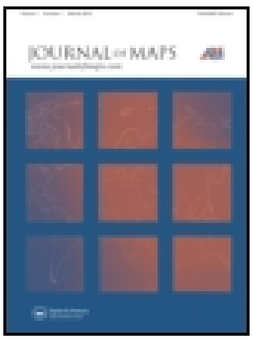

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SCIENCE

# Volcanology of the Southwestern sector of Vesuvius volcano, Italy

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**ABSTRACT**

Here we present a new volcanological map of the Southwestern portion of the Vesuvius volcano at a scale of 1:10,000. Mapped units were subdivided into Unconformity-Bounded Stratigraphic Units. This work constitutes a significant development with respect to previous maps, particularly for the medieval lavas. It also includes a series of volcanic–tectonic lineaments, which have never been reported in any of the previous cartographic works. Archeological and historical data were used for mapping the lava emitted during the last 2000 years. All the historical lava flow paths and tephra deposits of the last 4000 years that were reported on the map and evidence the intimate relationship between volcanological and morphological features, and the development of human activity on this very densely populated sector of the volcano.

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**KEYWORDS**
Vesuvius; Unconformity-Bounded Stratigraphic Units (UBSU); volcano cartography

## 1. Introduction

Previous geological maps made for the Vesuvius volcanic area (Johnston-Lavis, 1891; Le Hon, 1866; Rosi, Santacroce, & Sbrana, 1986; Santacroce & Sbrana, 2003) provide cartographic details that are limited to the emplacement of only the most recent lava flows emitted from that volcano. Recently, Principe et al. (2004) unequivocally demonstrated, based on new archaeomagnetic dating, that a substantially larger number of medieval lavas are present. Principe et al. (2004) also demonstrated that eccentric vents generated most of these lava flows with steep fronts that are still visible on the Vesuvius shoreline. The new detailed volcanological map of the Southwestern sector of Vesuvius (Main Map) correctly identifies all of the medieval lava units outcropping in this sector of the volcano and their relationships with the pyroclastic deposits emitted during the *Avellino*, *Pompei* and AD 1631 explosive eruptions.

## 2. Geological outlines

The Somma-Vesuvius volcano complex is located in the Campanian Plain (Figure 1) on the coast of the Gulf of Naples (Southern Italy), at the intersection of NW–SE and NE–SW striking fault systems (e.g. Bigi et al., 1990; Cassano & La Torre, 1987; Finetti & Morelli, 1974; La Torre, Nannini, & Sbrana, 1983). It is a composite volcano formed by the young cone of Vesuvius (Arnò et al., 1987), surrounded by the poly-phased edifice of Monte Somma (Principe, Brocchini, & Perillo, 1999), affected by multiple collapses (Cioni, Santacroce, & Sbrana, 1999). The activity of the Somma-Vesuvius complex started approximately after the Phlegraean Fields *Campanian Ignimbrite* super-eruption, 39 years ago (De Vivo et al., 2001), while the last Vesuvius eruption occurred in 1944 (Arnò et al., 1987). During the last 4000 years of activity, Vesuvius experienced several main explosive events: the small-scale Plinian eruption of AD 1631 (Rosi, Principe, & Vecci, 1993), the sub-Plinian AD 472 eruption (Arnò et al., 1987; Rolandi, Munno, & Postiglione, 2004; Rosi & Santacroce, 1983; Sulpizio, Mele, Dellino, & La Volpe, 2005, 2007), and the two large Plinian eruptions that occurred at AD 79 (*Pompei* eruption; Sigurdsson, Carey, Cornell, & Pescatore, 1985) and 1995 ± 10 cal BC (*Avellino* eruption; Rolandi, Mastrolorenzo, Barrella, & Borrelli, 1993; Sevink et al., 2011; Sulpizio, Bonasia, et al., 2010; Sulpizio, Cioni, et al., 2010). Mild explosive activity (from Strombolian and violent Strombolian to sub-Plinian) took place during intra-Plinian periods (Andronico & Cioni, 2002; Arrighi, Principe, & Rosi, 2001; Cioni, D'Oriano, Bertagnini, & Andronico, 2013; Di Renzo et al., 2007; D'Oriano, Cioni, Bertagnini, Andronico, & Cole, 2011), and a number of lava flows originated from the central crater ('Gran Cratere') or from fissures

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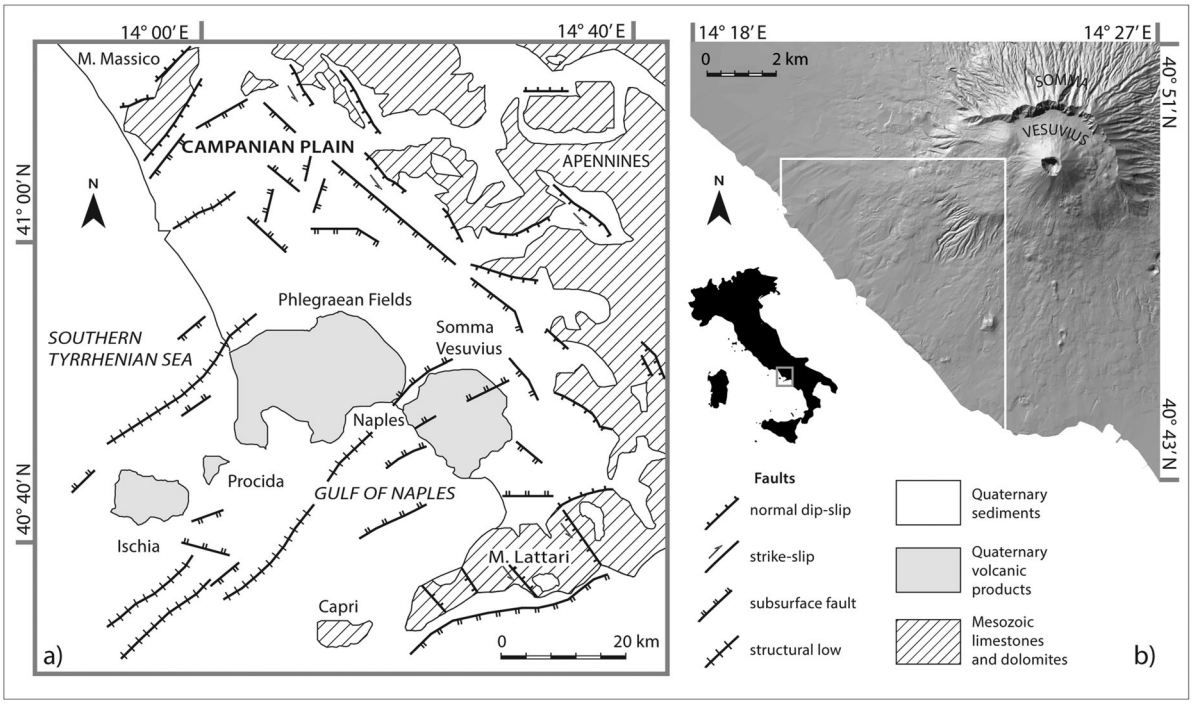


**Figure 1.** (a) Geological sketch map of the Campanian Plain (modified from: Bigi et al., 1990; Cassano & La Torre, 1987; Finetti & Morelli, 1974; La Torre et al., 1983). (b) DTM model of the Somma-Vesuvius volcano with the delimitation of the mapped area (white line).

opened on the main Vesuvius cone ('Gran Cono') (Principe, Rosi, Santacroce, & Sbrana, 1987, 2004).

Before the work of Principe et al. (2004), it was assumed that the eccentric activity was limited to several lava flows emitted in modern times from vents opening at the base of the main Vesuvius cone (e.g. 1760, 1794, 1861 eruptions) (Principe et al., 1987).

## 3. Mapping methodology

Field mapping was conducted using 1:5000 scale topographic maps produced by *Cassa del Mezzogiorno* (Southern Italy Development Agency) in 1978 (Plates 448,132, 448,133, 466,011, 466,012, and 466,014). This basemap was produced by the *Cartografia Tecnica Numerica Provinciale della Regione Campania* (Technical Digital Cartography of the Campanian Regional Authority) in 2004 and 2005 at the same scale, which is based on aerial photographs taken during the years 1998–1999.

The digital map, using WGS84 UTM 33N, was subsequently superimposed onto the Shaded Relief derived from a Digital Terrain Model (DTM) with a spatial resolution of 1 m. The DTM was obtained from LiDAR data of the Regione Campania made available by the Ministero dell'Ambiente e della Tutela del Territorio e del Mare.

The volcanological map (SM-1) was produced based on the outcropping areas, field, historical, archaeological, and morphological data sets. The cartography takes into account the flow directions of each lava flow and its relationships with the pre-existing morphology and deposits. Detailed maps of the outcrops collected during fieldwork (Figure 2) can be obtained upon request. However, it has to be noted that these maps will be soon outdated due to the relentless construction activity, since many of the recognized outcrops are found along roads or in quarries and construction sites.

The volcanological map reproduces the original pattern of each lava flow without the possibility to distinguish between the surviving lavas and its inferred distribution. The present work matches all the previous information with the final lava patterns.

In heavily developed areas, geological mapping is by necessity a compromise from the outcropping stratigraphic units and their portions covered of asphalt and concrete. In the Vesuvius area the intense and long-lasting mining activity of lavas and lapilli covers ('pozzolana') magnifies this problem. All the villages around Vesuvius are built for the large part with these volcanic products. The original pattern of lava flows was partially erased by excavations and covered by a carpet of buildings (Figure 3(a)). On the other hand, lavas and 'pozzolana' quarries (Figure 3(b)), road cuts and construction sites, when present, were instrumental to allow access to the outcrops. Mapping of the lava units that date back to the nineteenth century was made easier by the fact that the lower slopes of the Vesuvius cone areas, where they extensively outcrop, fall within the Vesuvius National Park, so preserving the original morphologies of the lava flows.

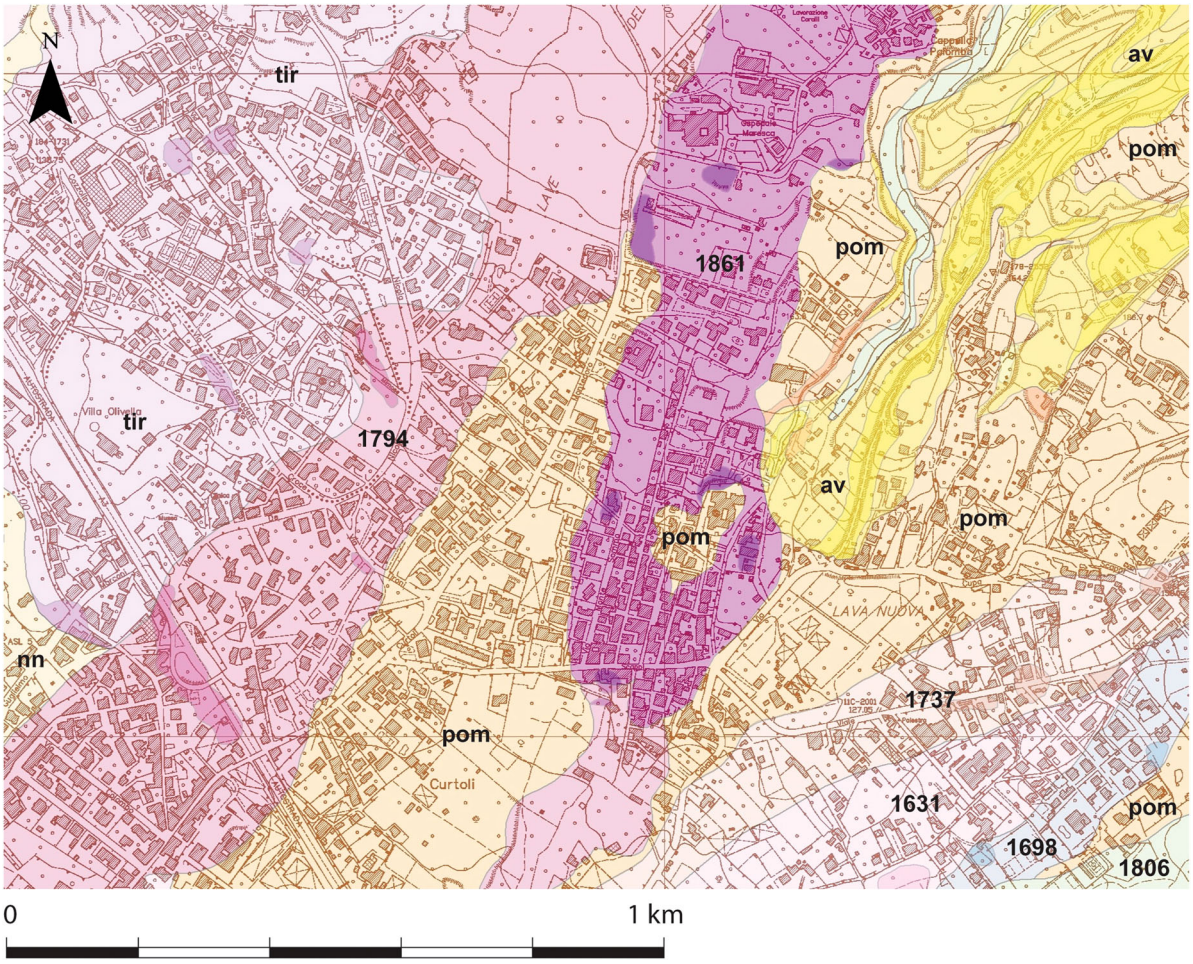


**Figure 2.** Detail of the outcrop map. The main outcrop areas of lavas and pyroclastic deposits are shown. Symbols refer to the Main Map legend (SM-1).

### *3.1. Unconformity-Bounded Stratigraphic Units*

In our cartography (SM-1) we used lithostratigraphic units as mappable objects in the field; hence the smallest formal lithostratigraphic units (NACSN, 1983) on the map are beds (essentially lapilli beds) and flows (lava flow or pyroclastic flow deposits). The basic lithostratigraphic unit (i.e. the formation) was not used in this case because our map represents only a portion of a wider geological body (i.e. the Vesuvius volcano).

The mapped lithostratigraphic units were grouped into Unconformity-Bounded Stratigraphic Units (UBSU) (SM-1; Synthematic sketch map). Chang (1975), Salvador (1987, 1994), and Murphy and Salvador (1999) proposed the Synthem as the basic unconformity-bounded unit. An unconformity-bounded unit is defined as 'a body of rocks bounded above and below by specifically designated, significant, and demonstrable discontinuities inside the stratigraphic succession (angular unconformities, disconformities, etc.), preferably of regional or interregional extent' (Salvador, 1987). When it is needed and useful, a Synthem may be subdivided into two or more Subsynthems, and two or more Synthems may be combined into a Supersynthem (Salvador, 1987). In the same context, unconformity is defined as a surface of erosion and/or non-deposition between rock bodies, representing a significant hiatus or gap in the stratigraphic succession, caused by the interruption of deposition for a considerable span of time (Salvador, 1987). These different discontinuity surfaces must be observable in the field (Bonomo & Ricci, 2010).

With respect to other types of units often used in volcanological maps (such as lithotypes or eruptive units), the use of UBSU represents a clearer and more pragmatic approach to stratigraphic analyses in order to achieve a better, more descriptive, and more lucid interpretation of the whole geologic history of the area in which the volcanic districts insist (Salvador, 1987). The use of unconformities is an objective manner to synthesize the volcanic evolution and to distinguish major phases on the basis of reproducible field characteristics, while also taking into account the geological (in the sense of not-volcanological) events that occurred inside and/or at the limit of a given volcanic district (Groppelli & Viereck-Goette, 2010; Principe & Giannandrea, 2008).

In volcanic areas the unconformities are due to a number of causes that are specific to volcanic activity,


**Figure 3.** (a) Aerial photo of *Torre del Greco* town. Note the large number of buildings. (b) Aerial photo of *Villa Inglese* quarried area (77 in Table 1). (c) The front of the 1794 lava flow, still outcropping along the coast of *Torre del Greco* town. In the background the bell tower of the church of *Portosalvo*. (d) The *Calastro* ('cal' on the volcanological map) lava outcroppings along the coast of *Torre del Greco* town, underneath the old *Molini Marzoli* edifices.

such as a period of quiescence, an erosional phase, a shifting of the feeding system, an abrupt change in eruptive style, or a volcano-tectonic event, like the formation of a caldera or of a sector collapse (e.g. Groppelli & Viereck-Goette, 2010). The rank of an unconformity depends on its geographic extent, the duration of an associated hiatus, or its volcanic-structural significance.

The application of the unconformity-bounded units' concept to volcanic areas can face problems of scale (temporal and spatial) as hiatuses are usually short, because of the sometimes-limited areal extent of units, and because the data on the timing and duration of eruptions are usually limited. Here we paid particular attention to the timing and clustering of eruptions since the working area represents only a time–space portion of a larger and older volcanic edifice. This involves the need to use objective and replicable cartographic criteria, so that the work can maintain its validity when compared with the complete stratigraphy of the volcano.

### 3.2. Archaeological and historical criteria

The existence of maps of Vesuvius that date back to the eighteenth century (Carafa, 1775; La Vega & La Vega, 1797; Morghen, 1794; Figure 4(a)–(c)) constituted an invaluable source of information for the accurate implementation of the present work. These maps allowed us to track the changes of toponymy and topography in an area that has been repeatedly disrupted by volcanic activity. Furthermore, the Johnston-Lavis (1891) map produced during 1888–1889 (Figure 4(d)) was instrumental for mapping lava units, especially those of the nineteenth century.

The *Pompei* eruption in AD 79 covered all the Southern sector of Vesuvius under 10s m of loose lapilli and ashes, and deposits of pyroclastic flows and lahars. Despite the highly destructive impact, this event preserved most of the Roman presence in the territory, for example, *Ercolano, Pompei* and *Oplontis* villages, and today Roman ruins dot the lowermost slopes of Vesuvius. Archaeological sites in the mapped area were used as a stratigraphic marker during fieldwork.

Another useful tool for the control of lava flow patterns was the census of information regarding building age and transformations, of a large number of churches, chapels, and historical edifices (mansions and rural villas) (Table 1) built between the sixteenth and twentieth century at the foot of the volcano, especially along the old road called *Strada Regia delle Calabrie* (De Seta, Di Mauro, & Perone, 1980), now


**Figure 4.** Historical maps of the Vesuvius Southwestern sector. (a) The map of La Vega and La Vega (1797) reports some of the better exposed lava units before and after the AD 1631 eruption in this sector of the volcano. Note that AD 1631 pyroclastic flows deposits ('Terra di Fuoco', literally 'fiery soil'), and the deposits of the *Pompei* eruption ('Terra Vecchia', literally 'old soil'), in many places are not covered by other eruption deposits. *Pompei* eruption is named 'Tito' eruption, because that eruption dates AD 79 at the time of the Roman imperator *Titus Flavius Caesar Vespasianus Augustus* (from AD 79 to AD 81). (b) Portion of the topographic map printed by *Giovanni Carafa Duca di Noja* in 1775. This map represents the most accurate description of the Vesuvian area in the eighteenth century. (c) The accurate cartography of the front of the 1794 lava flow that destroyed *Torre del Greco* town, on the plate of *Antonio Ciofi* engraved by Morghen (1794). (d) Plate III (Locality *Granatello-La Scala*) of the Mt. Vesuvius' geological map, compiled by Johnston-Lavis (1891) and drawn in six sheets at the scale of 1:10,000 on the topography produced by the students of the Military Geography Institute of Florence in 1875–1886.

*Via Nazionale*, running near the coast, from the city of Naples to *Torre del Greco* and *Torre Annunziata* in the South.

The remarkable historical record for the Vesuvius area is due to the long history of human presence in a land with a pleasant climate, fertility of the soil, and access to the sea and overland (well before the construction of the Roman consular roads). After Roman times, an important contribution to land development can be attributed to the establishment of Naples (15 km away from the Vesuvius summit) as the capital of the Kingdom of the Two Sicilies (1266) and, few centuries later (1738), by the construction, due to *Carlo III Borbone*, of the Royal Palace of *Portici*.

This resulted in a large number of witness's reports of eruptive events still preserved in specialized Italian and European libraries (Principe, 1997) that helped with reconstructing the eruptive history and corresponding volcanic deposits. Aware of the fact that these carry the reputation of being often fictional and imprecise, an appropriate selection of chronicles and treatises, based on historiographical criteria (Principe, 1998), effectively supported our field and cartographic work.

**Table 1.** Sites and buildings of interest for cartography. Numbers in the first column (ID) refer to the numbered stars on the map (SM-1).

| ID | Name | Municipality | Date of building | Historical note |
|---|---|---|---|---|
| 1 | Palazzo Amoretti | Portici | 1744 | Historic building belonging to Vesuvian Villas of the Miglio d'Oro. |
| 2 | Villa Zeno | Portici | Eighteenth century (1740) | One of the lesser-known eighteenth century mansions. Built on a pre-existing structure, as it was represented in the plant of the Duke of Noja. Its facade is baroque and in the nineteenth century makeover, it was transformed into a neoclassical style. |
| 3 | Villa D'Amore | Portici | Nineteenth century, on the older building of eighteenth century | Already present in the map of the Duke of Noja, it was built at the beginning of the eighteenth century, but in 1898 it was subjected to an architectural intervention that radically changed the look, adding more bodies, and destroying the rich garden. |
| 4 | Palazzo Landriani | Portici | 1750–1754 | The eighteenth century complex, building and Chapel of the Holy Cross, was designed and built between 1748 and 1752. Also known as Orsini Gravina Palace, for the acquisition of the Duke of Gravina. The original architectural structure, with typology to C-shaped, used in Neapolitan buildings of the eighteenth century, it remained unchanged until today. |
| 5 | Palazzo Perrelli | | Yet in the Duke of Noja's map of 1772 | One of the oldest buildings in the area, turned into neoclassical. |
| 6 | Epitaph of the eruption of 1631 | Portici | 1632 | It was placed by Vicerè Zunica as future warning of the dangers of the volcano, following the disastrous eruption of Vesuvius of 1631. |
| 7 | Villa Materi (Palazzo Capuano) | Portici | 1025 | Together with the Saint Anthony Church, they are the oldest buildings in Portici. They are the symbols, respectively, of the temporal power and of the power of the Church. It was originally the Ducal Palace, the seat of the feudal lord of the area. Of the historic building, it remains the tower, the oldest part of the house, originally separated from the body of the sixteenth century building. |
| 8 | Palazzo Mascabruno | Portici | Between 1740 and 1754 | It has rustic forms and consists of an inner courtyard bounded by buildings, surrounded by a distinctive grove of 'live oak'. It was the country residence of the Marquis Mascabruno. |
| 9 | Convent of Sant'Antonio | Portici | 1337 | Tradition wants that the church and the convent were founded by Saint Francis. This is, however, contradicted by the sources. The monumental church of Saint Anthony is a testimony to the ancient history of this Vesuvian city. |
| 10 | Villa D'Elboeuf | Portici | 1711 | This palace was the first of 122 Vesuvian villas of the Miglio d'Oro to be built, in chronological order. It was elegant and beautiful, a masterpiece in the baroque style. |
| 11 | Royal Palace of Portici | Portici | 1738–1742 | Historic house in neoclassical style built by King Charles of Bourbon, as a royal palace, before the construction of the most imposing Royal Palace of Caserta, inside a large park with a garden in English style and an amphitheater. |
| 12 | Church of Sant'Agostino | Ercolano | 1613 | It is the Church of Our Lady of Consolation and was part of the Augustinian Order of Discalced Hermits. 18 November 1929, the Archbishop of Naples, Cardinal Alessio Ascalesi, raised it in the parish. |
| 13 | Basilica di Santa Maria di Pugliano | Ercolano | Eleventh century | Papal Basilica from 1574, it is the main church of Herculaneum and the oldest in the city and the Vesuvius area. The name 'Pugliano' probably derives from *praedium pollianum*, a suburban farm Herculaneum belonged to such Pollio or Pollio. In 1631, the church was spared by the eruption Vesuvius. Its plant is a Latin cross, with three naves and a transept asymmetrical. There are works of great artistic and historical value. The imposing bell tower was built between the second half of the sixteenth century and early seventeenth century. |
| 14 | Vesuvian Aqueduct | Ercolano | | |
| 15 | Palazzo del Principe di Capracotta | Ercolano | Eighteenth century | It was built in the seventeenth century, in baroque style, and was the seat of the Municipality of Resin, in the Bourbon period. |
| 16 | Ancient Fort of Granatello | Portici | 1738–1739, years of building | It was built about a mile away from the Palace of Portici, for preventing attacks from the sea. |
| 17 | Villa Riario-Aprile | Ercolano | Eighteenth century | Or Riario Sforza, it was built in the second half of the eighteenth century, and is one of the largest of the Miglio d'Oro. It has one of the parks most beautiful and spectacular of the entire Vesuvian area, although it is not the most luxurious. |

(*Continued*)

**Table 1.** Continued.

| ID | Name | Municipality | Date of building | Historical note |
|---|---|---|---|---|
| 18 | Villa Campolieto | Ercolano | Eighteenth century (1755–1775) | Vesuvian villa situated along the Miglio d'Oro. It was built between 1755–1757 and 1775, by Lucio di Sangro, duke of Casacalenda. Its plan is quadrangular, divided into four separate bodies from the arms of a central gallery of a central Greek cross, with, in the center, a well-light dome by four oval windows. The anterior facade is oriented toward Vesuvius, while, the posterior one toward the Gulf. |
| 19 | Villa Onorato Battista | Ercolano | Nineteenth century | It still keeps its initial plan, although you can detect dissonant works, dating back to the post-earthquake, which, in a rough and superficial, they were intended to strengthen the structure. |
| 20 | Villa Favorita | Ercolano | 1768–1792 | More exactly Favorita Real Villa, it is one of the most sumptuous villas of the Vesuvian eighteenth century of the Miglio d'Oro. |
| 21 | Villa del Principe di Migliano | Ercolano | Eighteenth century | It has a plan with a 'C' shape and, originally, had two floors. Then it has undergone considerable successive amendments, also the raising of a plan. Even inside the building, it is possible to highlight structural changes. |
| 22 | Church of Santa Maria del Pilar | Ercolano | 1748 | It was built by lawyer Giuseppe Sorge, at the middle of eighteenth century. At the beginning, it was born as chapel of the family building family, close to the agricultural land of the large property that he owned on the opposite side of the 'Strada Regia delle Calabrie', and it was dedicated at the queen of Spanish, because she gave as gift the picture of the Madonna of the Pilar. |
| 23 | Rione INA 167 | Ercolano | | |
| 24 | Cappella della Grotta | Ercolano | | |
| 25 | Masseria Oliva dei Monaci | Ercolano | | |
| 26 | Don Orione Clinic | Ercolano | | Rehabilitation center |
| 27 | Maresca Hospital | Torre del Greco | | Hospital |
| 28 | Vesuvius Cafè | Torre del Greco | | Bar |
| 29 | Carmelitani Scalzi Church and Convent of the ex Padri Teresiani | Torre del Greco | 1686 | After the disastrous eruption of 1631, as a vote for the narrow escape, the city of Naples built a small church dedicated to the patron Saint Gennaro, because he defended it to Mount Vesuvius, along the Royal Road to Torre del Greco. Shortly after, the same city built next the church a convent where they settled some Discalced Carmelite Fathers, called Santa Teresa. The church was named like the saint. |
| 30 | Church of San Pietro | Torre del Greco | About 1019 | Ancient church dedicated to San Pietro for a legend, later denied, that wanted that he landed right on the shores of Calastro. After continuous and repeated destruction and damage, it was rebuilt in its present form in 1306. |
| 31 | Villa Finizzi | Torre del Greco | | |
| 32 | Hospital of incurables | Torre del Greco | 1570 | In 1570, a Neapolitan, Don Ferrante Bucca of Aragon, founded this hospital for the treatment of dropsy, with a small church, in classically baroque style, dedicating all to Our Lady of Mercy. |
| 33 | Villa Santa Teresa | Torre del Greco | At the beginning of 900 | |
| 34 | Preventorium | Torre del Greco | | |
| 35 | Villa delle Terrazze (Ospedale Bottazzi) | Torre del Greco | Nineteenth century | Inside the hospital structure, Ospedale Bottazzi, there is one of the most beautiful villas of the city of the nineteenth century. Its structure dates back to late eighteenth century and it has been recently renovate. Its name descends from the beautiful garden surrounding composed of many overlapping terracings decorated with classical elements of the Italian garden. Very interesting are the fountain in the inferior garden and the fishery in the lava rocks sited in the superior garden, the esedra and the beautiful portico in front of the facade. |
| 36 | Palazzo Vallelonga | Torre del Greco | 90's of seventeenth century | Monumental building situated along the Miglio d'Oro. It was built in the nineties of the seventeenth century, when the Castiglione Morelli family of Vallelonga became owner of a large feud in the land of Torre del Greco. The large farm had consisted of several small buildings, intended to habitation that the agricultural processing and animals shelter. The beauty and tranquility of the place determined the decision of the Marquis of Vallelonga, at the beginning of the eighteenth century, to transform the rustic factories in comfortable homes. |
| 37 | Chiarina a Mare Restaurant | Torre del Greco | 1898 | Restaurant-pizzeria near the beach of 'The Scala', in Torre del Greco. |

(*Continued*)

**Table 1.** Continued.

| ID | Name | Municipality | Date of building | Historical note |
|---|---|---|---|---|
| 38 | Ancient Fort of Calastro | Torre del Greco | 1703 | Its shape was inferred from the representations of Morghen and La Vega, drawn up after the eruption of 1794. Similar to the one of San Giovanni in Teduccio, it was built on a slab of lava. |
| 39 | Church of Santa Maria del Principio | Torre del Greco | About at the beginning of 1000 | It was built in 1100 and it is one of the most ancient church of the city. It thinks that the cult of Holy Mary of the Principle had the beginning at the origin of the Christianity. During the 1794 eruption, the shrine of the Madonna, near the little church, was saved from the lava. To find it, under the rubble, perfectly intact, were some Franciscans. The structure now stands exactly where the discovery occurred. |
| 40 | Church of Santa Maria delle Grazie and Monastero dei Frati Minori Osservanti detti Zoccolanti | Torre del Greco | About 1600 | The church of Our Lady of Grace, with the adjoining monastery built around the end of the sixteenth century thanks to the funds of alms citizens 'torresi', were on a small hill outside the town, near the door of Cape Tower. In the eruption of 1794 the lava engulfed the church and surrounded the monastery, raising the level of the ground in front of them. The church, after the eruption, was renovated and restored in the upper left: the window of the second order of the exterior became the current front door. |
| 41 | Church of Santissima Annunziata | Torre del Greco | 1568 | It was built, according to local historian Francesco Balzano, in 1568, together with the annexed convent of the Capuchin Fathers. Over the centuries has undergone significant transformations that have profoundly changed the original structure. The complex was also involved, although marginally, during the Vesuvian eruptions of 1631 and 1794. The church, in ancient times, was in the baroque style, with a superior eighteenth century sacristy, covered with fine wood. The interior, all in white stucco, is divided into two naves and the central one has the time some eighteenth century paintings. |
| 42 | Church of Santa Maria di Portosalvo | Torre del Greco | 1801 | It was built on the spur of lava, called 'scarpetta', formed with the eruption of 1794 of Vesuvius, and it was dedicated to Mary of Portosalvo, protector of the sailors and the fishermen of the district, because there, it missed a church. It has an unique nave with a circular cupola. |
| 43 | Palazzo Baronale | Torre del Greco | About 1383 | It is one of the most ancient buildings of the city. It was the dwelling of Francesco Carafa. Now, of this, there is only the northern wing. In 1851 became headquarters of the Town Hall and it underwent important transformations. |
| 44 | Church of Santa Maria di Costantinopoli | Torre del Greco | At the end of sixteenth century | It is one of the historical-artistic evidences of the city. It survived by the lava of the 1794 eruption of Vesuvius, at the beginning, it was a private chapel of the Carafa, when this family lived in the Baronial Palace. In this, there was the ancient sculpture of the Madonna with the Child, brought in the city by Andrea Maldacena corsair. |
| 45 | Basilica di Santa Croce | Torre del Greco | 1517 | It was built between the end of the fifteenth century and the beginning of the sixteenth century. It became parish in 1584, with the Trento Council (1545–1563). Its facade is oriented toward the sea and it is divided in two orders: one inferior with four central Corinthian columns, and one superior with a big central body with a large window. Its inside is a latin cross with three naves. It resembles the Basilic of Saint Peter in Vatican. |
| 46 | Church of San Giuseppe alle Paludi | Torre del Greco | 1674 | It was built in 1674 by a Napoletan priest, Gennaro Di Martino, in a manor farm, called 'Joseph, Jesus and Mary' or also of the 'Holy Family', sited on the area called 'dry sea', formed along the coast, during the eruption of 1631. After, its name was changed in 'Saint Joseph of the Marshes', because in that area there were marshes of volcanic material. Inside, it has only white nave, with baroque decorations. |
| 47 | Church of Santa Maria del Carmine | Torre del Greco | 1565 | It was built in sixteenth century by Carmelitah Fathers of Major Carmine of Naples with the adjacent convent, that, now, it is headquarters of the State Art Institute and Coral Museum. Its history is connected to the Vesuvian eruptions of 1631, when it was partially destroyed and of 1737, when it was damaged. Its style is baroque and it has only one nave, with three chapels on each side. |

(*Continued*)

**Table 1.** Continued.

| ID | Name | Municipality | Date of building | Historical note |
|---|---|---|---|---|
| 48 | Church of Santa Maria del Pianto or delle Anime del Purgatorio | Torre del Greco | 1664 | It was built by faithfuls in 1664, behind the Carmine Church, on the very deep pit where many people were buried because of the plague of 1500. At the beginning, it was a little chapel where masses were said for these dead. During the 1737 eruption, it was devastated by Vesuvian lava and it became no praticable. On its ancient walls, in 1742, it was built a church, called 'Purgatorio'. Inside, it has only one nave. |
| 49 | Villa D'Amato | Torre del Greco | | |
| 50 | Palazzo del Cardinal Spinelli | Torre del Greco | 1744 | It is one of the most luxurious Vesuvian villas. It was built in the late eighteenth century, by Gennaro De Laurentis. The central balcony of the building opens with an arch topped by an oval niche, where there is a relief of San Gennaro. At the end of the Park of the villa, still intact, there is a commemorative plaque attesting to its construction as a votive offering after the eruption of 1804. |
| 51 | Church di Sant'Antonio di Padova | Torre del Greco | 1952 | It was built on the ancient rural chapel dedicated to Saint Gennaro, there before of 1742. Its building works lasted 27 years, from 1925 to 1952. Its style is new-romantic. It consists of, outside, in a facade with a *pronao* and, inside, in a long body divided in three naves. |
| 52 | Chapel of Christ, Mary and Joseph | Torre del Greco | | |
| 53 | Villa Cervasio | Torre del Greco | | |
| 54 | Villa Sora | Torre del Greco | First century after Christ | Roman suburban villa, in reticulated and brick opera, with wall paintings and floor mosaics, discovered during excavations carried out in the eighteenth century under the reign of Charles of Bourbon and Ferdinand IV. |
| 55 | Case Montella | Torre del Greco | | |
| 56 | Villa Fienga (ex Guglielmina) | Torre del Greco | Eighteenth century | |
| 57 | Epitaph of the eruption of 1631 | Torre del Greco | Seventeenth and eighteenth century | It is a celebratory monument built in Vesuvian stone, substantially different from that of Portici, also built after the eruption of 1631. On this epitaph were applied two plaques in two different historical periods: the first, from 1562, reminds posterity the construction and rehabilitation of the road by the Viceroy de Ribera, on the upper part of the monument, which was lost after the eruption of 1631 and was found years later; the second recalls the eruption of 1631 which destroyed the monument and caused a lot of damage to various countries around Vesuvius. |
| 58 | Villa Mennella | Torre del Greco | Eighteenth century | Belonging to the Vesuvian villas of the Miglio d'Oro, it is a villa of the eighteenth century, with a neoclassical structure. |
| 59 | Villa Guerra | Torre del Greco | Eighteenth century | It was built in eighteenth century, of modest sizes and simple shapes, belonged to Avitable Family. |
| 60 | Thermae Gymnasium | Torre del Greco | First century after Christ | The Terme Gymnasium date back to the first century BC and were discovered in 1881 by artillery colonel Giuseppe Novi, who had as supervisor Michele Ruggiero, the director of excavations of Pompeii. The building complex covers a large surface with a series of terraces that sloped down to the sea, where there was a landing place. The building is a villa just as great as that of the district of Sora. Now, the complex resurfaces with his intermediate terrace. |
| 61 | Villa Merola | Torre del Greco | | |
| 62 | Little Chapel of San Vito in Villa Ercole | Torre del Greco | | |
| 63 | Villa Ercole | Torre del Greco | Eighteenth century | It is one of the most beautiful residence of late eighteenth century, recently restored. It shows nearly intact its noble and solemn structure. Here, it is possible to arrive through a long boulevard. At the beginning, it was in a big park, now, rich of greenhouses. It consists of three floors and it has simple architecture. Its main facade is asymmetric with decorations in stucco. |
| 64 | Torre di Bassano | Torre del Greco | | So called from the place where it is located, it was built by the University as a defense tower. Placed in a dominant position on a rocky waterfront overlooking the sea, it has a square shape, thick walls and embankments outside; inside, the ground floor with the stores, the second with the quarters of the guards, the third, which is an uncovered terrace, with artillery emplacements. |

(*Continued*)

**Table 1.** Continued.

| ID | Name | Municipality | Date of building | Historical note |
|---|---|---|---|---|
| 65 | Villa Mennella Vaccaro | Torre del Greco | Eighteenth century | Vesuvian villa of the eighteenth century, along the Miglio d'Oro, with neoclassical structure, consists of a facade in nineteenth century style, that shows, along the entire ground floor, a rusticated stucco that determines a strong contrast with the rest of the facade plastered. |
| 66 | Roman ruins | Torre del Greco | | |
| 67 | Torretta Fiorillo | Torre del Greco | | Fiorillo Turret is a monument little known but very important. The turret already existed at the end of the eighteenth century, as witnessed by some papers of the time, and its presence gave the name to the district. The name Fiorillo belonged to the family owners of the agricultural land in which there was also a large farm. The tower probably was used to spot the game and direct the operations of hunting within the great royal reserve of Mortelle that extended until Torre Annunziata. |
| 68 | Church of Santa Maria la Bruna | Torre del Greco | 1621 | From seal of Decio Carafa result that the first chapel dedicated to the Virgin of Carmelo, said of Brown, was built in 1621, on land donated by Isabella Gonzaga, Princess of Stigliano, in the place called 'The Mortelle'. The name comes from the painting of a black Madonna, also known as 'Our Lady of Muroli', insects that affect the screws. She is dressed to the Greek. The small chapel was destroyed by the eruption of 1631, but the image of the Virgin was not overwhelmed because placed at the top. |
| 69 | Villa Macrina | Torre del Greco | Eighteenth century | Named after the Marquise Macrina Palomba in Rivellini and has the typical structure of the farmhouse, that from the farm is transformed into place to stay and rest. The large garden surrounding the villa is built today by citrus groves and tall trees, such as palm trees and pines. The building consists of three floors and a basement. The central body is adorned with a rusticated gray color that contrasts with the yellow of the remaining structure. |
| 70 | Villa Volpicelli | Torre del Greco | | |
| 71 | Palazzo Aurisicchio-Cicchella (Club Trotula) | Torre del Greco | Eighteenth century | Dating back to the seventeenth century, it was built by order of Joseph Aurisicchio, chief warden of Ferdinand IV, with the hope of being able to accommodate the king, returned from hunting in the area of 'The Mortelle'. However, the king would not never granted to him this privilege. It has a very elongated rectangular plan and consists of a long central body on the front of the street, in added to it two wings that end one with a terrace balustrade and the other with a rustic covered loggia that opens both toward the sea and toward Vesuvius. On the main front, very extensive, are placed the three doorways: the large central arch of the main entrance and the two minor sides. The architecture is quite simple. |
| 72 | Villa Bruno-Prota | Torre del Greco | Eighteenth century | Of the early years '700, originally it belong of the marquises Curtis and after of Prota family, it is particular for its unusual direction: its facade is tangential to the driveway, which corresponds to the direction road-sea. This could almost make to think that the reason is to want to take advantage of the best of the resources of the surrounding landscape. |
| 73 | Villa San Gennariello, now Villa Ruggiero, Villa Aurgo | Torre del Greco | Eighteenth century | It was built before of 1731, year engraved on a marble inscription situated under the recess with the bust of Saint Gennaro, for invoking protection from him for Vesuvius. |
| 74 | Masseria Donna Chiara | Torre del Greco | Eighteenth century | It was built about eighteenth century. Its name derived from woman Chiara Invitti, son of the merchant don Carlo Invitti, that, in the early eighteenth century, married Don Flavio Gurgo of the Royal Council of Saint Clare of Naples. |
| 75 | Church of San Vincenzo a Postiglione | Torre del Greco | 1900 | It was built in 1900 by Vincenzo Postiglione, owner of Villa Prota. |
| 76 | Roman ruins | Torre del Greco | | |
| 77 | Palazzo Borriello-Villa Inglese | Torre del Greco | Eighteenth century | So called because it belonged to the English lord William Hamilton, ambassador of the United Kingdom of Great Britain in Naples, collector of art, volcanologist, and researcher of the Vesuvian area (1730–1803), that married the famous lady Emma Hart. At the beginning, it had the entrance on the main street, maybe destroyed during the eruption of 1760. |

### 3.3. Unconformity Bounded Stratigraphic Units

The stratigraphy of the last 4000 years of Vesuvius activity has been subdivided into five Synthems. The unconformities separating these Synthems are angular unconformities, erosional surfaces, disconformities (i.e. irregular or uneven erosion surfaces or indications of weathering in essentially parallel bedding), and soils, corresponding to a significant depositional hiatus in the stratigraphic succession. Lithostratigraphic units were distinguished during fieldwork on the basis of their lithologic characteristics and stratigraphic position (NACSN, 1983). On the map (SM-1) lithofacies symbols have been superimposed on the colors indicating each bed or flow unit. This allows a more immediate identification of different lithologies such as lapilli covers or pyroclastic flow deposits.

The 36 lithostratigraphic mapped units have been grouped into Synthems and Subsynthems as follows (SM-1; Synthematic Subdivision and Figure 5).

#### 3.3.1. Present-Vesuvius Synthem

This Synthem comprises the *Piano delle Ginestre* and the *AD 1631* Subsynthems. The top surface of the *Piano delle Ginestre* Subsynthem is represented by the present-day morphology, whereas the base, which separates it from the *AD 1631* Subsynthem, is represented by the collapse surface of the Vesuvius cone after the AD 1631 small-scale Plinian eruption (Rosi

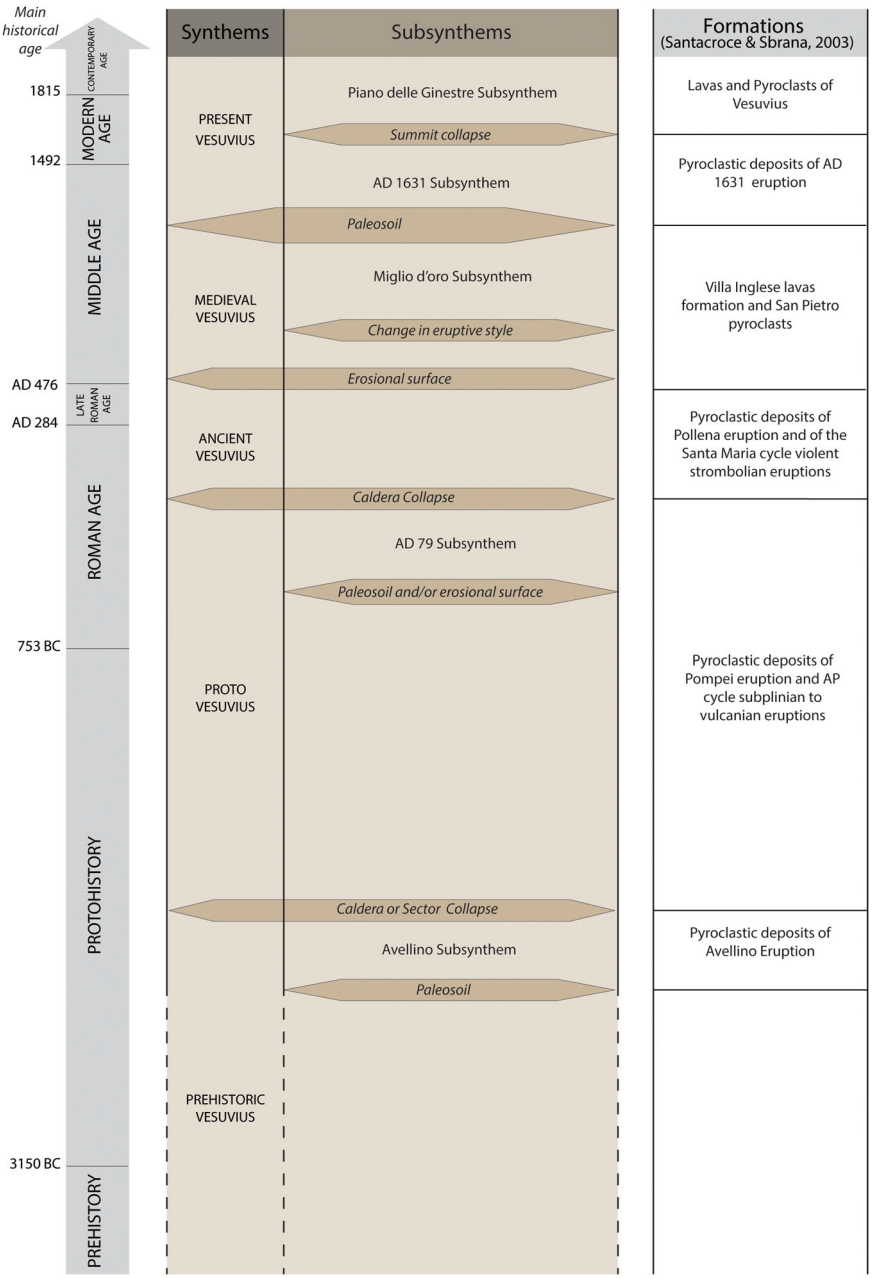


**Figure 5.** Stratigraphic sketch of the last 4000 years. First column: historical time scale; second column: synthematic subdivision and related unconformities (this work); third column: lithostratigraphic subdivision from Santacroce and Sbrana (2003), inferred from the entire volcano.

et al., 1993). The unconformity at the base of the *AD 1631* Subsynthem is a soil deposit (Figure 6(a)) developed during five centuries of volcanic rest before the AD 1631 eruption (Principe & Marini, 2008; Rosi et al., 1993). It separates the *Present-Vesuvius* Synthem from the *Medieval-Vesuvius* Synthem.

The *Piano delle Ginestre* Subsynthem consists of 19 lava units and a bed of lapilli tephra, emitted during the whole period from post-AD 1631 activity to 1944. The majority of the lava units have limited thickness (from 1 to 5 m), and were emitted either from the main crater or from vents opened at the base of the Vesuvius main cone (Principe et al., 1987), and did not reach the shoreline. There are only three exceptions to this general behavior, which are: (i) the 1861 fissure lava flows, that were emplaced immediately after the 1858 crisis (Arnò et al., 1987); (ii) the 1858 eruption with the formation inside the *Canteroni* and *Piano delle Ginestre* area of a number of lava domes and *coulées* with rope structure, and (iii) the main lava unit of the 1794 eruption which entered the sea with a thick and steep front and destroyed 4/5 of the ancient city of *Torre del Greco* (Figure 3(c)). As a whole, the lava flows and pyroclasts emitted during the post-AD 1631–1944 period have phono-tephritic composition (SM-1; TAS Chemical Classification). The mineral assemblage comprises clinopyroxene, leucite, plagioclase, olivine, biotite, and Fe–Ti oxides in various proportions (Arrighi et al., 2001; Belkin, Kilburn, & De Vivo, 1993).

Pyroclastic deposits emplaced during the AD 1631 eruption represent the *AD 1631* Subsynthem. Here

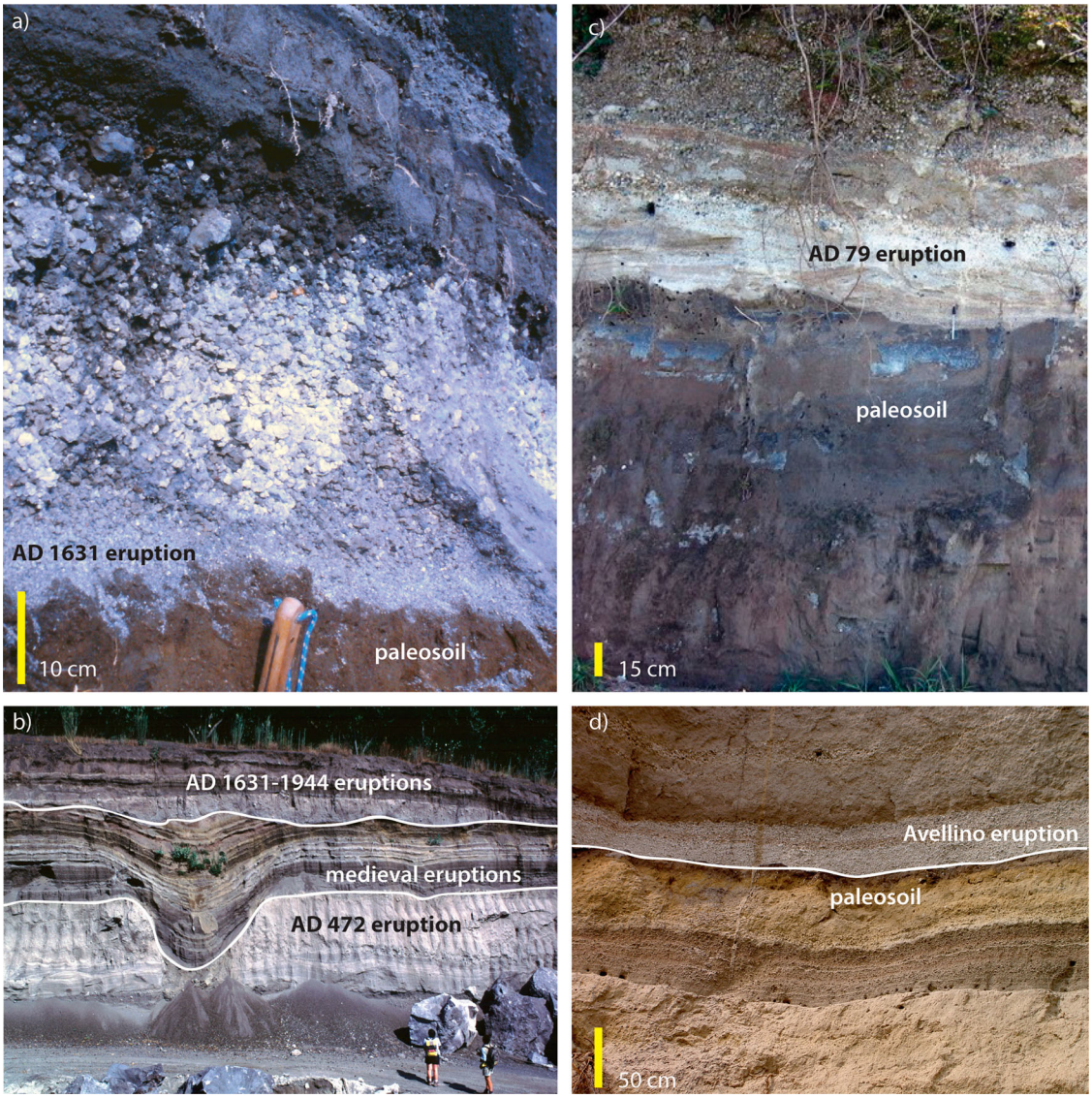


**Figure 6.** Unconformities within the pyroclastic sequence of the last 4000 years. (a) The five centuries old paleosoil at the base of the deposits of the AD 1631 small-scale Plinian eruption outcropping in the type section at *San Leonardo* (outside of the map, North-East of the Vesuvius cone; modified from Rosi et al., 1993). (b) The carved morphology formed as a result of a new drainage setting on the AD 472 sub-Plinian eruption deposits in *Pozzelle* quarry (outside of the map, South-East of the Vesuvius cone) (from Principe & Tanguy, 2009). (c) A palaeosoil with traces of cultivation underlying *Pompei* eruption deposits outcropping at *Case Sarciniello* (North-West of the 1794 eruption lowermost vents). (d) The orange-brown paleosoil underlying the *Avellino* Plinian fallout in the quarry of *Trapolino* (outside of the map, North of the Vesuvius cone) (from Principe & Tanguy, 2009).

the mapped area shows outcrops of concentrated pyroclastic density currents deposits. The AD 1631 concentrated pyroclastic density currents deposits are mainly unconsolidated, gravity controlled, and extremely rich in old lava blocks, skarn fragments, and cumulates. The juvenile fraction is made of dark-green scoriae with clinopyroxene and euhedral leucite phenocrysts as the most evident phases (Rosi et al., 1993). Chemical classification of the flows' juvenile fraction ranges from phono-tephrite to tephri-phonolite (SM-1; TAS Chemical Classification).

#### 3.3.2. Medieval-Vesuvius Synthem

The *Medieval-Vesuvius* Synthem contains a number of short and thick lava units (Figure 3(d)) that constitute the *Miglio d'Oro* Subsynthem. The *Miglio d'Oro* Subsynthem gathers the mainly effusive eruptive episodes of activity that occurred between the ninth and twelfth centuries, including a lapilli bed related to the AD 1139 explosive eruption that outcrops in several places inside the study area (SM-1; Stratigraphic Sections). Few explosive events, not recorded in the study area, occurred before the *Miglio d'oro* activity period and close to the AD 472 large eruption (D'Oriano et al., 2011; Rolandi, Petrosino, & Mc Geehin, 1998; Santacroce & Sbrana, 2003). The *Medieval-Vesuvius* Synthem is separated from the *Ancient-Vesuvius* Synthem by an erosional surface with drainage patterns superimposed on the pre-existing morphology produced by the *Pompei* eruption deposits. In other areas of the volcano this surface sits on the top of the AD 472 eruption deposits (Figure 6(b)).

#### 3.3.3. Ancient-Vesuvius Synthem

The boundary between the *Ancient-Vesuvius* Synthem and the *Proto-Vesuvius* Synthem is the unconformity generated by the AD 79 eruption-related caldera collapse (Cioni et al., 1999). The AD 472 eruption deposits do not outcrop in the mapped area.

#### 3.3.4. Proto-Vesuvius Synthem

The deposits of the *Pompei* eruption that occurred in AD 79 (Sigurdsson et al., 1985) extensively outcrop in the Southwestern sector of Vesuvius, and under Medieval and Present-Vesuvius deposits. The deposits emitted during this eruption are found as a thick cover (10 s m in the more proximal sites), filling old valleys and hiding previous drainage. The lower limit of the *AD 79* Subsynthem is marked by a thick paleosoil found on top of the ash deposits of the *Avellino* eruption, and that, in some places, shows traces of cultivation (Figure 6(c)). Other eruptive episodes occurred in the time span between the *Avellino* and *Pompei* eruptions (Arnò et al., 1987). This is the case for the *Camaldoli della Torre* scoria cone (Di Renzo et al., 2007). In deep cuts of the *Cappella Bianchini* area, tephra related to the mild explosive eruptions named AP by Andronico and Cioni (2002) are also present. Due to the lack of pyroclastic covers in the Southwestern sector of Vesuvius (Arrighi et al., 2001), in large areas of the map the top of the AD 79 deposits, eroded and carved by a new drainage pattern, still represents the present-day morphology. On the map 'nn' refers to where these deposits have been reworked and involved in the present soil. The chemical composition of the *Pompei* pumices ranges from tephri-phonolite to phonolite (SM-1; TAS Chemical Classification).

#### 3.3.5. Prehistoric-Vesuvius Synthem

The *Avellino* (1995±10 BC; Sevink et al., 2011) Plinian eruption deposits extensively outcrop at the base of the reconstructed stratigraphic sequence. The boundary between the *Proto-Vesuvius* Synthem and the *Prehistoric-Vesuvius* Synthem is defined by the *Avellino* eruption-related caldera collapse (following Cioni et al., 1999; Sulpizio, Bonasia, et al., 2010; Sulpizio, Cioni, et al., 2010) or sector collapse (in the view of Milia, Raspini, & Torrente, 2007, 2008, 2009; Rolandi et al., 2004), and the tuff-ring morphology formed in the last phase of this eruption (Cioni et al., 1999).

The base of the *Avellino* eruptive sequence is not visible in the mapped area; nevertheless, it is commonly accepted to overlay a marked dark-brown paleosoil (Sulpizio, Bonasia, et al., 2010; Figure 6(d)). The presence at Vesuvius of such a paleosoil allows us to assume *Avellino* deposits as a Subsynthem.

### 3.4. Petrographic features

The chemical composition (SM-1; TAS Chemical Classification; Le Maitre, 2002) of each unit was determined on representative samples and the results are in agreement with the geochemical literature data, where present, for lavas (Belkin et al., 1993) and tephra (Arrighi et al., 2001; Cioni et al., 1995; Di Renzo et al., 2007; Rosi et al., 1993; Sulpizio et al., 2005). The main petrographic characteristics, mineral assemblages of phenocrysts and microlites, vesicularity, and rock color of all lithostratigraphic units, were reported on SM-1 (Main Petrographic Features).

### 3.5. Morphological and volcano-tectonic elements

A series of morphological elements (i.e. alignments of eruptive vents, drainage irregularities, fault steps, and shoreline morphology) were mapped in the field and used as kinematic indicators of structural patterns inside the mapped area. Eccentric vents opened during the Modern-Vesuvius period (1858, 1861, and 1794) are related to a N070° and a N040-050° fracture trend (SM-1; Volcano Tectonic Sketch Map, modified from Principe et al., 2010). Of particular interest are

the eleven vents aligned on the N070° oriented eruptive fissure opened on 8 December 1861, during the last eccentric eruption that occurred in this sector of the volcano. The 1861 lava flow emission was also followed by the opening of an impressive trend of N040-050°-oriented fractures propagating from the end of the N070° eruptive fracture into the sea, causing the destruction of the town of *Torre del Greco* (Palmieri, 1862). Medieval lava flow vents are instead aligned along tectonic elements of the N320° trend (SM-1; Volcano Tectonic Sketch Map).

## 4. Discussion and conclusions

The map presented here was produced using data collected from different sources (archeological, historical, and toponymy) and different methodologies (archaeometric and petrological), combined with detailed fieldwork. This *holistic* methodology enabled us to describe the territory at very high detail. Combining the lithostratigraphy with the UBSU, defined on the basis of the unconformity surfaces recognized within the volcanic successions, the 36 lithostratigraphic units have been grouped into just five Synthems.

This UBSU-based subdivision has been compared with the formations listed on the Santacroce and Sbrana (2003) map (Figure 5) resulting in good correspondence between these and our UBSU, with the exception of the *Santa Maria* and *Pollena* formations, which are not recognized in the surveyed area. This fact confirms the validity of UBSU approach and shows that mapping only real and objective units (e.g. lavas, pyroclastic flows, and discontinuities) allows the production of an effective map, despite the limited stratigraphic interval and covered area (about 30% of the Somma-Vesuvius volcanic area).

The chemical composition of Vesuvius lavas is quite homogeneous. Nevertheless, it is possible to distinguish in the field the different units based on their color, vesicularity, and abundance of phenocrysts. Indeed the mineral assemblages were often helpful in solving some problems of unit attribution, even when the lava was found to be affected by important variations of the absolute and relative phenocryst abundances, controlled by density contrast mechanisms during the ascent in the conduit and/or the emplacement (Principe, 1979).

Finally, this map includes a series of volcanic–tectonic lineaments that have never been reported in any of the previous cartographic works.

## Software

All the data collected during the fieldwork were imported, managed and processed using Esri ArcGIS™, compiling a geo-referenced database, based on vector objects organized in shape-files and using raster data as support.

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No potential conflict of interest was reported by the authors.

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