IL NUOVO CIMENTO Vol. 30 C, N. 6 Novembre-Dicembre 2007
DOI 10.1393/ncc/i2007-10272-4

A preliminary study of the subsoil of the Roman Amphitheatre of Catania (Sicily) through integrated geophysical and stratigraphic data

S. Imposa(1)(2)(*), F. Barone(1), F. Chiavetta(3), G. Coco(4), M. Corrao(4) and D. Chisari(5)

(1) *Dipartimento di Scienze Geologiche, Università di Catania - Corso Italia 57 95129 Catania, Italy*
(2) *C.R.I.Be.Cu.M, Centro di Ricerche sulle cause di degrado per il recupero dei Beni Culturali e Monumentali - Corso Italia 57, 95129 Catania, Italy*
(3) *Assessorato Regionale Beni Culturali e P.I. - Soprintendenza BB.CC.AA. di Catania Via Luigi Sturzo 62, 95100 Catania, Italy*
(4) *Geocheck S.r.l. - Via P.A. Secchi 7, 95130 Gravina di Catania (CT), Italy*
(5) *Comune di Catania, LL.PP., S.I. e N.I., - P.O. 02. Coordinamento Geologico Via Domenico Tempio 64, 95100 Catania, Italy*

(ricevuto il 12 Settembre 2007; revisionato il 13 Marzo 2008; approvato il 18 Marzo 2008; pubblicato online il 3 Luglio 2008)

Summary. — To reconstruct the stratigraphy of the subsoil and the geometry of the lava deposits beneath the Roman Amphitheatre located within the city of Catania (Sicily) we performed non-invasive geophysical prospections (seismic and electric tomography). In urbanized contexts this kind of surveys represents the best support to following more specific studies aimed at the conservation of monuments. Seismic tomography allowed us to reconstruct seismostratigraphic sections by imaging the distribution of seismic waves velocity in the internal ambulatory wall and its substrate and outside the Amphitheatre. Electric tomography allowed us to image the resistivity distribution outside the Amphitheatre and to locate anomalies related to the possible presence of cavities, water table and waste waters. The stratigraphic data obtained from mechanical drillings carried out in the study area were used to calibrate the information obtained from the geophysical surveys.

PACS 93.30.Ge – Europe.
PACS 93.85.Bc – Computational methods and data processing, data acquisition and storage.
PACS 93.85.Rt – Seismic methods.

1. – Introduction and historical account

The aim of the present study is to reconstruct the stratigraphy and morphology of the substrate of the Roman Amphitheatre of Catania. This monument, built in the II century b.C., is located in the Stesicoro square, in the historical centre of Catania. The monument

(*) E-mail: imposa@unict.it

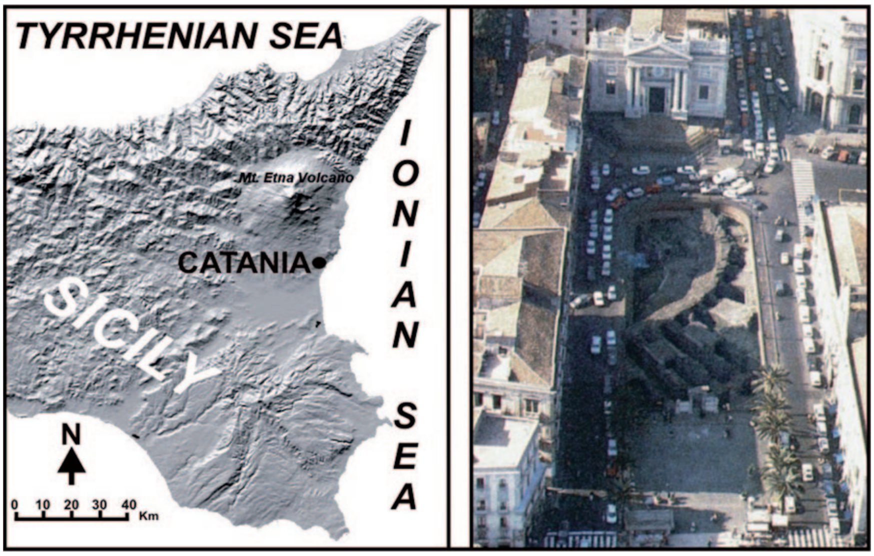

Fig. 1. – Left: location of the investigated area. Right: a picture of the Roman Amphitheatre, mostly buried below the present city level.

has undergone several events that have contributed to its partial destruction: between the V and VI centuries a.C., King Theodoric authorized the taking of the collapsed lavic ashlars and in the XI century part of the remaining ashlars was used to build the S. Agata Cathedral; in the XVI century, fearing an enemy attack, the civic Senate decreed the demolition of the upper orders of the Amphitheatre to fortify the defensive walls [1]. Of the original three-orders *cavea* with three entrances, only the lower order, in Doric style, is preserved. The ruins of the Amphitheatre are presently mostly covered by the modern buildings reconstructed after the 1693 Val di Noto earthquake (fig. 1).

The main and central element of this monument is the ellipse-shaped arena, with the longer axis of 60 m and the shorter one of 39 m. Considering the external circumference of 192 m, it is one of the largest in Italy after the ones in Roma and Siracusa.

2. – Geologic and geomorphologic setting

The area of the Roman Amphitheatre of Catania is highly urbanized, so that only a small part of the monument is visible and the rest lies below the present road paving (fig. 1). The geologic setting of the study area is characterized by beds of ancient lava (Larmisi's lava) that cover the morphologically depressed areas and is in turn covered by rubble material (fig. 2). In particular, from top to bottom, the following units are recognized [2]:

– Detritus and filling material: sandy-gravely deposits associated to old and recent coastlines and detritic material derived from the partial degradation of the Amphitheatre itself.

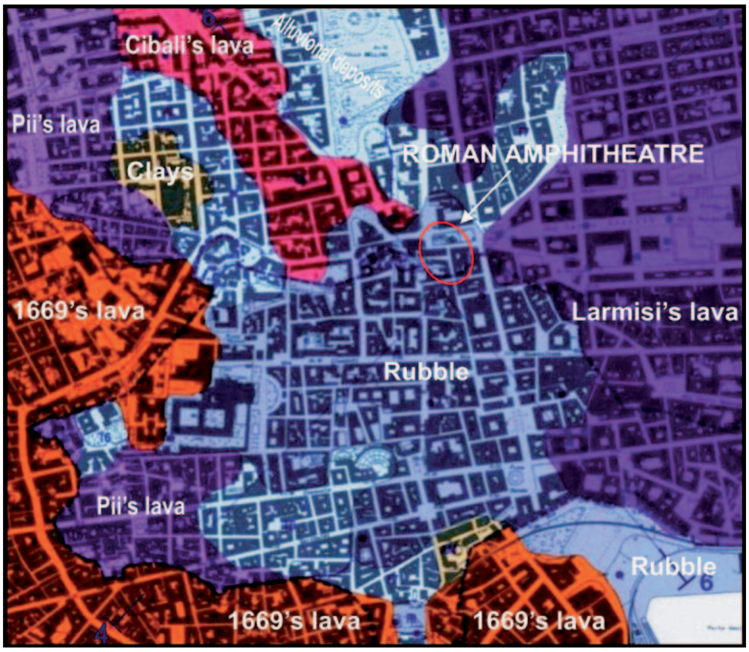

Fig. 2. – (Colour on-line) Geologic map of the investigated area.

– Lava: volcanic deposits which generally appear with a top scoriaceous vacuolated portion and a lower massive portion, with different degrees of fracturing and void inclusions.

– Marly clays: this is the basal formation. It consists of pelitic sediments without a clear stratification, mixed to other fine-grained layers.

3. – Mechanical drillings

In the study area three mechanical drillings were performed using the mechanic rotation method. A continuous logging sampled the litostratigraphic succession from the ground surface to a maximum depth of 21.8 m. In particular, the drilling M1 was carried out near the S. Biagio church, outside the Amphitheatre, at an elevation of 20.5 m a.s.l., and is 13 m deep, M2 was drilled 50 m east of the monument entrance, at an elevation of 14.1 m a.s.l., and is 21.8 m deep, M3 was drilled inside the arena at an elevation of about 9 m a.s.l. and reached a depth of 6.4 m (fig. 3). Stratigraphic data were then used to calibrate the information obtained from the geophysical prospections.

4. – Geophysical prospections

4·1. *Electric tomography*. – In recent years geoelectric methods have been largely applied in near-surface surveys giving a significant contribution to address a wide class of geologic problems. New acquisition systems, as multielectrode array configurations, are combined with innovative inversion techniques to obtain tomographic images of the electrical properties of the subsurface [3].

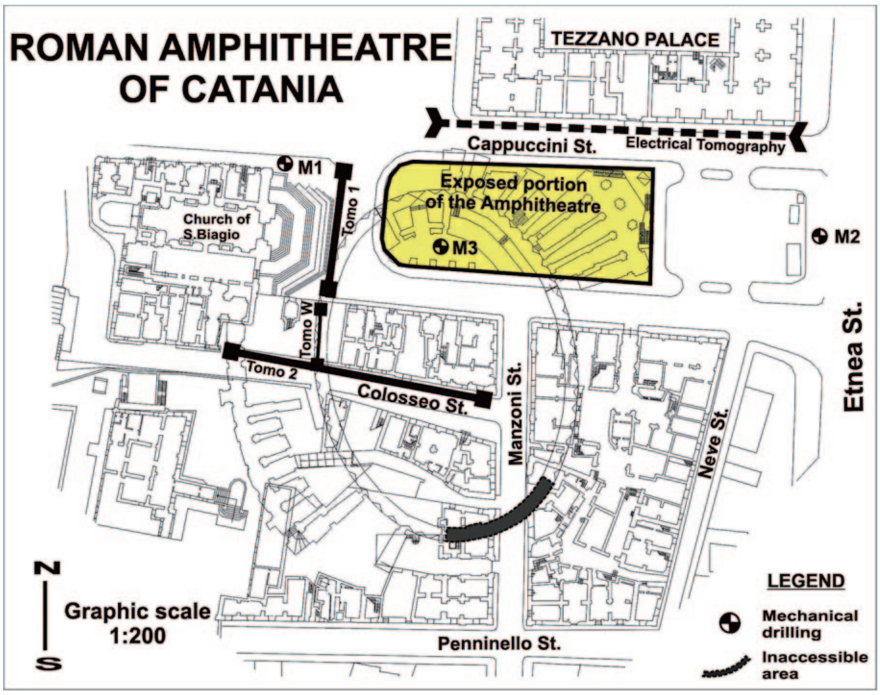

Fig. 3. – Map of the Roman Amphitheatre and surrounding areas: solid lines represent the trace of the seismic tomography profiles performed along the wall of the internal ambulatory (TOMOW), outside the S. Biagio church (TOMO1) and along Colosseo street (TOMO2). Dashed line represents the trace of the electric tomography profile.

One of the recent developments is the use of 2D Electric Resistivity Tomography (ERT) surveys to map areas with moderately complex geology [4]. Such surveys are usually carried out using several tens of electrodes, 25 or more, connected to a multi-core cable. Electrodes are located on the ground surface to send into the ground the electric currents and measure the generated voltage signals.

From a technical point of view, an ERT survey can be carried out using different electrode configurations (Wenner, dipole-dipole, etc.). In the present study we used the Wenner array since it is the most efficient in terms of the ratio of received voltage per unit of transmitted current [5] and is characterized by the lowest number of measurements compared with other arrays employed in geoelectric surveys [6].

We used a georesistivimeter consisting of a digital (16 bit resolution) multi-electrode (up to 256 channels) with up to 100 microvolts, that is able to switch the electrodes placed along the investigate profile from releasing electrodes (points of electric charging in the soil) to measuring electrodes, and vice versa.

The inter-electrode spacing depends on the length of the profile and on the maximum depth of investigation needed [7]. We used, according to Wenner geometry, an inter-electrode spacing of 2.0 m. The measurements are then transformed in a matrix of resistivity values that is inverted to obtain electro-resistivity images [8].

4·2. *Seismic tomography.* – Seismic tomography is a methodology that is used to map seismic velocity variations in a subsurface volume. This is done by comparing arrival

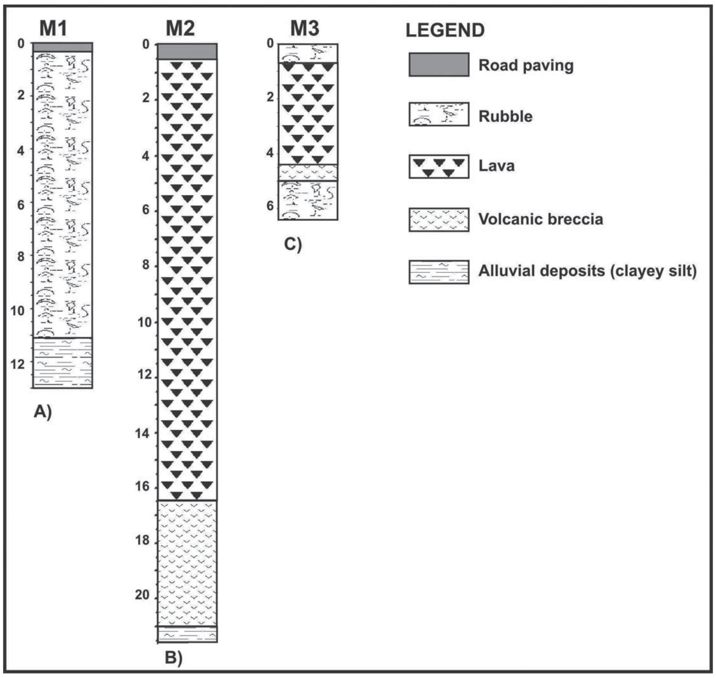

Fig. 4. – Stratigraphic columns obtained from the mechanical drillings.

times of seismic waves that traverse the volume in different directions and are recorded by an array of receivers (geophones) deployed at the surface over the volume of interest.

In this study the source of seismic waves is a sledge-hammer and waves are recorded by a multichannel seismograph with the following technical characteristics:

– *signals sampling capacity between* 0.002 *and* 0.00005 s;

– *"time break" communication and transmission system*;

– *high pass and band reject filters*;

– *automatic Gain Control*;

– *double A/D* 12 bit *converter.*

Seismic data have been analyzed using the GSAO (Generalized Simulated-Annealing Optmization) method [9]. This method allows the non-linear optimization of the inversion of the arrival times of direct and refracted waves and has the advantage of being independent on the starting velocity model [10].

5. – Analysis and discussion of the data

5˙1. *Mechanical drillings.* – In fig. 4 are shown the stratigraphic columns obtained from the mechanical drillings previously described. From top to bottom, the M1 drilling, ubicated near the St. Biagio church, is characterized by 30 cm of road paving, followed

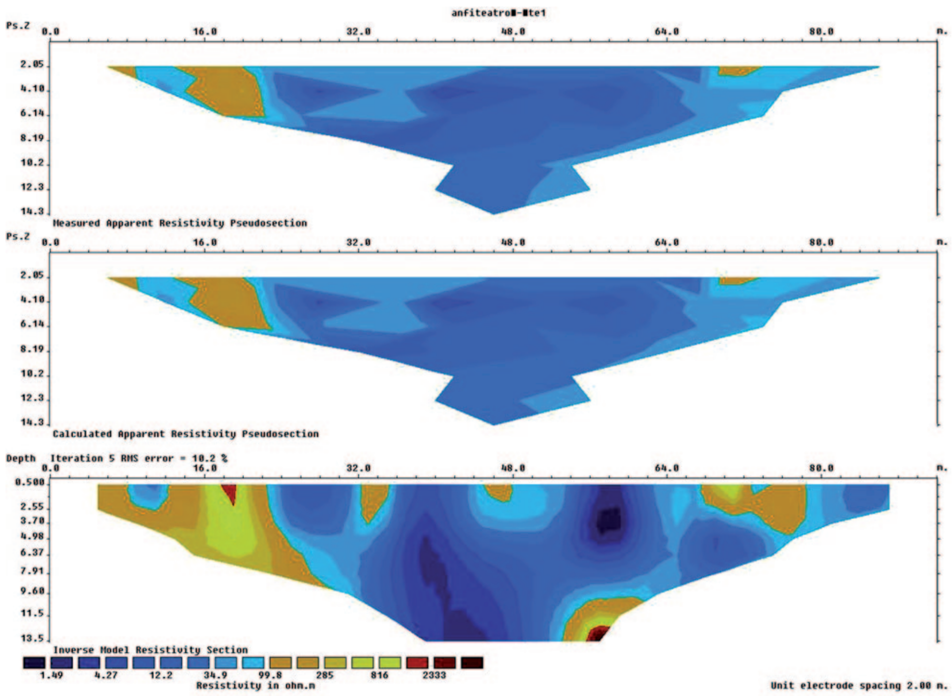

Fig. 5a. – (Colour on-line) Profiles of measured (top) and calculated (middle) apparent resistivity; the bottom panel shows the tomographic section without topographic correction.

by rubble material down to a depth of 11.1 m and by a clayey silt layer, that can be ascribed to an alluvial deposit, to a depth of 13.0 m.

The M2 drilling, located nearby the Amphitheatre entrance, shows a 50 cm thick road paving followed by a dark grey coloured vacuolar lava from 0.5 to 1.5 m, locally fissured lava from 1.5 to 4.3 m, vacuolar lava from 4.3 to 7.8 m, massive lava from 7.8 to 16.5 m (in fig. 3 these units are shown as a single layer) and scoriacea lava with sand from 16.5 to 21.0 m; below the lava deposit a yellowish gravelly-sandy stratum is present down to the bottom. At site M3, ubicated within the arena, rubble and filling material were drilled in the first 70 cm of depth, followed by a stratum of vacuolar lava down to a depth of 1.3 m and massive lava, locally fissured, to a depth of 4.4 m. Then, we found a layer of volcanic breccias to a depth of 5.0 m and a slimy-clayey layer down to 6.4 m.

5˙2. *Electric tomography*. – A 92 m electric tomography profile was carried out along the Cappuccini Street, in front of the Tezzano Palace (fig. 3). The maximum depth of investigation is 13 m in the central part of the section. Figure 5a shows the measured and calculated apparent resistivity (upper and middle panels) and the inverse model resistivity image without topographic correction (lower panel). Figure 5b shows the 2D resistivity image along the acquisition profile, inclined following the westward sloping of the street. A topographic correction was performed using a portable GPS.

The chromatic scale of fig. 5c represents the resistivity values that were normalized to differentiate three significant ranges of variation. The reddish anomalies, in the left part of the section, are characterized by the highest values of resistivity and are due

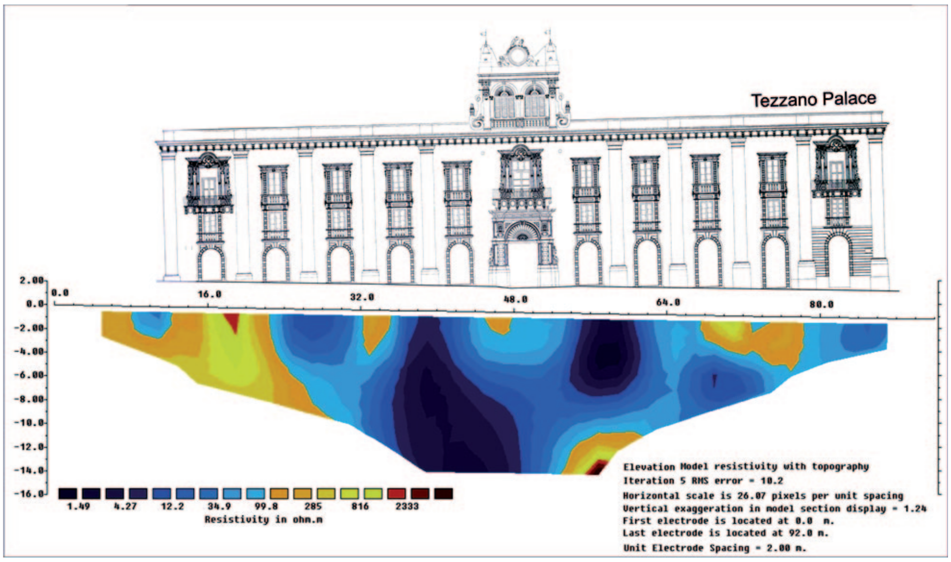

Fig. 5b. – (Colour on-line) Electric tomography section imaged in front of the Tezzano Palace with topography correction.

to the presence of drains for the discharge of meteoric waters. Light-blue anomalies, corresponding to low-resistivity zones, are located in the central area of the prospection and extend to the maximum depth investigated. They are due to infiltration of waste waters, as confirmed by the direct observation of percolations inside the Amphitheatre.

5˙3. *Seismic tomography*. – We carried out three seismic profiles for a total length of 93 m: TOMOW, along the wall of the Amphitheatre internal ambulatory, TOMO1, parallel to the S. Biagio church front, and TOMO2, along the Colosseo Street that partly overlies the Amphiteatre (fig. 3). For logistic reasons and being in an urbanized area, the seismic surveys outside the amphitheatre were configured to reduce the number of geophones and bursting as much as possible.

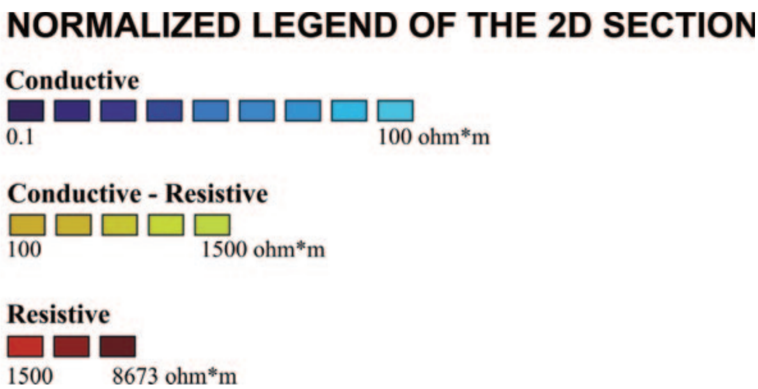

Fig. 5c. – (Colour on-line) Normalized chromatic scale representing the apparent resistivity values.

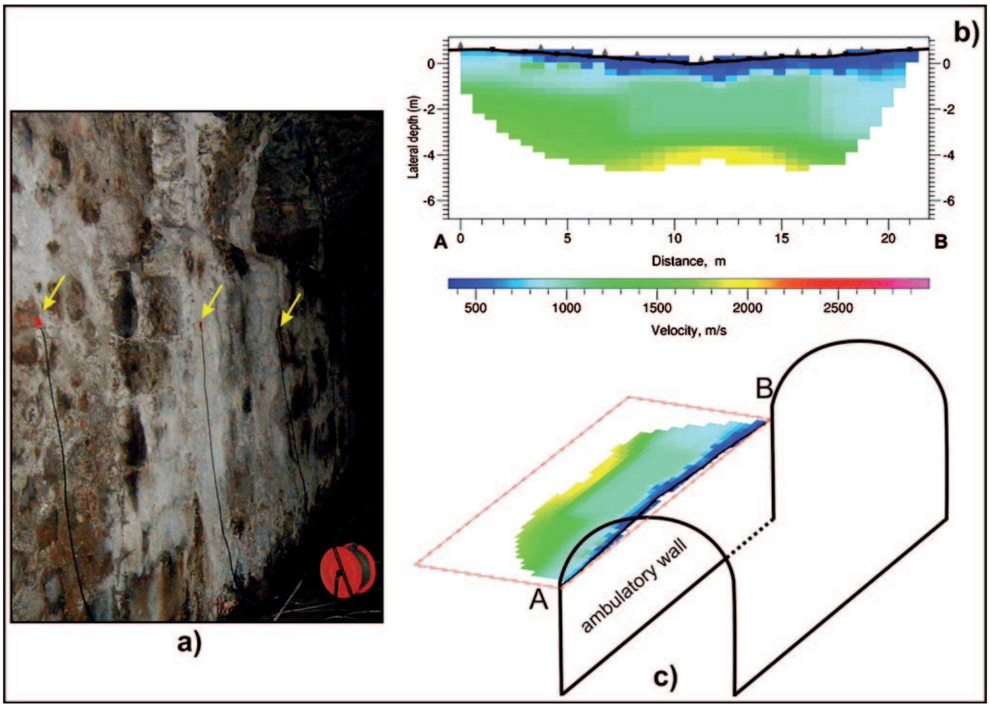

Fig. 6. – (Colour on-line) a) Internal ambulatory wall. Arrows indicate geophones used for the seismic tomography; b) seismic tomography image of the internal ambulatory wall (TOMOW profile). Triangles show the location of the piezoelectric sensors; c) projection of the tomography image along the ambulatory wall.

5·3.1. TOMOW. Along the TOMOW profile (fig. 6a) we deployed 14 geophones with G-spacing equal to 1.5 m, for a total length of 21.0 m. The seismic image of the internal ambulatory wall shows an irregular morphology of the substrate (figs. 6b, c). Beyond the gallery wall covering (in blue), as thick as 50 cm, we imaged a layer characterized by a P-wave velocity (V_p) of 1000–1200 m/s that can be ascribed to fractured lava. Massive lava with $V_p \geq 1800$ m/s is found at a horizontal distance of 3.5–4.0 m from the wall.

5·3.2. TOMO1. Along the TOMO1 profile we deployed 12 geophones with G-spacing equal to 2.0 m, for a total length of 24.0 m. This profile is parallel to the front of the S. Biagio church (fig. 3). The tomographic image of fig. 7 shows a marked lateral anisotropy in the central part of the section, where velocity varies abruptly from 1000 to 2500 m/s, that we interpret as the contact between massive and fractured lava.

5·3.3. TOMO2. Along the TOMO2 profile we deployed 16 geophones with G-spacing equal to 3.0 m, for a total length of 48.0 m. This profile was carried out along the Colosseo Street (fig. 3). The seismic image is characterized by a rather regular morphology of the substrate, with sub-horizontal seismic strata (fig. 8).

The seismic stratum with Vp varying between 100 and 2000 m/s represents vulcanoclastic units and fractured lavas, while the substrate with P-wave velocity higher than 2500 m/s is made of massive lava, as in the central part of the TOMO 1 section.

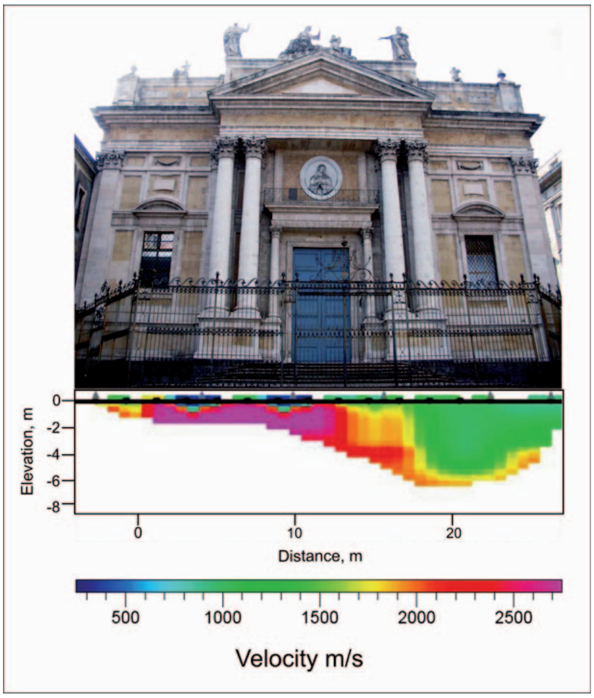

Fig. 7. – (Colour on-line) Seismic tomography image in front of the San Biagio church (TOMO1 profile).

6. – Conclusions

The aim of this study was contributing to reconstruct the stratigraphy and morphology of the sedimentary and volcanic deposits that are present in the subsoil of the Roman Amphitheatre of Catania. For this study we have adopted non-invasive geophysical prospections such as seismic and electric tomography.

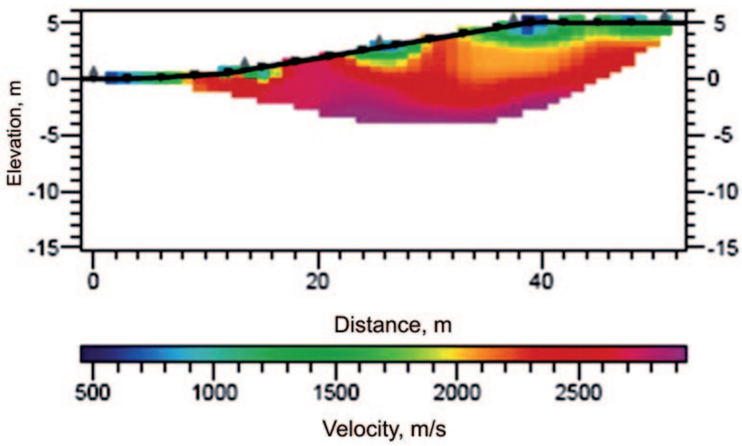

Fig. 8. – (Colour on-line) Seismic tomography image beneath Colosseo street (TOMO2 profile).

Inside and around the Amphitheatre we have carried out three seismic profiles, for a total length of 93 m, and an electric profile of 92 m. The geophysical prospections were calibrated and integrated with the stratigraphic data obtained from the M1, M2 and M3 drillings.

A seismic profile was carried out in the internal ambulatory to investigate the thickness of the lava flow beyond the ambulatory wall. From the interpretation of the tomographic section it is evident that the lava leaned against the wall without damaging the internal ambulatory. On the contrary, the lavic flow entered and heavily damaged other parts of the Amphitheatre, like the central arena. Two more seismic profiles acquired outside the Amphitheatre shows that the lava deposits are rather shallow, between 5 and 8 m.

As for the electric tomography, we have reconstructed a 2D image of the apparent resistivity along a section underlying Cappuccini street in front of the Tezzano Palace, north of the Amphitheatre. The resistivity pattern allowed us to identify and locate significant heterogeneities caused by the presence of fluids (presumably sewage from the palace itself) that percolate inside the monument. The infiltration of fluids affects a quite large area and, as observed inside the Amphitheatre, causes structural instability, mainly in the vaults that support the upper ambulatories. This is also testified by detachment and collapse of material. The present study results can be considered as a starting point to plan future investigations aimed at the recovering and preservation of this monument. They can be also used to address future archaeological explorations aimed at locating buried structures of anthrophic or natural origin.

* * *

SI was supported by grants (PRA 2005-2006) from the University of Catania.

REFERENCES

[1] Sposito C., *L'anfiteatro Romano di Catania: conoscenza-recupero e valorizzazione*, Vol. **I** (Flaccovio editore) 2003, pp. 1–135.
[2] Monaco C., Catalano S., De Guidi G., Gresta S., Langer H. and Tortorici L., *Mem. Soc. Geol. Ital.*, **55** (2000) 425.
[3] Sharma P. V., *Environmental and Engineering Geophysics* (Cambridge University Press, New York) 1997, p. 475.
[4] Griffiths D. H. and Barker R. D., *J. Appl. Geophys.*, **29** (1993) 211.
[5] Roy A. and Apparao R., *Geophysics*, **36** (1971) 943.
[6] Xu B. and Noel M., *Geophys. Prospect.*, **41** (1993) 791.
[7] Edwards L. S., *Geophysics*, **42** (1977) 1020.
[8] Dahlin T. and Loke M. H., *J. Appl. Geophys.*, **38** (1998) 237.
[9] Sathish K. Pullammanappallil and John N. Louie, *Bull. Seismol. Soc. Am.*, **84** (1994) 1397.
[10] Optim, 2001. User's Manual SeisOptR@2DTM Version 2.8, Optim LLC, UNR-MS 174, 1664 N. Virginia St., Reno, Nevada.