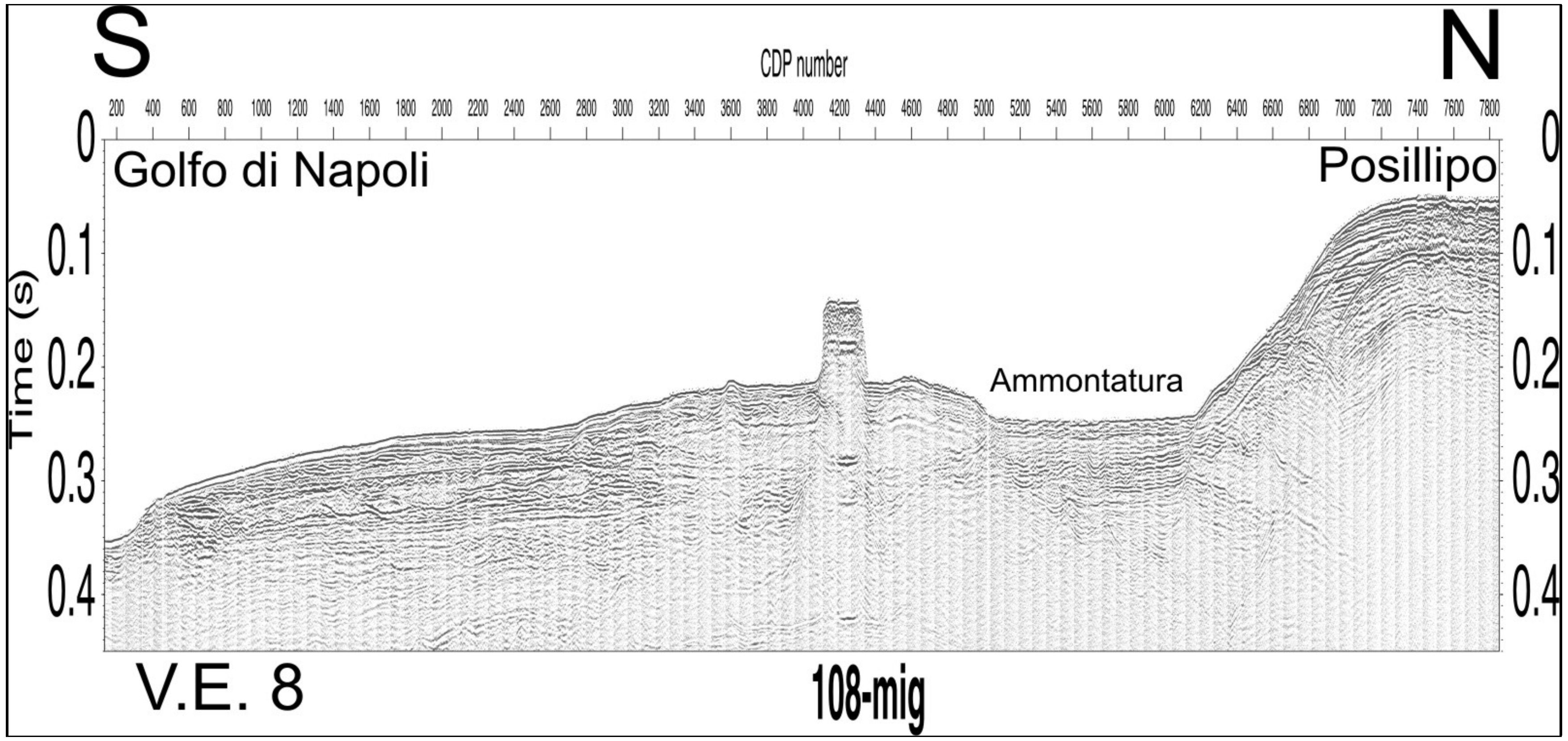
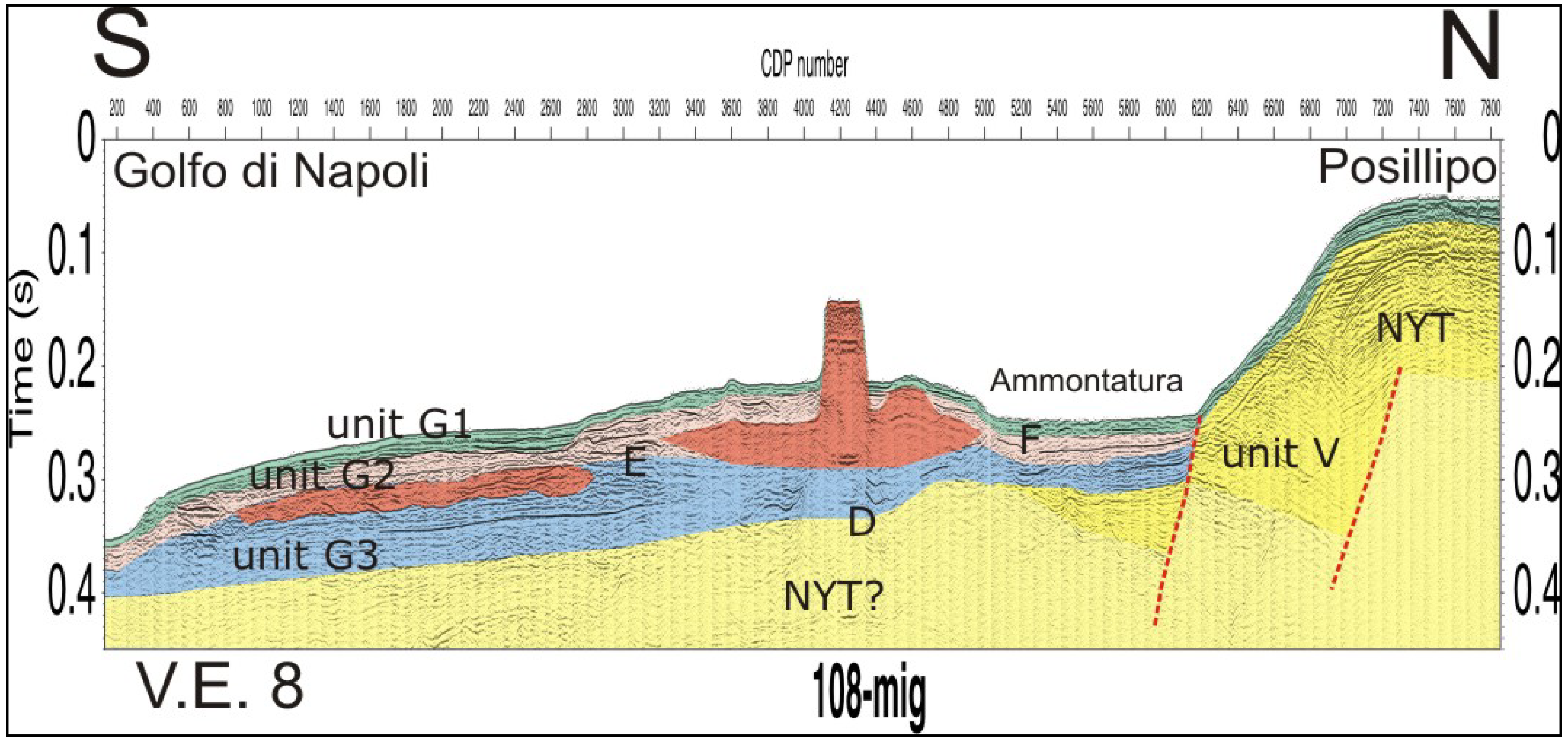
Fig. 59: Profile GeoB08-108 and corresponding interpretation.


S
N
CDP number
Time (s)
Golfo di Napoli
Posillipo
Ammontatura
V.E. 8
108-mig


S
N
CDP number
Time (s)
Golfo di Napoli
Posillipo
Ammontatura
unit G1
unit G2
unit G3
E
D
F
NYT
NYT?
unit V
V.E. 8
108-mig

5.5 Discussion

Subsidence and uplift played another important role in the sedimentary history, both long-term and just year-long vertical movements. In addition, the eustatic sea level shift considerably affected the depositional patterns within Pozzuoli Bay (the level increase from a low stand of approximately -120 to -130 meter after the Last Glacial Maximum to the present level at 0 m). The grouping of reflections with similar seismic facies into units and their internal features allowed for a basic classification into sedimentary and volcanic origin. By evaluating the contact relations of the units, an elementary and relative stratigraphic framework could be identified directly from the seismic record.

Seismic lines show a complex structural patterns. Inferring the nature of the deposits, marine or volcanic, and deriving their temporal genesis was delicate because both tasks strongly interrelate; changing one of requires reconsidering the other. Another major constraint was the absence of drill cores with the help of which a firm attribution of reflector to stratum would have not been possible.

As a consequence the interpretations in this thesis were to a large extent done with the aid of published studies on marine acoustic data (D'Argenio et al., 2004; Milia&Giordano, 2002; Milia et al., 2000; Milia&Torrente, 2007; Milia et al., 1997). With the contribution of GeoB profiles, a composite image on stratigraphy of the seismic units and their nature could be established.

Figure 60 summarizes the knowledge of the strata succession within Pozzuoli Bay in one stratigraphic column ('4+6'). In the town of Pozzuoli, a 4 km long and 25 to 40 m high marine cliff, La Starza Terrace, crops out. The Neapolitan Yellow Tuff (NYT) of 15 ka B.P. makes up the basal unit of La Starza and is directly overlain by a thick succession of marine sediment packages which cover the time span from 15 to 4.8 ka B.P.. Overlying the marine units, only continental deposits younger than 4.8 ka B.P. are found and indicate permanent emersion of La Starza since then. At 8.2 ka B.P. a paleosoil layer is interbedded within the marine succession and indicates a (short?) time of emersion above sea level. A similar but slightly more detailed stratigraphy was derived at Cuma and central Campi Flegrei (column '1+2'). The dated paleosoil layers could be correlated to unconformities which subdivide the marine package within the bay.

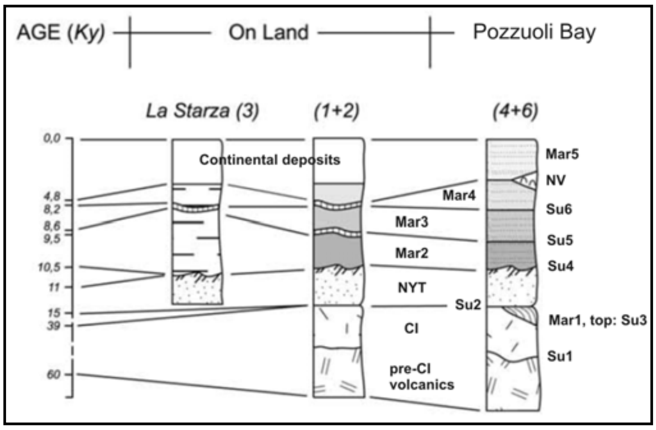


Fig. 60: Correlated stratigraphic colums on- and offshore Campi Flegrei. Mar = Marine unit, Su = Erosional surface, NV = Nisida volcano/complex, NYT = Neapolitan Yellow Tuff, CI = Campanian Ignimbrite. Thin wavy bands: paleosoil layers, used for inferring ages of unconformities Su5 & Su6. Locations of the colums: 1 - Cuma, West Campi Flegrei; 2 - Campi Flegrei; 3 - La Starza Marine Terrace, town of Pozzuoli; 4 - Pozzuoli Bay central basin; 6 - South of Penta Palumno Bank. (Modified from A. D'Argenio et al., 2004)

Interpretation of profiles permitted to reveal some information about the evolution and the general succession and nature of the deposits within the central basin of Pozzuoli Bay. The focus is on profiles 065 since it shows a rather undisturbed image of the whole successions of defined units filling the basin and is to be the most useful to deduce a stratum for each unit. For reconstructing the evolution of the seismic units, not only fault activity but also the eustatic sea level rise since the emplacement of the NYT at 15 ka B.P., and a notably subsidence of the inner part of Pozzuoli Bay has to be taken into account. Several meters of uplift occurred at some places within very short timespans of only years or even single, very short-lived events. The interplay of subsidence and uplift of the inner part of Pozzuoli Bay caused relative sea level shifts and hence changing depositional environments.

A subaerial deposition has to be assumed for the Neapolitan Yellow Tuff (NYT). Otherwise, if the NYT had been subsided below sea level in the meantime, e.g. by its accompanying caldera collapse, one would expect a cover of marine sediments. Profile GeoB-065 (fig. 58), unit V correspond to the NYT and no subdiving unit was imaged. For the NYT, D'Argenio et al. 2004 state a rough erosional surface as well as Milia et al. in various studies (e.g. 2000, 2006). The subaerial deposition of the NYT is supported by the shape of the top reflection of unit V (horizon D - fig. 58).

On top of the NYT, unit G3 is found, which covers the rough NTY topography and levels it. Unit G3 were defined as the marine package M2 by A. D'Argenio et al., 2004. This means, that sea invaded the area after the emplacement of the Yellow Tuff. The change to a marine environment has to be related to (1) strong and relatively fast subsidence of the whole NYT unit between the coast and the southern banks and (2) a sea level rise sufficient enough to overflow the lowest point between Nisida and P. Palumno Bank and sink the created basin. The collapse of the NYT caldera probably had a substantial contribution to the creation of a wide and deep depression, which was filled completely with the marine unit C up to the sea level. The maximum thickness of unit G3 is about 45 ms TWT, corresponding to ~33 m, according to the highest/lowest thicknesses of M2 (D'Argenio et al., 2004). This unit (M2) was deposited by the first flooding of an inner basin, created by strong subsidence and coeval sea level rise from 11 to 8.6 ka B.P.

The transition from unit G3 to unit G2, marks a change of deposition and tectonic activity. It is thought, that the sea level rise was slower than the vertical displacement: unit G2 probably formed before the full drowing of the area due to volcanic activity

For instance, unit G2 is presumably very homogenious in composition, supported by the absence of notable impedance contrasts. Indicative for a homogeneous in composition are very weak internal reflections.

Unit G1 was concordantly deposited, onlapping on the clinoform patterns of unit G2. Despite any expectations, from the seismic facies and their contact relations alone, no clear indications could be drawn on the composition of the units. This means, that a discrimination between volcanic products and marine sedimentation was not feasible by mere visual means for most of the units of the seismic profile.

The top reflection of the unit NYT was fairly better distinguishable from the above/below encasing.

5.6 Geologic evolution of Pozzuoli Bay

Geophysics is essential for exploration of undersea volcanic areas. A full reconstruction of the geologic evolution of Pozzuoli Bay by A. D'Argenio et al., 2004, is drafted in fig. 61. In Pozzuoli Bay, the analysis of the CAFE seismic data allowed for the reconstruction of the main volcanological events characterizing this area.

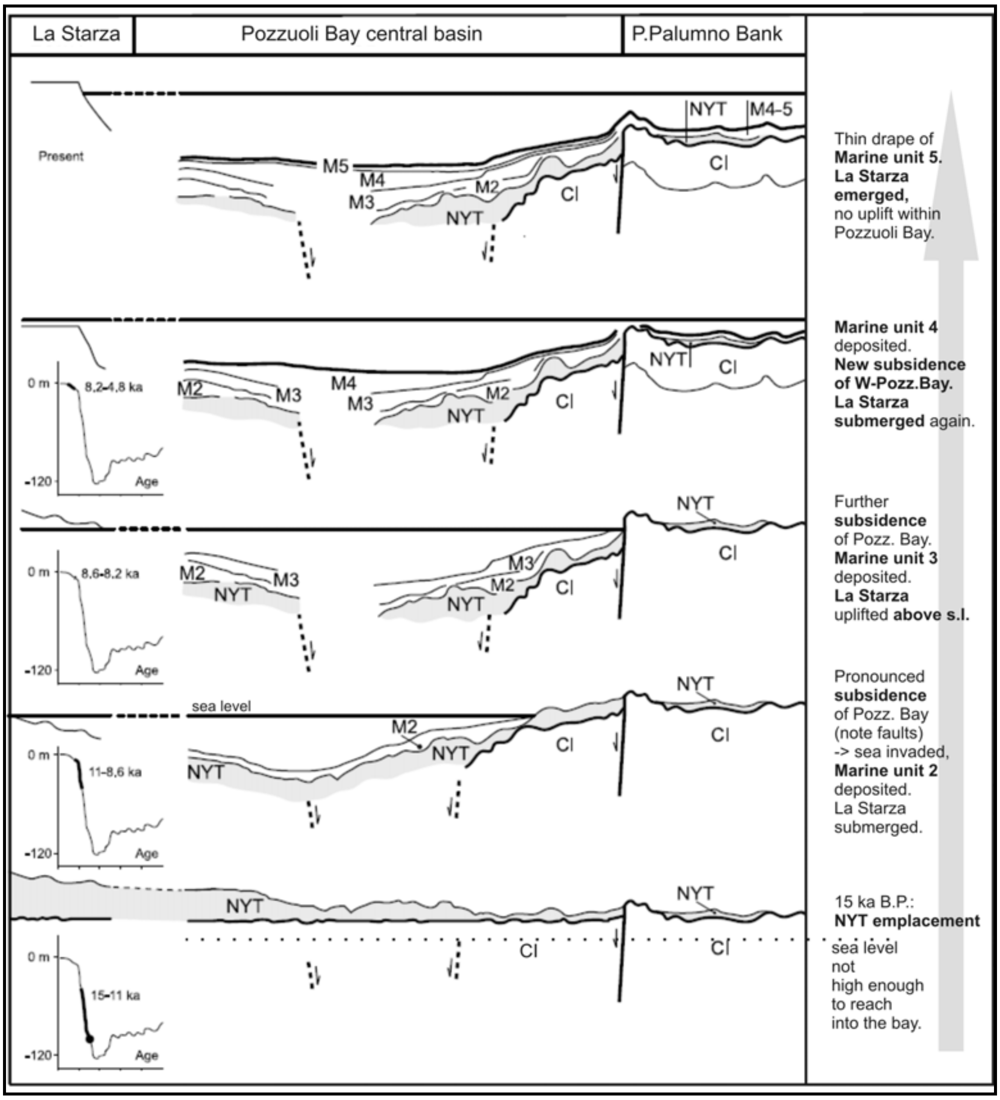


Fig. 61: Schematic sections across the Gulf of Pozzuoli, N-S cross section. The sections, based on seismic profiles, illustrate the main steps within the geological evolution of the area during the last 39 ka., considering eustatic sea level rise and subsidence/ uplift. Deposition of Campanian Ignimbrite CI at 39 ka B.P. was subaerial. NYT top boundary is a rough erosional surface with subaerial character. LSMT, La Starza Marine Terrace, CB, Central Basin, PPB, Penta Palummo Bank, OS, outer shelf (from D'Argenio et al, 2004).

During description and especially while interpreting the GeoB profiles, it became evident that this reconstruction and the self-defined seismic units quite reasonably match (fig. 62). Consequently, the above specified evaluation of the profiles was guided by this reconstruction.

The main volcanological events are the following:

- After the NYT (12 ka) eruptions there was a collapse involving the present submarine sector of Pozzuoli Bay. The volcanic activity was probably subareal; during this time span the sea level was in a lowering stage (Wurmian regression about 18 ka). The collapse was probably driven by NE-SW and NW-SE regional faults (Bruno, 2004).
- A phase of inflation matched with the eustatic sea level. Subsidence affected part of Pozzuoli Bay providing a high rate of deposition and generalized marine conditions gradually established. The first marine unit "Unit G3" began to form after the NYT emplacement, during the quick and progressive subsidence of the inner sector of the Gulf (formation of the Central Basin). At this time, the Miseno and Penta Palummo banks probably formed little island (D'Argenio et al., 2004). Unit G3 formed from 11 to 8.6 ka, a period characterized by intense volcanism (from 11 to 9.5 ka, part of Epoch I of Di Vito et al., 1999) and quiescence (from 9.5 to 8.6 ka, paleosol A of Di Vito et al., 1999).
- The development of the marine unit G2 marks the definitive establishment of the marine conditions on the whole Gulf of Pozzuoli (rising and subsequent highstand of sea level), which probably lasted from 8.2 to 6 ka. Unit G2 is limited on top by the angular unconformity E. The last marine unit "unit G1", formed between 6 ka and the present, contains the deposition of thin sedimentary succession
- Volcano-tectonic movements developed in the internal sectors of the gulf during the last 6 ka. Vertical movements (ascending and descending bradyseism) are exceptionally intense in the area close to the harbour of Pozzuoli. The seismic profiles reveals also the presence of recent epi-superficial magmatic intrusion and small deep magma intrusions. This very recent volcanic activity has been also demonstrated with 40Ar/39Ar dating method (Insigna et al., 2006).

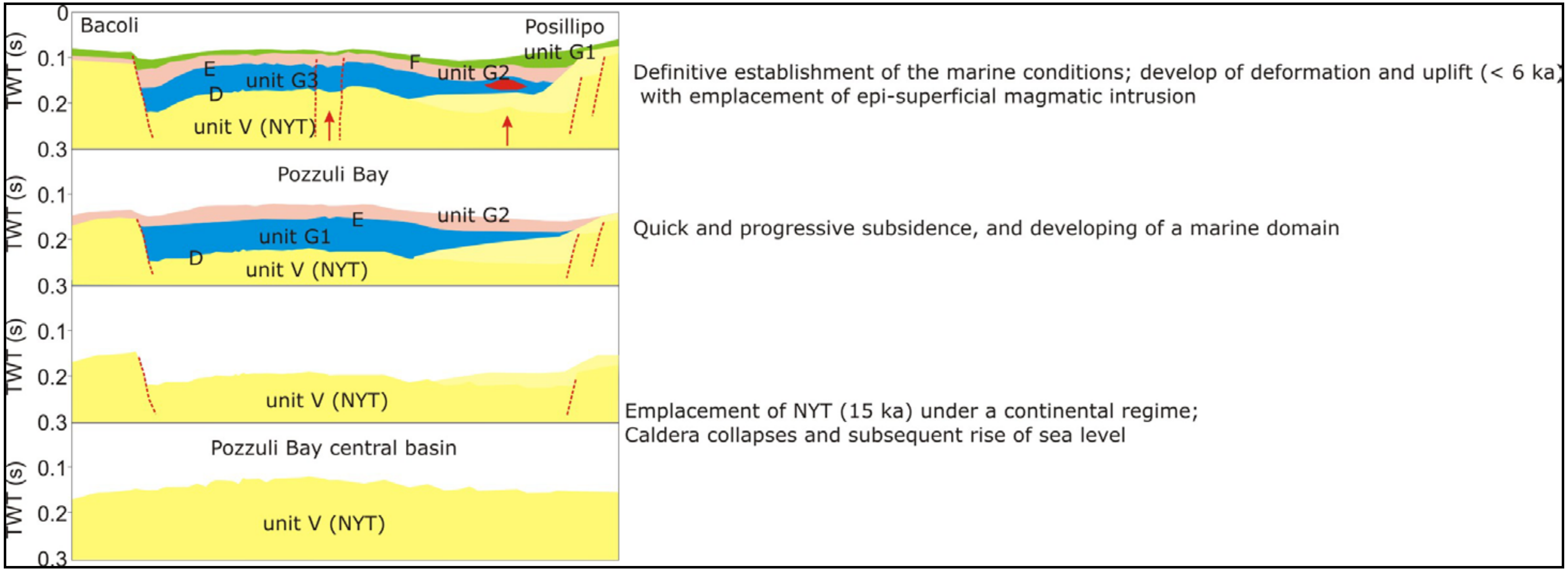


Fig. 62: Geologic evolution of Pozzuoli Bay, W-E cross section, considering eustatic sea level rise and subsidence/uplift. Reconstruction based on seismic data. NYT top boundary is a rough erosional surface with subaerial character. Marine units G1, G2, G3 deposited conformably onto each other.

CONCLUSIONS

Seismic interpretation leads to a general geo-volcanological and structural framework of the Bay of Naples. The reprocessing (Bruno et al., 2000, 2002, 2003) of seismic data, aiming to the enhancement of signal to noise (S/N) ratio, yielded an improvement of data quality.

In Campi Flegrei offshore area, it was possible to define two episodes of magma emplacement occurring during Lower Pleistocene and Middle-Upper Pleistocene, respectively. This permit to affirm that volcanism in the Neapolitan area is a long process operating episodically from the Lower Pleistocene onwards.

The faults evidenced in CF area have a prevailing strike NE-SW and ENE-WNW as also shown by Bruno et al., 2003. A structural consideration of the area suggest that NE-SW trending faults which border the Campi Flegrei area reflect the occurrence of oblique extension along which great vertical displacement occurs.

I attempt, using the seismic information, to reconstruct the Quaternary tectonic and stratigraphic evolution in the Campi Flegrei area; I present a five-stage scenario (see fig. 47; chapter 3, para. 3.4):

1) Onset of extensional block faulting; 2) Subsidence and basin grow; 3) First episodes of magma intrusion on the footwall of normal faults; 4) Uplift of Campi Flegrei-Ischia ridge; 5) Second episodes of magmatic intrusion; stop of subsidence.

Intrusive processes, particularly well imaged below Ischia Island, could have ultimately be responsible for the rapid uplift of Ischia resurgent structure. The interpretation of seismic lines (i.e. Na-09: fig. 20 – chapter 3 para. 3.2 and Na-13: fig. 20 – chapter 3 para. 3.2) are used to unravel the mechanics of uplift of Ischia Island. NW-SE strike fault localized to the north of Ischia, in fact, could be directly connected to the resurgence of Ischia. Resurgence consists of the uplift of part of a volcanic system and is commonly interpreted as being due to the ascent of magma (Smith and Bailey, 1968; Lipman, 1984; Marsh, 1984).

Resurgent domes are often bordered by dipping reverse faults (Phillips, 1974; Mandl, 1988; Orsi et al., 1991). The structure of calderas and resurgences has been recently investigated through analogue models (Marti et al., 1994; Kennedy et al., 1999; Acocella et al., 2000; Roche et al., 2000; Acocella et al., 2001a; Acocella et al., 2001b; Walter and Troll, 2001; Troll et al., 2002). These experiments show structures similar to those individuated in seismic line Na-13 (see fig. 29; chapter 3, para. 3.2): high angle reverse faults border resurgences, whereas normal faults form subsequently. The reverse faults are the structural boundaries of resurgences, mechanically consistent with a differential uplift; conversely, the normal faults are a result of the gravitational collapse induced by the reverse faults (e.g. Acocella et al., 2000). The lack of eruptions in the area of the resurgent dome in the last 33 ka suggests that resurgence locally replaced volcanic activity. This observation is consistent with the fact that the mechanical energy required for resurgence has been evaluated as being equivalent to the thermal energy of a medium-sized eruption (Acocella et al., 2000). The presence of a shallow magma body beneath the island supports the theory of the bending of an elastic plate subjected to thrust from laccolith resurgence and also the hypothesis of the resurgence of Mount Epomeo due to the thrust of a laccolith intrusion with faults bordering the uplifted (Carlino et al., 2006).

The data of Campi Flegrei onshore area are affected by a strong reduction of S/N ratio, approaching the CF Volcanic District, since sedimentary units are progressively substituted by volcanics. This change, caused by a great dispersion of seismic signal, allowed to draw a curve roughly encircling volcanic lithotypes. The seismic survey of the CF onshore area, constrained by well log, have been interpreted in terms of four seismo-stratigraphic units (see tab. 1 – chapter 2; para. 2.2.2) which are correlated with the stratigraphic units of the southern Apennines. Seismic reveals also that the carbonate bedrock which is characterized by an irregular shape with a structure that deepens

towards the NW, upon which the Campi Flegrei volcanic district, and more to the south Somma–Vesuvius complex, have developed.
In particular, the observations made on seismic sections Na-307-78 (see fig. 51; chapter 4, para. 4.2) and Na-306-78 (see fig. 52; chapter 4, para. 4.2), allow seeing that:
- the lithotypes, which constitute the southern sector of Volturno Plain, show a dip to the SW;
- the carbonate basement has a regional deep towards south; moreover the basement seems to be affected by sin-sedimentary listric faults.
- the passage from pyroclastic lithologies to alluvional deposits is clearly recognizable.

The interpretation of high resolution data discussed in Pozzuoli bay area, based also on the findings of A. D'Argenio et al., 2004, suggest that during the last 15 ka, a complex shallow sedimentary architecture developed in response to sea-level change, volcano-tectonic movements and sediment supply. The latter acted as the leading force in the organization of the pattern of the seismo-stratigraphic units recognized in this area. The high complexity of the structural framework of the bay is due to the superimposition of caldera collapses in a region affected by extensional tectonics.
The profile GeoB-065 (see fig. 58; chapter 5, para. 5.4.2) indicates the existence of a caldera-like structure in the Campi Flegrei and clearly outline its western rim.
The geological and historical information on the Gulf of Pozzuoli suggests that volcano-tectonic processes acted at different time and space scales. Uplift of Monte Nuovo, "bradyseismic" crises or minor vertical movements recognized at the margins of the volcanic banks and in the La Starza succession, can be seen as episodic phenomena if compared with the long-term subsidence of the Central Basin.
Four major seismic units were defined along the interpreted GeoB profile. From the bottom to the top, they represent deposits of the two large volcanic eruptions which shaped Pozzuoli Bay by caldera collapses

(e.g. Rosi & Sbrana, 1987): Campanian Ignimbrite (39 ka) and Neapolitan Yellow Tuff (15 ka) eruptions. (Deino et al., 2004). On top of NYT unit follows a thick succession of marine deposits which reflect Pozzuoli Bay's history of tectonic subsidence, uplift events and sea level rise. Reflector terminations such as onlaps and the identification of prograding wedges and clinoforms in the CAFE profiles could be brought in accordance with a sophisticated reconstruction of the bay's evolution by A. D'Argenio et al., 2004.
To conclude high resolution multichannel seismic profiles allowed for the recognization of volcanic bank and buried volcanic structures which correspond to small laccolith-type magmatic intrusions. The data clearly shows that in some areas of the Gulf of Pozzuoli recent deformative processes are still present acting.

The results of this study indicate that high resolution seismic reflection profile across an undersea volcanic field turns out to be a very useful tool for the identification of active deformational features off a large volcanic and urbanized area that has experienced historical ground uplift and earthquakes. This methodology can therefore greatly contribute to the evaluation of geological hazards in active volcanic regions including undersea sections. The definition of the mean structures and their relationships to the volcanic activity represent key elements for understanding the volcanic system and for evaluating its volcanic hazard. CF area is inhabited by around 400,000 people, who are exposed to an high risk from the still active magmatic system, which is well illustrated by the historic eruption of Monte Nuovo in 1538, as the recent uplift episodes (1969–1972 and 1982–1984), should reveal.
It has been calculated (Acocella et al., 2000) that the energy required to reactivate pre-existing fractures, because of the cohesion loss at shallow depths, is considerably smaller than the energy required to activate newly-formed fractures. This evidence suggests that future volcanic activity in CF area is more likely to occur in correspondence to major pre-existing fractures, such as the regional systems.

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