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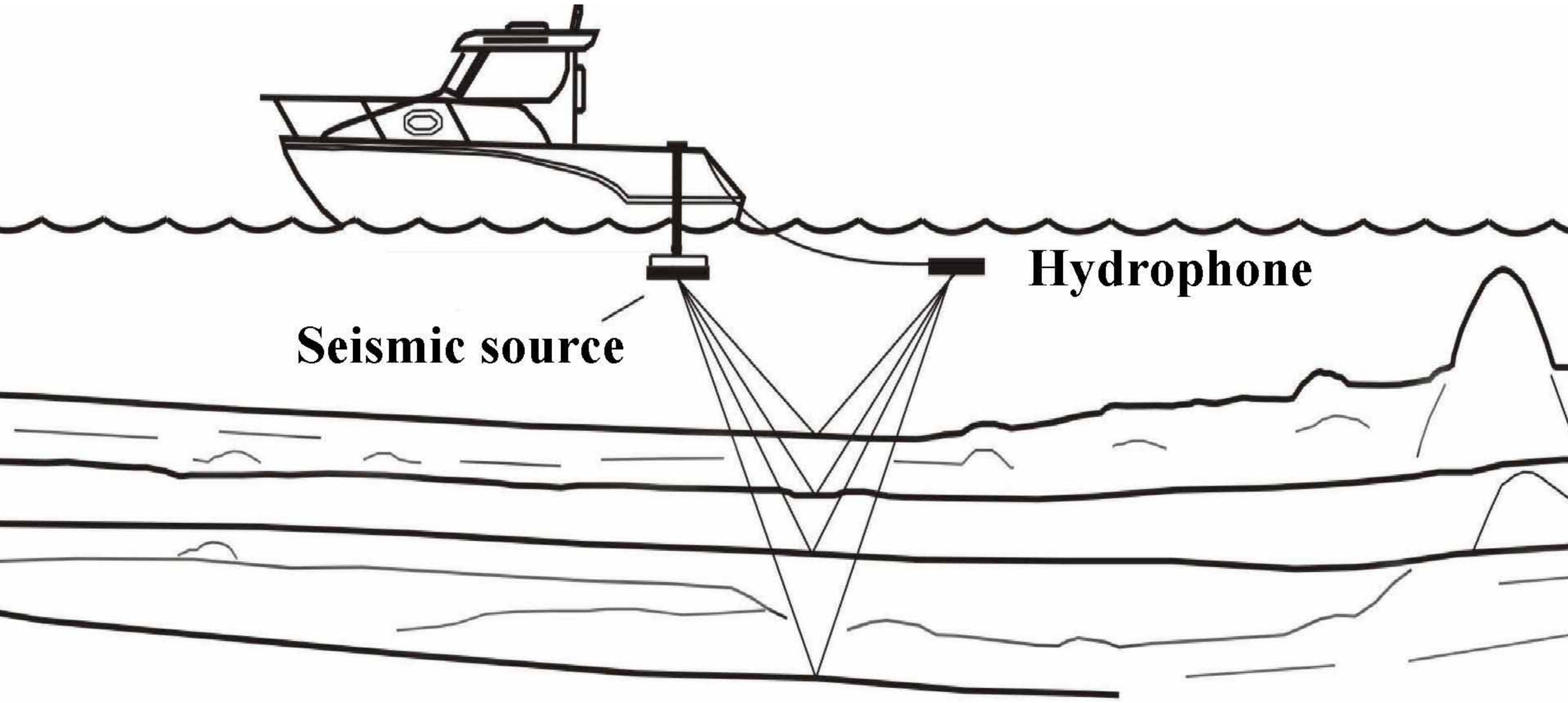

RAPPORTI TECNICI INGV

High resolution seismic survey in Mondragone and Baia Domizia, coastal area Gaeta Gulf (Italy)

497

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High resolution seismic survey in Mondragone and Baia Domizia, coastal area Gaeta Gulf (Italy)

Alberto Giordano[1,*], Luigi De Luca[1], Pietro Aucelli[1], Francesco Peluso[1], Gerardo Pappone[1], Francesco Giordano[1], Giuseppe Corrado[2], Marcello Schiattarella[2], Vincenzo Bruno[1] and Pasquale Giordano[3]

[1]DiSAm | University of Naples “Parthenope”, Naples, Italy
[2]DiCEM | Università degli Studi della Basilicata, Matera, Italy
[3]JMA Wireless Italia Technology Center, Castel San Pietro Terme (BO), Italy

**Corresponding author*

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Abstract

A high-resolution seismic survey was carried to identify and map the geometry of the stratigraphic succession present beneath the seabed in front of Mt. Massico, in the coastal area of Mondragone/Baia Domizia (Gulf of Gaeta). For a preliminary study, aimed at the calibration and adjustment of the adopted methodology, some representative areas of the different depositional, morpho-lithostratigraphic types have been appropriately selected. This choice was made based on the available stratigraphic and bathymetric information. The joint interpretation of the seismic profiles and sedimentological and stratigraphic survey performed with continuous coring [Aiello et al., 2021] has allowed us to correlate and in particular, to determine the orientation of different faults identified during the inland geological field survey. For the acquisition, we used the high-resolution seismic source Boomer mod.230 from EG&G.

Keywords Boomer; Gaeta Gulf; Campanian Margin; D-Seismic

Introduction

The study area focuses on the coastal zone of Mt. Massico, a carbonate horst that separates the two main alluvial, coastal plains on the Tyrrhenian side of southern Italy, namely the Garigliano Plain and the Volturno Plain (Figure 1).

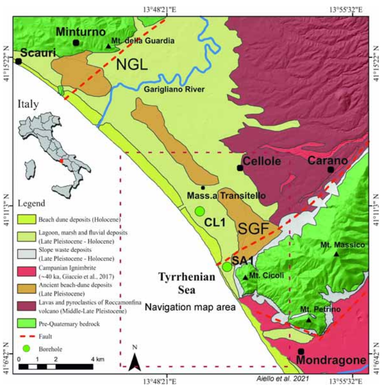
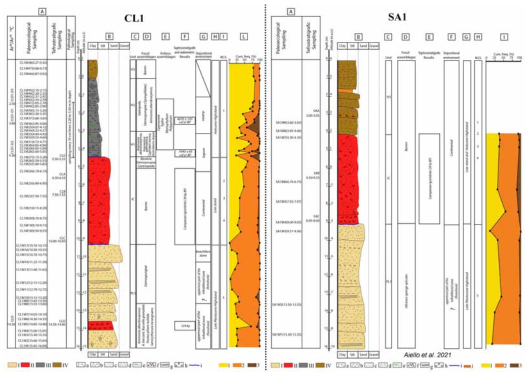


Figure 1 The figure shows the geological map of the study area [Aiello et al., 2021].

This area is bounded by main faults oriented NW-SE and NE-SW, [Ortolani et al., 1978; Mariani et al., 1988; Milia et al., 1997; 2017; Brancaccio et al., 1990; Abate et al., 1998; Amorosi et al., 2012; Bellotti et al., 2012; 2016; Corrado et al., 2018; 2020; 2022; Di Lorenzo et al., 2021; Budillon et al., 2022; Ruberti et al., 2022; Iorio et al., 2024]. All these basins are filled with thick successions of clastic and pyroclastic deposits and volcanic products (up to four thousand meters), due to compensation of tectonic subsidence [Ippolito et al., 1973; Cosentino et al., 2006; Milia et al., 1997; 2017; Aiello et al., 2021]. Two core drillings were carried out in the southern portion of the Garigliano Plain, not far from the carbonate horst of Mt. Massico: the CL1 hole, located in the municipality of Cellole, at coordinates 13°49′43″E, 41°10′57″N, and the SA1 hole, located in the municipality of Sessa Aurunca, at coordinates 13°50′48″E, 41°9′20″N, near the north-western slope of Mt. Massico (Figure 2). The data from the wells [Bartole et al., 1984; Mariani and Prato, 1988; Aiello et al., 2021] provided significant information on the structure and stratigraphic setting of the plain, which encompasses a continuous pre-Quaternary sequence from the Upper Miocene to the Lower Pliocene. The Quaternary units of this area are made up of marine-coastal deposits, silty marsh deposits and pyroclastic products of the Roccamonfina volcano and the Campi Flegrei volcanic district.

Figure 2 Sedimentological log of the CL1 and SA1 cores.



1. Seismic data acquisition system

In the coastal area of Mondragone/Baia Domizia (Gaeta Gulf), in front of Mt. Massico, a high-resolution seismic survey was conducted in May 2018 to identify and map the geometry of the stratigraphic succession present in the seabed, within the XXXI cycle of the PhD (Phenomena and risks) of the University of Naples "Parthenope", entitled: *Quaternary evolution of the main Tyrrhenian coastal plains of southern Italy: interaction between climate, tectonics and repercussions on the dynamics of currents*. For a preliminary study, aimed at calibrating and refining the adopted methodology, some representative areas of the different depositional, lithostratigraphic and morphological typologies were appropriately selected. This choice was conducted based on the available stratigraphic and bathymetric information [Vigor project, 2014].
The stratigraphic data from the cores CL1 and SA1 [Romano et al., 1994; De Alteris et al., 2006; Aiello et al., 2021; Di Lorenzo et al., 2021; Florio et al., 2022] were used to interpret and calibrate the seismic lines and build several geological sections useful to constrain the tectono-sedimentary evolution of the study area during the Late Quaternary.
The interpretation of the seismic profiles combined with the sedimentological and stratigraphic investigations conducted with continuous core drilling geognostic surveys [Aiello et al., 2021; De Alteris et al., 2006; McGee, 2000; Yilmaz, 2001; Giordano et al., 2020] confirmed the orientation of some faults identified in the study area on the SE slope of Mt. Massico, as in the case of the Padule locality near Mondragone [Romano et al., 1994; Cinque et al., 2000; Corrado et al., 2020]. The high-resolution geophysical method allowed to identify different geomorphological structures, such as paleo-riverbeds and pockmarks.
The data acquisition system used during the seismic survey consists of: a seismic source composed of an electrodynamic transducer, Figure 3, type Boomer [Verbeek, 1995; McGee and Verbeek, 1995; Simpkin, 2005] and an energization unit (power unit), consisting of the trigger capacitor bank (mod. 231) and the power supply (mod. 232A), produced by EG&G (Figure 4a). The power used varies from 100 to 500 Joule/shot, with an output voltage of 4 kV in direct current.
The electrodynamic transducer EG&G mod. 230-1 is characterized by an araldite plate (Figure 5), mounted on a catamaran frame, so as to remain suspended in the water at a constant depth that minimizes turbulence due to drag (Figure 3a).
This system is particularly suitable for seismic reflection exploration [Rayleigh, 1945; Urick, 1967; De Dominicis, 1990; Mirabile et al., 1991; Jones, 1999] and allows to work even in

restricted areas near the coast, in shallow waters and to investigate the subsurface up to depths of several hundred meters.

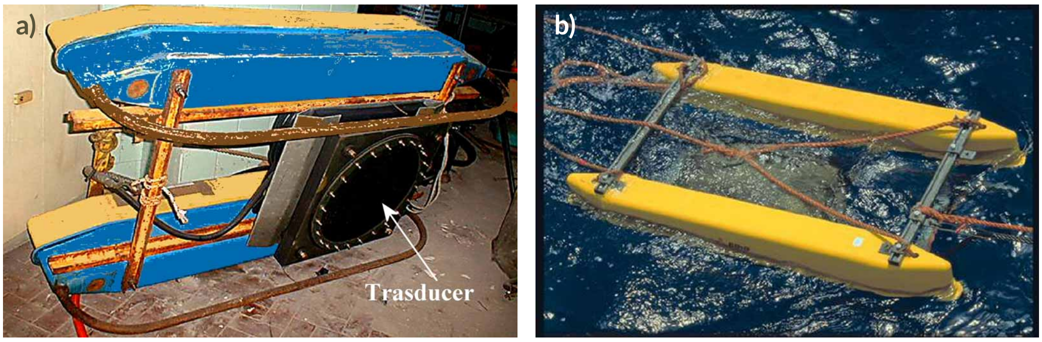


Figure 3 a) Boomer source seen from below, mod.230. **b)** Boomer source in the sea. The Boomer source offers excellent repeatability and stability of the pulses (signature), in a frequency range between 200 and 4000 kHz. In favorable conditions, these characteristics lead to a decimeter resolution.

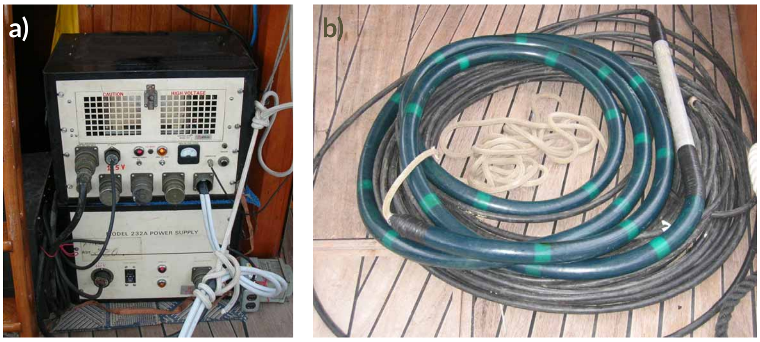


Figure 4 a) The trigger capacitor bank (mod. 231) and the power supply (mod. 232A) are shown in the figure. **b)** Hydrophone used during seismic prospecting. The hydrophone was designed and built by Marine Geophysics Laboratory of the University of Naples "Parthenope", DISAM department.

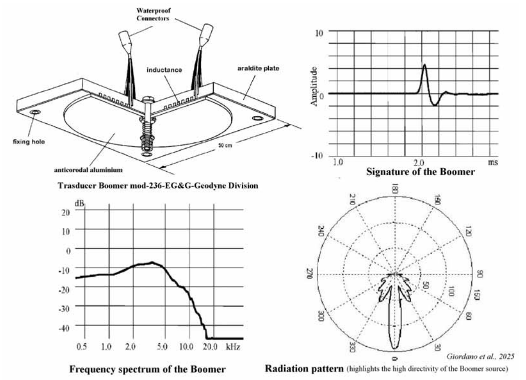


Figure 5 The image shows the Araldite plate, the frequency spectrum, the radiation pattern and signature of the Boomer [Giordano et al., 2020].

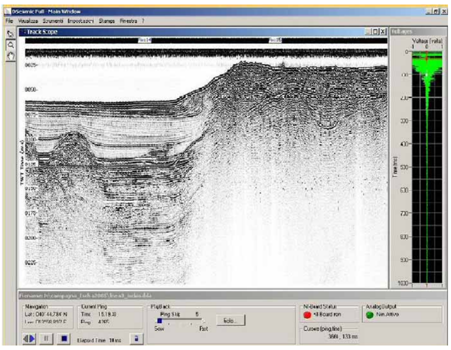
The maximum number of pulses accepted by the transducer is 8 pulses/sec at 150 Joule but given the characteristics of the investigation (maximum depth of about 8-10 meters) it was energized four times per second 4 pulses/sec at 400 Joule.

In our case, the reflected signals are acquired by a hydrophone, designed and self-built at the Marine Geophysics Laboratory of the University of Naples "Parthenope", DISAM department, using Teledyne piezoelectric elements with known electrical and radiative characteristics (Figure 4b). These, inserted in an antifreeze rubber tube, are immersed in oil whose characteristics present a negligible acoustic impedance. The sensors are positioned at a predetermined distance from each other, based on the vertical resolution to be achieved (note the electrical and radiative characteristics of the boomer (Figure 4b).

2. Results

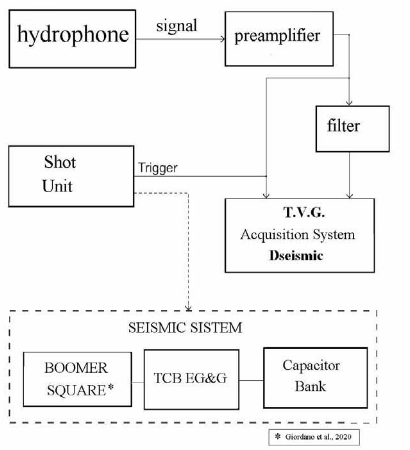
The depth of the seabed explored during the investigations varies between 5 and 15 meters approximately, therefore the hydrophone used, having a fundamental wavelength of λ~0.25 meters, has provided us with a very high resolution on the seismic profiles, [Verbeek, 1995; McGee and Verbeek, 1995; McGee, 2000]. The signals are then sent to an analog filter chain (Kron-Hite Mod. 3700) with high precision in frequency with a range from 0.2 Hz to 20 KHz with known impulse response and unitary amplification. The function used is to limit the band of the acquired signals to avoid the aliasing phenomenon. The acquisition device is composed of a PCI-MIO 16E acquisition card from National Instruments equipped with an A/D converter with a sampling frequency of up to 200 Khz. The card is managed by the D-seismic software, [Corradi et al., 2002; 2003; 2009; Giordano et al., 2003] (Figure 6) which is able to perform, in real time, an analysis of the seismic signal (amplitude spectrum), allowing to identify any corrections to be made to the acquisition parameters, improving their dynamics, before the creation of the seismic line.

Figure 6 D-Seismic – The main window.



The D-seismic software is able to georeference both the entire seismic line and the single acquired shot. It is interfaced via the serial port to the Trimble DSM 232 differential GPS system. Figure 7 shows the block diagram of the entire acquisition system.

Figure 7 Block diagram of the acquisition system [Giordano et al., 2020]. The hydrophone and the source were towed with a longitudinal offset that varied depending on the depth of the sea bottom. To reduce the disturbance caused by the vessel's engines, the system was located at a distance of 5 m from the edge of the boat, in Figure 8 the acquisition geometry.



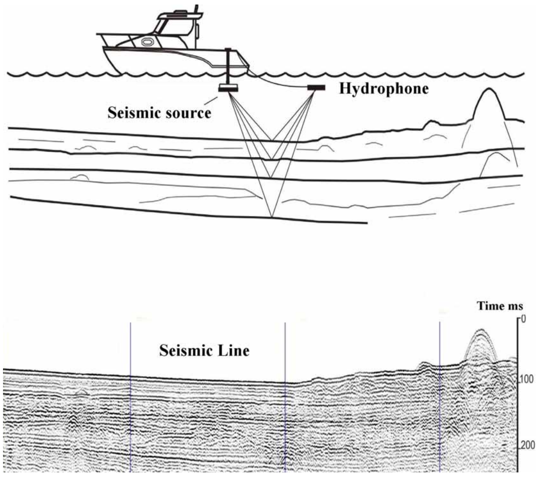


Figure 8 Working operations. Seismic signal acquisition geometry.

3. Processing and interpretation of seismic profiles

A seismic survey was performed on the shelf offshore coastal of Mt. Massico. During the survey, seven seismic lines were acquired using the high-resolution seismic reflection technique for a total length of about 28 km and a vertical exaggeration of 20x. The lines are oriented parallel to the coast with two transversal transects included for verification and control according to the navigation plan shown in Figure 9. The seismic profiles acquired were processed and interpreted. In this work, particular attention is given to selected lines that reveal notable structural dislocations. This survey allowed the identification and definition of the stratigraphic and structural framework of the subsurface units.

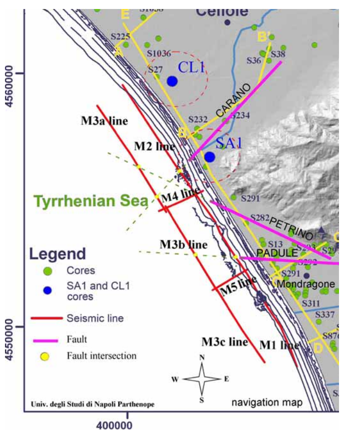


Figure 9 The figure shows the navigation map of the acquired seismic lines and the relative intersections of the hypothetical faults traced from the mainland to the sea. The position of the wells CL1 and SA1 are visible in the figure.

For the seismic lines, the following acquisition parameters were respected: sampling frequency fc = 12 kHz, spacing between traces of 6 s, ship speed of 1.8 m/s and acquisition window with listening time of 0.5 s. In addition, a high-pass filter (HP) up to 4 kHz was applied to make the signals band-pass. When necessary, in the post-processing phase, in the face of signals with low dynamics, the TVG (time-varying gain) amplifier was used. The seismic lines [Urick, 1967; Jones, 1999; Mirabile et al., 1991; Giordano et al., 2003; 2020; 2025] before interpretation, were processed in the Matlab environment, applying a two-dimensional convolutional filter, (MathWorks, Matlab) in order to highlight the impedance contrast between the various identified reflectors and any hidden reflectors.

From the results seen, there are presences of sub-vertical discontinuities, highlighted by the arrow, on both line M1 and line M3B, lines parallel to each other (Figures 10 and 13). Other relevant dislocations are evident on line M2 and line M3A (Figures 10 and 11). These intersect almost perfectly on the M2 line (Figure 11) at a distance of about 2.5 km from the beginning of the line. Furthermore, from the interpretation [Bruno et al., 2000; Yilmaz, 2001] of the lines, a stratigraphic interval is noted with a succession of three discontinuity surfaces characterized by high-amplitude electrical signals from a geophysical point of view, which deepen respectively to about -10 m, -22 m and -30 m from sea level, taking into account the average speed in water of about 1530 m/s [Wilson, 1960; Stabile et al., 2007]. The formula of the speed of sound is:

$$v = \frac{s}{T} \tag{1}$$

with *s* the space traveled and T the time taken between bottom and receiver.
During seismic acquisition, we have to consider the double path of the acoustic signal from the sea surface to the seabed, so the formula becomes:

$$v = \frac{2 \cdot s}{T} \tag{2}$$

Inversely we have that the space traveled (TWTT) will be:

$$s = \frac{v \cdot T}{2} \tag{3}$$

Example: with a T = 100 ms, the space traveled by applying (3) will be:

$$s = \frac{v \cdot T}{2} = \frac{1530 \cdot 100 \cdot 10^{-3}}{2} = 76.5\, meter \tag{4}$$

Clearly this speed of sound is valid in seawater, in particular the Tyrrhenian sea, [Stabile et al., 2007] and not in the underlying sediments. Therefore on the seismic lines the values entered for depth (Figures 10 - 13) are approximate values, partly because in sediments the speed of sound is certainly greater given the different density compared to seawater. Starting from the seabed, three seismic units have been identified, named with the letters A, B and C.
Unit A in yellow: it presents a homogeneous and marked stratification, due to the high amplitude of the seismic signal, in turn characterized by a high frequency content. A thickness ranging from about 15 m on the M3b line to about 25 m, with peaks of about 30 on the M2 line, can be seen. This is made up of clays, silts, sands and gravels, therefore a depositional unit of the upper transgressive phase of the Upper Pleistocene; as deduced from the CL1 core.
Unit B in red: it presents a main horizon at about 25 m on the M3a line, but it emerges at the surface or almost on the other lines, like the M3b. It presents a chaotic and irregular acoustic response, classic of pyroclastic materials, pumice and scoria. Depositional unit of the lower descending phase of the Upper Pleistocene.
Unit C in orange: 15 m to 25 m thick just below unit B, with variable signal amplitudes and useful information in the profile covered by multiple signal interference. Overall composed of sand, clay and sedimentary bodies. Highly stationary depositional unit of the Upper Pleistocene. The outermost lines M3A and M3B (Figures 12 and 13) characterized by a bathymetry of about -15 m, are of great interest, as the reveal the presence of a large outcrop unit [Bartole et al., 1984; Wezel et al., 1985; De Rita et al., 1986; De Vivo et al., 2001; Aiello et al., 2021; Di Lorenzo et al., 2021].
The seismic profiles relative to lines M4 and M5 are perpendicular to the coastline and extend in the SE–NW direction, intercepting the M2 and M3a lines and coinciding with the northern and southern footslopes of Mt. Massico respectively; show evidence of weak tectonic deformation caused by faults subparallel to the coastline.

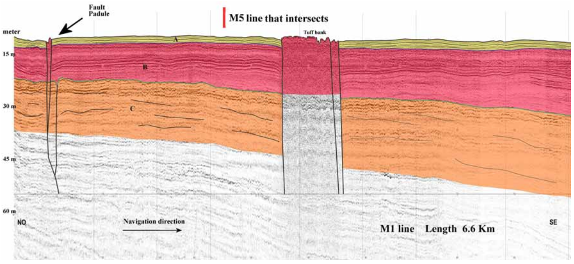


Figure 10 M1 line: the presence of the Padule fault is evident.

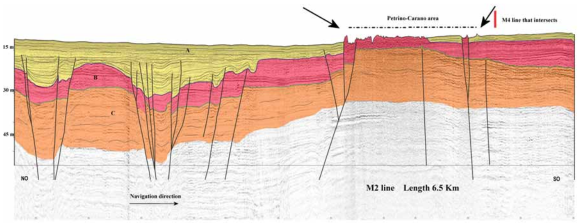


Figure 11 M2 line: Petrino-Carano area of the faults presence highlighted.

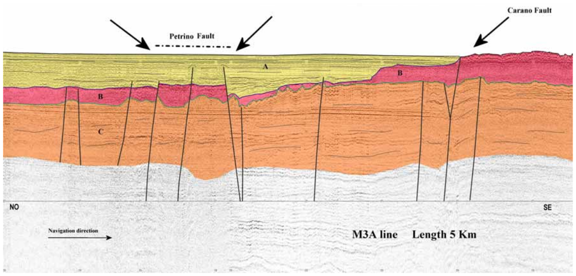


Figure 12 M3A line: Petrino-Carano area of the faults presence highlighted.

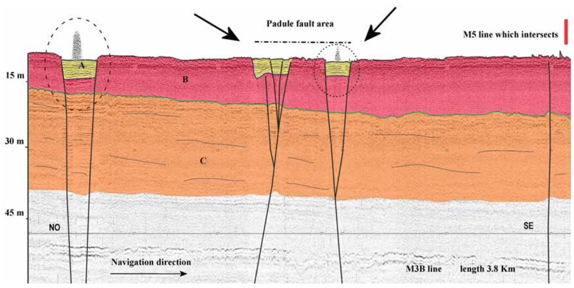


Figure 13 M3B line: the presence of the Padule fault is evident.

4. Conclusions

The use of the Boomer system for seismic survey on the shallow seabed of the Domitian Coast produces, within the limits of environmental disturbances, good high-resolution seismic sections. The average signal penetration varies between 15 and 35 meters depending on the material crossed and the bathymetry. In optimal conditions, reflectors were identified at depths greater than 30 m. The Boomer system allowed to discriminate three seismic units of great interest A, B and C, correlated with the data from the CL1 and SA1 wells. This methodology, supported by geological surveys, facilitates the identification and mapping of the main geometries of the Quaternary deposits. The hypothetical fault structures were correctly detected. Hot spot areas of particular geological interest were identified, clearly visible on the M3B line.
This is due to the rise of hot, low-enthalpy fluids from the ocean floor, where they form metric-sized reliefs and depressions, giving rise to plumes in the water column (Figure 14).

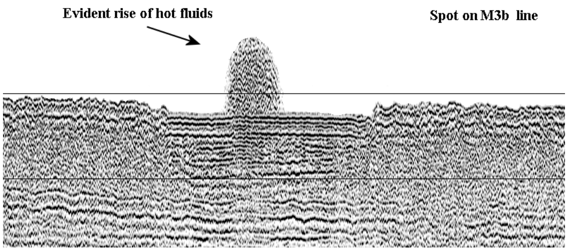


Figure 14 The image clearly shows the rise of hot fluids from the seabed, giving rise to plumes in the water column.

Acknowledgements

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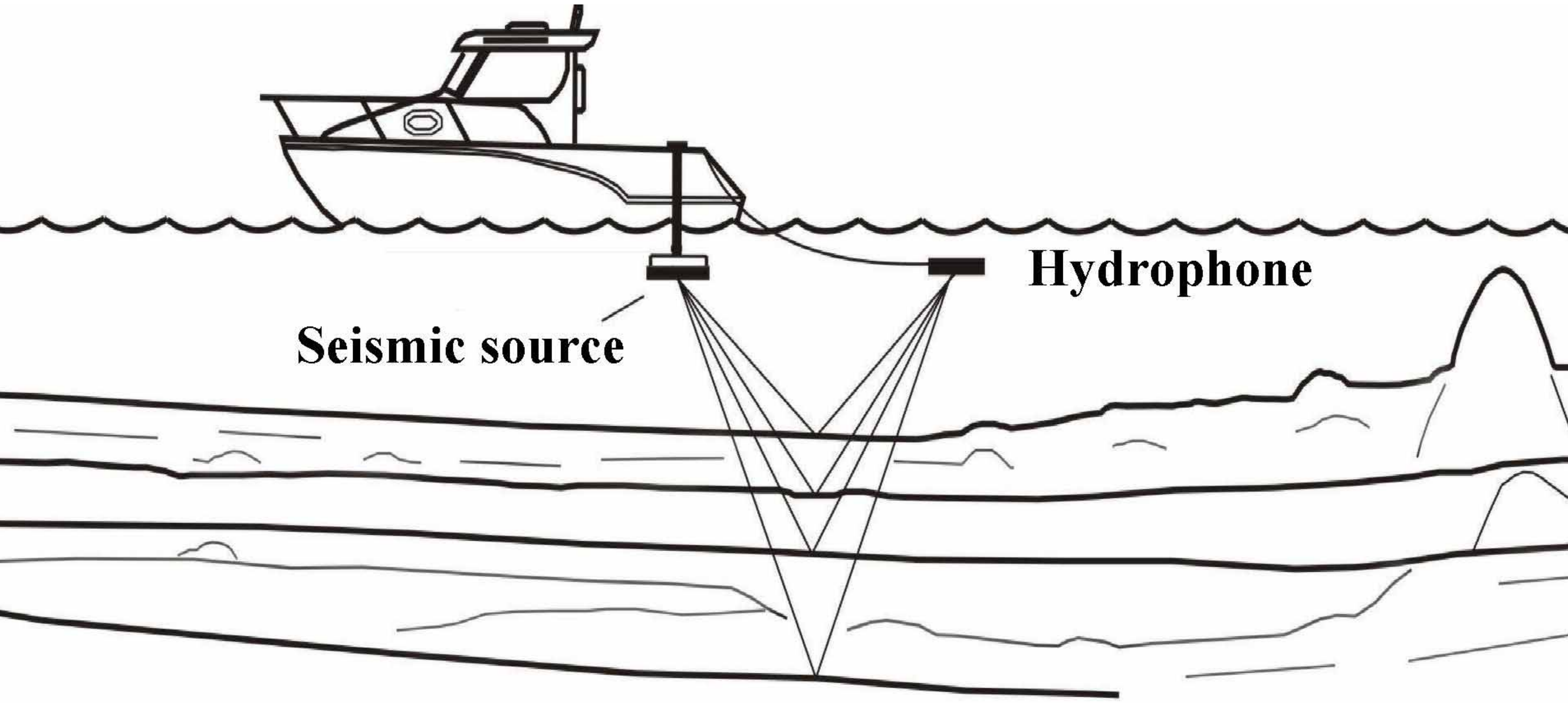

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