Geological Field Trips

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Archaeoseismic evidence in Roma (pre-congress field trip)

6th INQUA International Workshop on Active Tectonics Paleoseismology and Archaeoseismology
19-24 April 2015, Pescina, Fucino Basin, Italy

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Archaeoseismic evidence in Roma, Italy

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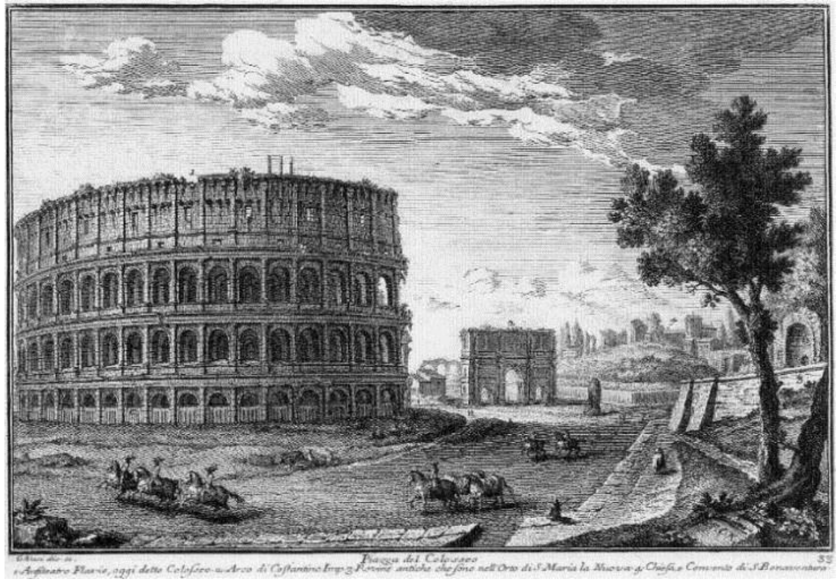


Quamdiu stabit Colyseus stabit et Roma
quando cadet Colyseus, cadet et Roma
quando cadet Roma, cadet et mundus
(Beda Venerabilis, 672-735)
“As long as the Colosseum stands, Roma will stand
when the Colosseum falls, Roma will fall
when Roma falls, the whole world will fall."

Abstract

This half day-long field trip aims at observing field evidence of archaeoseismicity in the historical center of Roma. The focus is on the area of the Colosseum, Roman forum, Imperial Forums and the area from the Theater of Marcellus to the Antonina Column. The major damages are seen in the Colosseum, enhanced by an uneven substratum.
Only in some cases there is epigraphic and/or historical evidence of seismic damage. More often, the seismic cause and the attribution to one or more events is conjectural, based on archaeoseismic evidence and available chronological constraints. The main documented seismic events causing damage in Roma have occurred in 443, 484-508, 618, 801, 847, 1439, 1703, 1812, 1915. The estimated intensity is generally VII MCS. The archaeoseismic analysis is fundamental to assess seismic hazard in Roma, where damaging events are relatively rare but the direct and indirect documentation wide since Roman times.

Keywords: Seismicity, archaeoseismicity, Rome, Colosseum, Roman Forum

Program

The first stop will be dedicated to observe the Colosseum from outside. After, we enter the area of the Forum Romanum (Stop 2) that we leave from the exit under the Campidoglio. Then we cross the square and admire the landscape from this elevated position (Stop 3). Returned to via dei Fori Imperiali, we observe some evidence in the area of the Imperial Forums, included the Column of Traianus (Stop 4). Then we stroll to the Column Antonina (Stop 5) and the Pantheon/Santa Maria sopra Minerva (Stop 6). Largo Argentina follows (Stop 7) and, finally, the Theater of Marcellus (Stop 8). From here, we return to Piazza Venezia and get to the meeting point by public transportation.

1. Excursion notes

1.1. Introduction

The city of Rome, capital of Italy and UNESCO World Heritage Site, is located in the central-western portion of the Italian peninsula (Latium region), where the river Aniene joins the Tiber. With around 2.8 million residents, Roma is the most populated town in Italy.
Traditionally, Roma was founded in 753 BC by Romulus after having killed in duel his twin brother: a bloody birth for the future capital of a wide and enduring empire spanning most of Europe, Northern Africa and Middle East. A town grown to host more than two million citizens two thousand years ago which, reduced to nearly a village in the Middle Ages after the loss of its empire, was able to rebuild a new and even longer lasting kingdom, that of Christianity, founded on faith, but often defended with blood.

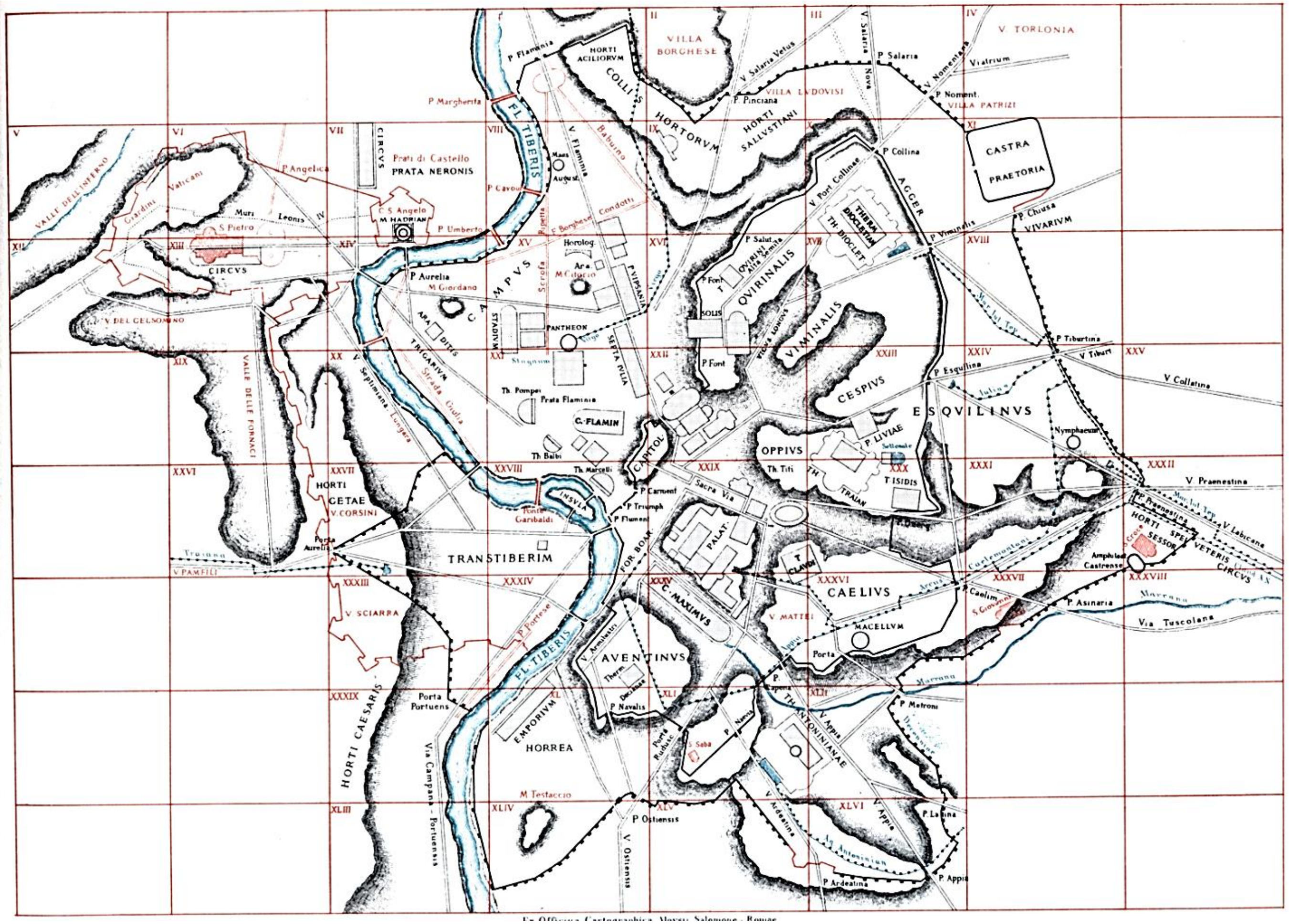


Fig. 1.1 – Morphology of Rome within its ancient city walls. The Seven Hills (*septimontium*) are indicated by their Latin names (from north, clockwise: Quirinalis, Viminalis, Esquilinus, Caelius, Aventinus, Palatinus, Capitolinus). The Tiber valley and its main tributaries are in blue. The Tiberina islet is also evident. (from Rodolfo Lanciani, Forma Urbis Romae, 1901).

Thanks to its unique and almost uninterrupted role since its foundation, a nearly continuous historical record is available of the major events occurred in the city, from historic accounts and monuments that have survived time. For two millennia, even after the Enlightenment, Latin has maintained a key role as the basic language of science and culture in the western world. This privileged and unparalleled situation should have allowed also a precise record of the natural phenomena, including earthquakes, that have hit Rome. Indeed, this is only partially true. Many invaluable historical sources were lost. What we have, sometimes mutilated, like the monumental history of Rome of Livy (Ab Urbe Condita Libri CXLII), reports the natural phenomena often as prodigia, carrying a religious significance, most of the times exaggerating their size and forgetting to give essential details. The situation improves with time, but still earthquakes are generally reported in a few words, despite cited as disasters, leaving often a doubt about their actual size or even time and place of occurrence.

The most accurate synthesis of the seismicity of Rome since the Republican Period (I century B.C.) to the XX century is provided by Galli and Molin (2014), who have reviewed the whole bulk of literary, epigraphic and archaeoseismic evidence. Another precious source, especially focused on late Roman-Early Middle Ages archaeoseismic evidence, is Galadini et al. (2013). Most of the archaeological sites cited ahead find an analytical illustration in these papers, to which (including the references therein) the reader is addressed for further reading. Precious sources of archaeological information on ancient Rome are found in Richardson (1992) and Coarelli (2007).

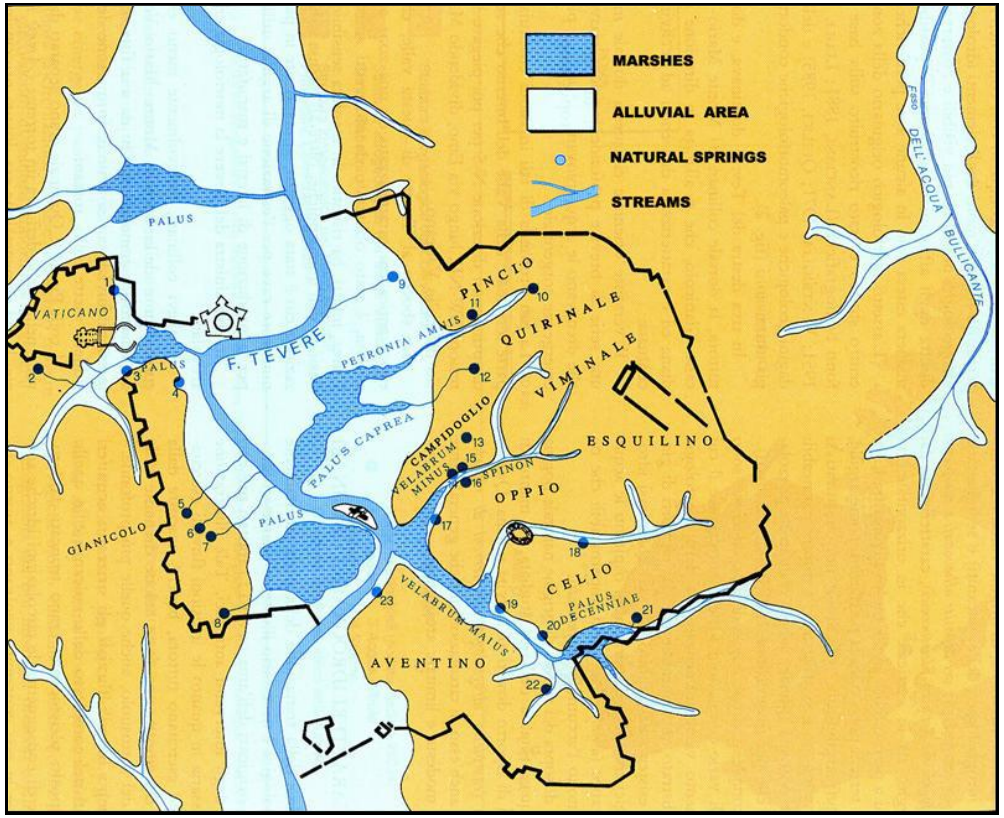


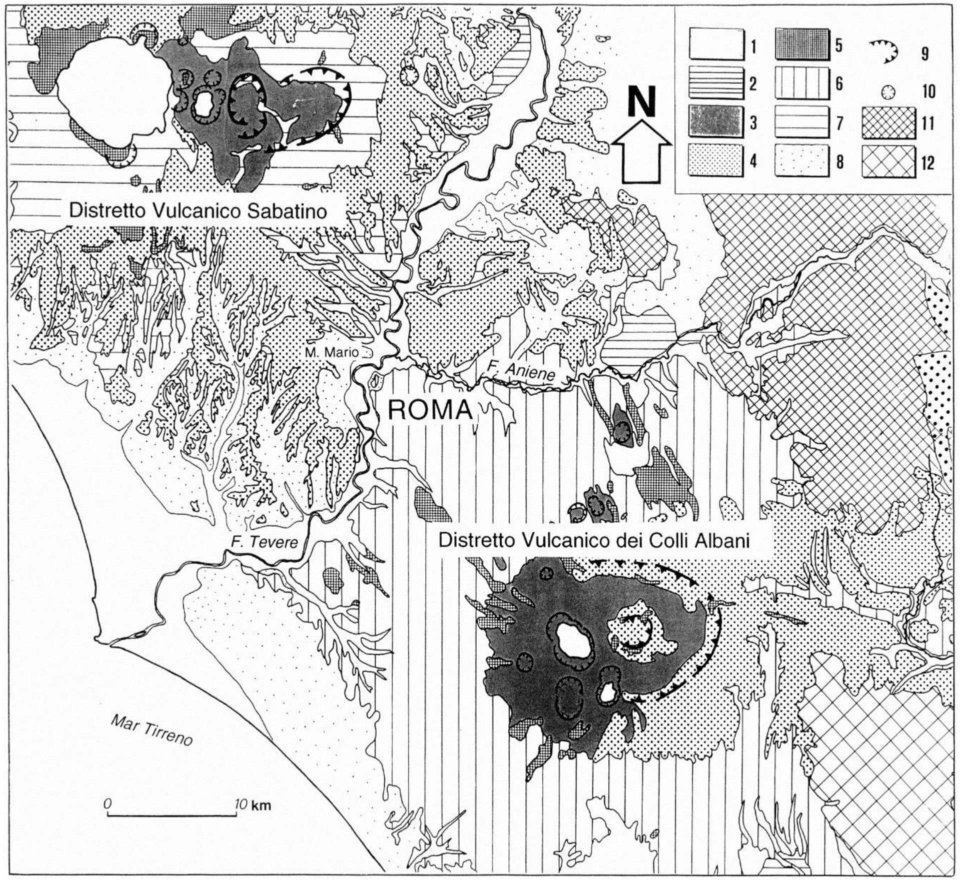
Fig.1.2 – Original hydrological pattern of Roma (from Corazza and Lombardi, 1995).

The local stratigraphy and geomorphological setting have contributed to the good fortune of the founders of Roma. The Tiber river valley narrows considerably where it crosses the eastern outer slopes of the volcanic apparatus of the Alban Hills (Fig. 1), more or less where their deposits had come in contact with the similar products of the Sabatini volcanic field. The cap of relatively hard volcanic deposits (ignimbrites) has protected from erosion the softer uplifted marine and continental sediments underneath. As a result, the deep incision of the drainage network following the Last Glacial sea level drop 18 ka ago has shaped a system of tabular hills bounded by cliffs and steep slopes. The subsequent sea rise has sensibly reduced the gradients of the drainage system, determining the meandering of the Tiber and the development of a broad flood plain with wide humid environments (marshes and swamps).

The first Romans chose to settle on the hilltops (the Palatine and Capitol hills hosted the first fortified villages), because of many good reasons. The septimontium (system of seven hills - Fig. 1) offered ample nearly

flat surfaces, away from the periodic river floods. The city was protected against enemies by the steep slopes on several sides and by the Tiber, which provided a barrier from the west. The only ford for many miles up and down stream was near the Palatine Hill across the Tiberina Islet (Fig. 1) and could be easily patrolled by early Romans. Also the swampy areas flanking the Tiber (e.g., the Velabrum) added a further protection. The early Romans could benefit of the abundant water of the river and of the many springs along the slopes. The volcanic rocks were a good construction material, easy to quarry and shape, and the outcrops of marine and lacustrine clays provided the furnaces with the source material for pottery and brick production. Also relevant was the very fertile volcanic soil, which added to the favourable climate and the water abundance. So, many gardens, vineyards and farms have flourished around and inside Roma up to the XIX century.
From such a favourable site, Romans begun their nearly continuous territorial expansion lasted for over a millennium. With time, due to the urban expansion (more than two million people lived here in imperial times), Romans had to face environmental and sanitary problems. A large urban sprawl took place at the end of the Republican age, making necessary the reclamation of the areas along the Tiber banks and its tributaries, with the drainage and infill of marsh areas, as the Velabrum and the Campus Martis. Actually, the reclamation of the forum area started already with the Etruscan kings of Roma, the Tarquins, in the VII century BC. The fills were realized mostly by dumping waste material coming from fires, earthquakes and demolitions. A system of culverts ending into the Cloaca Maxima (main sewer) drained the valley between Capitolium, Palatinus and Velia: another system of culverts was implemented between Palatinus and Aventinus in order to allow the realization of the Circus Maximus. The original morphology was locally reshaped, as is the case of the saddle between the Quirinalis and Capitolium hills, removed to make room for the Forum Traiani and the area of the Domus Aurea and later of the Amphitheatrum Flavium.
Many voids are distributed inside the volcanic bedrock, mainly quarries, aqueducts, cisternae (water tanks), catacombs, which cause locally a severe risk of abrupt collapses.
Frequent were the devastating inundations of the Tiber; earthquakes often rocked the town, although widespread damage was rare. To all this added fires and periodic epidemics and, since the last days of the empire, repeated looting from invaders.
Nevertheless, the life of the city has continued, although with many lows and only a few highs, until it has become the capital of Italy, again a single country after fifteen centuries. Since then, Roma’s population has increased from less than 100,000 to over three millions. The rapid and chaotic modern expansion of the city has dramatically enhanced the risk level from geo hazards, imposing costly but so far effective interventions for the protection from floods, while the earthquake hazard has remained for too long underestimated, notwithstanding the vast historical evidence (see “Notes on the seismicity of Roma”).
Due to the wide diffusion of Holocene-Latest Pleistocene alluvial sediments several tens of meters deep and artificial fills even ten meters and more thick, to which a general lowering of the water table adds, subsidence and differential settling are common phenomena, often resulting as a significant source of hazard for many recently developed urban areas (Comerci et al., 2015). Finally, a far from trivial volcanic hazard may come from the unrest of the Alban Hills, as shown by uplift, seismicity, thermal and gas anomalies, and even possible historical manifestations of activity (Anzidei et al., 2009; Funiciello and Giordano, 2010). The urban development and the local morphology before the many artificial changes of the last 140 years are documented in a wealth of historical maps with impressive precision dating back to the XVI century (e.g., Archivio Storico Capitolino, 2002).

1.2 – Notes on the geological setting



The geology and stratigraphy of Roma and surroundings is relatively well known and detailed (Heiken et al., 2007; ISPRA 2008), thanks to the many boreholes drilled for public and private constructions (e.g., Ventriglia, 1971) and high resolution mapping (e.g., CARG Sheet 374 "Roma"). A useful summary for a geo-tour is in Funiciello et al. (2004).

Fig. 1.3 – Structural sketch of the region enclosing Roma (from Marra et al., 1995). 1 recent alluvial deposits, 2 travertines, 3 hydromagmatic units, 4 pyroclastic fall deposits, 5 lava flows, 6 Alban Hills ignimbrite units, 7 Sabatini ignimbrite units, 8 Plio-Pleistocene sedimentary units, 9 caldera rim, 10 crater rim, 11 Pelagic Meso-Cenozoic sedimentary units, 12 Carbonate shelf Meso-Cenozoic sedimentary units.

Roma lies in a wide gentle landscape extending from the southwestern flank of the Central Apennine chain to the Tyrrhenian Sea coast, bounded by volcanic apparatuses and structural highs (Figure 2). Its origin is linked to the Neogene extensional tectonic evolution of the Tyrrhenian Sea - Apennines boundary (Patacca et al., 1992; Mattei et al., 2010). A neo-autochthon marine sedimentation has filled this subsiding area since the Late Messinian. However, during the Plio – Quaternary, the interplay between climatic changes, with their alternating depositional and erosive phases, and extensional tectonics and related volcanism, have caused a complex suite of geological features (Funiciello and Giordano, 2008; Parotto, 2008). Well consolidated marine clays crop out at various spots in town (often hidden by recent constructions), but mainly along a structural ridge parallel to the right bank of the Tiber river, at the base of the Mt. Mario, Vaticano and Gianicolo hills (Funiciello and Giordano, 2008). To the east and west of this fault-bounded ridge, these clays lie at various depths, being particularly thick in tectonic lows of the bedrock, as in the Circus Maximus area (at least 870 m) (Marra and Rosa, 1995).

An erosive phase, corresponding to the first big glaciation marking the passage to the Pleistocene, interrupted this marine cycle. Two subsequent marine transgression cycles followed, dating at the Early Pleistocene. Mainly made of sandy units (Mt. Mario formation), they indicate a much shallower marine environment, partly due to uplift of the basement and partly to the main eustatic sea level fluctuations during this period (Marra et alii, 1995; Marra and Rosa, 1995; Cosentino et al., 2009).

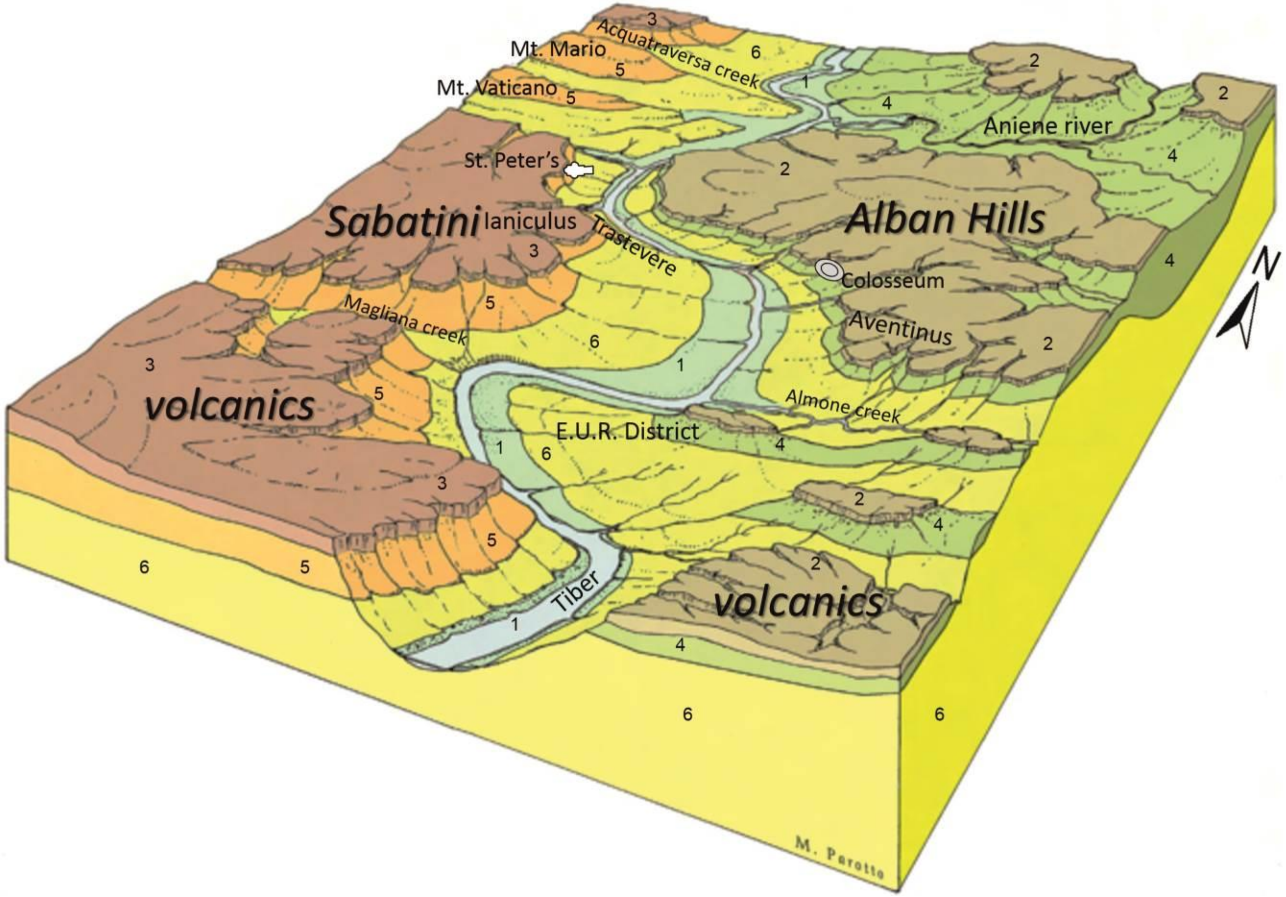


Figure 3. Highly schematic paleomorphology of the Roma area during the last sea level lowstand (20-22 ka; from Parotto, 2008, modified). Well evident are the incision of the pre-volcanic marine and continental basement and the caps of mostly ignimbrites from the Sabatini and Alban Hills volcanic centres, roughly separated by the Tiber valley. Nowadays, a large part of the valley floor is filled by post-glacial, mainly Holocene, fluvial and palustrine deposits and made ground. Also the Tiber river bed shows now a different system of meanders. The Aniene river and the Acquatraversa, Almone and Magliana creeks are the main tributaries of the Tiber in the city area. 1. Late Pleistocene-Holocene alluvial deposits of Tiber and its tributaries; 2. Volcanic products of Alban Hills volcanic district (Middle-Late Pleistocene); 3. Volcanic products of Sabatini volcanic district (mainly ignimbrites; Middle Pleistocene); 4. Acquatraversa Fm. (fluvial gravel and sand of Paleo-Tiber, Early-Middle Pleistocene); 5. Mt. Mario Fm. (sandy-silty clays and grey to yellowish sands, Early Pleistocene); 6. Mt. Vaticano Fm. (overconsolidated grey-blue clays, Late Pliocene) (Comerci et al., 2015).

The general cooling and concurrent basement uplift toward the end of the Early Pleistocene change the environment from marine to coastal, then to continental, with fluvial–lacustrine deposits carried by the Paleo-Tiber and its tributaries (Bozzano et al., 2000). Since about 0.6 Ma, the activity of two main volcanic districts near Roma, the Alban Hills to the southeast and the Sabatini Mounts to the northwest changed forever the landscape with their pyroclastic flows, lavas, hydromagmatic explosions that left huge strato-volcanoes and calderas. While the activity of the Sabatini mts. ended ca. 250 ka ago, the last Hydromagmatic Phase of the Alban District dates to 37 ka (Marra and Rosa, 1995; Karner et al., 2001). According to Funiciello et al. (2003), there is archaeological and stratigraphic evidence of nearly historical volcanic activity, possibly confirmed by some descriptions in the Annals of Livy. Actually, thermal anomalies, gas emissions, seismic activity and the ongoing uplift testify that this volcanic apparatus is far from extinct.
Continental deposits are interlayered with the volcanic products, mostly fluvial and lacustrine deposits (including diatomites and travertine) with resedimented levels of volcanics. They are temporally separated by erosive phases, corresponding to the glacial periods. However, the cap of relatively hard volcanic deposits (ignimbrites) has substantially protected from erosion the softer uplifted marine and continental sediments underneath.

As a result, the deep incision of the drainage network (Figure 3) following the Last Glacial sea level drop (22-20 kyr ago) has shaped a system of tabular hills bounded by cliffs and steep slopes. The Pliocene bedrock was locally eroded down to about 50 m below the sea level in Roma. The subsequent sea rise (end of Pleistocene-Holocene) has sensibly reduced the gradients of the drainage system, determining the meandering of the Tiber and the development of a flood plain greatly broadening seaward and of a delta with wide humid environments (marshes and swamps). The valleys carved into the volcanic deposits were filled by soft alluvial sediments, mainly sands, silts and clay often rich in organic matter, recently buried in town by artificial fills that may reach the thickness of 20 m (Bellotti et al., 1995; Marra and Rosa, 1995; Autorità di Bacino del Fiume Tevere, 2004; Campolunghi et al., 2007; Parotto, 2008).

1.3. Notes on the seismicity of Roma

The reader is addressed to Galadini et al. (2013) and Galli and Molin (2014) for a detailed discussion. Numerous earthquakes have hit Roma during historical times, some originating from the Apennines and others from more local sources (especially the Alban Hills) (Fig. 2.4). The maximum felt macroseismic intensities do not reach the VIII degree MCS (Mercalli-Cancani-Sieberg scale), according to Galli and Molin (2014), who provide the most recent and detailed account on the seismicity of Roma so far available. Other important sources of information are the various Italian seismic catalogues and macroseismic databases (Boschi et alii, 1997; Rovida et al., 2011), accessible through the web site of the Italian Seismological and Volcanological Institute (INGV). The Table 2.1 is based on such summaries, with integrations from other sources reporting events not taken into account there.
It is noteworthy that various authors report different lists of events for the Roman to Medieval period, primarily because of lack of really dependable and detailed sources, so a fully reliable seismic history is still to come, if ever possible, for Roma. Ancient sources quote many damaging seismic events in Roma, starting from 83 BC. However, generally there are no details about the damage pattern and for most of them there is no certainty about their epicentral location, or even if they had been truly felt in Roma. Being the capital city, many events were reported as happened in Roma, even if occurred elsewhere.
The event in 847 is cited in chronicles and documented by archaelogists in several damaged monuments, including various churches and the Colosseum. The 1231 event (IX MCS according to Postpischl, 1985, VIII max in Boschi et alii, 1997), occurred in the Cassino area between Roma and Naples, was certainly felt in Roma, but the information about damages is to be better checked.
After the Roman-Medieval period, the most damaging events occurred in 1349 and 1703, when the intensities were at least VII MCS. Also the 1915 Fucino earthquake in Central Apennines produced widespread but moderate damage in Roma, about 80 km away from the epicentre, with again intensity VII MCS.
So, several earthquakes produced effects inside Roma of degree VII, or slightly above it, i.e. causing localized partial collapses and damages of brick and stone masonry. Where documented, damages have affected primarily the lower areas, where buildings were founded above Holocene or late Pleistocene alluvial deposits. Indirect evidence of seismic shaking and ground acceleration can be gathered from specific features displayed by ancient monuments, e.g. the Traianus's and Marcus Aurelius's columns (see ahead) and the collapse of temples with regularly aligned fallen columns (church of S. Petronilla in 801 or 847). Although poorly documented, the seismic event in 801 could have been the strongest earthquake felt in Roma during historic times.

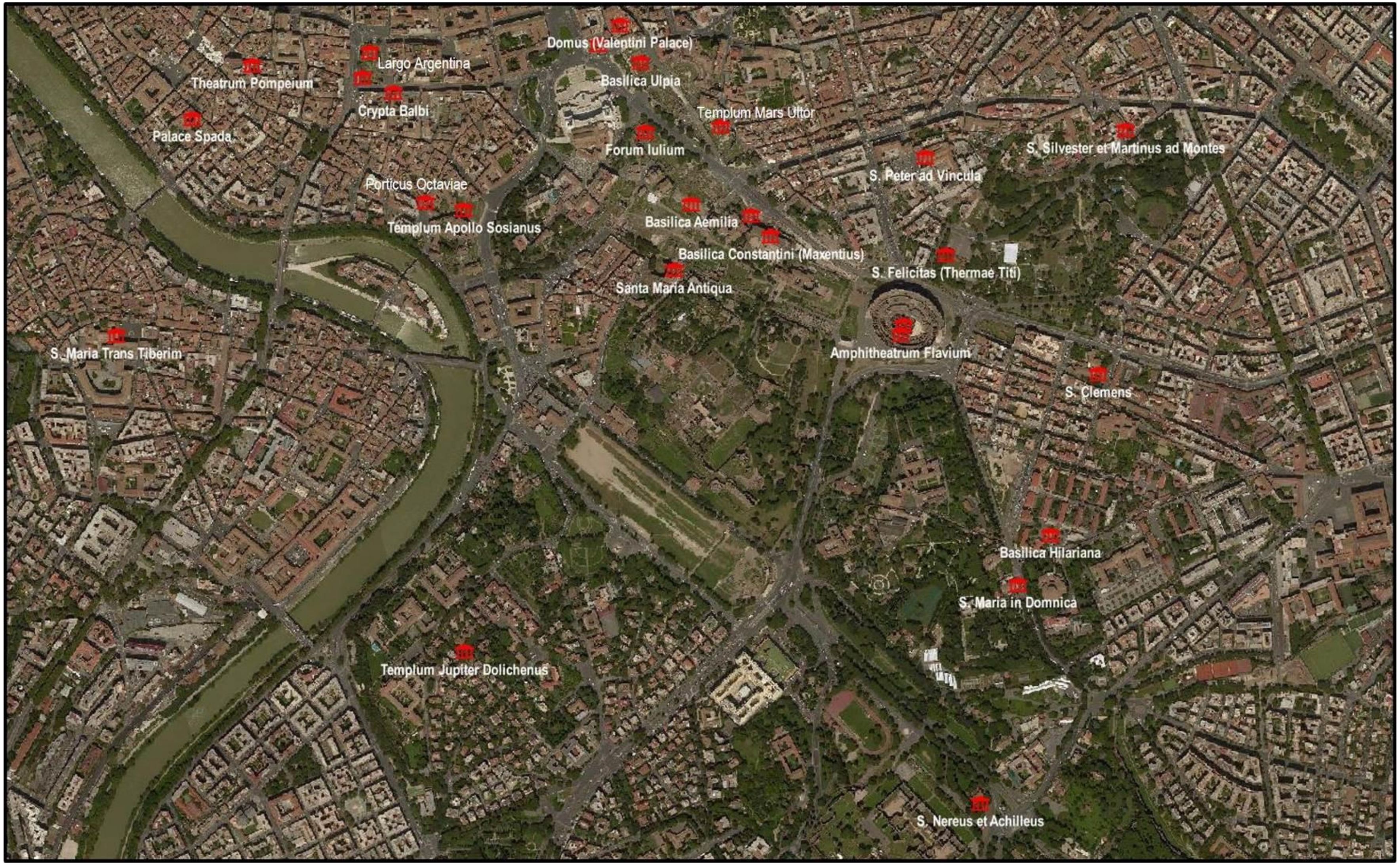


Fig.1.4 – Sites of potential late Antiquity archaeoseismic interest in the historical center of Roma.

The earthquake of 1812 (VI – VII MCS) is of special interest, being probably the strongest with epicentre located very close to the city, which suffered modest damages but well distributed over the urban area. In close agreement with the distribution of effects of the 1915 Fucino earthquake (see Fig. 2.3), the most serious damages in 1812 were seen inside the Holocene alluvial plain near the Tiber.
Due to the massive expansion of the city during the last 140 years above the Holocene alluvial deposits of the Tiber and its tributaries, a major apprehension is now shared by most scientists about the actual seismic hazard in such areas, where poor soil properties, prone to

seismic amplification at low frequencies, are coupled with a structural design lacking seismic reinforcement. As a matter of fact, many recent earthquakes have shown the significant destructive potential of even moderate seismic events in soft sediments and artificial fill, arising concern for the many hundred thousands of citizens living and working above them.

Table I - Historic earthquakes with reported damages (based on Galli and Molin, 2014 and Galadini et al., 2013). Some relevant ancient sources (italics) specified in last column.

Date	Earthquake source	Epicentral intensity	Known effects in Roma	Intensity in Roma	Main *ancient source*
83 BC	?	?	Collapse of some temples	VII	*Appiano*
72 BC	?	?	Damages and collapse of several houses	VII	*Flegonte*
15	?	?	Collapse of parts of the *Servian* city walls	VI-VII	*Cassio Dione*
51	?	?	Collapse of houses	VII	*Cassio Dione*
443	Campania	?	Possible damage to *S. Paul's Outside the Walls*, collapse of several houses, damage to Pompeius' theatre, *porticus* in Largo Argentina, domus under Palace Valentini, Colosseum, buildings under St. Clemens, St. Peter *ad Vincula*	VII	*Paolo Diacono*
484 or 508	Fucino basin	?	Damage to Colosseum, possible damage to Temple of Mars Ultor, churches of St.Paul's, St. Felicitas, St. Agnes, St. Sylvester ai Monti; *porticus Octaviae*, remains under Palace Spada, *Palation Onorii*, Iuppiter Dolichenus' sanctuary on the Aventinus, *Basilica Hilariana*, *Templum Pacis*, temple of Apollo Sosianus, little *porticus* of Largo Argentina	VII-VIII	
618	?	**?**	Possible damage to Basilica Hilariana	?	
801	Central Apennines (L'Aquila?)	IX? *"in some places towns and mountains fell down"*	Collapse of *S. Petronilla* with parallel fallen columns (847?), collapse of the roof of S. Paul's *Outside the Walls,* possible damage to St. Mary i*n Domnica*	VII	*Eginardo*
847	Venafro	?	Damages of *Colosseum*? and *S. Maria in Trans Tiberim* (collapse of apse). Partial collapse of *S. Maria Antiqua*, Trajan's forum buildings, *Basilica Ulpia*, *Basilica Aemilia*, Maxentius' Basilica, Sts. Nereus and Achilleus' church, Crypta Balbi. Hypothetical damage to St. Laurence's portico	VII	*Liber Pontificalis*
1.6.1231	Cassino	VIII	Damages to *Colosseum*?	V	CFTI
9.9.1349	Venafro	X	Partial collapse of Conti and Milizie towers, damages in *St. Paul's* (bell tower), *St. Peter's* and *St. John's in Laterano*, St. Mary *in Ara Coeli*, Sts. Apostles churches. Collapse of part (?) of *Colosseum.* Possible damage to Marcellus theatre/fortress and to St. Laurence's bell tower. Possible final collapse of Basilica Ulpia and Basilica of Maxentius	VII	*Villani, Petrarca,*
2.2.1703	L'Aquila, Central Apennines	X	Collapse of 2 arches of *Colosseum*, damages in *St. Laurence*, cracks in *S. Peter's* in *Vaticano* and in the *Quirinale* building, no collapse of houses, effects on underground waters (varying water table in wells and muddy waters)	VII	*Valesio*
22.3.1812	Roman area	VI - VII	Modest damages and minor collapses in some churches, walls and buildings in several areas of the city, particularly close to the Tiber. Damage to the temple of Venus and Cupid	VI - VII	
13.1.1915	Fucino basin	X - XI	Damages to 20 palaces, collapse of 5 meters of the upper wall of the *Claudius'* aqueduct, damages in some churches and ancient ruins	VI - VII	

2. Itinerary

STOP 1 - Colosseum

STOP 2.1-2.4 – Forum Romanum

STOP 3.1-3.2 – Capitolium and Forum Caesari

STOP 4.1-4.5 – Imperial Forums

STOP 5 – Column of Marcus Aurelius

STOP 6 – S. Maria sopra Minerva

STOP 7 – largo Argentina

STOP 8 – Porticus Octaviae and Theater of Marcellus

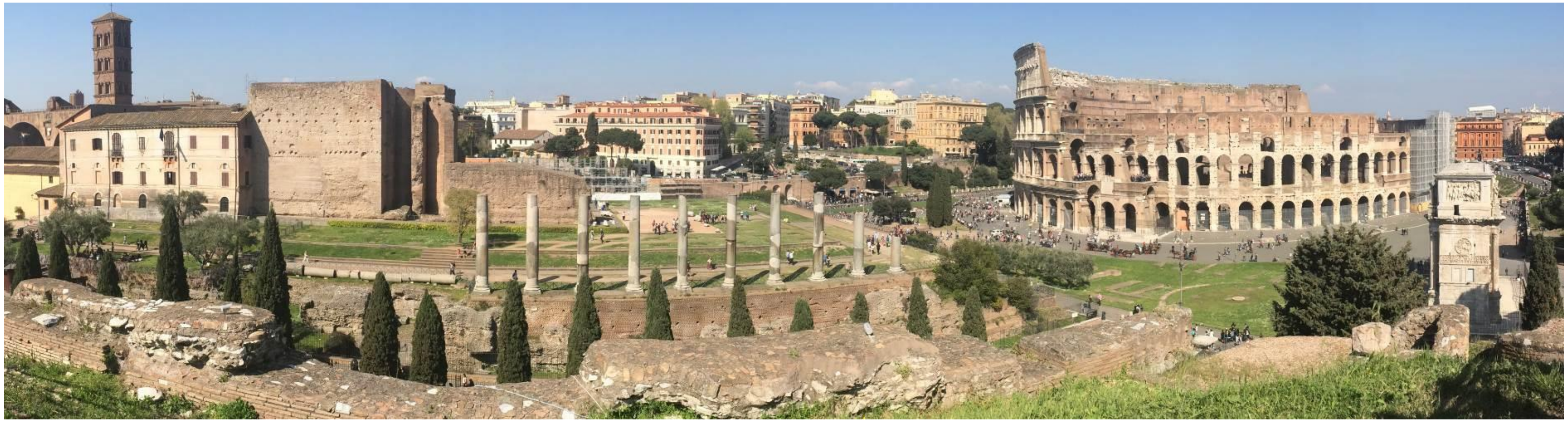


Fig. 2.1 – View of the Forum Romanum and Colosseum with Temple of Venus and Roma in the center.

STOP 1 – Colosseum

Built since the 72 AD during the reigns of emperors Vespasianus and his son Titus, its final dedication took place in the year 80 AD. Its correct name is *AmphiTheatrum Flavium,* from the gens (family) Flavia to which these emperors belonged. However, already in the VIII century it was popularly named Colosseum (Colyseus), due to the presence nearby of an enormous (30 meters high) bronze statue, the Colossus, representing Nero (*Colossus Neronis*), transformed after his death by Vespasianus into a statue of god Helios (sun, *Colossus Solis*), melted down in the Middle Ages, likely in the VIII century.

Fig. 2.1.1 - 3D view of Colosseum (Google Earth), with indicated an approximate trace of the Labicanus stream. The missing portions of the first two rings are evident on the southern side of the mon-

ument.

The Colosseum, elliptical (188 x 156 meters) in shape and once 52 m high, was made of more than 100,000 cubic meters of travertine (*lapis tiburtinus*) coming from the quarries near Tivoli, and 6,000 tons of concrete and other stone blocks. The travertine blocks were linked by means of 300 tons of iron clamps. Marble plates covered the outer face. It could host more than 45,000 spectators (87,000 *loca* according to ancient sources), attending various types of games, mainly violent fights among gladiators (*munera*) and wild beasts mock hunting (*venationes*). There were many independent accesses (*vomitoria*) to the seats (*podium* and *cavea*), which allowed an easy exit at the end of the performance.
The playground (arena, from *rena* = sand) was made of wood covered with sand (Upper Pliocene marine sand quarried along the slopes of Monte Mario), to absorb the blood and soften the effects of falls. Gladiators and beasts entered the arena from the rooms hosted underneath through underground passages. A sort of canopy (*velarium*) sheltered the spectators from the sun.
The Flavian Amphitheatre lies (Figs. 2.1.1 and 2.1.2) between the hills of *Oppius* and *Caelius* and the Velia (a ridge connecting the Palatine and Oppius Hills removed in 1932 to realize via dell'Impero), inside the valley of a small stream (Labicanus), tributary of the Tiber through the low humid area called *Velabrum* under the Palatine. This stream is still visible in the buried depths of the nearby Saint Clemens. The valley was partially dammed under Emperor Nero to realize an artificial pond (*stagnum Neronis*) encircled by a colonnade, part of his wide residence *Domus Aurea* (Golden House). After the death of Nero, the next emperor Vespasianus drained the pond, without significant excavations, and realized an annular concrete platform, over 13 meters thick, on which travertine pillars were laid. These are the foundations of the *AmphiTheatrum*.

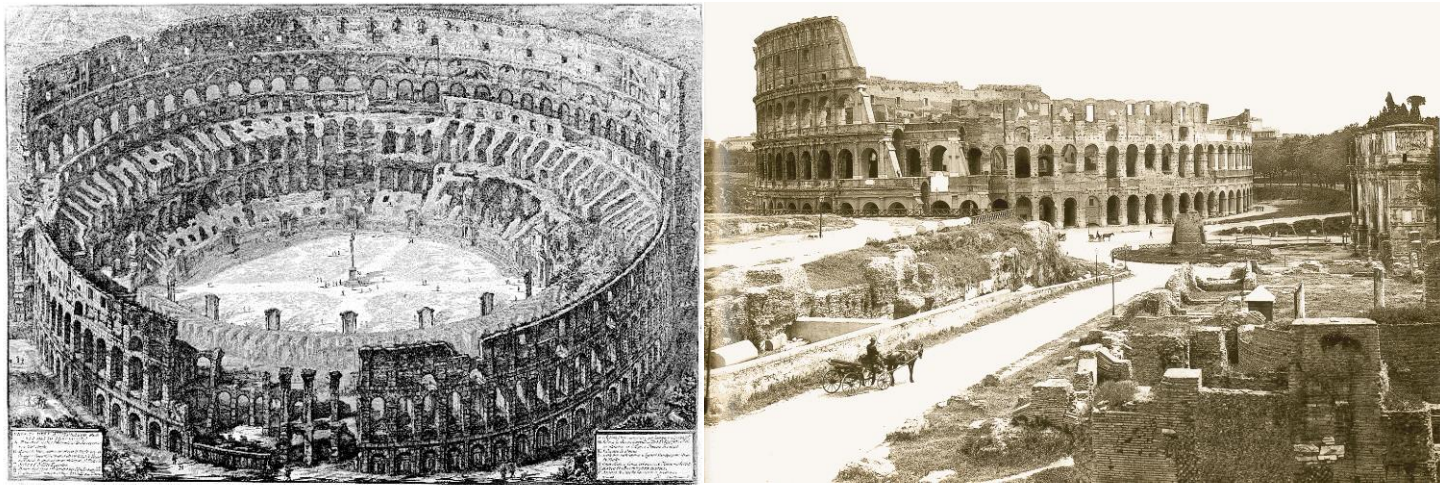


Fig. 2.1.2 - Left (etching of Piranesi, 1776): on the southern side of Colosseum most of the seismically-induced damages occurred. The first two rings are missing and the third one collapsed after the 1703 earthquake. Right: major restorations started only in 1845; they are evident by the smooth red brick surfaces on the travertine. In this Alinari's photograph of the end of 1800, Meta Sudans and Collina Velia (left of the cart) are still present.

The foundation ground is partly made of Pleistocene alluvial sediments with good bearing capacity and partly, the southwest side, of fine-grained soft Holocene deposits filling the talweg of the *Labicanus* stream (Bozzano et al., 2000). The uneven subsoil characteristics probably determined irregular settlements and were the most likely cause of partial collapses, concentrated in the southern side where the two outer ring are missing and the next one has been largely rebuilt in 1845 after its collapse in 1703 (Fig. 2.1.2, left). The most likely cause of this behaviour is a differential site response during earthquakes (Fig. 2.1.1). Both walls and alluvial sediments have been found to share a similar resonance period of ca. 0.5 seconds.

The amphitheatre was damaged by earthquakes in 443 (according to the *Historiae Romanae* of Paulus Diaconus) and in 484 or 508 AD, based on the inscription in Fig. 2.1.3, where a *Decius Marius Venantius Basilius* declares to have directly paid restoration works after an earthquake. The uncertainty is because two Decius were *consul*, one in 484 and another in 508. Portions of the colonnades in the *summa cavea* (upper seating section, for the plebeian spectators) fell down and also the *arena* and the *podium* suffered major damages (the latter are the parts restored by Venantius). Likely, more serious were the damages, including partial collapses of the external walls, caused by the 847 and 1349 earthquakes. It must be recalled that this monument fell in ruin since its abandonment at the end of the empire, because of the earthquakes cited before and fires ignited by lightning, to which it must be included also the dislike of Christians for violent games and the impossibility to find more wild beasts. Actually, to its decadence contributed also the weakening of its structure due to the stealing of the iron clamps linking the travertine blocks. So, this magnificent monument ended up as a quarry providing building stones for many Middle Ages to Baroque palaces of Roma or even for the production of quicklime, sharing such an unfortunate destiny with many other Roman monuments. Only after the damages caused by the 1703 earthquake, the popes decided substantial restoration works, initially with the aim to transform it in a church.

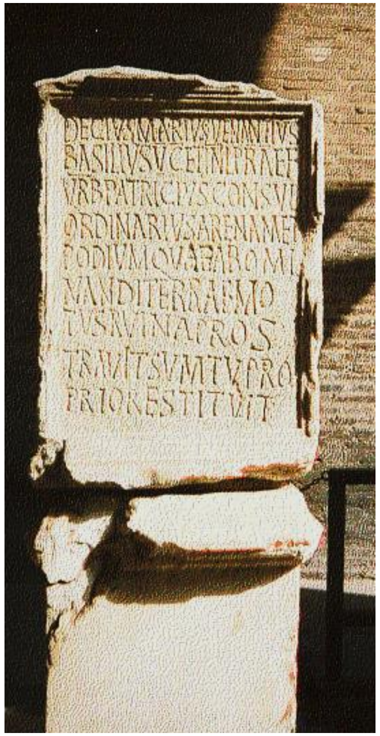


Fig. 2.1.3 - Marble plate inside the Colosseum remembering the restoration of arena and podium after an earthquake in 484 or 508, i.e., the same year of the consulate of Venantius, that was in one of these years. The poor quality of this inscription testifies of the decadence of Roma (text: DECIVS MARIVS VENANTIVS | BASILIVS V(ir) C(larissimus) ET INL(ustris) PRAEF(ectus) | VRB(i) PATRICIVS CONSVL | ORDINARIVS ARENAM ET | PODIVM QVAE ABOMI|NANDI TERRAE MO|TVS RVINA PROS|TRAVIT SVM‹P›TV PRO|PRIO RESTITVIT - DECIMUS MARIUS VENANTIUS | BASILIUS, VERY FAMOUS AND WELL KNOWN PREFECT | OF THE CITY, PATRICIAN, REGULAR CONSUL | RESTORED THE ARENA | AND PODIUM WHICH | DREADED MOVEMENTS OF THE EARTH | CAST DOWN INTO RUIN | AT HIS OWN EXPENSE).

STOP 2 – *Forum Romanum*

From the Colosseum an exciting walk on the Sacra Via across the Forum Romanum, with its triumphal arches and temples, will lead to the foot of the Capitolium, where volcanic deposits of the Sabatini and Alban Hills crop out along the incision between Capitolium and Palatine hills. This area has been the heart of Roma during its Republican and Imperial periods, entirely drained with the realization of the Cloaca Maxima ("main culvert"). It lost relevance after the fall of the Empire and became just another quarry, whose monuments were partially saved only because partially or totally buried under a mixed rubble, above which buildings were erected afterwards. The area between the Capitolium and the Colosseum was systematically excavated only since the beginning of the XIX century (during the Napoleonic occupation of Roma), with major works carried out during the '30s to realize via dell'Impero, later via dei Fori Imperiali, which cuts in two halves the once continuous area of the fora. Regrettably, many monuments were lost forever to make room for this street, e.g., the Collina Velia (Fig. 2.1.2, right). On the other hand, many historical sites, often referred to in the works of the Roman writers, were unearthed and restored since then. This work is still ongoing today and new archaeological monuments are made visible.

In the forums, the archaeologists have unearthed fallen columns and walls at several places in position suggesting a sudden collapse. The early medieval earthquakes have been invoked often as the causes of such damages, but, as underlined by Galadini et al. (2013), in many cases such interpretation remains conjectural for the lack of precise age constraints and other possible explanations. An archaeoseismological analysis is generally impossible now, because of the subsequent restorations.

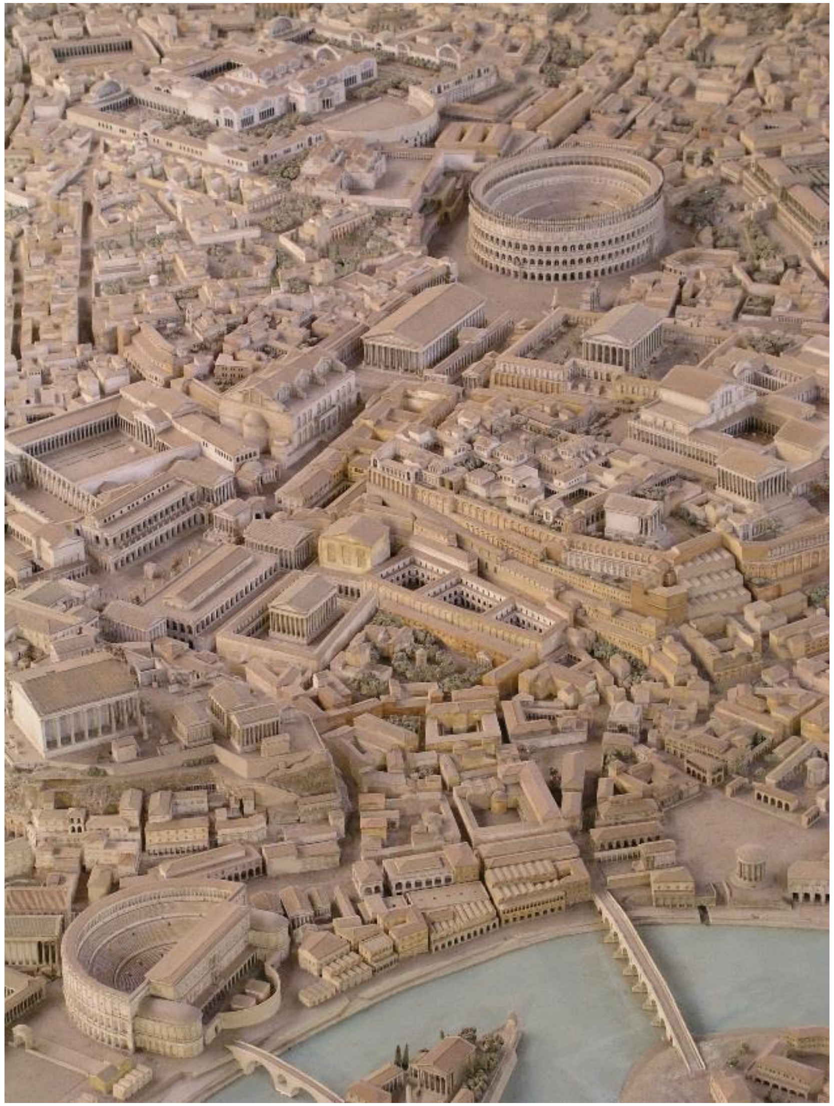


Fig. 2.2.1 - Plaster reconstruction by Italo Gismondi of the Forum, Palatine and Capitolium areas down to the Tiberina islet (bottom), on display in the Museum of Roman Civilization of Rome.

In the area crossed by the *Sacra Via*, there are several monuments interpreted to have suffered from seismic shaking. The first we meet (**Stop 2.1**) is the *Templum Veneris et Romae (*Temple of Venus and Roma), followed by the *Basilica Constantini* (commonly known in Roma as Basilica di Massenzio). The south aisle and nave of the latter likely collapsed in the earthquake of Pope Leo IV in 847. The *Templum*, probably the most splendid temple in Rome, was built by Emperor Hadrian: on its ruins the pope Leo IV built the Church of Sancta Maria Nova, renovated in the XVII century as the current church of Santa Francesca Romana. Interestingly indeed, Sancta Maria Nova was built in replacement of the church of Sancta Maria Antiqua (**Stop 2.2**), also inside the area of the Forum, at the foot of the Palatine under the *Domus Tiberiana*, heavily damaged by the same 847 earthquake, according to many sources (see Galadini et al., 2013). The church was rediscovered in 1702 (Fig. 2.2.2) and fully unearthed during excavations in 1900, which completely destroyed another very old church (Santa Maria Liberatrice) built on it. Now we may only see some cracks in the walls (the site is not open for visits), but the excavations showed large fallen blocks of tuffs from the slope and parts of walls of Domus Tiberiana that had collapsed the roof and part of the hillside wall.

Damage from the 443 (508?) and 801 or 847 earthquakes have been proposed for the panorama of collapses seen also in other monuments of the Forums and surroundings, e.g. the *Basilica Paulli* or *Aemilia* (**Stop 2.3**) (see Table I and Fig. 2.2.3).

Fig. 2.2.3 – Façade of the Basilica Aemilia as found by the archaeologists in 1899. Photograph in the Archive of the Sovrintendenza ai Beni Archeologici of Roma.

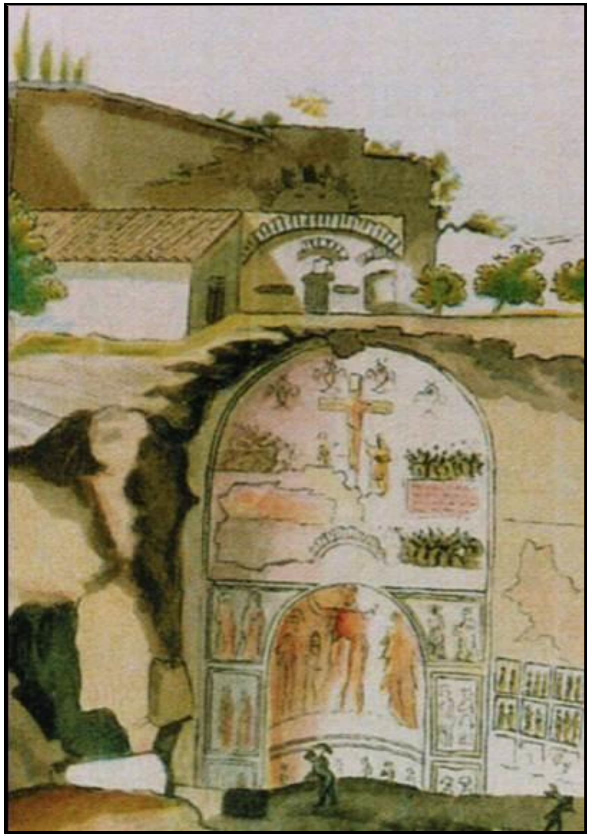


Fig. 2.2.2 - Remains of the church of Sancta Maria Antiqua, heavily damaged by tuffs boulders detached from the slope of the Palatine hill during the 847 earthquake, in a drawing by F. Valesio dated 1702. The apse and the left wall appear to be preserved with their frescoes.

STOP 3 – *Capitolium*

We exit the Forum area and climb up the Capitolium. The Campidoglio (*Capitolium*) hosts now the City Hall and accommodates an important art museum. Michelangelo designed the square, with the bronze statue of Marcus Aurelius in its centre. Nearby once stood also the *Aedes Iovis Optimi Maximi Capitolini* (i.e., the Temple of Jupiter Optimus Maximus, dedicated to the Capitoline triad: Jupiter, Juno and Minerva). Standing on the panoramic terrace (**Stop 3.1**, Fig. 2.3.1), we have the *Tabularium* (record building) and the Palazzo Senatorio resting on it on our left. Under us runs the *Clivus Capitolinus*. From here there is a great view of the Forum archaeological area, including the *Palatine*; Roma with the Apennines and the Alban Hills is in the background.
We go back to the *Vicus Iugarius* passing beside the *Carcer* (jail) *Tullianum* (left) and the *Forum Caesari* and the *Aedes Veneris Genetricis* on our right (**Stop 3.2**, Fig. 2.3.2), also believed to have been damaged by one or more medieval earthquakes. Actually, there is no available dating constraining the observed collapses, so that this interpretation is highly conjectural (Galadini et al., 2013). Following the ancient *Clivus Argentarius* with its *tabernae* (shops for silversmiths and also moneylenders), we reach Via dei Fori Imperiali. The most ancient city walls (Servian Walls), dating back to the kings period, run nearby encircling the Capitolium on its northern side.

Fig. 2.3.1 – View from the terrace on the Forum Romanum of Stop 3.1. In primo piano al centro è il Templum Saturni.

Fig. 2.3.2 – *Forum Iulium or Caesari*. The three tall columns are what remains today of the *Templum Veneris Genetricis*. In background the tilted Turris Militum (Torre delle Milizie).

STOP 4 – Imperial Forums

At the eastern edge of the archaeological area across the street (**Stop 4.1**, Fig. 2.4.1), we note a stocky square tower, the Conti's tower (*Turris Comitum*). Its construction was completed in 1238, possibly on the northeast remains of the *Templum (Forum) Pacis* (Temple or Forum of Peace), suspected to have collapsed because of an earthquake in 484 or 508 AD, based on fallen columns (Fig. 2.4.2, from Galli and Molin, 2014).

Fig. 2.4.1 – Panorama on the *Forum Nervae* and *Forum Augusti*, with the Conti's Tower in background on the right. The *Templum Martis Ultoris* is on the left.

Originally, the tower reached a height of 50 to 60 meters, but the 1349 earthquake beheaded it, so that it is now 29 m high. Also the tilted T*urris Militum* (Torre delle Milizie) on the left was damaged by the same event. More or less corresponding to the current via Cavour, ran the *Velabrum* stream, so the damages here might be related to ground motion amplification of the soft river sediments on which the tower rests. Microzonation studies have found that the Holocene alluvial deposits have their resonance period at about 0.5 seconds.

Just northwest of the tower (left side from the stop), separated from the Forum Pacis by the ca. east-west running *Argyletum* (that was a main street connecting the eastern boroughs, in particular the *Subura*, with the fora), we have the Imperial forums, partially buried under the modern streets: *Forum Nervae (Transitorium)*, *Forum Augustum* (or *Augusti*) and *Forum Traiani*.

In the *Forum Augusti* (**Stop 4.2**), confining to the west with the *Forum Iulium* (or *Caesari*), Octavianus Augustus built the *Templum Martis Ultoris* (Temple of Mars Avenger), one of the most beautiful temples in Roma according to Suetonius. Now we can see only three standing columns, risen during the early XX century restorations. The intention of Octavian was probably that to compete, and surpass, the magnificence of the adjoining Forum Iulium with its *Templum Veneris Genetricis*. The collapses in both areas are referred again to one of the early medieval earthquakes.

In the *Forum Traiani* (**Stop 4.3**), the most impressive monument is currently the column dedicated to the victories of the Emperor Traianus, but at his times the *Basilica Ulpia* and the *Forum Traiani* and the Trajan markets were imposing constructions. Part of the Basilica is still buried under via dei Fori Imperiali, while the apse is under the Palace of Roccagiovine (Fig. 2.4.3).

Fig. 2.4.2 – Collapse of monolithic columns in the south edge of the Templum Pacis directly above opus sectile slabs (Galli and Molin, 2014).

Fig. 2.4.3 – Above: Basilica Ulpia with the Column of Traianus in the background. Below: basement of the column with crisscrossing fractures, possibly due to seismic shaking

The *Columna Traiani* (**Stop 4.4**), 38 meters high, is made of 19 drums of *Lunensis marmor* (marble from the Apuan Alps in northern Tuscany) with diameter 2.66 meters. It commemorates, in the form of a *cochlea* (snail) "comics" strip carved as a basso rilievo (bas-relief), the victories of this emperor over the Dacians (inhabitants of the present-day Romania) in 101-102 and 105-106 AD. Following the spiral evolution of the basso rilievo from bottom to top (200 meters long), all the significant events of the wars against the king Decebalus are described. There are a few cracks along the column and there is evidence of vertical impact at its bottom (Fig. 2.4.3, below), possibly related to weak seismic shaking, in the order of 0.04 g. Here the foundation of the column is on firm ground: the column's top is believed to mark the original ground elevation before the excavation made between the *Quirinalis* and *Capitolium* hills to obtain a sufficient flat surface to build the Forum Traiani and the Basilica.

Moving a few meters toward Piazza Venezia, we meet a fenced area (**Stop 4.5**), where remains of a building of the Hadrian period stand. The geometry of the ruins, with subvertical floors and collapsed walls and arches, and chronological estimates allow to attribute the collapse most likely to the 847 earthquake (Galadini et al., 2013).

Fig. 2.4.4 – Tumbled down structures of a building of the Hadrian period (Galadini et al., 2013). The tallest block has intruded in a strongly deformed undelying floor.

STOP 5 – *Columna Marci Aurelii Antonini* (commonly called Colonna Antonina)

This coclide (spiral, from cochlea: snail) column celebrates in its bas-relief the victory of the emperor Marcus Aurelius over Marcomanni (Germans) in 172-173 AD and Sarmatians (174-175 AD). Realized during the reign of Commodus (180-192 AD) on ground that had been reclaimed from a former marsh, it follows the example of the older column of Traianus (see **Stop 3.4**).

This extraordinary monument, made of *Lunensis marmor*, marble from the Apuan Alps (Tuscany), is 29.5 meters high (42 m including its base, but it was 46 m before restoration), made of 26 piled up drums, diameter ca. 240 cm (Fig. 2.5.1). An inner helicoid staircase of 200 steps, lit by 56 small windows, permits to reach its roof top. Here, where in origin the bronze statue of Marcus Aurelius stood, a Christian symbol (the statue of Apostle S. Paul) was posed during the restoration of the column in 1589 under pope Sixtus V to signify the supremacy of Christianity over the pagan Roma (Fig. 2.5.2). At that time, the original Roman basement (10.5 m high) was shortened of about 4 meters, corresponding to the new upraised ground level. Close to the column run the ending section of the ancient via Flaminia, named via Lata in the XVI century, now via del Corso, one of the main streets of Roma.

One geologic peculiarity is the few centimetres mismatch of drums between spirals 9 and 10, more or less in the middle of the column length (Fig. 2.5.3), best seen where the winged Victoria is inscribing a shield. Such misalignment cannot certainly be due to an error during its construction. A possible explanation involves the effect of seismic waves from one of the late Imperial to mediaeval earth-quakes cited before. However, someone may wonder if the heavy restoration works at the end of XVI century could have produced this mismatch.

Fig. 2.5.1 – Column of Marcus Aurelius today, with the statue of St. Paul on top.

Actually, this possible evidence of seismicity is seen in a column that, alike the *Columna Traiani*, stands up since the II century AD, but other similar columns were lost without knowing the cause. Thus, me may infer that the earthquakes felt in Roma were never strong enough to collapse the two columns or even significantly dislocate their slices, one of them even standing on reclaimed ground. Moreover, no offsets similarly to what observed for example in the columns of the Parthenon in Athens, is reported for the many temple columns in Rome. Yet, it must be considered that only for a very few columns there is some evidence that they have never been moved or restored during their history.

Fig. 2.5.2 – The Column before the 1589 restoration by Domenico Fontana.

Fig. 2.5.3 – Mismatch of drums between spiral line 9 and 10 from below, side facing the current via del Corso.

STOP 6 – *Sancta Maria supra Minervam*

The marble plates still fixed on the façade of this beautiful church (one of the few churches in Roma still conserving its original structure in Gothic style) give evidence of the water level reached during six floods (1422, 1495, 1530, 1557, 1598 and 1870) (Fig. 2.6.1). If in time, we move to the next stop through Piazza Navona, probably the most beautiful square in Roma with its splendid baroque fountains, churches and palaces. Its shape reproduces that of the Roman circus of Domitianus buried underneath. During the 1598 flood the water reached here 5 meters of elevation. In the Baroque age, thanks to the rich availability of water after the restoration of several aqueducts, this square was artificially flooded in August (then the floor had a concave shape) to refreshen the citizens and for boat games (*naumachiae*), following an ancient Roman tradition.

Fig. 2.6.1 – Not only earthquakes.. Water level reached during some floods of the Tiber. The oldest water mark dates back to 1422, the most recent to 1870.

Fig. 2.7.1 – The archaeological area of Largo Argentina. Three temples are aligned in this middle part.

Stop 7 - Archaeological area of Largo Argentina and surroundings

We walk across largo Argentina, with its archaeological area in the middle, miraculously spared by the urban sprawl after the conquest of Roma in 1870 by the Savoia army (Fig. 2.7.1). Here again, the northern porticus was damaged by the 443 earthquake and likely also the

theater of Pompeius nearby, completely buried under buildings. Galli and Molin (2014) report several epigraphic and historical pieces of evidence of damages and partial collapses for this event, whose source region and intensity cannot be assessed today.
We move along via delle Botteghe Oscure, where we see the remains of a temple whose columns were found aligned during the excavation in 1938 (Galadini et al., 2013). Crossing the street, we get to the Crypta Balbi, a large archaeological area buried by modern buildings. Especially in the area of the exedra, huge collapses of the upper structure have been attributed to the 847 earthquake (Galadini et al., 2013).

Stop 8 *Porticus Octaviae* and *Theatrum Marcelli*

We enter in the Roman Ghetto to meet some columns of the quadriporticus of Octavia sticking out of the current pavement. Reaching the *Theatrum Marcelli* (Marcellus was the son of Octavia, sister of Octavianus Augustus, but the construction was started by Julius Caesar), we see the damages of the external walls of the Theatrum, similar to those of the Colosseum, but not attributed here to any earthquake (Fig. 2.8.1). Close by, there are three standing columns, what remains today of the Temple of Apollo Sosianus. Such columns were found lying in a position suggesting a sudden fall, possibly caused by the 508 earthquake (Galli and Molin, 2014) (Fig. 2.8.2). Such attribution is doubted by Galadini et al. (2013), putting forward local ground instabilities as an alternative possible cause.

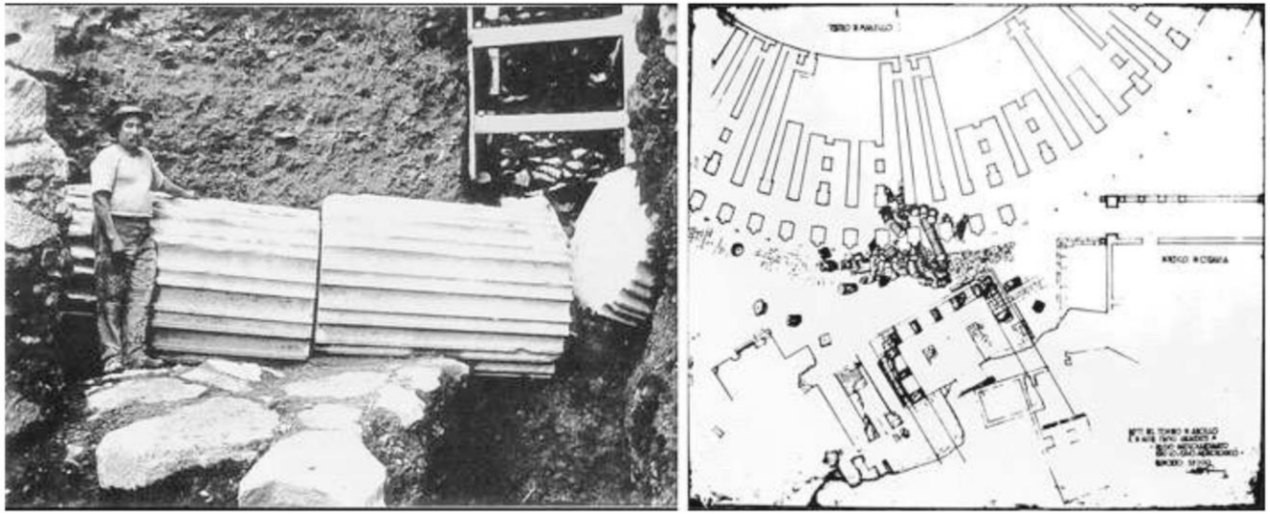


Fig. 2.8.1 – The Theater of Marcellus with its restorations (darker) and the erected left columns of the temple of Apollo Sosianus.

Fig. 2.8.2 – Left: column of the Temple of Apollo Sosianus fallen on a Late Antiquity street. Right: map of fallen columns as found during the 1930s excavations (from Galli and Molin, 2014).

Back to Piazza Venezia, where the completely out-of-place mass of the Vittoriano stands out, monument built to celebrate the victory of Vittorio Emanuele II over the popes destroying in the making many Medieval, Renaissance and Baroque constructions. Here we get the Bus 64 that will take us to Termini Station where we can catch the Metro B to Tiburtina Station (Meeting Point at the end of Field trip).

Acknowledgements

The content of this guide is mostly based on the works of others, in particular Galli and Molin (2014) and Galadini et al. (2013), who are gratefully acknowledged for their invaluable efforts to unravel the seismicity of Roma, efforts also based on the studies of many researchers, historians, archaeologists, seismologists, geologists, who are not directly cited here but in the papers cited above. Instead, any mistake or misinterpretation found in this guide is totally mine.

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