The "taranta[1]" effect of the 1743 earthquake in Salento (Apulia, southern Italy)

P. GALLI and G. NASO

Dipartimento della Protezione Civile, Roma, Italy

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ABSTRACT The Salento Peninsula (Apulia, southern Italy), along with a few other regions in Italy, is traditionally considered a low seismic hazard area. However, in 1743 it was affected by the catastrophic effects (I_{max}=IX-X MCS) of an earthquake, that probably occurred offshore, in the Salento Plateau (Ionian Sea). Subsequent damage had a complex pattern, whereby some towns were almost razed to the ground and others, nearby, suffered only slight damage. By means of an integrated geological, geotechnical and geophysical analysis we tried to cast a light on the causes of this peculiar distribution of seismic shaking, which we finally modelled by means of a one-dimensional simulation. These results, together with the re-analysis of the macroseismic distribution of the earthquake, and the seismotectonic knowledge of the region, suggest that the 1743 event was a strong, deep one that occurred far from Salento. The event induced high amplification, mainly in the villages (i.e., Nardò and Francavilla Fontana) founded on thin Pleistocene basins filled with soft sediments. The highest amplification peak, due to both the spectral content of the earthquake, as well as to the resonant period of the sedimentary basins, occurred in the same frequency range as most of the buildings of the time, that is ~3 Hz. This terrific double-resonance effect seems to be the main cause for the highest intensity evaluated in Salento, which, would otherwise, have been struck by effects possibly close to VII-VIII MCS.

1. Introduction

There are few places in Italy where one may presume to live safely away from earthquakes, and Salento (southern Apulia) can be considered one of these. Suffice it to observe the epicentre distribution of the historical events and/or the current Italian map of seismic hazard (Ordinanza PCM, 2006), where southern Apulia is characterized by 10% probability to exceed 0.025-0.075 g peak ground acceleration (*PGA*) value in 50 years (Figs. 1 and 2).

However, what happened in the heel of the Italian boot on February 20, 1743 is something that clashes with this reassuring image. Hundreds of people died the evening of that day, and other hundreds were injured by the strongest earthquake which ever struck Salento in the past 6-7 centuries, or more. Two towns, in particular, were almost completely destroyed: Nardò and Francavilla Fontana, located more than 60 km away one from each other, whereas many others suffered severe damage. However, one of the most interesting aspects concerning this anomalous earthquake is that close to villages literally razed to the ground, there were others which suffered only slight damages. For

[1] Taranta is a Salento folk shake dance, which simulates the violent spasms caused by the tarantula spider venom.

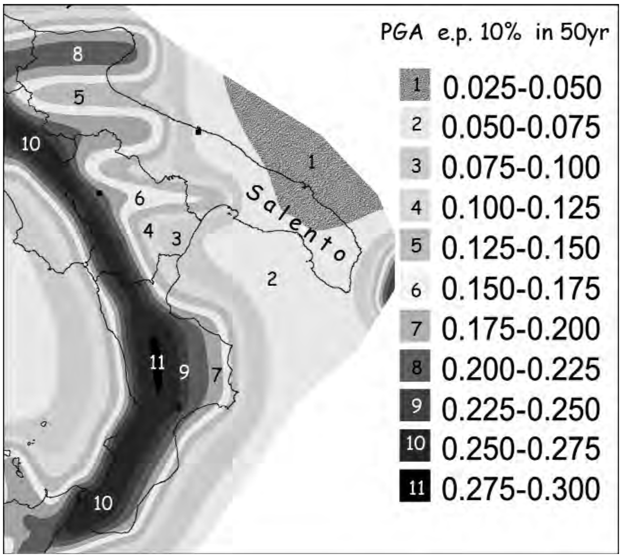

Fig. 1 - *PGA* exceeding probability in the investigated area (mod. from Ordinanza PCM, 2006). Note Salento, which lies in an area with 10% probability for 0.025-0.075 g in 50 years.

example, only 5 km separates the villages of Nardò and Galatone, both built in a quite flat area, as almost all the Salento's towns. In Nardò about 300 people died, and the town was almost completely crushed (more than one third of the buildings collapsed: IX-X MCS); in Galatone, on the other hand, nobody was injured, and no important damage was reported (VI-VII MCS). The same fact occurred in many other places of Salento (i.e., Leverano VIII-IX MCS vs. Copertino VII MCS; Francavilla Fontana IX MCS vs. Grottaglie VII MCS) and along the Greek coast (e.g., Lefkada), where the same earthquake produced the same patchy effects in several villages (Fig. 3).

In this paper, we try to analyze if and why site effects induced local disruption. First of all, we carried out geological, geotechnical and geophysical surveys in Nardò (and in other neighbouring villages) with the aim of reconstructing a geotechnical model of the subsoil.

On the other hand, all available historical sources concerning the 1743 event have been collected and re-analysed in order to depict the intensity distribution of the whole earthquake. Historical researches have been carried out in local archives for evaluating, in detail, the distribution and kind of damage in Nardò and other villages.

On the basis of the seismotectonic framework proposed for the region, we defined real and synthetic characteristics for some seismic events, to be possibly compared with the 1743 one. Earthquake parameters, together with the geotechnical model of the subsoil, have been used as input data in numerical one-dimensional simulation, the results of which have been matched with the data gathered through microtremor analyses.

The results obtained, both in terms of frequency range and motion amplification, are pretty consistent with the effects historically observed in Nardò and in other villages of the Salento peninsula during the 1743 earthquake, providing a reasonable explanation as far as the relationship between seismogenic source, geologically induced site amplification and damages are concerned.

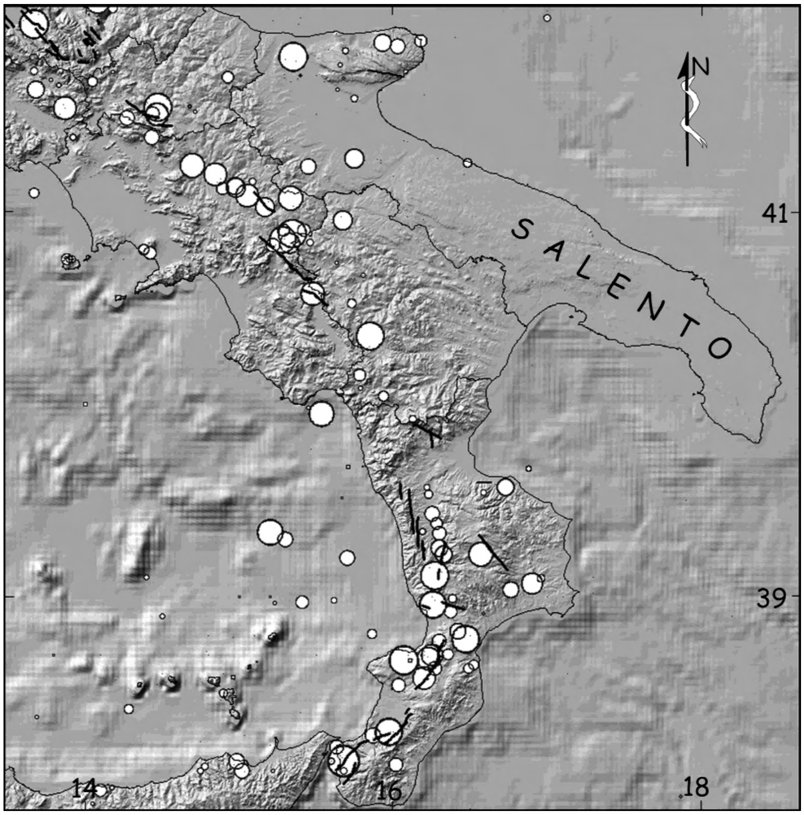

Fig. 2 - Epicentral distribution of earthquakes in southern Italy [4.9<*Mw*<7.5; modified from Working Group CPTI (2004)], together with the main known seismogenic structures [modified from Galli *et al.* (2006)]. Note the absence of any significant earthquake along the Salento peninsula.

2. The February 20, 1743 earthquake

The earthquake is parameterized by Working Group CPTI (2004; from now on CPTI04) with an epicentral intensity I_o=IX-X MCS, and an averaged magnitude M_{aw}=6.9, its epicentre being located offshore the southeastern Salento coast. On the other hand, it appears in the Greek catalogue (Papazachos and Papazachou, 1997; from now on P&P97) with I_o=IX MM, M_w=6.8, but located southeast of the island of Corfu, which is more than 100 km away from the CPTI04 epicentre (Fig. 3).

This discrepancy is due to the anomalous intensity distribution of this event, whose effects were strongly felt (I_s≥VI-VII MCS) from the Gargano peninsula to the Straits of Messina in Italy (Kingdom of Naples, at that time) and from the southern Albanian coasts in the Balkans to the island of Zante (ruled at that time by the Republic of Venice, as was most of the eastern coast of the Adriatic Sea and the Ionian Islands; Fig. 3). Although it is very difficult, and arbitrary to choose an epicentre in between the two mesoseismic areas (i.e. Salento and Ionian Islands), it looks like the one provided by P&P97 is not consistent with the whole intensity distribution, since it just focuses on the damage suffered in Greek localities. However, according to the historical sources concerning both Greece and

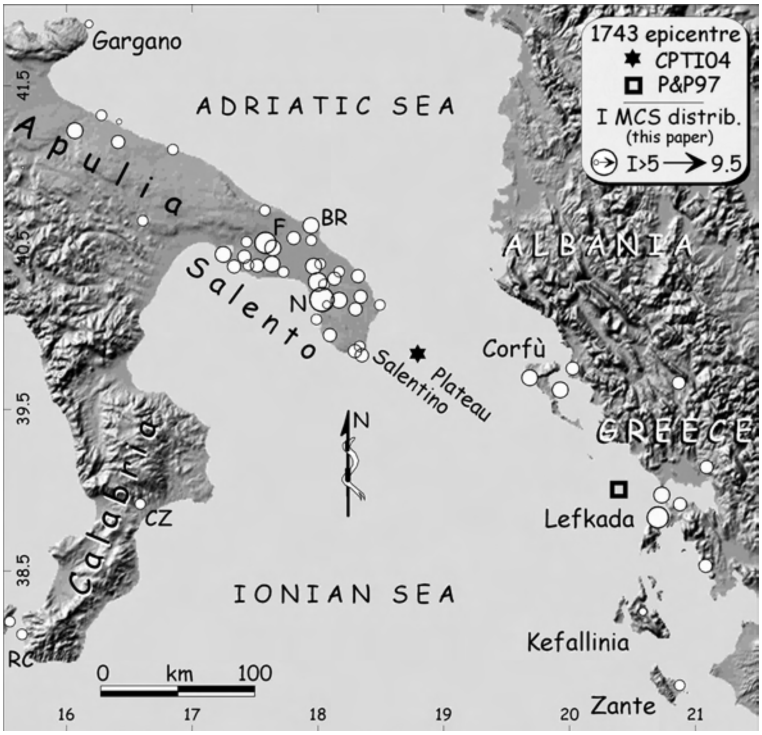

Fig. 3 - Intensity datapoint distribution evaluated for the 1743 earthquake on the basis of primary historical sources. (BR, Brindisi; CZ, Catanzaro; F, Francavilla Fontana; N, Nardò; RC, Reggio Calabria). Note the very wide damage extension (i.e., the I_s=VII area is elongated more that 500 km), and the two different epicentres according to Working Group CPTI (2004), and Papazachos and Papazachou (1997). In Greece, and in particular, in the Ionian Islands (Corfù, Lekfada, Kefallinia, Zante) the 1743 damage cumulated on that caused by several earthquakes that occurred in the decades before.

Salento (i.e., ASL, 1742a, 1745, ASVe, 1743a), and taking into account the fact that the Italian hours roughly started from the sunset of the day before, it seems that the opposite Ionian coasts were struck at the same time (~23:00 in the Ionian Island vs. 23:00-23:45 in Italy, local time; i.e., 16:00-16:45 GMT). In other words, unless two separate shocks occurred at the same hour near the Apulian and Balkan coasts, respectively, it appears that damage in southern Italy and in Greece-Albania was actually induced by the same earthquake.

After Baratta (1901, and references therein), the earthquake has been recently studied by Margottini (1981), De Simone (1993), Boschi *et al.* (1995), and Camarda (1997), all providing many valuable primary sources. By integrating these works with some new accounts found in the Italian archives (i.e., Archivio Segreto Vaticano, Archivio di Stato di Venezia, di Napoli, di Lecce, and others), it has been possible to reassess the MCS intensity distribution for 84 Mediterranean localities, from Malta to Trento (Table 1).

In Greece, the earthquake mainly struck the village of Amaxichi (today Lefkada; I_s=IX MCS), where 7 persons died under the ruins of many houses and churches (ASVe, 1743a), whereas only the walls of the Santa Maura fortress remained almost untouched (but not the inside village; ASVe, 1743b). All the citizens were exempted from taxes for the entire year 1744 (ASVe, 1744) by Venice, because of the seriousness of the damage. Heavy damage was reported also in the nearby town of Preveza (VIII MCS), and on the island of Corfu (Kerkira and Castel Sant'Angelo, both I_s=VIII MCS). Other villages of inland Greece and Albania were hit by the 1743 event, as reported in Table 1.

Nevertheless, it is worth noting that in the few decades prior to 1743, many Ionian islands experienced repeated, strong earthquakes that led to a dramatic increase in the vulnerability of the buildings. The island of Lefkada was heavily damaged on November 22, 1704, when 13 people died in Amaxichi and 3 in Kastro [that is, more than in 1743 (VVA, 1704)]; in 1710 in Zante many houses collapsed [May 17 (Barbiani, 1863)], and two people died; in Kefallinia 280 houses collapsed in 1714 [September 8 (Michael, 18th Cent.)]; again in 1722 (June 5), on the island of Lefkada, many houses collapsed, and in 1723 (February 20-22), when few houses were also destroyed in Zante (Sathas, 1867). In 1729 (July 8) in Zante "*all public and private buildings collapsed in part or they were shattered*" (ASVe, 1729). In Corfù, the 1743 damage accumulated on top of the damage caused by a strong earthquake only two years before [June 23, 1741 (ASV, 1741)]. Finally, on February 25, 1742, a frightful earthquake caused dozens of casualties in Zante, many collapses and severe damage to all the buildings on the island [see Albini *et al.* (1994) and reference therein].

Therefore, one should take into account the fact that the intensity calculated for all the Ionian Islands was strongly influenced (i.e., increased[2]) by the damage induced by all these events.

On the other side of the Ionian Sea, Apulia was the region most affected, although the earthquake was strongly felt all over Calabria, causing sparse damage and casualties in Catanzaro and Reggio Calabria [CZ and RC in Fig. 3; Scionti and Galli (2005)]. However, in Salento nine localities had I_s≥VIII MCS, whereas the villages of Nardò (IX-X MCS; N in Fig. 3) and Francavilla Fontana (IX MCS; F in Fig. 3) experienced large disruption, with several casualties, especially in the former.

A historical source of Brindisi [BR in Fig. 3; Scalese (1743)] also reported that the sea level withdrew locally. This fact could be related to the effects of a nearby submarine landslide (Brindisi is the only place where this effect was observed), rather than to the coseismic deformation of the sea bottom in the far epicentral area.

In the very far field, the shaking was felt in many towns of northern Italy (Table 1), and in Malta, where it caused some damage. Thus, on the whole, the VII MCS area extended along a relatively narrow NW-SW belt, between Gargano and Zante, for a length, of at least, 500 km.

2.1. The effects in Nardò and in some neighbouring villages

At the time of the earthquake, Nardò was a rich citadel, with ~8500 inhabitants living in 2÷3-storey buildings (some very old and badly preserved), and with numerous churches and monasteries (Pacichelli, 1703). According to several eyewitnesses, the earthquake started at 23:30 (local time; 16:30 GMT), being felt as three separate shocks, that lasted for a very long time, at least seven-eight minutes (ASL, 1742a, 1743d, 1743e). The last shock (probably due to the surficial waves) induced the most powerful effects ["*like boiling water*"; (ASL, 1742b). "*like the sea-wave during a tempest*"; ASL, 1743a)], causing the collapse of a large part of the town (ASL, 1743a).

Apart from thirty houses (ASL, 1743e), all the remaining buildings (~95%[3]) were seriously damaged (most of them had to be destroyed later), and 30% collapsed totally (ASL, 1743a), causing a number of casualties ranging between 160 to more than 400 [according to the different local sources: 349, mainly women and children (ASL, 1742a)s; that yields ~5% of casualties], and

[2] It is worth noting, moreover, that the subsoil of Lefkada was subjected to extensive liquefaction phenomena (Papathanassiou *et al.,* 2005) that, together with the frequent earthquake-induced landslides, increased the level of damage during seismic shaking.
[3] Currently, 676 19th century buildings (and older) are inside the city-walls (ISTAT data, courtesy of F. Bramerini). It is reasonable to suppose that in the first half of the 18th century the number was quite the same. Therefore 30 houses represent only 5% of the total.

Table 1 - List of the localities affected by the 1743 earthquake in Salento and in the rest of Italy, Greece, Albania, Malta and relative MCS intensity evaluation I_s. L indicates the predominant lithology of the substratum (C, bedrock: limestone, calcarenite, and marl; S, sand; SC, sandy clay). Note that except Oria (C*; which is the only place located on a sharp hill) and, partly, Taranto, 100% of villages founded on bedrock were affected by $I_s \leq$VII-VIII, whereas 100% of villages on sandy clay (SC) had I_s =VII-X MCS.

Locality	lat	lon	I MCS	L		Locality	lat	lon	I MCS
Salento						**Italy**			
Nardò	40.178	18.031	IX - X	SC		Canosa di Puglia	41.223	16.066	VIII
Francavilla Fontana	40.529	17.583	IX	SC		Corato	41.153	16.411	VII - VIII
Leverano	40.288	17.998	VIII - IX	SC		Bari	41.106	16.846	VII
Brindisi	40.636	17.945	VIII	SC		Barletta	41.318	16.279	VII
Galatina	40.175	18.168	VIII	SC		Catanzaro	38.914	16.586	VII
Manduria	40.399	17.634	VIII	SC		Matera	40.665	16.607	VII
Oria	40.498	17.642	VIII	C*		Messina	38.187	15.549	VII
Salice Salentino	40.384	17.964	VIII	SC		Reggio Calabria	38.108	15.647	VII
Taranto	40.458	17.246	VIII	C/SC		Vieste	41.882	16.179	VI - VII
Carpignano S.	40.196	18.340	VII - VIII	C		Trani	41.277	16.418	VI
Castrignano del C.	39.833	18.348	VII - VIII	C		Melfi	40.994	15.653	V - VI
Guagnano	40.401	17.950	VII - VIII	SC		Pesaro	43.904	12.905	V
Leporano	40.383	17.334	VII - VIII	C		Napoli	40.855	14.260	IV - V
Madonna di Pasano	40.388	17.516	VII - VIII	C		Rimini	44.059	12.567	IV - V
Maglie	40.119	18.299	VII - VIII	C		Senigallia	43.714	13.223	IV - V
Mesagne	40.558	17.808	VII - VIII	SC		Vicenza	45.549	11.549	IV
Racale	39.959	18.094	VII - VIII	C		Mantova	45.152	10.775	III - IV
Salve	39.859	18.294	VII - VIII	C		Mirandola	44.887	11.065	III
San Pietro in L.	40.307	18.129	VII - VIII	S		Parma	44.801	10.329	III
Tuturano	40.544	17.946	VII - VIII	SC		Roma	41.895	12.482	III
Vanze	40.322	18.318	VII - VIII	C		Varese	45.818	8.825	III
Alessano	39.889	18.331	VII	C		Venezia	45.438	12.335	III
Avetrana	40.349	17.726	VII	C		Milano	45.464	9.189	II - III
Calimera	40.250	18.280	VII	C		Bagnara Calabra	38.286	15.805	f
Campi Salentina	40.398	18.019	VII	C		Cosenza	39.303	16.251	f
Copertino	40.271	18.048	VII	C		Fermo	43.160	13.716	f
Gallipoli	40.055	17.988	VII	C		Manfredonia	41.623	15.908	f
Grottaglie	40.535	17.433	VII	C		Milazzo	38.224	15.240	f
Lecce	40.351	18.169	VII	C		Padova	45.406	11.876	f
Lizzano	40.391	17.448	VII	C		Palmi	38.358	15.849	f
Masseria Li Sicuri	40.223	18.112	VII	C		Trento	46.064	11.124	f
Monteparano	40.443	17.414	VII	C					
Ostuni	40.729	17.577	VII	C		**Greece and Albania**			
Otranto	40.144	18.491	VII	C		Amaxichi	38.831	20.703	IX
Galatone	40.147	18.070	VI - VII	C		Castel Sant'angelo	39.694	19.683	VIII
Ceglie Messapica	40.645	17.516	VI	C		Kérkira	39.621	19.925	VIII
Martina Franca	40.705	17.336	V	C		Préveza	38.969	20.733	VIII
Casarano	40.010	18.160	f	C		Arta	39.143	21.089	VII - VIII
Lizzanello	40.302	18.223	f	C		Butrint	39.752	20.026	VII - VIII
Massafra	40.588	17.113	f	C		Ioannina	39.663	20.869	VII - VIII
Sava	40.403	17.557	f	C		Vónitsa	38.912	20.879	VII - VIII
						Xeromero	38.533	21.083	VII - VIII
Malta	35.833	14.417	VII			Zakinthos	37.794	20.875	VII
						Kefallinia	38.250	20.583	VI - VII

Fig. 4 - Memorial stone recording the collapse of the San Francesco di Paola church during the 1743 earthquake in Nardò (*Templum hoc…terraemotu eversum…*; this church, destroyed by the earthquake).

hundreds of wounded. The rebuilding costs were estimated at ~230,000 ducats (22% for the "poor" inhabitants; 27% for the rich ones; 47% for churches and convents; 4% for demolition and removal), plus other expenses for the restoration of several sacred and prestigious buildings (ASL, 1743c).

With the exception of the church and convent of the Franciscan friars, located *extra moenia*, all the ecclesiastical buildings were seriously hit or just collapsed (ASL, 1743b), as the whole church of San Francesco di Paola (Fig. 4), the monasteries of Santa Teresa ("…*half*"), and Santa Chiara ("…*a quarter*"), the Conservatory of the Purità ("…*a third*"), together with the church, the church of Sant'Agostino ("…*opened in two*"), the Bishop's Palace ("…*partly ruined*"), the whole nave of the cathedral together with the bell tower, the San Domenico church ("…*ruined*") and its bell tower (Fig. 5); as well as, parts of the city-wall, towers, the prison, the Sedile (i.e., the civic hall), and the Governor's Palace (Fig. 6).

On the basis of all the information collected for Nardò, we evaluated a site intensity of IX-X MCS. On the other hand, in the town of Galatone (located just 4 km away from Nardò, VI-VII MCS), the earthquake effects were very light, no serious damage was reported by any contemporary sources (only the San Sebastiano gate had, perhaps, some slight damage). This is indirectly highlighted by the fact that the Marquis of Galatone gave hospitality to several homeless people of Nardò, sending also rescue teams and food to that town (ASL, 1742a).

This anomalous "intensity pair" (IX-X MCS vs. VI-VII MCS) has been roughly observed in many other localities of Salento. Suffice it to quote the cases of Leverano (VIII-IX MCS), where many buildings collapsed together with the main church (ASN, 1744; Fig. 7), and Copertino (VII MCS), located just 4 km away from the former and with only isolated damage to old buildings and to the city wall-gate.

Fig. 5 - Nardò: memorial stone recording the collapse of the San Domenico bell tower.

Or Francavilla Fontana (IX MCS), where many houses collapsed together with many churches, causing a dozen casualties, [(Leo, 1795) and see Camarda, (1997) for details on the effects in Francavilla and in neighbouring villages; Fig. 8], and Grottaglie (VII MCS), located 12 km away, which suffered only sparse damage.

This alternating level of damage in the Salento peninsula is summarized in Fig. 9, where the intensity values (I_s >VI MCS), assigned on the basis of all the available primary information, are shown.

Fig. 6 - Memorial stone recording the collapse (…*funditus dilapsam*..) of the Governor's Palace in Nardò.

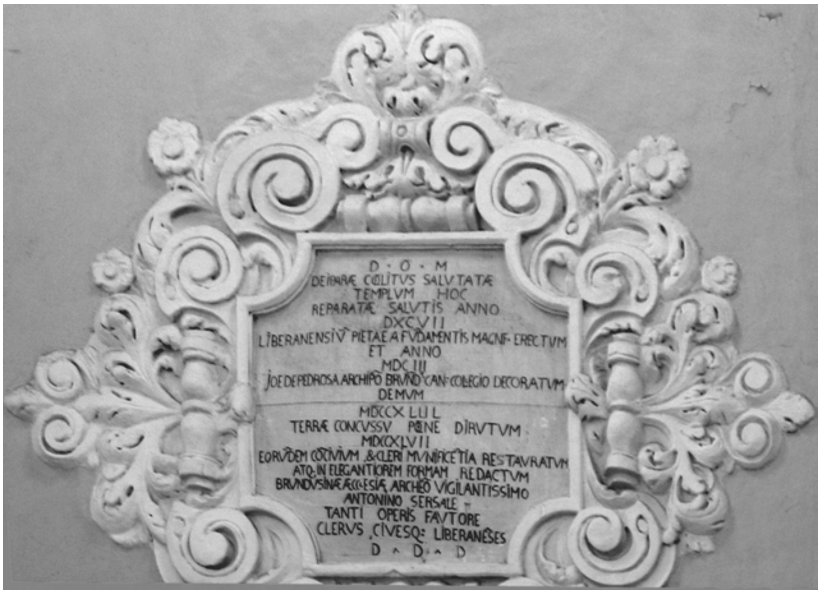

Fig. 7 - Memorial stone recording the collapse of the main church of Leverano due to the 1743 earthquake (*…terrae concussu pene dirutum…*; almost destroyed by the Earth shaking).

2.2. Other earthquakes felt in Nardò

As already stressed, CPTI04 does not report any other earthquake with the epicentre in Salento (except in 1826, with light damage in Manduria and Crispiano). As far as the effects of earthquakes occurring outside this region, it is worth noting that the 1743 earthquake is the only one that ever caused damage in Nardò[4] (only other effects of I_s ≤IV MCS are known), whereas only 2-3 other strong earthquakes (M>6.5) of the Apennine chain (Fig. 2) were responsible for sparse damage in isolated villages (Stucchi *et al.,* 2007).

On the other hand, Salento has always felt the earthquakes originating in the Aegean region. Amongst the largest, it is worth recalling the one that occurred in southeastern Peloponnesus in 1886 (August 27, M=7.5; P&P97), which was strongly felt all over the region with effects of ~V MCS in Lecce and possibly higher in many costal localities [i.e., Brindisi, Castellaneta, Otranto, Gallipoli and Taranto; ~VI MCS; De Giorgi (1898)]. Or the one in 1897 (May 28, M=7.5;

[4] For completeness, it is worth noting that according to a local Middle Age chronicle (Chronicon Neritinun, 15th cent.); other earthquakes struck Nardò in 1245 and in 1350, inducing damage and collapses. Although some scholars considered this source a forgery (e.g., De Giorgi, 1898; Chiriatti, 1910), recent restoration work carried out in the Nardò cathedral put in evidence the fact that the northern aisle was actually reconstructed around the first half of the 13th century by using a different and less crumbly masonry (i.e., *carparo* instead of *pietra leccese*, Pleistocene and Miocene calcarenites, respectively), and adopting lanced arches instead of round-headed ones (i.e., those still visible in the southern aisle). Moreover, coeval restoration within the church is also attested by a lost memorial stone quoting the year 1249 [according to the transcription provided by B. Tafuri, in Chronicon Neritinum (15th cent.); or 1234, according to the reading of De Giorgi (1901)]. Therefore, it is possible that an earthquake occurred prior to 1249 (i.e., the 1245 quoted by the Chronicon) might have induced the partial collapse of the Nardò cathedral, analogously to what happened in 1743. Finally, the lengthening of the church and the reconstruction of the *façade* in 1354 by the abbot Nestore (De Giorgi, 1901), could be due to the other earthquake quoted by the Chronicon in 1350 (the September 1349 earthquake being too far to induce damage to Salento). Other strong earthquakes should have occurred also in the following century, as testified by a memorial stone put on the *façade* in 1725 (and removed after the 1743 earthquake), which reported that the church was “*vetustate ac terremotu labentem*” (falling because of age and earthquakes).

Fig. 8 - Memorial stone recording the damage (…*a magno terraemotu concussa*..; struck by a great earthquake) in the Marruci Palace (Francavilla Fontana) in the 1743 earthquake.

P&P97), with epicentre near Zante, which was felt throughout over Salento with an I_s~IV-V MCS (De Giorgi, 1898). Other effects [I_s≤V-VI MCS; see Castenetto *et al.,* (1986)] were due to the earthquakes of 1903 (August 11, south of Peloponnesus, *M*=7.9, h=80 km; P&P97), of 1926 (June 26, Rhodes, *M*=8.0, h=100 km; P&P97), of 1953 (August 12, Kefallinia, *M*=7.2; P&P97), of 1962 (August 28, Korinthos, M=6.8, h=95 km; P&P97), and of 1983 (Kefallinia, *M*=7.0, h=14; P&P97)

Almost all these events, apart the distance from Salento (from 300 to 1000 km), have in common that they occurred at a great hypocentral depth, being all intraplate earthquakes (i.e., related to the lithosphere subduction under the Hellenic Arc). The analogies between these events and the 1743 one (i.e., very extended damage area, in Apulia and Greece) could represent one of the tools for understanding the possible source characteristics of the earthquake investigated in this paper.

3. Seismotectonic framework of the area

The Neogene-Quaternary kinematic evolution of Italy is controlled by the interaction between the African and Eurasian plates, currently converging at rate ~10 mm/yr along a ~N-S direction (De Mets *et al.,* 1990). The two plates face in the Mediterranean area, but their collision is highly complicated by the presence of Adria, a microplate (Anderson and Jackson, 1987), or an indentation of Africa toward Eurasia (e.g., McKenzie, 1972), which caused active compression all along its borders during the converging process. Actually, in the southern Apenninic Arc this compression front is no longer active, at least since the Early-Middle Pleistocene (Cinque *et al.,* 1993). Therefore, seismicity of the northern and eastern border of Adria is mainly due to active shortening, whereas seismicity along the Apennine is due to extensional tectonics, located westward to the chain front (Fig. 10).

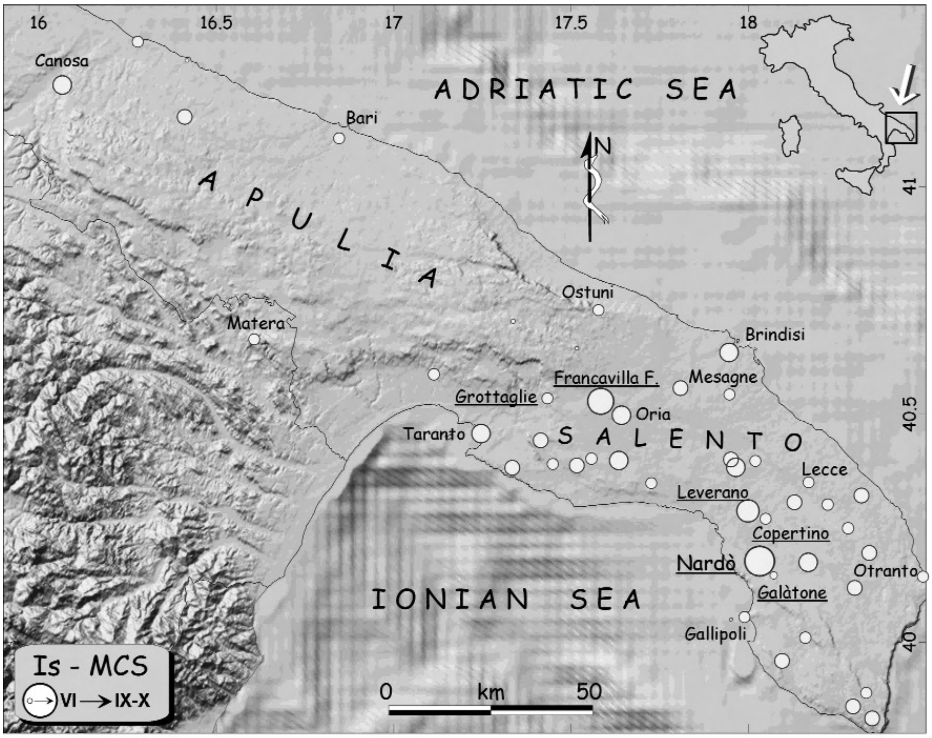

Fig. 9 - Shaded relief map of the almost flat Apulia carbonate plateau, showing the 1743 intensity datapoint distribution reassessed on the basis of all the available primary news. Note the closely alternating high-low values, such as: Nardò (IX-X MCS) and Galatone (VI-VII MCS); Leverano (VIII-IX MCS) and Copertino (VII MCS); Francavilla Fontana (IX MCS) and Grottaglie (VII MCS). Without the damage-peaks suffered by some villages, it seems that the Salento peninsula (i.e., the villages founded on the carbonate basement) would have generally experienced effects close to *Is*=VII-VIII MCS. Underlined labels refer to villages where extensive HVSR were performed.

In particular, in the southern Apennine Arc, the subduction of the Adria lithosphere seems to have ceased diachronously from north to south. This is shown by the history of the frontal thrust sheet when running after the flexural-hinge retreat of the slab; in short, the front is sealed by early Pleistocene marine sediments in the northern sector, whereas early Pleistocene deposits are still involved in compressional deformation in the southern sector (Cinque *et al.,* 1993), and late Middle Pleistocene ones in the Bradanic trough (Pieri *et al.,* 1997). After the flexural subsidence ceased, the whole Apulia area underwent uplifting and gentle tilting toward NE, emerging definitely from the sea (Cinque *et al.,* 1993).

Further south, the Calabrian accretionary wedge in the Ionian Sea exhibits an irregular sea-floor (Merlini *et al.,* 2000, and reference therein), which could, instead, reflect recent compressive tectonic activity, whereas its front overthrusts the deposits of the narrow Taranto trench (i.e., the southern end of the Bradanic trough). A similar feature seems to occur also external (west) to the Dinarides-Hellenides, whose thrust front runs offshore the Ionian Islands of Corfu-Lefkada-Kefallinia-Zante.

The two fronts are separated by the Apulian swell (Fig. 10), which could be imaged as a huge NW-SE anticline, involving ~100 km of lithosphere normal to its axis (Merlini *et al.*, 2000), and extending from the Apulia-Salento onshore area to the Apulian Plateau in the Ionian Sea. This swell is constituted by a thick Permian-Early Tertiary sedimentary sequence (Apulian carbonate platform, widely outcropping in Apulia in its uppermost terms) and by a crystalline continental crust (Auroux *et al.,* 1985), possibly representing the northern passive continental margin of a Paleo-Ionian Ocean (Catalano *et al.,* 2000).

It is possible that the western limb (dipping toward Calabria) of this crustal anticline continues into the subduction plane under the southern Apennine Arc, which has currently slowed down (or blocked?), whereas the conterminous Ionian Oceanic lithosphere is still easily subducting westward, beneath the Calabrian Arc, 400-500 km down into the astenosphere [see the relative Benioff plane; Amato *et al.* (1993)].

Seismic reflection profiles show that the western limb close to the hinge of the Apulian anticline is affected by spaced conjugated normal faults (i.e., grabens, with vertical throw <500 m), which possibly cut the sea-floor, displaying 200-300 m high scarps (Merlini *et al.,* 2000; Argnani *et al.,* 2001). The average trend of these grabens is NE-SW, and they could structurally continue those that outcrop inland at the toe of the Salento (Argnani *et al.,* 2001; see Fig. 10). However, as far as the latter are concerned, there is no indication of either geomorphological or geological recent activity. On the eastern limb of the swell, analogous graben features exist, although they are clearly sealed by Pleistocene sediments (Merlini *et al.,* 2000).

According to Argnani *et al.* (2001), the Apulian lithosphere flexuring is due to the double load of the Hellenide (east) and Apennine-Calabrian Arc (west) thrust and fold belts. However, beside the load of these accretionary complexes, in the frame of Apennine-Dinarides convergence, the arching and uplift of the Apulian swell could be better explained by the dramatic slowing down of the western subduction of the Adria continental lithosphere under the Apennine, possibly increased by the eastward relative "push" of the mantle against the Ionian slab (Doglioni *et al.,* 2006).

3.1. A possible source for the 1743 earthquake

By comparing Fig. 3 and Fig. 10, it appears that the most suitable area for the 1743 epicentral location falls offshore, on the Salentino Plateau (Fig. 3). In particular, the macroseismic barycentre (VII-VIII MCS area) is around 19.2°E - 39.6°N, or farther east, considering that intensity in the Ionian Islands partly accounts for cumulated damage due to the previous earthquakes (i.e., lowering the Is values in the Greek localities the epicentre would be "attracted" towards Salento).

Nevertheless, this area is currently not characterized by either important or diffuse seismicity[5], except for some moderate events that have been localized around 18.9°E - 39.6°N in the past few decades, with a mainshock that occurred in 1974 (M_L=5.4; followed by a M_L=4.3 foreshock on October 22). This earthquake has a transpressive focal mechanism, with subhorizontal, N67°E trending P-axis (Favali *et al.,* 1990), accounting for an ~NE-SW shortening.

According to Merlini *et al.* (2000), the structures that could be responsible both for the 1743 event, and for other smaller earthquakes of Salento are the normal faults mentioned that affect the upper Apulian swell (Fig. 10). Argnani *et al.* (2001) suggest that the largest stress accumulation coult exist, instead, at depth, in the inner arc, which is subject to NE-SW compression and where both the 1974 and 1743 earthquakes might have originated. Due to the small radius of curvature of the Apulian lithosphere [~600 km; see Moretti and Royden (1988)], it is possible that a decoupling

[5] As observed in the Italian and Balkan inland areas, or in the Kefallinia NE-SW fault zone [i.e., see events previously quoted for the 18th century, up to the recent *Mw*=6.2, 2003 earthquake at Lefkada, in Karakostas *et al.* (2004)].

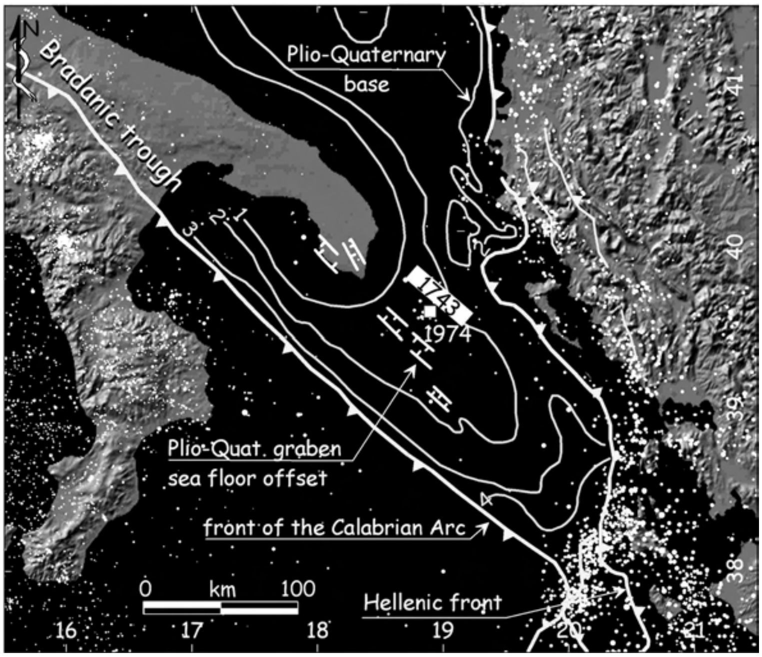

Fig. 10 - Sketch of the Apulian swell, evidenced by the isobaths of the Plio-Quaternary base [modified from Argnani *et al.* (2001)]. This huge anticline structure, outcropping in the Apulia region, is characterized by a low seismicity level, if compared with that of the Apennine and Balkan chains, and of the Ionian Islands [data from Castello *et al.* (2006); Makropulos *et al.* (2007); $2.0<M_L<5.5$)]. Nevertheless, sparse epicentres occurring close to the hinge of the ridge might indicates current stress accumulation (i.e., the M_L=5.4, 1974 event). The white box indicate the hypothetical 1743 source.

between the upper brittle crust and the lithospheric mantle took place at a relatively shallow depth, allowing contemporary extension and compression above and below a neutral surface. The surficial normal faults could be related to the outer-arc extension (Bradley and Kidd, 1991), occurring close to the anticline hinge, and being coeval to the maximum flexural curvature of the entire Adria plate.

Therefore, if the 1743 event originated in the area of the macroseismic epicentre (and/or close to the instrumental epicentres recorded in the last few decades), the size of its seismogenic source had to be large enough to cause damage in Greece, Italy, and Malta, as well as, moderately deep at least, to be so largely felt up to the Alps[6]. Taking into account the fact that the coseismic shaking experienced by villages founded on flat "seismic bedrock" was ~VII-VIII MCS (i.e., Lecce, Ostuni, Gallipoli, Copertino, Grottaglie, Otranto, Galatone, and others, while the maximum intensities were due to site amplification: see the next chapters), the relative *PGA* values might have been in the order of ~0.1-0.15 g (e.g. in Decanini *et al.,* 2004). Therefore, considering an average distance of ~100 km between the presumed epicentre and southern Salento, and by applying a conventional attenuation relation for shallow earthquakes, these values of *PGA*/distance would request an improbable source *M*=8.3 sized (i.e., Sabetta and Pugliese, 1996) or much more [*M*=9.5, Ambraseys *et al.* (1996)]. On the other hand, if the earthquake is placed at depth, a more reasonable magnitude value is obtained by applying an attenuation model designed also for deep earthquakes (Shedlock, 1999). In this case, the supposed *PGA* value of 0.1-0.15 g affecting inland Salento would match with a *M*~7.0 sized earthquake at ~100 km, and at a depth of ~30÷40 km.

In summary, following Argnani *et al.* (2001), our hypothesis is that the 1743 source was a large ~NW-SE compressive structure, deeply located below the hinge of the lithospheric Apulian anticline, in the volume subject to NE-SW shortening (as testified by the P-axis of the 1974 earthquakes). Notwithstanding the large source dimension (~40 km-long, according to the magnitude), due to the considerable fault depth, the rupture did not induce significant deformation of the sea floor, as shown by the absence of any trace of tsunami all along the Ionian Sea coast (apart from the isolated case of Brindisi, in the Adriatic Sea). The NW-SE fault trend might have driven directivity effects both toward NW (Salento) and SE (Lefkada Island), which are necessary in order to explain the elongated shape of the macroseismic distribution. In actual fact, several 1743 witnesses felt the earthquakes as separate shocks occurring a few minutes from each other, accounting for double or multiple ruptures of the fault, possibly in opposite directions[7].

Finally, as far the normal fault affecting the upper 2÷3 kilometres of the anticline, although they are linked to the same plate flexuring mechanism, it does not seem likely that their dimension (length and depth) are sufficient to generate the earthquake needed to cause 0.1-0.15 g at 100 km of distance (i.e., M=8.3-9.5, according to shallow event attenuations). Moreover, the sea-floor faulting would have generated a devastating sea-wave, which, conversely, did not occur.

4. Multidisciplinary investigations in the Nardò area

In order to ascertain whether and why local amplification caused the devastation of Nardò and, analogously, of other villages in 1743, the geology of this town have been investigated in detail by collecting all the available data, and by performing geological survey and new geophysical analyses. In particular, the geometry, thickness and dynamic properties of the subsoil have been reconstructed and characterized by means of 18 existing boreholes, 1 down-hole, 6 refraction microtremors (4 of which performed *ad hoc*), 12 seismic refraction, 58 environmental noise measurements (all performed *ad hoc*), and geotechnical laboratory test previously carried out on 12 samples.

4.1. Geological survey

Nardò is located in the western side of the Salentina peninsula, about 6 km away from the coast (see Fig. 4). The area is an almost flat plateau (~40 m a.s.l.), carved on the carbonate Altamura formation (inner shelf limestones, Senonian), and on thin layers of marly-limestone and silty clays (Galatone fm., upper Oligocene), carbonate open shelf succession (i.e., Pietra Leccese, Burdigalian-lower Messinian), and calcarenites (Gravina fm., Middle Pliocene-Pleistocene). In the most depressed portions of the plateau middle-upper Pleistocene coastal plain deposits (sand, clay, biocalcarenites) outcrop, which fill, sometime, rounded basin, such as the one where Nardò lays (~12 km^2), or the similar hosting Francavilla Fontana, Leverano, and others.

The geological/geophysical investigation carried out at the site shows that the Nardò basin is filled by 15÷25 m of sandy-clayey units, overlaying the Gravina calcarenites, that are 15÷30-m-thick, locally (Fig. 12).

The latter unconformably lies on both the Altamura limestone, and the Galatone marls, which are faulted one against the other along a N330° normal plane. Moreover, the downtown area is characterized by a continuous layer of anthropic deposits (up to 3 m of tiles, bricks, masonry stones,

[6] In Italy, shallow earthquakes attenuate ~1 MCS degree every 20 km, much more than what observed for deep events, as for those intraslab in southern Tyrrhenian Sea or in the Aegean Sea [~1 MCS/50 km; Galli and Molin (2007)].
[7] A part from the delay among the P, S, and Lg wave arrivals that, probably, induced the sensation of separate shocks occurring within a few dozens of seconds (i.e., a 15 s delay between P and S arrival should fit with a ~100 km epicentral distance).

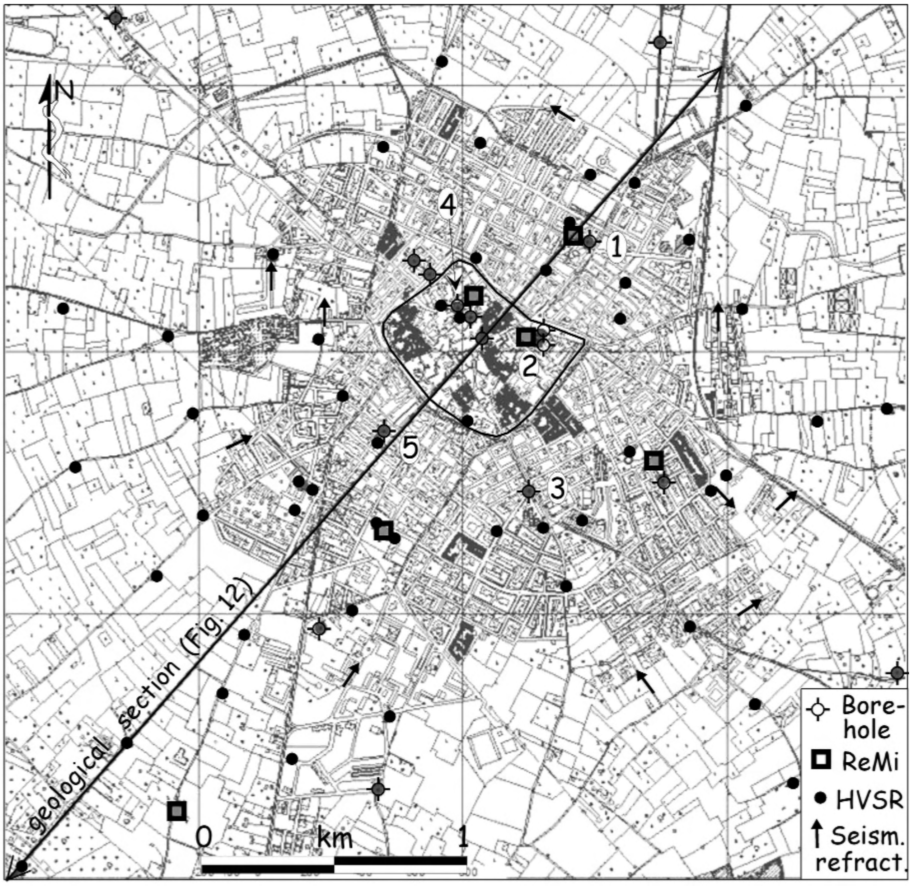

Fig. 11 - Map of all the analyses available for the Nardò territory. The thick line envelops the old Nardò downtown. 1-5 indicate sites where comparison between HVSR and numerical analyses were performed (see also Table 4).

sparse in sandy-silty matries), accounting for the long history of the town (see upper layer in Fig. 12).

4.2. Geophysical and geotechnical analyses

In order to evaluate the shear wave velocity (V_s) of the subsoil, four refraction microtremor (Re.Mi.) profiles have been carried out in the Nardò municipality, and other two have been reanalyzed. Data were then calibrated with the result of an existing down-hole test, and with seismic refraction surveys.

As known, the Re.Mi. technique provides a simplified characterization of a volume of the subsoils along 1D vertical profiles (Louie, 2001). Since V_S are a function of the elastic moduli of the different masses in the subsurface, soil/rock contacts or contrasts between weaker and stronger geological material horizons can be easily detected and interpreted from Re.Mi. analyses.

Fig. 13 shows two V_S (m/s) profiles carried out close to the border of the basin (A) and in the Nardò downtown (B). The different velocities of the substratum in the two sectors of the basin are easily detectable. In A, the Gravina calcarenites (sub-outcropping) are characterized by a V_S~800 m/s, whereas the same are visible between 23-32 m; on the other hand, in B the first 20 m can be

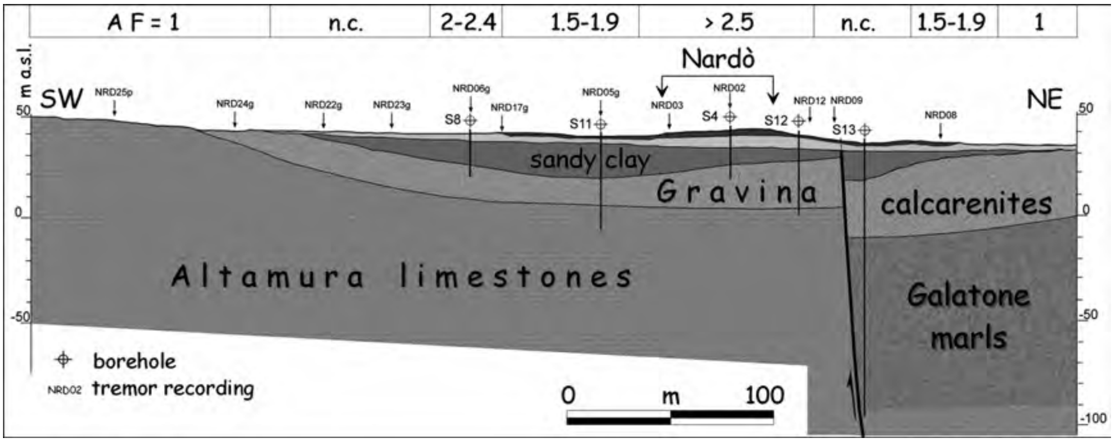

Fig. 12 - Geological sketch across the Nardò basin, based on original geological survey, boreholes stratigraphy and tremor recordings inversion (gathered applying the “4 law”; i.e., (Hz)=V_s/4H). The sandy clay infilling tapers towards the border of the basin, reaching a maximum thickness SW of downtown Nardò. The seismic basement is constituted by the Gravina calcarenites, outcropping SW in the section, and observed in several boreholes. AF intervals in the upper side are amplification factors obtained through numerical analyses (see following chapters).

associated with the clays and sands of the basin’s infilling, with V_S<400 m/s. Both profiles show, at depth (23 m in A; 32 m in B), the presence of high shear wave velocity (~1400 m/s), related to the Altamura carbonate unit.

Besides the information on the dynamic properties of the substratum, we collected several local soil parameters with the aim of defining a realistic geotechnical model for numerical analyses. For the same purpose, these data also enabled us to select the characteristic dynamic shear modulus and damping ratio curves, as far as the Nardò lithologies are concerned in an appropriate database (Naso *et al.,* 2005). The laboratory data were completed with information gathered through numerous classical geotechnical *in situ* tests, like SPT and CPT. In brief, we collected parameters related to unit weight (γ), maximum shear modulus (G_0), plasticity index (IP), liquid limit (w_l), plastic limit (w_p), fine content (<75 μ FC), void ratio (e), undrained cohesion (c_u), and SPT N_{value}, partly reported in Table 3.

4.3 Microtremors analyses

Since the first empirical studies (Aki, 1957), a lot of methods have been proposed in order to retrieve site information from tremor spectra recorded at a single station. The one most used one is the HVSR (Horizontal to Vertical Spectral Ratio) technique, which investigate the ratio between the spectral and horizontal components of motion (Nakamura, 1989).

With the aim of estimating a reliable main resonance frequency for the different sectors of the Nardò subsoil, we carried out 58, 20-minute-long microtremor recordings spread out the downtown, and in the surroundings of the city. Other 40 sparse recordings were performed in Brindisi, Copertino, Francavilla Fontana, Galatina, Galatone, Gallipoli, Grottaglie, Leverano, Oria, Ostuni, Otranto, Mesagne (see Fig. 3 for location).

All the tremor recordings presented in this study have been acquired with digital tromograph

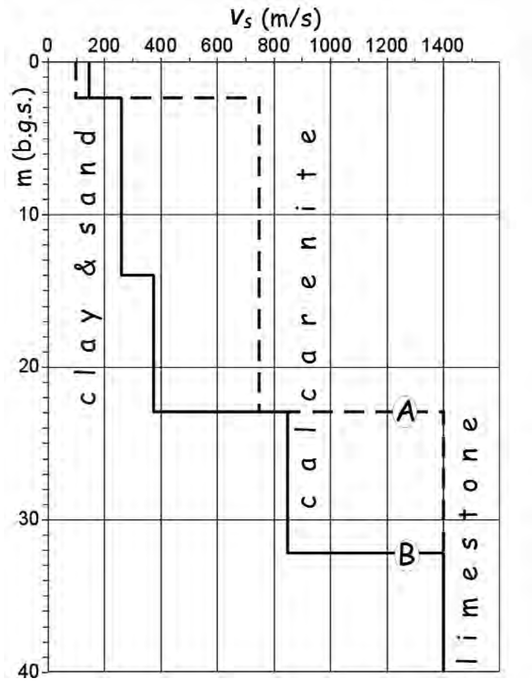

Fig. 13 - Shear wave velocity obtained by means of Re.Mi. analyses close to the border of the Nardò basin (dashed A), and downtown (B). Both profiles show at depth high values (1400 m/s), due to the Altamura limestone, whereas in the first ~20 m they differ by more than 300-400 m/s. In A the Gravina calcarenites outcrop, with V_S~800 m/s; in B the soft clayey infilling of the basin accounts for low velocity (~300 m/s).

Tromino (Tromino, 2007), which is a highly portable all-in-one device equipped with three orthogonal electrodynamic sensors (velocimeters). The extreme portability of this instrument allowed us to make measurements on any kind of site out of reach using instruments mounted on vehicles or using classical heavy seismographs.

The results of each analysis were obtained through Tromino's dedicated software (Grilla: Castellaro *et al.,* 2005). In short, after the tremors had been digitized at 24 bits (for all the 3 motion components), the acquired signal is divided into windows of 30 s, each window being detrended, tapered with a Bartlett window, and, finally, padded with zeros. The FFT (Fast Fourier Transform) is then computed for each window as well as the amplitude spectrum. The spectra of each window are smoothed using a triangular function *f* (width equal to 5% of the central frequency), and the HVRS is computed at each frequency, for each window. The final HVSR function, at each frequency, is given by the average of the HVSR of each window. Each measurement point provides a spectral ratio and an estimation of the fundamental frequency.

The predominant frequencies calculated for Nardò are shown in Fig. 14, whereas in Fig. 15, the same have been interpolated by using a Kriging algorithm, in order to provide a "snap-shot" of the frequency resonance all over the Nardò area.

By cross-matching the HVSR results and the geological/geophysical data, the entire municipality area has been roughly subdivided into three different zones.

The first one is far from the urban area, where carbonate and calcarenitic rocks widely outcrop; this area does not show any significant predominant frequency (Figs. 14a and 15).

The second zone matches mainly with the northern and eastern surroundings of the *extra-moenia* town, and with the broad country-side around Nardò. It is characterized by the presence of ~10 m of Pleistocene-Holocene material lying over the seismic bedrock, and by the predominant frequency between 4-10 Hz (Figs. 14b and 15).

The third zone extends both to the historical down-town, and to the SW sector of the *extra-moenia* sector. Here the subsoil presents the thickest values as far as the clayey-sandy units are concerned (10-22 m of Pleistocene-Holocene deposits), besides 3 m of anthropic layers; the predominant frequency shows high peaks between 3-4 Hz (Figs. 14c and 15).

We were not confident enough to produce an amplification map for the observed fundamental frequencies, since the HVSR method provides only relative levels of amplification. Therefore, for the evaluation of the size of the amplification, we preferred the numerical analysis presented in the next chapter.

Finally, as mentioned before, several HVSR were calculated also for other villages hit by the 1743 earthquakes. In particular, tremor recordings were carried out where severe damage was experienced, but located close to others with moderate effects.

Fig. 16a shows the results for the couple Nardò-Galàtone (5 km one from the other; the latter founded directly over the Gravina calcarenites), where the absence of predominant frequency in Galàtone is clearly visible. Fig. 16b shows the same effect for Francavilla Fontana-Grottaglie (12 km one from each other); the former village lies within a Pleistocene basin similar to the Nardò one, characterized by the same lithologies and with a comparable depth. The HSVR peaks are, therefore, in the same frequency range (3-4 hz), whereas Grottaglie has an almost flat trend, accounting for the fact that it is founded on the Gravina calcarenites.

Fig. 16c, shows, instead, the couple Leverano-Copertino (4 km one from each other). The former has a pronounced peak between 2-3 Hz, and is founded on the same clayey soft sediments, as Nardò and Francavilla Fontana. The latter, which does not have a predominant frequency, was built partly on the *Pietra Leccese* and on other Pleistocene calcarenites.

The hundred HVSR analyses performed in Salento demonstrated that the villages founded on the carbonate basement of Apulia, or on its Tertiary-Pleistocene calcarenitic coverage, are not characterized by any predominant vibration frequency. Conversely, those built on the soft, clayey-sandy infilling of the thin (~20-30 m) coastal basin, are all characterized by pronounced peaks within frequencies of 3-4 Hz (i.e., in the range of engineering interest for ~3-storey masonry building).

5. Numerical analysis

5.1. Seismic input

In order to identify suitable strong-motion records to be used as input data in the numerical analyses, we adopted the 1743 earthquake parameters discussed in chapter 3, and summarized in Table 2.

These parameters permitted us to search and download from a strong-motion database and databank (Ambraseys *et al.,* 2002) four records, that share similar values of magnitude, and epicentral distance with the 1743 event. The selected time-histories have been recorded on rock (or stiff soil), and show a *PGA* close to the one hypothesized for the Salento villages founded on rock [~ 0.1-0.15 g, i.e., VII-VIII MCS; Decanini *et al. (*2004)].

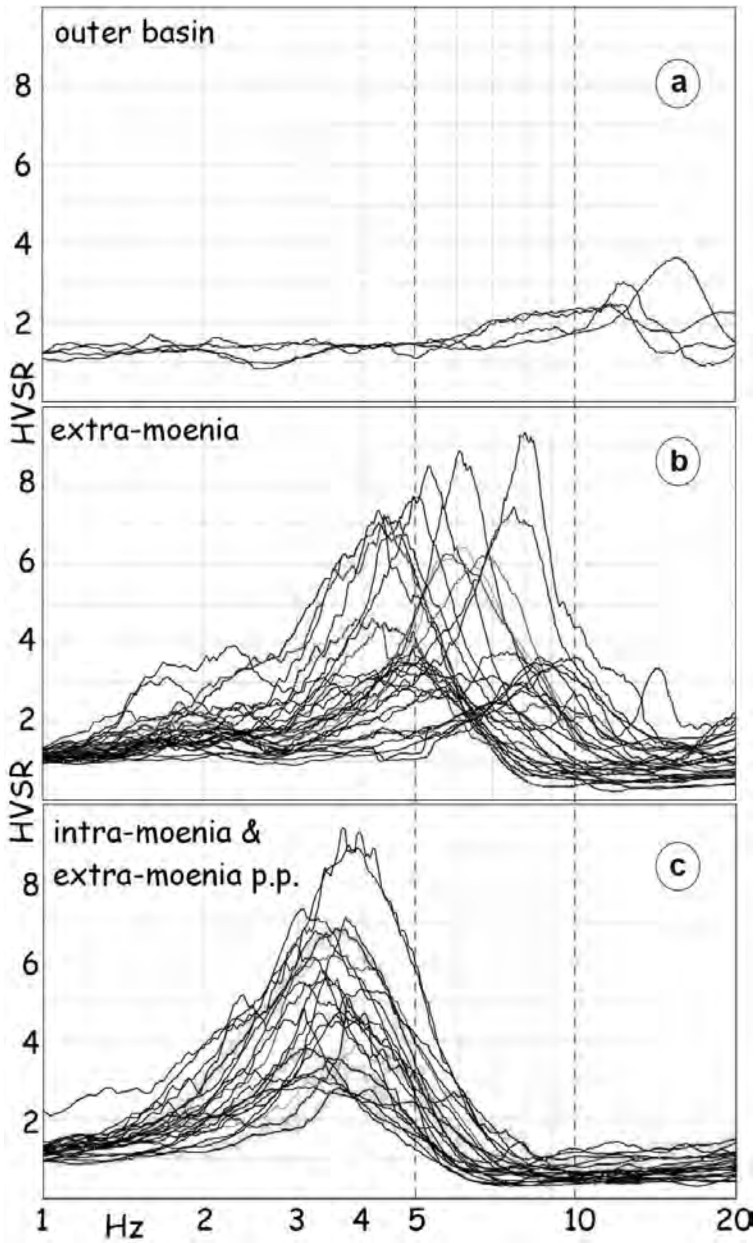

Fig. 14 - Main frequencies calculated through the 58 microremor recordings in Nardò and surroundings: a) HVSR obtained close to the basin border, i.e., on bedrock (no amplification for any frequency); b) HVSR obtained in the broad area outside the down-town and in the northern and eastern *extra-moenia* sector, over <10 m soft deposits (amplification >4<10 Hz); c) HVSR obtained *intra-moenia* and in the SW quadrant of the *extra-moenia* town, where the soft basin infilling is 23 m thick.

5.2. Geotechnical subsoil model

On the basis of the geophysical and geotechnical analyses performed and/or collected at the site, a generalised geotechnical model has been developed, including the lithotechnical units summarized in Table 3 (in stratigraphical order from top to bottom). The geotechnical parameters needed for the dynamic analyses have been assigned to each unit/stratum on the basis of the data collected and presented in the previous chapter. Generally speaking, a typical model for the numerical analysis consists of 3 strata, laying over a bedrock. The depth of the seismic bedrock, in the zone not

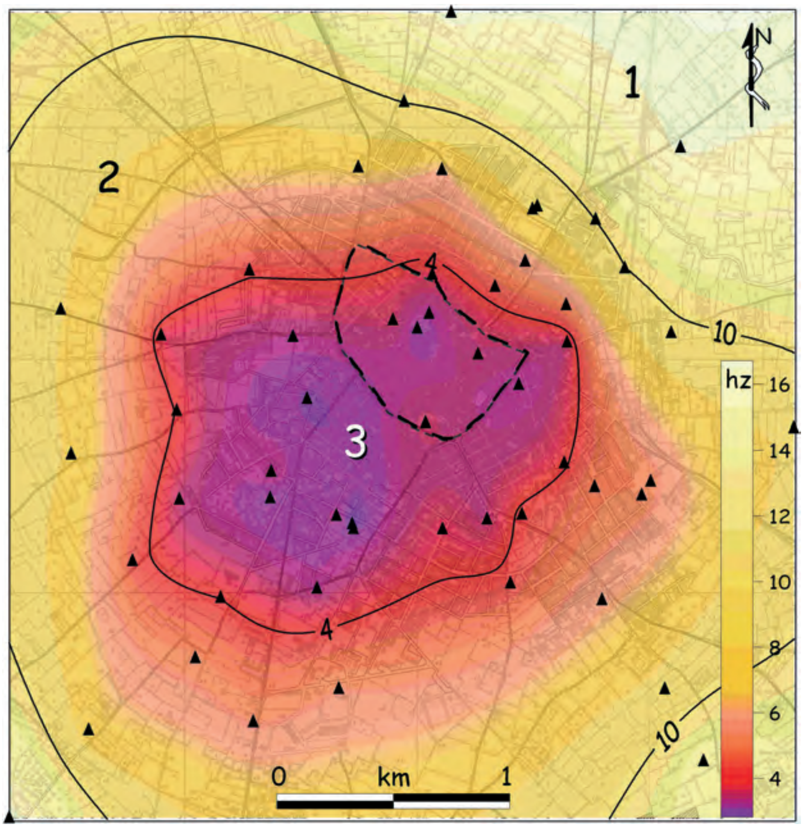

Fig. 15 - "Snap-shot" of the HSVR peak distribution in the Nardò municipality. This image has been obtained by interpolating the observed values (triangles) through a Kriging algorithm. Contour lines envelop the area with 10 Hz and 4 Hz, respectively (zones 1-3). This image surprisingly matches with the shape of the Pleistocene sedimentary basin (see Fig. 12), which developed over the Gravina and Altamura bedrock; the depocenter of this small basin (12 km^2) falls SW of downtown Nardò (dashed line). The 1743 Nardò town falls entirely inside zone 3, which is the one that shows predominant frequency in the range of engineering interest.

investigated with Re.Mi., and seismic refraction array was constrained from geognostic and geological data.

In the geotechnical model, we also included degradation curves of the dynamic shear modulus and of the damping ratio, which have been deduced from a database of the Italian Civil Protection Department for lithologies comparable to those of the Nardò area (Naso *et al.,* 2005).

5.3. Analyses

Numerical analyses were performed through the software Proshake (Proshake, 2000), an upgraded version of the site-response analysis computer program Shake (Schnabel *et al.,* 1972); the use of 1-D schemes was performed which accounted for the variability of the mechanical characteristics in the lithostratigraphic successions (Table 3). The software used was originally designed to analyze subsoil models approximating horizontal infinite layers, with shear waves propagating in the vertical direction. The software also incorporates non-linear soil behaviour, whereas each layer is homogeneous and isotropic with the known thickness, mass, shear modulus and damping factor.

The geotechnical model in Table 3 has been used to compute the transfer functions and the amplification factors between a reference site (seismic bedrock, i.e. a rock outcropping with a flat horizontal surface, characterised by a V_s of about 750-800 m/s; Gravina calcarenites) and the top of

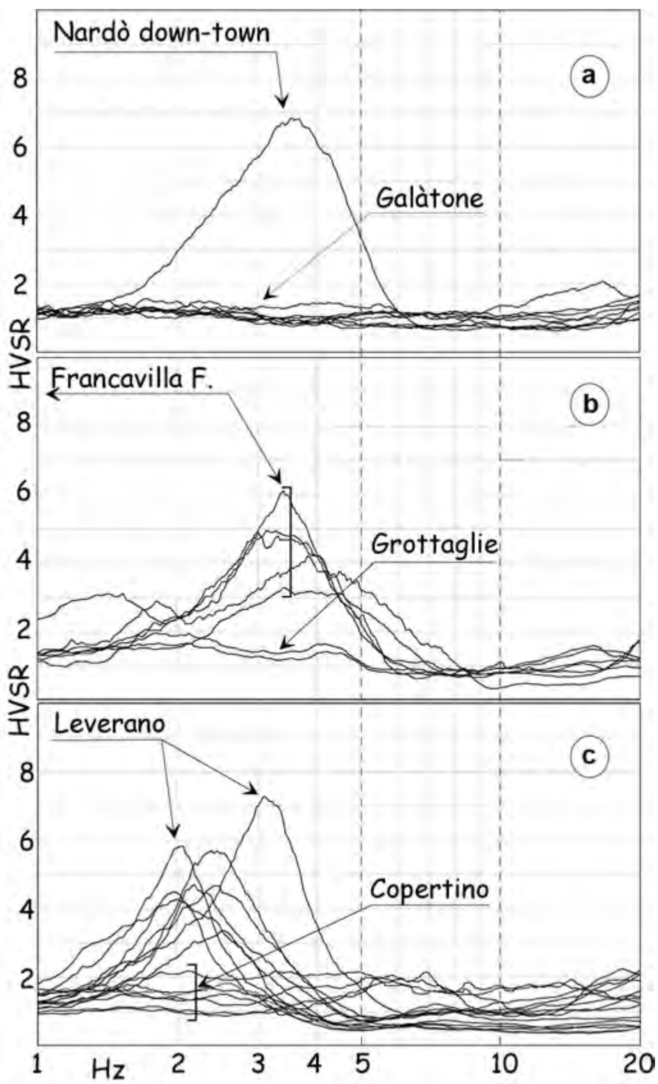

Fig. 16 - Main frequencies calculated through dozens of microtremor recordings in some villages of Salento: a) comparison between one of the several HVSR’s obtained in downtown Nardò and those regarding Galatone (founded on bedrock and with no amplification for any frequency); b) comparison between HVSR obtained in Francavilla Fontana (same soft sediment as in Nardò) and Grottaglie (bedrock); c) comparison between HVSR obtained in Leverano (soft sediments), and Copertino, built over stiff rock.

the horizontally layered model.

Besides the geotechnical model, we assumed that the reference input motion was generated by plane shear waves (S waves), vertically impinging on the surface. This assumption is valid if the seismic source is very far and the incoming time history is only made by S waves.

In the Nardò case, the basin boundaries were not analyzed (Fig. 12); here, in fact, the resultant motion is composed by the free-field motion (i.e. the incident waves) and the scattered motions (i.e. the waves reflected, diffracted and refracted from the basin boundary).

5.4. Results

The soil response has been synthetically expressed in terms of elastic spectra, calculated for each soil columns (Fig. 17).

Table 2 - The 1743 earthquake and site parameters evaluated in this paper. Coordinates refer to the barycentre of the supposed seismogenic source (Fig. 10). The epicentral intensity (I_o) has not been evaluated, due to the offshore location of the source. Site parameters are related to the broad southern Salento area, i.e. to villages founded on carbonate rocks. The expected predominant period of the earthquake at a 100 km period (T) has been identified by using simplified estimates from non-linear regression analyses (Rathje *et al.,* 1998).

Earthquake parameters								Site parameters		
Lat	Lon	I_o	$I_{max.}$	M	Depth	Fault length	Expected T at 100 km	Distance	Site lithology	Expected *PGA*
			MCS		km	km	s	km		*g*
39.70	19.10	(-)	IX - X	~7	~30-40	~40	0.25 - 0.30	~100	Rock-stiff soil	0.10 - 0.15

The spectral intensity *SI* (Housner, 1952) has been selected in order to represent the seismic amplification, since it relates to the structural damage better than to the other ground motion parameters. *SI* has been computed in a period range of 0.1-0.5 s, which is the range of the fundamental periods of most of the anthropic structures in the area:

$$SI(PSV) = \int_{0.1}^{0.5} PSV(T,\xi)dT$$

where: *PSV* is the pseudo-velocity spectral ordinates, *T* the period and ξ the damping set to 5% of the critical damping.

The spectral intensities were computed for the following seismic motions:

a. *SI* (input), spectral intensity of the reference spectrum (seismic bedrock);

b. *SI* (output) spectral intensity of each computed amplification spectrum.

The amplification factor (*AF*) was defined on the basis of the following ratio:

AF= *SI* (output)/ *SI* (input).

AF represents the mean value of the velocity spectrum ratio in the high frequency range. Therefore, it only gives a general indication of the motion amplification for the low period range, therefore referring to low masonry constructions or stiff buildings (as those existing in Nardò in the 18th century), but not to more flexible structures like isolated ones.

In Fig. 12 the range of *AF* values along the analyzed geotechnical section are reported across the town area. Particularly, it can be observed that the amplification varies from the centre of the basin (*AF* = 1.5-1.9) toward the boundary (*AF* = 1); the highest amplification factor (*AF*>2.5), instead, has

Table 3 - Geotechnical model of the Nardò area subsoil, as deduced from geological, geophysical, and geotechnical analyses carried out at the site. γ= natural weight; V_s= shear wave velocity; *IP*= plastic index; *W*= water content (%); *D*= damping; *n*= Poisson coefficient.

ID Strata	Tickness	Litology	*g*	V_s	*IP*	*W*	*D*	*n*
1	1 - 3	Anthropic fill	1.75	120 - 150	11	13	0.05	0.45
2	2 - 12	Clayey sand	1.80	250	7	17	0.05	0.40
3	8 - 15	Sandy clay	1.90	380 - 400	17	10	0.05	0.40
Seismic bedrock		Calcarenites	2.00	750 - 800			0.05	0.35
Geological substratum		Dolomite and limestones	2.20	1400 - 1600			0.05	

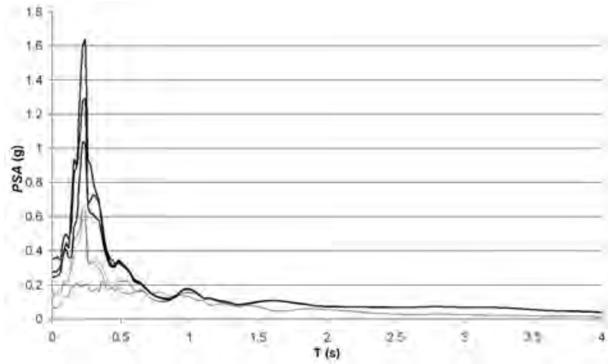

Fig. 17 - Acceleration response spectra computed for four sites in Nardò. Thick lines show the output response spectra; thin lines are the input response spectra. The *PGA* of the input spectra are in the range of 0.08-0.15 g; the *PGA* of output spectra are in the range of 0.25-037 g.

been calculated in the downtown Nardò.

As already mentioned, the HVSR technique described in the previous chapter does not inform us about the *AF* of the subsoil, but does give important information on the fundamental period [*T*; Sesame (2005)]. In Table 4, the predominant frequencies obtained with the transfer function of numerical simulation are compared to those obtained by the HVSR technique. This matching reveals a good overall concordance for the predominant frequency.

In particular, the good-fit between two transfer functions obtained for site 2 is shown in Fig. 18.

As a concluding remark, the numerical analyses performed on the basis of the 1743 hypothesized source parameters, and of the geotechnical model defined for Nardò show the presence of an important amplification (*AF*>2.5) of the seismic motion in the frequency range close to 3 Hz, which is the same range supported by the HVSR analyses. Since the geological and morphological condition of several other villages of Salento are similar to Nardò, and considering also the same HSVR results obtained in some of these, it is reasonable to assume that the same amplification peaks might take place also in these localities, concurring in the increase of the damage level due to seismic shaking. This fact is partly shown in Table 1, where villages founded on bedrock constantly show a lower I_s value (~1-2 MCS degree), with respect to those on soft basins.

As far as the Greek "side" is concerned, it is worth noting that analogous results have been gathered by Dimitriu *et al.* (2001), who processed some weak and strong-motions recorded in Lefkada, showing that the mean HVSRs were around ~2.5-3.4 Hz. Considering that the subsoil of Lefkada is made of a soft 10÷15-m-thick layer (sandy clays), lying over a stiff marly basement (Papathanassiou *et al.,* 2005), it is likely that, as for to Nardò, strong site amplification took place during the 1743 earthquake in this town too, contributing to the damaging of the buildings.

6. Conclusion

We focused on the February 20, 1743 Ionian earthquake, and on its broad and strong effects, which were felt from the Alps to Malta. By collecting all the available primary historical sources, the MCS intensity value for 83 localities has been revaluated, allowing, in particular, to highlight the alternating high-low intensity distribution in the Salento area.

On the basis of the macroseismic distribution, and of the seismotectonic framework assessed for

Table 4 - Comparison between predominant frequencies computed with HVSR technique and numerical analysis. Site numbers refer to Fig. 11. V_s represents the mean value of the related thickness of the layer over the bedrock.

SITE	Thickness	V_s	Frequency	Frequency
	(m)		Num. An.	HVSR
4	20.5	261	3.1	3.1
2	25.0	337	3.1	3.5
1	11.5	220	4.7	5.7
5	23.0	279	3.0	3.0
3	18.0	336	4.6	4.8

the Apulian-Ionian region, the 1743 seismogenetic source parameters have been thus tentatively defined. We suggest that the event might have been due to a large ~NW-SE reverse fault (*M*~7 sized) that occurred at a considerable depth (~30-40 km) in the inner sector of the Apulian swell, probably close to the area affected recently by moderate seismicity (i.e., *M*<6 with NE-SW P-axis).

In order to ascertain the presence of site amplification factors which could explain the highest intensities recorded at several places of Salento, the geological framework of Nardò has been reconstructed by means of surficial survey, geophysical analyses, and by collecting dozens of boreholes and geotechnical data. Results account for the presence of a local Pleistocene basin, filled by ~20 m of soft sediments, and lying over carbonate rocks of the Apulian shelf. This situation is typical of many other villages of Salento, as ascertained in Leverano and Francavilla Fontana.

Subsequently, 58 microtremor recordings were performed in Nardò, and dozens of others in several Salento villages hit by the earthquake, which provided just as many HVSR analyses. Results show the presence of a dominant resonance frequency between 3-4 Hz in villages founded on soft basins, whereas no predominant resonance frequencies appeared in localities built directly on the carbonate Apulian basement.

On the basis of the whole geotechnical and geological data of the Nardò basin a reference

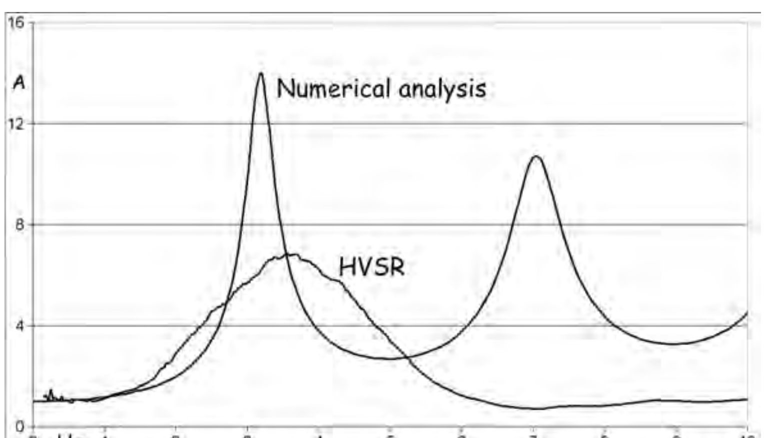

Fig. 18 - Comparison between the predominant frequency computed with HVSR technique and numerical analysis for the site 2 in Fig. 11.

geotechnical model has been thus defined. This model, together with the hypothesized source parameters, has been used for numerical analyses aimed at the definition of the transfer functions and of the local amplification factors. Results are in perfect agreement with the HVSR outputs, showing a high amplification in the Nardò downtown area for frequency ~3 Hz.

Therefore, according to all the aforementioned data and results, it seems that the 1743 highest intensities (i.e., strong damage level) in Salento has been controlled for some, by local amplification factors, and in particular by a "double-resonance" phenomenon that occurred in the localities founded on the soft Pleistocene deposits, such as Nardò, Francavilla Fontana, Leverano, and possibly, others not investigated in this paper (as Lefkada, in Greece). Resonance took place due to the hypothesized period of the incoming earthquake (~0.3 s), which is the same as the measured period of the Nardò basins (~ 0.3 s; with an AF >2.5 between 0.1-0.5 s); both fit in with the eigen-vibration period of the masonry buildings of the time (~0.3 s)[8], causing the devastating "taranta" shaking described by the eyewitnesses.

In other words, the considerable depth of the 1743 seismogenic source, its directivity effects (toward Salento and Lefkada; i.e., in a NW-SE direction), and the strong site amplification in the same range of vibration of the 18th century buildings, were the terrific concurring causes for both the large areal distribution of effects, and the locally high gravity of damages.

As a concluding remark, we think that the evaluation of site effects is a necessary step for the correct parameterization of historical earthquakes (i.e., epicentre, epicentral intensity, equivalent magnitude, especially in areas "missing" certain seismogenetic structures), and for seismic hazard assessment (e.g., to avoid over-conservative estimates of hazard, due to the double weight of the site effect). In other words, similarly to accelerometric record, where data are corrected according to the geotechnical characteristics of the site, results from macroseismic studies should be filtered from local amplification effects (e.g. in Gallipoli *et al.,* 2002).

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[8] Assuming roughly that the fundamental period of a masonry building $T_1 = 0.05\ H^{3/4}$, and that the Nardò houses were of 2-3 stores, (i.e., 9-12 m high; H), see "Norme Tecniche per le costruzioni in zona sismica" (Ord. P.C.M. 20.03.2003, n° 3274).

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Corresponding author: Paolo Galli
Dip. Protezione Civile Nazionale
Via Vitorelliano 4, 00189 Roma, Italy
phone: + 39 06 68204892; fax: + 39 06 68202877; e-mail: paolo.galli@protezionecivile.it