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ORIGINAL PAPER

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Chronology of Vesuvius' activity from A.D. 79 to 1631 based on archeomagnetism of lavas and historical sources

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Abstract The activity of Vesuvius between A.D. 79 and 1631 has been investigated by means of precise archaeomagnetic dating of primary volcanic deposits and taking into account the stratigraphy of lavas and tephra, historical written accounts, archaeological evidence related to the developing urbanisation, and radiocarbon ages. We found that the historical records are highly useful in constraining the timing of the main events, even if the data are often too scarce and imprecise for ascertaining the details of all phases of activity, especially their magnitude and emplacement of all the deposit types. In addition, some eruptions that took place in the 9th and 10th centuries appear to be unnoticed by historians. The archaeomagnetic study involved 26 sites of different lavas and 2 pyroclastic deposits. It shows that within the 15 centuries which elapsed between A.D. 79 and 1631, the effusive activity of Vesuvius clustered in the relatively short period of time between A.D. 787 and 1139 and was followed by a 5-century-long repose period. During this time Vesuvius prepared itself for the violent explosive eruption of 1631. The huge lavas shaping the morphology of the coast occurred largely through parasitic vents located outside the Mount Somma caldera. One of these parasitic vents is located at low elevation, very close to the densely inhabited town of Torre Annunziata. Among the various investigated lavas, a number of which were previously attributed to the 1631 eruption, none is actually younger than the 12th century. Therefore it is definitively concluded that the destructive 1631 event was exclusively explosive.

Keywords: Archaeomagnetism · Historical records · Vesuvius · A.D. 79–1631 · Lavas

Introduction

Vesuvius' activity from A.D. 79 to 1631 involved both late Roman activity, which occurred from A.D. 79 to 472, and medieval activity (Rolandi et al., 1998), which took place from A.D. 472 to 1631. This terminology is based on the rough temporal coincidence between the fall of the Roman Empire and the beginning of Middle Age (A.D. 476), which lasted until 1492. During this period, two small-scale plinian eruptions occurred, in A.D. 472 and 1631, respectively (Rosi & Santacroce, 1983; Rosi *et al.*, 1993). In fact, there is little information regarding the volcanic activity of the Vesuvius between the plinian eruption of A.D. 79 and the nearly continuous activity that occurred after the small-scale 1631 plinian eruption (Arnò et al., 1987). This continuous activity was made up of lava effusions (Fig. 1), together with strombolian, violent strombolian, and subplinian episodes (Arrighi et al., 2001). Little data exist in the literature on the time of deposition and distribution of the lavas discharged during the 15-century-long period from A.D. 79 to 1631. Moreover, determination of the stratigraphic position of the so-called "medieval" lavas within the overall stratigraphy of the Vesuvius has been hindered by urban development along the Vesuvius' coast. In spite of this unclear stratigraphic position, many authors, even in recent literature, attributed many of these large lavas that shape the coast morphology to the 1631 eruption (Di Girolamo, 1970; Burri & Di Girolamo, 1975; Rolandi & Russo, 1989; Rolandi et al., 1993; Lirer et al., 2001). This

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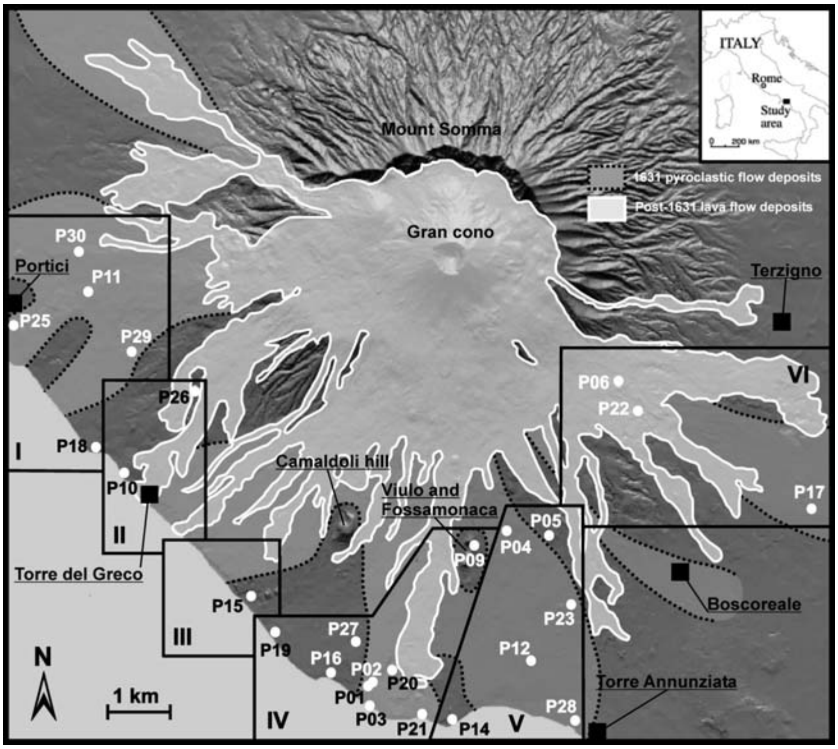


Fig. 1 Sampling map (topography from IGM-DTM data, courtesy of G.Vilardo, INGV-Vesuvian Observatory, Naples). Roman numerals: sampling sectors as discussed in the text. White dots: sampling sites (see Table 3 for the number of samples at each site). The distribution of lavas erupted between 1631and 1944 (simplified from the CNR, 1986, geological map), and the pyroclastic flow deposits of the 1631 eruption (from Rosi *et al*. 1993) are also shown

idea of large 1631 lavas originates from a relatively recent reconstruction of the 1631 eruption (Le Hon, 1865,1866), that has been uncritically adopted by almost all later authors. According to Rosi et al. (1993), the 1631 eruption did not produce any lava flow.

This matter has important implications for determining the degree of volcanic risk in the Vesuvius area, because the 1631 eruption has been taken as representative of the maximum expected hazards posed by the volcano in the mid-to-long term (Barberi et al., 1995). In order to assess the potential hazard of the Vesuvius, it is also necessary to ascertain whether eruptions were uniformly distributed in time or clustered in climaxes with very high eruption rates, alternating with periods of much less intense activity (Heiken, 1999). Such information exists for the relatively short period from 1631 to 1944 (e.g. Carta et al., 1981 and Arrighi et al., 2001), but is lacking for the much longer time interval from A.D. 79 to 1631 . The aim of this paper is to fill the gap mainly through critical reading of historical records and archaeomagnetic dating of the “medieval lavas”.

Historical and geochronological data

Historical sources

It is commonly believed that the information provided by the historical sources on the Vesuvius’ activity from A.D. 79 to 1631 is scarce and fragmentary. Such a belief arose in comparison with the large amount of documentation published after the 1631 eruption (Cerbai & Principe, 1996). However, the written sources available on the Vesuvius’ activity between A.D. 79 and 1631 provide useful records of the main events and at least some details on the types of volcanic activity.

All the post-1631 accounts, dealing with Vesuvius’ history or its “latest” eruption, contain more or less complete lists of the volcano’s past eruptions, as well as a number of references to printed sources that deal with the Vesuvius as far back as Greek and Roman times. Perhaps the most complete and reliable of these lists is presented in the milestone work “Bibliography of Vesuvius” by Furchheim (1897). An accurate critical collection of the written sources on Vesuvius’ activity from A.D. 79 to 1631 was given by Alfano (1924). Other authors have subsequently dealt with the chronology of the Vesuvius’ eruptions between A.D. 79 and 1631 (Preusse, 1931; Figliuolo & Marturano, 1998; Nazzaro, 1998, Gasparini & Musella, 1991) without substantial changes to Alfano’s conclusions. Recently, Stothers & Rampino (1983) considered not only written and associated archaeological sources on Vesuvius’, but also on all the volcanic eruptions that occurred throughout the Mediterranean area before A.D. 630. The investigated printed sources are rather different from those usually quoted by people working on Vesuvius and include not only Latin and Greek texts, but Byzantine, Syrian, and Armenian sources, as well.

It is important to note that all these studies have been performed based on the more common printed sources. Detailed work on manuscript and ecclesiastic documents found in archives and libraries is still required in order to

Table 1 The activity of Vesuvius between A.D. 79 and 1631 as inferred by historical sources. Citations refer to the printed sources. "Activity" refers reported weak, more or less continuous strombolian activity, with possible emission of intracaldera lava flows. See Principe (2003) for a detailed discussion and the original texts

Eruptions	**Activity**	***Described Phenomena***
	172	Violent strombolian activity[1]
AD 203		Explosive eruption, with a plinian fallout phase[2]
	222–235	More or less continuous strombolian activity[3]
	379–395	At least fumarolic activity[4]. A phase of lava effusion possibly happened[5]
AD 472		5–6 November: large explosive eruption, with a plinian fallout phase, dispersed to NE (ashes as far as Costantinopoli), darkening and heavy rains . Huge *nuée ardentes* and severe destruction are described all around Vesuvius'[6]. From this eruption starts the cult of San Gennaro as protector of Naples against Vesuvius'
	512	More or less continuous strombolian activity[7]
AD 536		Explosive eruption, darkening in Mesopotamia lasted all the winter of this year.[8]
AD 685		February-March: earthquakes, plinian column and related fallout[9]. A not completely reliable source gives an account of lavas entering the sea[10]
AD 787		Autumn-Winter: lava fountains and lava (or pyroclastic?) flows "six miles long" [11]
AD 968		Eruption with lavas into the sea[12]
AD 991		Earthquake and explosive eruption ("*...erupting flames and vomiting ashes ...*") [13]
AD 999		Sudden lava fountains and lava emission (*"...piceas atque sulphurea repente flammas erumpere..."*), fine ashes [14]
1006 or 1007		At least explosive eruption, with rumble, vigorous throwing of blocks (3 miles from the crater) and unbreathable gas emissions [15]
1037		27 January or February: Effusive eruption with lavas into the sea ("*...eructavit incendium, ita ut usque ad mare discurreret ...*") [16]
1139		From 29 May to 5 June: explosive eruption, with black lapilli fallout and reddish ashes ("*... pulverem ferruginei coloris et subrubei ...*"), falling during 30 days as far as Napoli, Capua, Salerno and Benevento[17]
	1150	Violent strombolian activity[18]
1306?		Unlikely parasitic eruption with lavas into the sea[19]
	1500?	Fumarolic activity and unlikely phreatic explosion[20]

[1] Claudio Galeno Pergameno, *De Medendi Methodo Libri XIII*, liber V, cap.12
[2] Dione Cassio Niceo, *Historiae Romanae*, liber LXXVI.
[3] Dione Cassio Niceo, *Historiae Romanae*, liber LXVI.
[4] San Paciano, *Paraenesis ad poenitentiam.*
[5] Ammiano Marcellino, *Indictione decima*.
[6] Marcellino (Conte), *Chronicon* ; Procopio from Cesarea, *De Bello Gotico*, liber II, cap IV ; Carlo Sigonio, *Historiarum de Occidentali Imperio Libri XX, liber XIV & XVI*; Flavio Magno Aurelio Cassiodoro, *Opera Omnia quae extant*, Liber IV Variarum, Epistola 50.
[7] Marcellino (Conte), *Chronicon.*
[8] Procopio from Cesarea, *De Bello Gotico,* liber II (cap IV), liber IV (cap XXXV); Giovanni from Efeso, *Ecclesiastical History* (other references are listed in Stothers and Rampino, 1983).
[9] Paolo Diacono, *Historia Longobardorum*, liber VI, cap. IX; Giorgio Agricola, *De re metallica. De natura eorum quae effluunt ex terra*, liber IV.
[10] Appendix to the holy legend of San Gennaro (in Alfano, 1924).
[11] Gregorio Monaco, manuscript in greek, University of Messina library.
[12] Damianus Petrus, *Opera Omnia, Opusculum XIX*.
[13] Pompeo Sarnelli, *Cronologia dei Vescovi et Arcivescovi Sipontini*, 1730, pg.112.
[14] Damianus Petrus, *Opera Omnia, Opusculum XIX* ; Ubaldo Monaco, *Chronicum Ducum Neapolis*, in *Raccolta di varie croniche, diarii ecc, appartenenti al Regno di Napoli*, Napoli, Perger, 1781.
[15] Ridolfo Glaber, *Historia Francorum*.
[16] Anonymus Cassinensis, *Chronicon*; Anonymus Cavensis, *Chronicon*; Romoaldo Salernitano, *Chronicon*.
[17] Anonymus Cassinensis, *Chronicon*; Anonymus Cavensis, *Chronicon*; Falcone Beneventano, *Chronicon*; Romualdo Salernitano *Chronicon.*
[18] El Eldrisi, *L'italia descritta nel libro del Re Ruggero,* quoted in Baratta, *Il Vesuvio e le sue eruzioni*, Roma, Dante Alighieri, 1897.
[19] Pighius Stephanus Vinandus, *Hercules Prodicius seu Principiis juventutis vita et peregrinatio*, Antuerpiae, Cristoforo Plautinus, 1587, pg 466; Andrea Schottus, *Itinerarium Italiae*, Amstelodami, Jansson, 1655, pg 526 (into the Italian edition, dated 1669, the name of the Author became Francesco Scoto).
[20] Leone Ambrosio, *De Nola*, Venetiis, 1514, liber I, cap.I*: De Agro Nolano, deque montibus Vesuvio et Abella*.

produce a fully reliable picture of the activity of the volcano during this long historical period.

Table 1 (Principe, 2003) provides a summary of Vesuvius' activity between A.D. 79 and 1631 deduced from critical reading of the original sources proposed by previous authors. The number of confirmed eruptions and periods of activity is much smaller than that reported in the post-1631 literature on the Vesuvius, as is the number of the truly primary sources, meaning contemporary (or nearly so) to the described events. Such a misleadingly large number of sources and eruptions is due, as already noted by Stothers & Rampino (1983), to the proliferation of vicarious "second-hand" citations.

This common practice gave rise, for instance, to various reports of the "great eruption of A.D. 512", which was hypothesized by Alfano (1924) on the basis of a letter from Magno Aurelio Cassiodoro to King Teodorico of Italy and uncritically accepted in all the subsequent literature. However, a careful reading of Cassiodoro's letter reveals that it was simply a request for fiscal exemptions for a population still suffering the effects of a previous devastating eruption in A.D. 472.

No lavas outside the *Mount Somma* caldera are recorded by historical sources during the first centuries after the A.D. 79 eruption. On the contrary, Vesuvius' activity only involved a series of explosive events of variable violence until at least A.D. 685. The A.D. 472 eruption was by far the most important of these events. Plinian fallout and huge *nuées ardentes* can be clearly identified in the historical accounts of this eruption (Rosi & Santacroce, 1983).

An explosive eruption must have occurred around A.D. 536. This has been indirectly documented in the writings of Procopio from Cesarea, Giovanni from Efeso, and other authors in the western Mediterranean, who reported the darkening of the sky over Constantinople for many months, accompanied by an unusually harsh winter in Mesopotamia (Stothers & Rampino, 1983).

The eruption of A.D. 685 surely had a strong explosive component as well. Analysis of the historical sources does not clarify whether this eruption also involved lavas as popular tradition implies the lava underlying the old *Palazzo Baronale* of *Torre del Greco* originates from this event, and does not crop out anymore at present (Principe, 2003). A number of the subsequent eruptions (e.g. A.D. 787, 968, 999, and 1037) had large effusive components. The A.D. 991 event was apparently exclusively explosive, as well as those in 1006–7 and 1139 for which no effusive episodes are described. However, the last two eruptions were documented by authors living outside the Vesuvius' area. For this reason, in the absence of great damages to inhabited areas, the emission of lavas during these eruptions remains possible (Principe, 2003).

Although the summit of the volcano is described by Dione Cassio as a rounded depression "like an amphitheatre", without mention of any internal cone (Alfano, 1924) during the third century A.D., historical data suggest the gradual building of the *Gran cono* inside the *Mount Somma* caldera, starting from ~A.D. 172, due to intracaldera lava emissions and strombolian activity (Table 1). After the 1139 eruption, the *Gran cono* was certainly present inside the *Mount Somma* caldera, with an altitude lower than that of *Mount Somma,* and a large crater "resulting from the last eruption" (Boccaccio, 1353, in Alfano, 1924). This is the same general morphology of the volcano after the main explosive eruptions of the 1631–1944 period (Nazzaro, 1998; Arrighi *et al.*, 2001).

After the 1139 eruption, the next description of the Vesuvius in an active state, characterised by "emission of incandescent materials from the main crater" (strombolian activity), seems to be presented in the text of the Arab writer El Eldrisi, dated 1150 and quoted by Alfano (1924), who refers to Baratta (1897). The numerous sources subsequent to 1150 listed by Alfano (1924) only report that a mountain near Naples had occasionally erupted in the past, without providing further observations on eruptive activities coeval to the time of writing. There are, instead, some references to flames in the crater, visible especially at night, and probably attributable to the ignition of fumarole gases, rather than strombolian activity from the main crater.

A presumed eruption in 1306, with lava reaching the sea, is referred to by Leandro Alberti (1568), and Pighius (1587) as well as by Schottus (1655), who copied from Pighius. This eruption was also confirmed by Masculo (1633) on the basis of these sources. However, Alfano (1924) denied the existence of such an eruption, demonstrating on the basis of historical arguments that the 1306 date is a typographical error in the text of Alberti (1568) who intended to discuss the 1036 event (Principe, 2003).

The occurrence of at least one flank eruption at the Vesuvius during the period between A.D. 79 and 1631 is possibly recorded by a fresco, which once adorned the vestibule of the Basilica of *San Gennaro Extra Moenia* in Naples. The work has been attributed to the 15th century school of Andrea Da Salerno. Reprinted in Alfano (1924), it depicts the Vesuvius as observed from Naples, with two volcanic plumes, one issuing from the main crater (the elevation of which is lower than the peak of *Mount Somma*) while the other emerges from one or more vents situated on the southern flank of the *Gran cono*. The date of the eruption to which the fresco refers to is unknown. In other words, this fresco might simply be either a generic view of the erupting Vesuvius, or a copy of a previous work.

Historical accounts describe a number of parasitic cones, which by age and position may represent the vents of some lavas emitted between A.D. 79 and 1631. These include the *Viulo* and *Fossamonaca* cones, the morphology of which is still well visible today, the two cones at *Tironi* and the three cones at *I Monticelli* ("little hills"). Sorrentino (1734) described two scoria cones and associated lavas from the site known as "*i Tironi*", north of *Torre del Greco*, as well as three small scoria cones, called "*I Monticelli*", aligned in a roughly east-to-west direction behind the *Camaldoli* hill. All these cones are attributed to medieval eruptions by Sorrentino (1734). The cones of *I Monticelli* have been buried by the products of subsequent eruptions and only a few morphological traces remain at present, whereas the *Tironi* hills were already almost completely quarried by Sorrentino's time.

In 1514 the Venetian Leone Ambrosio described an event that took place in the year 1500. This could be a modest phreatic eruption. Apart from this source, however, no trace remains of the 1500 event in the various manuscripts, annals, and chronicles of the time. For this reason, its occurrence had already been disputed in the 17th century (Braccini, 1632).

Summing up, on the basis of available historical data, it seems probable that from the early 12th century to 1631, the volcano was in a state of repose, apart perhaps from more or less continuous fumarolic activity. Since the Vesuvius was practically inactive for such a long time, it caught most of the inhabitants unaware at the moment of its awakening on December 16th, 1631 (Rosi *et al.*, 1993).

Tephra chronology

The main stratigraphical markers of the entire post-A.D. 79 succession are the A.D. 472 deposits (Rosi & San-

Table 2 Available ^{14}C data for charcoal and paleosols (*) of the post A.D. 79 –1631 period. The most probable (bold type) eruption dates were defined in this work on the basis of calibrated age intervals, stratigraphic position, and physical characteristics, as given in the literature, and the historical data listed in Table 1. (**) Calibrated age given in Andronico et al. (1995)

1	2	3	4	5	6	7
Sample	**Locality**	**Age b.p.**	**Calibrated age**	**Literature attribution**	**Reference**	***Most probable eruptions***
R 715 / L 371E		1815±40	A.D. 135–320	Santa Maria	Andronico et al. (1995)	**A.D. 203**
PFSV 86A	LAGNO AMENDOLARE	1750±60		AD 472	Arnò et al. (1987)	
R939*	ARCIPRETE	1630±50		AD 472	Arnò et al. (1987)	
Rome 643		1605±35	A.D. 415–535	AD 472	Andronico et al. (1995)	**A.D. 472**
PFSV 83	LAGNO di POLLENA	1600±60		AD 472	Arnò et al. (1987)	
	TERZIGNO	1590±190	A.D. 59–861	AD 472	Rolandi et al. (1998)	**A.D. 472**
PFSV 86A	LAGNO AMENDOLARE	1580±60		AD 472	Arnò et al. (1987)	
PFSV 306*	CASE TRAPOLINO	1550±50		AD 512	Arnò et al. (1987)	**A.D. 536**
WW - 595	TERZIGNO	1440±60	A.D. 537–692	II eruption	Rolandi et al. (1998)	**A.D. 685**
Rome 644		1355±55	A.D. 645–760	PM5	Andronico et al. (1995)	**A.D. 685**
WW-6327	OTTAVIANO	1290±40	A.D. 661–863	II eruption	Rolandi et al. (1998)	**A.D. 685**
PFSV 101	LAGNO di POLLENA	1280±50		AD 787	Arnò et al. (1987)	
Rome 653*		1265±55	A.D. 685–885	PM5	Andronico et al. (1995)	**A.D. 685**
Rome 641		1230±55	A.D. 690–935	PM6	Andronico et al. (1995)	**A.D. 787**
Rome 652*		1166±55	A.D. 780–980	PM6	Andronico et al. (1995)	**A.D. 787**
WW-596	TERZIGNO	1140±60	A.D. 775–1017	III eruption	Rolandi et al. (1998)	787/**991**/999/1006–7
PFSV 86B	LAGNO AMENDOLARE	1050±85		AD 787	Arnò et al. (1987)	
	BOSCO REALE	950±90	A.D. 895–1279	IV eruption	Rolandi et al. (1998)	991/999/1006–7/1037/**1139**
WW - 597	TERZIGNO	950±50	1003–1279	IV eruption	Rolandi et al. (1998)	1006–7/1037/**1139**
PFSV 308 *	W of OTTAVIANO	470±55		1631	Arnò et al. (1987)	
PFSV 315	between POLLENA and CERCOLA	330±55	1485–1650**	1631	Arnò et al. (1987)	**1631**

tacroce, 1983, Mastrolorenzo *et al.,* 2002) and the 1631 deposits (Rosi *et al.*, 1993), both resulting from small-scale plinian events. On this basis, the tephra succession from A.D. 79 to 1631 can be divided into two parts. Andronico and coworkers (Andronico *et al*. 1995, 1996a,1996b) called the pyroclastic sequence prior to the A.D. 472 eruption the *" Santa Maria cycle"*, which includes the tephra of the A.D. 203 eruption, as already recognised by Johnston-Lavis (1884) and Arnò *et al.* (1987). Andronico *et al*. (1995, 1996a, 1996b) identified six main explosive-component eruptions subsequent to A.D. 472; their tephra deposits are interlayered with seven minor tephra layers. The first main tephra layer was attributed by Andronico *et al*. (1995, 1996a, 1996b) to the A.D. 512 eruption, however, this eruption has been shown to be an unlikely source (see discussion above). Therefore, we propose to attribute this first main tephra layer, starting the post-A.D. 472 succession, to the explosive eruption of A.D. 536.

In contrast to Andronico *et al*. (1995, 1996a, 1996b), Rolandi *et al.* (1998) identified only four main explosive eruptions in the post-A.D.-472 stratigraphy, and also attributed different ages to the layers. The last of these eruptions is represented by a lapilli fallout deposit which was attributed to the 1139 eruption by Rolandi *et al.* (1998). The description and stratigraphic position of this deposit correspond to the "ochraceous" lapilli fallout described by Principe *et al.* (1987), which is encountered in pockets above the medieval-age lavas in an area southeast of the Vesuvius, and beneath the 1631 pyroclastic flow deposits.

With the aim of identifying possible correlations between historically-defined eruption ages and the different tephra age attributions proposed by various authors, Table 2 reports all the ^{14}C ages available in the literature for the period from A.D. 79 to 1631. The last column in Table 2 reports the historically substantiated eruptions or eruptive periods in the age interval obtained by calibrating the ^{14}C ages. Of the eruptions deemed "possible" through study of the historical sources, the most probable ones (also based on stratigraphic position and physical characteristics) are presented. A newly determined radiocarbon age (see Appendix 1), based on charcoal fragments found under a lapilli fallout deposit of the A.D. 79–1631 period, confirms the occurrence of an explosive episode around A.D. 685.

Comparing Tables 1 and 2, it is evident that, despite the rather low precision of the ^{14}C age determinations, a good agreement exists between the ^{14}C ages and the historically documented eruption ages for the events with an explosive component, a fact that underscores the importance of historical data.

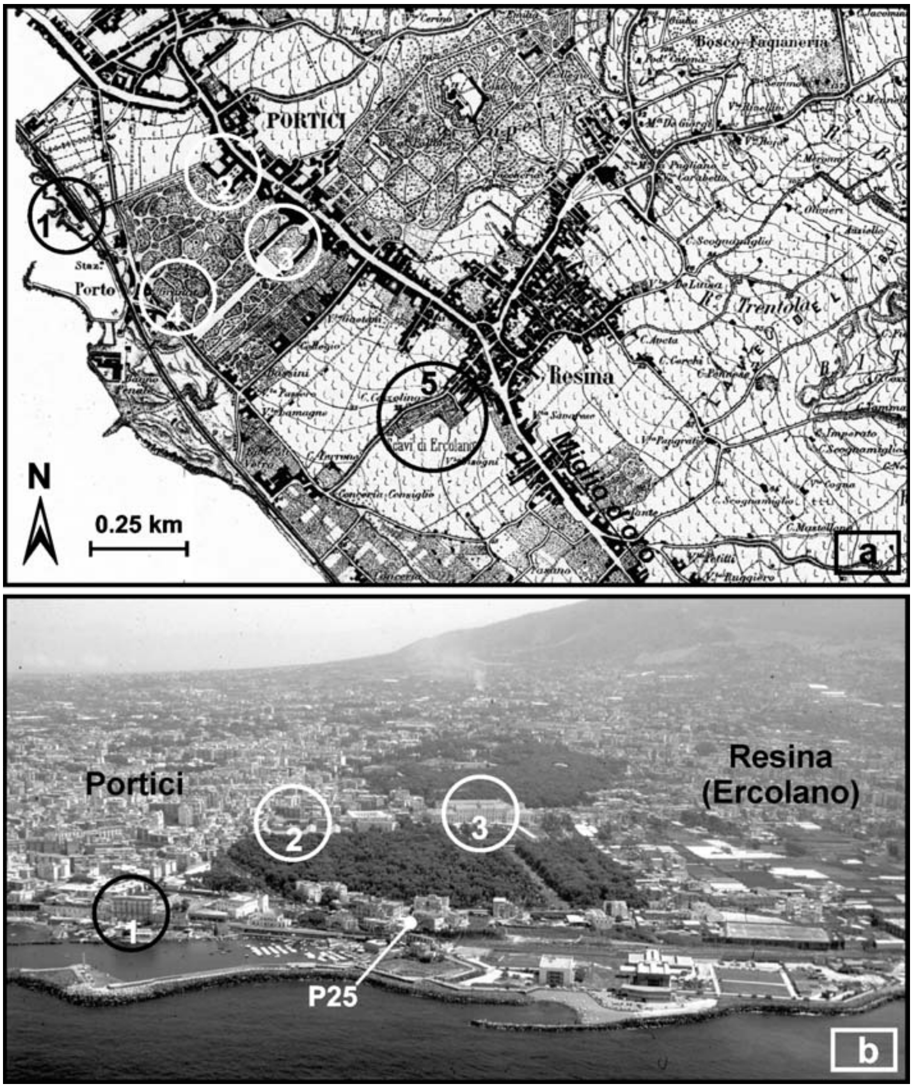


Fig. 2 a-b *Sector I.* **(a)** The *Granatello* headland on the Topographic map of Mount Vesuvius compiled and drawn in six sheets at the scale of 1:10.000 by students of the Military Topography Institute of Florence (1875–86). The small promontory of *Villa d'Elboeuf* (*1*) is formed by the A.D. 79 pyroclastic flow and debris flow deposits. A branch of the nuée ardentes of the 1631 eruption (Rosi *et al*., 1993) extended south of this, leaving *Palazzo Mascabruno* (*2*) untouched, but destroyng the ancient *Granatello* gardens (*4*) and partially covering the pre-1631 lava that gave rise to the main coastal morphology. Construction of the *Royal Palace* of *Portici* (*3*) and surrounding gardens began in 1738. (*5*) The Herculaneum excavations. **(b)** Aerial view of the current *Granatello* and *Royal Palace* areas; *P25* refers to the sampling site of the *Granatello* lava

Chronostratigraphy of lavas

The problem of the absolute age and stratigraphic position of lavas from A.D. 79 to 1631 was raised for the first time by Johnston-Lavis (1884,1891b) who believed that the lava effusions reported in historical sources for the period from A.D. 79 to 1631 were much less frequent than the explosive events. Moreover, he maintained that the lavas were confined inside the *Mount Somma* caldera surrounding the *Gran cono* (Fig. 1), which had not yet been filled. This convinction was due to the fact that, following

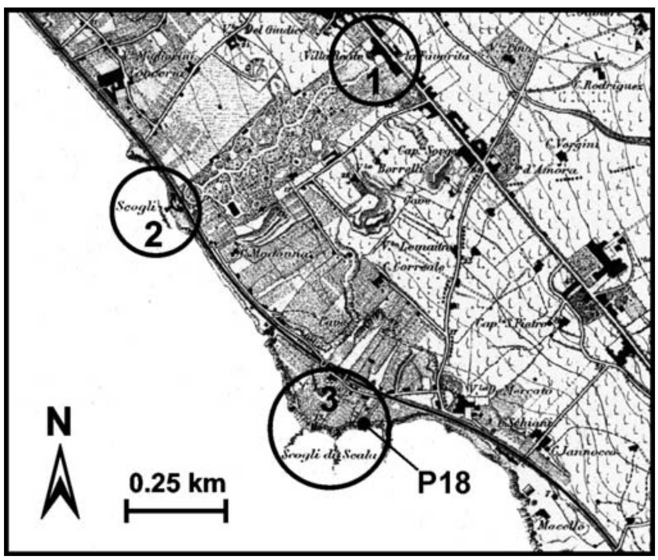


Fig. 3 *Sector I*, immediately south of the *Granatello* area. (*1*) The *La Favorita* country house and (*2*) its gardens that reach the sea at *Scogli della Favorita*. (***3***) A few hundred meters south, a huge lava crops out extensively on the headland of *Scogli della Scala* (now *Punta Quattro Venti*), sampled at *P18*. Topographic base as in Figure 2

Fig. 4 a-b *Sector II.* (**a**) Aerial photograph of *Torre del Greco* as it appears today. (**b**) Map of *Torre del Greco* drawn by G. Morghen after the 1794 lava destroyed four-fifths of the then existing town. (*1*) The lava headland of *Calastro* (sampling site *P10*). (*2*) The Monastery of the Minor Franciscan Order and the annexed church of *Madonna delle Grazie*. The Monastery was spared from the 1631 pyroclastic flow (Rosi *et al.*, 1993). (*3*) *Palazzo Brancaccio* and its gardens. (*4*) The *Torre del Greco* Town Hall housed in the one-time *Palazzo Baronale*. All these buildings lie on a morphological high spared by 1631 *nuée ardentes* and then by 1794 lava, that corresponds to an old lava, unfortunately not cropping out anymore, attributed by historical records to the A.D. 685 eruption. (*5*) The area affected by the pyroclastic flow deposits of the 1631 eruption ("*mare seccato*", which is Italian for "dried sea") and by the lava of the 1794 eruption afterwards

Le Hon (1865,1866), Johnston-Lavis attributed all the lavas cropping out along the coast to the 1631 eruption.

The belief that all the lavas along the coast belong to the 1631 eruption has been recently supported by the work of Vittozzi & Gasparini (1965), who performed absolute age determinations via the radioactive ^{226}Ra-^{238}U disequilibrium method on the lava of *Granatello* and on the three lavas of the *Villa Inglese* (see Figures 2, 3, 4,5, 6,7 for the locations). On the basis of these data, Burri & Di Girolamo (1975) ascribed the *Granatello* lava to 1631, and the *Villa Inglese* lavas to 1631, 1480 and 1139. Other lavas cropping out along the coast between *Portici* and *Torre Annunziata* (*Scogli della Scala*, *Calastro*, *Ponte di Riveccio*, *Torre Bassano*) have been attributed by Di Girolamo (1970) to the 1631 eruption, always on the basis of the data of Vittozzi & Gasparini (1965), without any stratigraphic support. At least for *Torre Bassano,* historical data do not support such attributions, since a watchtower was built between 1559 and 1567 over this lava (Principe, 2003, Fig. 5). Recently, Rolandi & Russo (1989) ascribed both the lava under *Masseria Donna Chiara* and the lava cropping out along the coast near *Torre Annunziata* between *Cantiere la Perla* and *Palazzo Monteleone* to the 1631 eruption.

Finally, although the emission of lavas during the 1631 eruption can be ruled out, based on volcanological evidence (Principe *et al.*, 2003) and historical documents (Rosi *et al.*, 1993), most of the lavas cropping out along

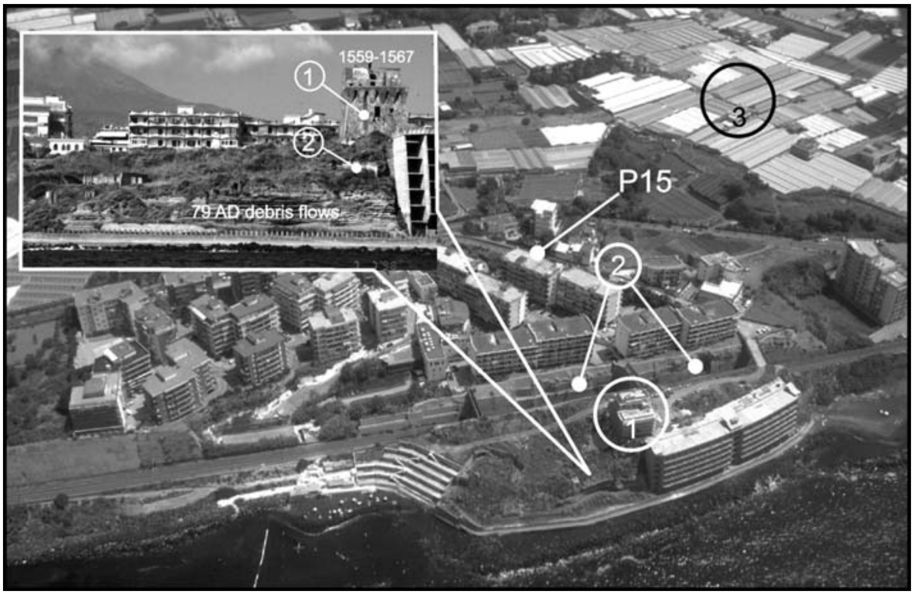


Fig. 5 *Sector III*. The *Torre Bassano* headland exhibits the morphology and stratigraphy typical of all the sector of the coastline from *Portici* to *Torre Annunziata*. In this site, the tower (*1*) was built between 1559 and 1567 on the promontory generated by a medieval lava that flowed into the sea. This lava crops out under the tower (*2*), along the road inland from the tower (*P15*), and along the railway (*2*), and covers a stratigraphic succession (see inset) including the A.D. 79 eruption-related debris flow and previous pyroclastic deposits. The pyroclastic flow deposits of the 1631 eruption (*3*) extend on both sides of the mophological high induced by the lava and are now covered by numerous greenhouses and vineyards

the coast of the Vesuvius are still attributed to the 1631 eruption by many authors. We intend to definitively clarify this subject with our archaeomagnetic data.

Synthesis of available chronological data

On the basis of the available chronological information, at least 11 main eruptions took place at Vesuvius' between A.D. 79 and 1631. The most important of these events is the small-scale plinian eruption of A.D. 472. An effusive component is described by historical documents for at least four of these eleven eruptions (Table 1), with lava fronts spreading outside the *Mount Somma* caldera rim, and reaching the sea in A.D. 787, 968, 999, and 1037. According to historical, radiocarbon, and stratigraphic data, significant explosive episodes took place at least in A.D. 203, 472, 536, 685, 787, 991, 999, 1006/7, and 1139, resulting in a sequence of lapilli fallout deposits. Within this sequence, a number of minor tephra deposits give evidence of additional minor explosive episodes not reported by printed chronicles and still not dated by radiocarbon or other methods.

Archaeomagnetic sampling and measurements

This archaeomagnetic study of the Vesuvius is based on the precise method developed at Saint Maur Laboratories from the Institut de Physique du Globe de Paris (IPGP), France (Thellier, 1981; Tanguy *et al*., 1985, 1999, 2003). Sampling and measurement procedures used in this work refer to the so-called "big sample plaster method" of Thellier (1981) for archaeological purposes and routinely applied at the Saint Maur Laboratories. Application of this methodology for dating of young volcanic products, its advantages, and limitations are given by Tanguy *et al.* (2003).

The sampling method involves the collection of several big samples, each weighing 0.5–1 kg, distributed over some tens of meters. Each block is first detached with a hammer and then replaced in its original position. Plaster of appropriate fluidity is poured on the block, to support a plate carrying a spherical spirit level, thus making a horizontal surface 6–7 cm in diameter on which the sun shadow is marked for calculation of the geographical north. In the laboratory, the samples are replastered in square moulds 12 cm in size. Measurements are performed by means of a large rotating induction magnetometer and an AF demagnetization device for big samples (Le Goff, 1975).

The advantages of this method with respect to traditional core-drilling are the extremely precise orientation of the sample in the field and the possibility of obtaining high-precision data on lavas, welded scoriae, and high-temperature-emplaced, non-welded, pyroclastic deposits (Hoblitt *et al*., 1985; Genevey *et al*., 2002). Another fundamental advantage is that the plaster method avoids the effect of any parasitic magnetization acquired during the drilling process (Lauer, 1978; Audunsson & Levi, 1989).

On the basis of their stratigraphic positions and additional field data (e.g., age of the oldest buildings sitting on the lavas, changes of locality names after the main

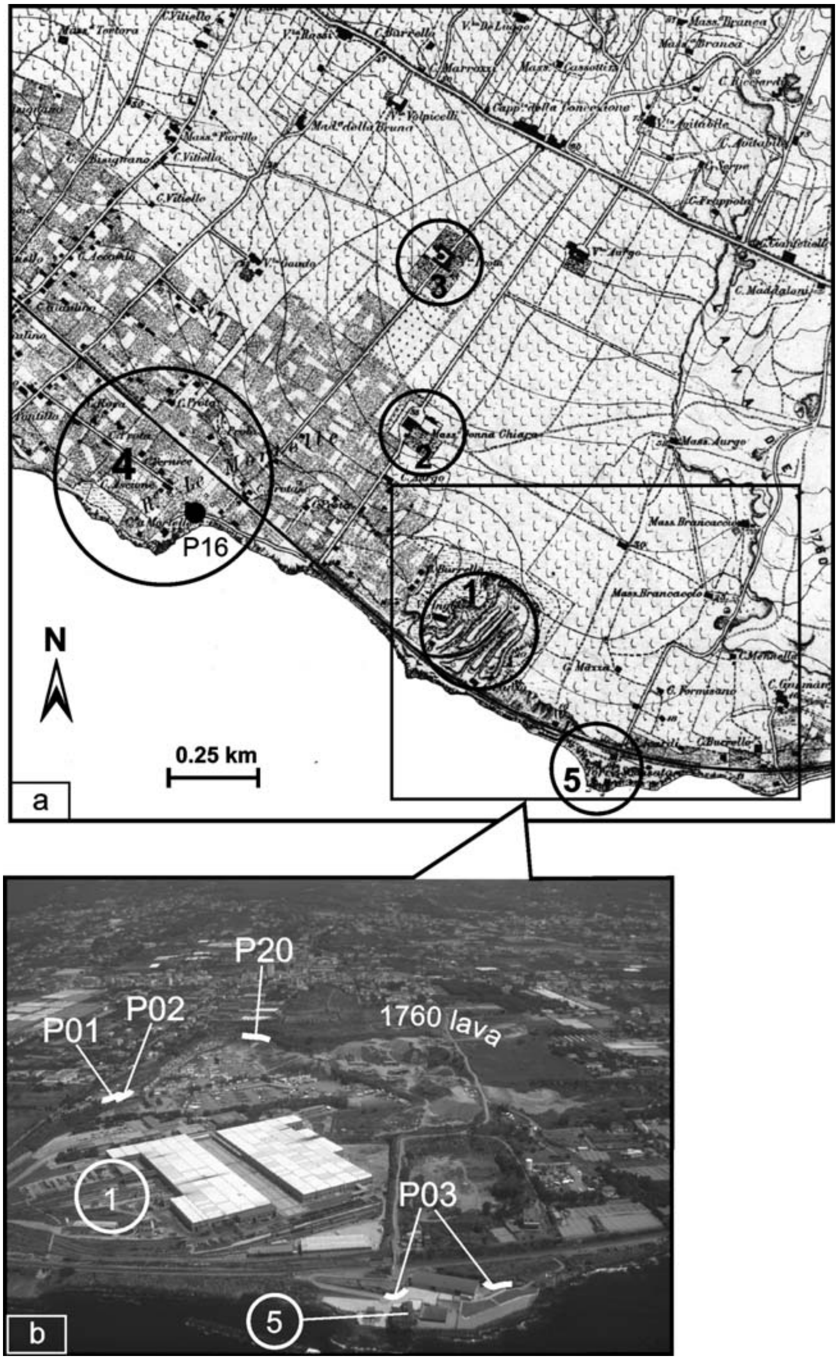


Fig. 6 a-b *Sector IV*. **(a)** Topography of the *Villa Inglese-Le Mortelle* area (topographic base as in Fig. 2) showing the smooth morphology induced by the medieval lava flows covered by subsequent tephra deposits, contrasting with the rough morphology of the of the *1760 lava* surface cropping out in the eastern sector of this figure. (*1*) The old lava quarry of *Villa Inglese*. (*2*) *Masseria Donna Chiara*. (*3*) *Villa Prota*. (*4*) *Le Mortelle*. (*5*) *Torre Scassata*. The quarry has been progressively enlarged and today has reached the lava emitted in 1760. **(b)** Present aerial view of the *Villa Inglese* quarry. Numbers refer to the sampling sites of the pre-1631 lavas flows extensively cropping out both inside the quarried area and on the coast beneath and inland of the Torre Scassata tower

eruptions, etc. ...) (see Appendix 2), a total of 26 sites have been selected and sampled for archaeomagnetic measurements, giving a total of over 400 analysed samples, covering nearly all the lava outcrops attributable to the A.D. 79–1631 period. Fig. 1 shows the location of the sites which are grouped in geographical sectors, whereas Table 3 gives the geographical coordinates and a description of each site. Some sites are located in correspondence to newly built road segments or work yards for the construction of new buildings, which have brought to light portions of the lavas covered by the 1631 *nuées ardentes*. Some of the sampled lavas cropping out along the coast do not appear on the 1:25,000-scale CNR (1986) geological map.

All the lavas of this period are petrographically very similar (Joron *et al*., 1987; Belkin *et al.,* 1998; Raia *et al*., 2000; Paiotti, 2000) (Table 4). The main phenocrysts are two clinopyroxenes (diopside and augite), which are both present in all lavas, and leucite. Olivine and a dark mica (phlogopite) are the other most important phases. The groundmass is composed of plagioclase (An_{80}), leucite, clinopyroxenes, and oxides. Modal analyses (Table 5) show the fact that correlations between different sites cannot be performed on the basis of petrographical

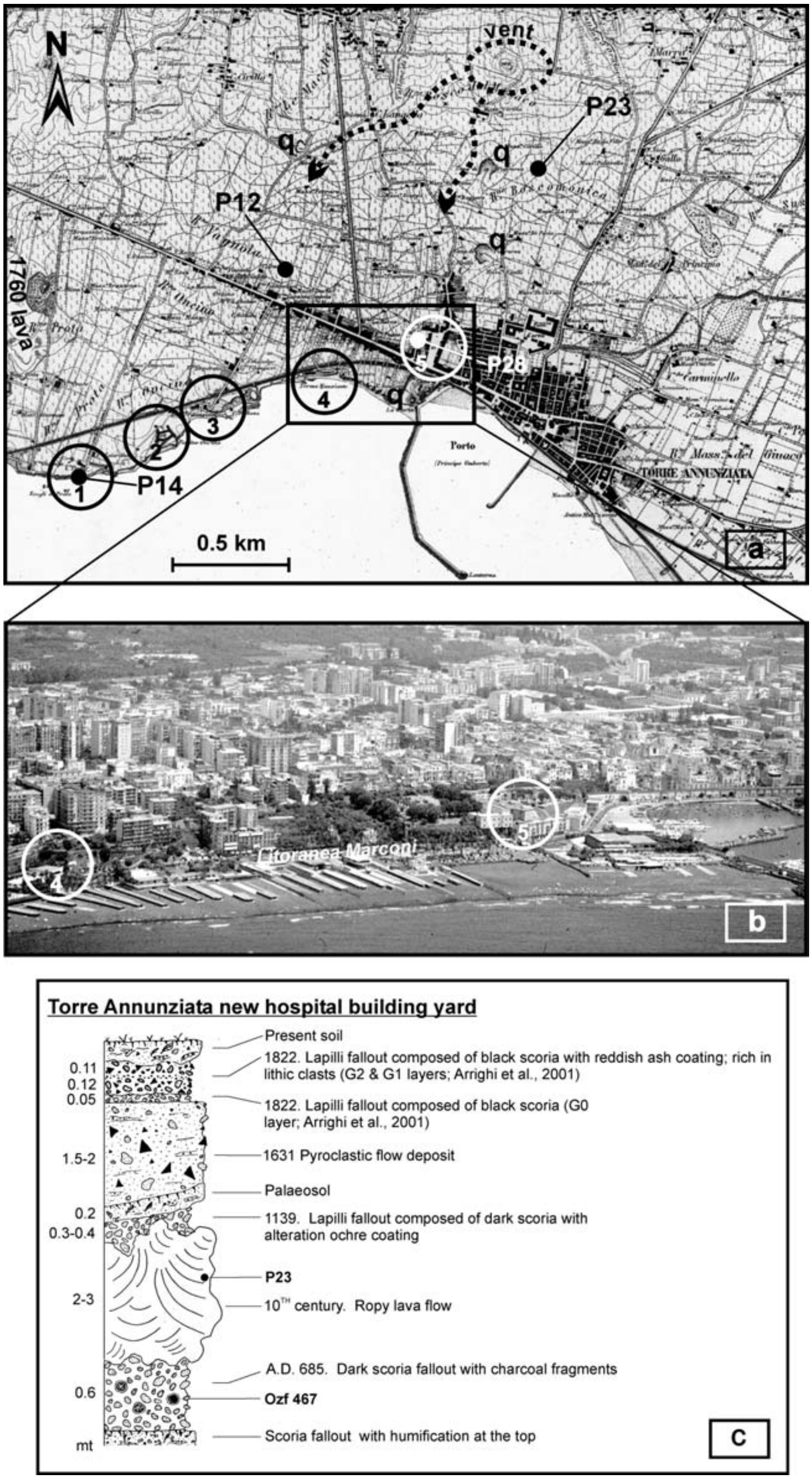


Fig. 7 a-c *Sector V.* **(a)** The shore of *Torre Annunziata* (topographic base as in Fig. 3). (*1*) *Scogli di Prota*. (*2*) The old "*Forte dell'Oncino*" fortress. (*3*) *Villa Filangeri*. (*4*) *Terme Nunziante-Lido Azzurro*. (*5*) *Palazzo Monteleone*. Originating from a vent near *Bosco del Monaco* (label 'vent' in this sketch map), a huge lava reached the sea forming the *La Storta* promontory, where the pier of *Torre Annunziata* is nested. Note the ancient lava quarries (*q*) marking the lava position between the vent and the sea. **(b)** Present aerial view of the *Torre Annunziata* waterfront. Some deposits attributed to the A.D. 79 and 472 eruptions are exposed under the aforementioned lava in the scarp along the *Litoranea Marconi* road, from *Palazzo Monteleone* (*5*) to *Lido Azzurro* (*Cantiere La Perla*) (*4*). **(c)** Stratigraphic section of the excavations for the new *Torre Annunziata* Hospital at *Rione Boscomonica* (*P23* in map **a**). Ozf 467 refers to a sample of charcoal, dated by means of radiocarbon method (see Appendix 1). Its calibrated age is 639–687 A.D

composition. In fact, samples coming from the same lava, as in the case of P01 and P20 sampling sites, may differ in mineral abundance (Lc and Cpx) and vesicularity, as already found for the similar lavas of the 1631–1944 Vesuvius activity (Principe, 1979).

For each site, an average of 12 archaeomagnetic analyses were performed on samples originating from different portions of the selected lava. The obtained mean value of the semi-angles of the 95% confidence cone of the average paleodirections (α_{95}) resulted in 1.2, with a range from 0.6 to 1.8 (Table 6).

Table 3 Details of the archaeomagnetic sampling sites. Geographical sectors are defined in Fig. 1

Site	*Coordinates*	*Sector*	*Samples*	*Sample Type*	*Locality*
P01	40°45’ 20” N 14°24’ 34” E	IV	10 (21–30)	Lava flow	Villa Inglese, near Torre Annunziata, upper lava on the W corner of the quarry
P02	40°45’ 21” N 14°24’ 34” E	IV	10 (11–20)	Lava flow	Villa Inglese, near Torre Annunziata, lower lava on the W corner of the quarry
P03	40°45’ 05” N 14°24’ 51” E	IV	15 (31–45)	Lava flow	Torre Scassata, along the coast, near Torre Annunziata
P04	40°46’ 23” N 14°25’ 57” E	V	16 (46–54, 106–107, 301–305)	Lava flow	New road towards W from the cemetery of Boscotrecase (900m from the crossing)
P05	40°46’ 20” N 14°26’ 18” E	V	7 (55–60, 62–63)	Lava flow	New road towards W from the cemetery of Boscotrecase (200m from the crossing)
P06	40°48’ 24” N 14°27’ 37” E	VI	9 (64 –72)	Lava flow	Terrioni quarry, W of Terzigno
P09	40°46’ 44” N 14°25’ 48” E	IV	10 (108, 110–111, 113–114, 195–199)	Scoria cone; juvenile scoriae	Fossa Monaca, NW of Torre Annunziata
P10	40°47’ 21” N 14°21’ 27” E	II	17 (115–131)	Lava flow	Calastro, Torre del Greco
P11	40°49’ 05” N 14°21’ 25” E	I	18 (132–142, 247–253)	Lava flow	NA-SA highway, Ercolano gate (Napoli direction)
P12	40°45’ 39” N 14°26’ 12” E	V	9 (143–151)	Lava flow	Torre Annunziata soccer field
P14	40°45’ 07” N 14°25’ 38” E	V	11 (154–164)	Lava flow	Villa Balke—Club La Vela (Scogli di Prota), along the coast, near Torre Annunziata
P15	40°46’ 13” N 14°22’ 59” E	III	15 (165–179)	Lava flow	Torre Bassano, along the coast road, back from the ancient tower
P16	40°45’ 30” N 14°24’ 08” E	IV	15 (180–194)	Lava flow	S.Vincenzo Postiglione, along the coast, near Torre Annunziata
P17	40°46’ 42” N 14°29’57” E	VI	15 (200–209, 334–338)	Lava flow	Passanti, near Terzigno
P18	40°47’ 34” N 14°21’ 14” E	I	17 (210–226)	Lava flow	Scogli della Scala, 4 Venti hotel beach
P19	40°45’ 44” N 14°23’37” E	IV	14 (227–239)	Lava flow	Lido Incantesimo, near Torre Annunziata
P20	40°45’ 20” N 14°24’ 34” E	IV	7 (240–246)	Lava flow	Villa Inglese, near Torre Annunziata, uppermost lava on the E corner of the quarry
P21	40°45’ 08” N 14°25’ 10” E	IV	18 (254–271)	Lava flow	Masseria Galassi, along the coast, near Torre Annunziata
P22	40°48’ 06” N 14°27’ 47” E	VI	12 (306–317)	Lava flow	Pozzelle, uppermost quarry, near Terzigno
P23	40°46’ 00” N 14°27’ 07” E	V	14 (320–333)	Lava flow	Masseria Bosco del Monaco, N of Torre Annunziata
P25	40°48’ 29” N 14°20’ 12” E	I	8 (339–346)	Lava flow	Granatello, Portici
P26	40°48’ 00” N 14°22’ 55” E	II	10 (347–356)	Lava flow	Vesuvius’ Café, San Sebastiano street, N of Torre del Greco
P27	40°45’ 30” N 14°24’ 17” E	IV	12 (357–368)	Lava flow	Masseria Donna Chiara, near Santa Maria La Bruna
P28	40°45’ 24” N 14°26’ 39” E	V	13 (369–381)	Lava flow	Torre Annunziata harbour, under Palazzo Monteleone
P29	40°48’ 27” N 14°21’ 42” E	I	12 (382–393)	Lava flow	Cupa dei Monti, N of Ercolano
P30	40°49’ 13” N 14°21’ 07” E	I	17 (395–406)	Lava flow	NA-SA highway, Portici -Bellavista gate
79	40°48’ 21” N 14°20’ 59” E		17(JCT, 1–17)	Unwelded pyroclastic flow; single juvenile clast	Ercolano ancient city, inside the Archaeological excavation
472	40°51’ 24”N 14°23’ 18”E		13(P08, 88–105)	Unwelded pyroclastic flow; single juvenile clasts	Pollena quarry

Results and errors

Fig. 8(a, b) displays a plot of the archaeomagnetic data obtained in this work in relation to the curve of secular geomagnetic variation proposed by Tanguy *et al*. (1999) for Mount Etna (Sicily), and Bucur (1994) for France, both reduced to the latitude and longitude of the Vesuvius (40°48’N, 14°25’E). With the purpose of checking the applicability of these curves to Vesuvius, we have also sampled the juvenile fraction of the pyroclastic flow deposits of the A.D. 79 and 472 eruptions (Table 3). The position of these two pyroclastic samples on the secular curve at the expected age (Fig. 8a) suggests that this curve can be used confidently for dating Vesuvian lava samples (see also Tanguy *et al*., 2003).

Fig. 8(a, b) shows that the reduced curves for France and Etna are nearly straight lines that run closely side by side from about A.D. 800 to 1200, where all but two of the analysed units are distributed. These units (P05 and P22) fall on a different curve referring to instrumental paleomagnetic record (Cafarella *et al*., 1992), indicating that they belong to the 1767 and 1701 lavas, respectively. The low α_{95} values result in small confidence circles and in relatively small uncertainties in age determination. For some sites, the positions of the confidence circles on the

Table 4 Synopsis of eruptions between A.D. 79 and 1631, based on historical, radiocarbon and archaeomagnetic data. (A): plinian and small-scale plinian eruptions. (B): violent strombolian to subplinian eruptions. (C): more or less continuous activity with strombolian to violent strombolian eruptions. Grey rectangle: mixed, effusive and explosive eruptions. (*): eruptions with lavas dated in the present work by means of the archaeomagnetic method

Sample	Cpx (Augitic)	Cpx (Diopsidic)	Leucite	Plagioclase	Olivine	Garnet	Apatite	Biotite	Nefeline	xenoliths		*Leucite*	*Nefeline*	*Plagioclase*	*Cpx*	*Olivine*	*Hematite*	*Dark mica*	*Fe-Ti Oxides*	*Vesicles*
P01	abundant		quite abundant				scarce			present		abundant		quite abundant	quite abundant	present	scarce	scarce	abundant	present
P02	abundant		present	scarce								abundant		quite abundant	quite abundant		scarce	present	abundant	quite abundant
P03	quite abundant		present				scarce			scarce		abundant		quite abundant	quite abundant		present	scarce	abundant	present
P04	present		scarce	scarce						scarce		abundant		quite abundant	present			scarce	abundant	abundant
P05	quite abundant		abundant	present			scarce			present		abundant		quite abundant	quite abundant	scarce	scarce		abundant	present
P06	abundant		quite abundant		present							quite abundant		present	present	scarce			abundant	quite abundant
P10	abundant		present		quite abundant							abundant		quite abundant	quite abundant		scarce	scarce	abundant	quite abundant
P11	abundant		quite abundant		scarce							quite abundant		quite abundant	quite abundant	present	scarce	scarce	abundant	quite abundant
P12	quite abundant		scarce				scarce			scarce		abundant		quite abundant	quite abundant			scarce	abundant	abundant
P13	quite abundant		present							present		quite abundant		present	quite abundant				abundant	quite abundant
P14	abundant		quite abundant				present			present		quite abundant		quite abundant	quite abundant		scarce	scarce	quite abundant	quite abundant
P15	quite abundant	present	abundant		scarce							present	scarce	present	present	scarce	scarce		abundant	present
P16	quite abundant		present	present	present					scarce		quite abundant		present	present	present	scarce	scarce	abundant	present
P17	abundant		quite abundant	scarce	present							quite abundant		present	present			present	quite abundant	present
P18	abundant		quite abundant		present							present		scarce	present	present			quite abundant	present
P19	quite abundant		present					scarce		present		quite abundant		present	quite abundant			present	present	abundant
P20	abundant		quite abundant				scarce			present		abundant		quite abundant	quite abundant	present	scarce	scarce	abundant	present
P21	abundant		present							scarce		quite abundant		quite abundant	quite abundant				abundant	present
P27	quite abundant		scarce				scarce			present		quite abundant		scarce	scarce	present		scarce	abundant	present
P29	abundant		abundant		present							quite abundant		present	present			present	abundant	quite abundant

Italic characters = groundmass

abundant   quite abundant   present   scarce

Table 5 Modal analyses of selected lava samples. Values are expressed in vol. % on 1000-point-analysis for each thin section

Sites	**Locality**	*Cpx* (%)	*Lc* (%)	*Cpx xenoliths* (%)	*Ol* (%)	*Plag* (%)	*Vesicles* (%)	*Groundmass* (%)
P01	Villa Inglese, upper lava	6.8	1.4	0.9			1.2	90.5
P02	Villa Inglese, lower lava	16.4	0.4				4.8	78.81
P03	Torre Scassata	7.9	5.0	0.9			1.9	84.3
P04	W cemetery of Boscotrecase (900m)	1.7	1.0	0.9			15.1	82.0
P06	*Terrioni Quarry*	8.0	4.9		1.9	0.1	5.4	79.4
P11	NA-SA Ercolano	21.1	3.6	0.9	4.7		7.2	63.3
P12	Torre Annunziata, soccer field	1.5	1.2				15.8	81.1
P14	Scogli di Prota-Villa Balke	5.7	2.6	0.2			14.7	76.6
P16	San Vincenzo Postiglione	6.7	4.5	0.9	1.9		0.6	85.9
P17	Passanti	7.3	3.8		0.5		3.9	84.3
P19	Lido Incantesimo	5.0	0.3	1.0			21.9	71.5
P20	Villa Inglese, upper lava	10.7	4.1	1.2			0.9	82.9
P21	Masseria Galasspi	7.2	0.7	0.6			1.9	89.2
P27	Donna Chiara	4.3	0.1	2.4			4.7	88.5

Table 6 Archaeomagnetic data. N= number of samples analysed for each site; α_{95} = semi-angle of the 95% confidence cone of the average paleo-directions; K = precision parameter from Ficher (1953) statistics; I = mean inclination; D = mean declination

Sites	*Locality*	*N*	α_{95}	*K*	*I(°)*	*D(°)*
P01+P20	Villa Inglese, upper lava (PA01), (PA20)	15	1,2	943	59,4	20,1
P02	Villa Inglese, lower lava	9	1,4	1040	60,4	16,8
P03	Torre Scassata	14	1,1	1199	60,6	15,8
P04	W cemetery of Boscotrecase (900m)	13	1,3	853	56,7	17
P05	W cemetery of Boscotrecase (200m)	8	1,3	1412	59,7	-16,7
P06	Terrioni Quarry	5	1,2	2563	66,7	7,0
P08	Pollena quarry (472 AD pyroclasts)	13	0,8	2596	56,7	4,8
P09	Fossa Monaca scoria cone	7	1,3	1650	60,2	18,8
P10	Calastro	15	1,1	1094	62,7	13
P11	Na-Sa Ercolano	9	1,8	654	58,6	16,9
P12	Torre Annunziata, soccer field	8	1,2	1784	63,4	12,3
P14	Scogli di Prota-Villa Balke	10	1,8	634	60,4	19
P15	Torre Bassano	14	1	1385	63,1	17
P16	San Vincenzo Postiglione	10	1,2	1454	66,9	12
P17	Passanti	7	1,4	1284	56,8	19.4
P18	Scogli della Scala	14	1,6	520	64	13,6
P19	Lido Incantesimo	11	1,2	1183	59,1	16,7
P21	Masseria Galassi	15	1	1374	67,2	3,3
P22	Pozzelle quarry	11	0,6	4870	66,4	-12,1
P23	Masseria Bosco del Monaco	9	1,2	1523	62,4	13,7
P25	Granatello	7	1,4	1395	64	11,7
P26	Vesuvius' café, N of Torre del Greco	10	1,7	711	60,8	17,7
P28	Torre Annunziata, palazzo Monteleone	11	1,1	1484	63,8	12,3
P29	Cupa dei Monti, N of Ercolano	10	1,3	1093	58,1	19,3
P30	NA-SA Portici-Bellavista	9	1	2085	63,4	11,4
79	Ercolano ancient city, inside the Archeological escavations	11	1,1	1573	58,7	-4,8

Table 7 Archaeomagnetic ages of the pre-1631 lavas analysed in this paper. Bold character: most probable eruption dates assigned in this work on the basis of both historical and stratigraphic considerations

Site	*Locality*	*Archaeomagnetic age*	*Attributed eruption*
P21	Masseria Galassi	800±20	**AD 787**
P06	Terrioni Quarry	850±40	9th century
P16	San Vincenzo Postiglione	870±30	9th century
P10	Calastro	900±30	10th century
P30	NA-SA Portici-Bellavista	900±20	10th century
P25	Granatello	900±30	10th century
P18	Scogli della Scala	900±40	10th century
P12	Torre Annunziata, soccer field	900±20	10th century
P28	Torre Annunziata, palazzo Monteleone	900±30	10th century
P23	Masseria Bosco del Monaco	920±30	10th century
P15	Torre Bassano	940±30	10th century, **968**
P09	Fossa Monaca	1000±40	968, **999,** 1006–07
P03	Torre Scassata	1000±30	968, **999,** 1006–07
P02	Villa Inglese, lower lava	1000±50	968, **999,** 1006–07**,** 1037
P14	Scogli di Prota-Villa Balke	1000±50	968, 999**, 1006–07**, 1037
P26	Vesuvius' café, N of Torre del Greco	1000±50	968, 999, **1006–07**, 1037
P01+P20	Villa Inglese, upper lava	1050±30	999, 1006–07,**1037**
P19	Lido Incantesimo	1050±30	1006–07, **1037**
P11	NA-SA Ercolano	1080±60	1037, **1139**
P29	Cupa dei Monti, N of Ercolano	1100±40	**1139**
P17	Passanti	1100±40	**1139**
P04	S flank W of Boscotrecase	1140±40	**1139**

curve are not significantly different, suggesting that these lavas belong to the same eruption.

Table 7 shows the archaeomagnetic ages and their range of error. Following the approach of Tanguy *et al.* (2003), it has been possible to obtain age determinations within ±40 years, with a higher precision of ±20 years in the best cases. These results are substantially better than those of the radiocarbon method (Table 2), at least for the considered time span, a fact that underscores the importance of archaeomagnetic dating of young volcanic successions. Only one site yielded unacceptable analytical results, the *Donna Chiara* lava (P27), owing to the poor outcropping conditions (only small lava outcops are accessible and most were probably displaced after cooling).

Short-period palaeomagnetic techniques (secular variation curve) have previously been applied by Carracedo *et al.* (1993) to investigate (1) some of the Vesuvian lavas, interpreted in the literature as products of the 1631 event, (2) the pyroclastic flow deposits of this same eruption and (3) other lavas unquestionably emitted after this eruptive

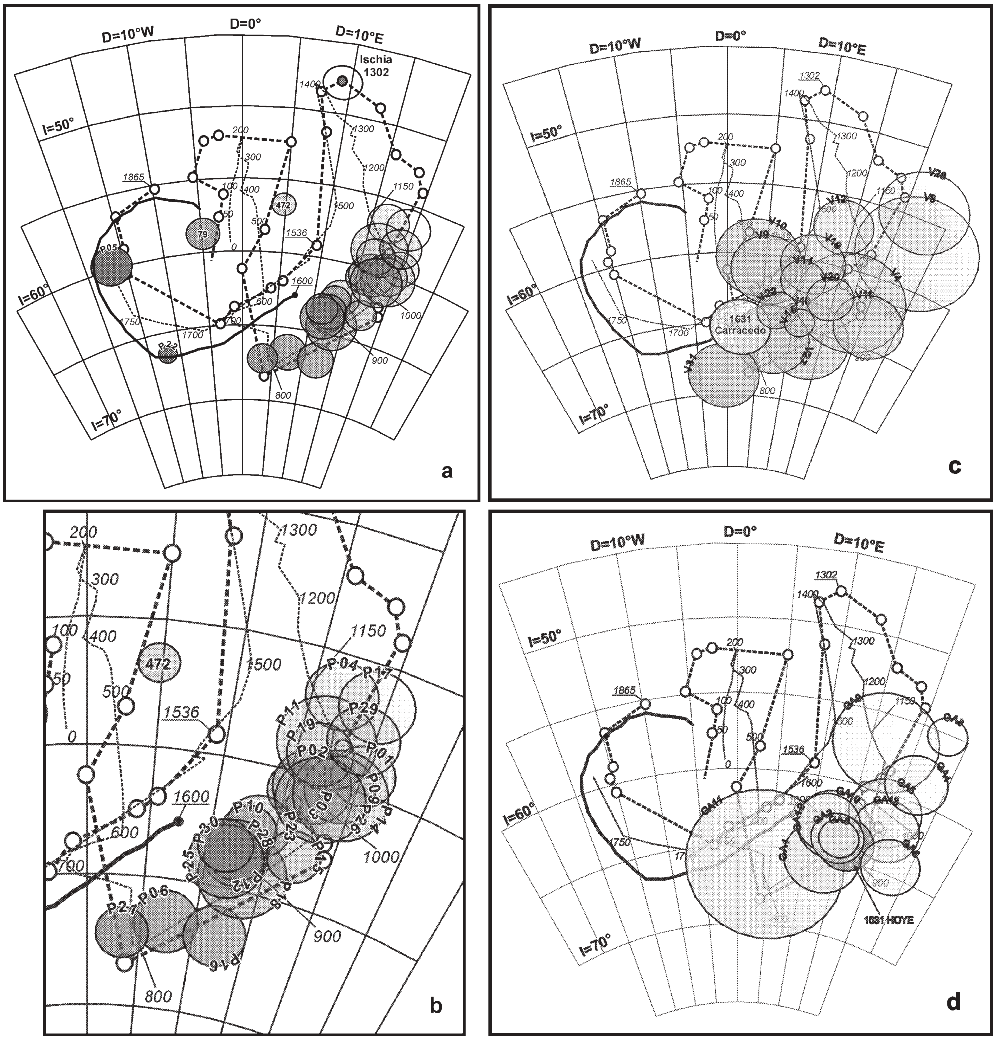


Fig. 8 a-d **(a)** Geomagnetic secular variation curves for Etna (Tanguy *et al.,*1999) and France (Bucur, 1994) (heavy and light dashed lines, respectively) reduced to the latitude and longitude of Naples, and geomagnetic curve based on the direct magnetic field measurements performed since 1640 (solid line; Cafarella *et al.*, 1992 and Thellier unpublished data, see in Bucur, 1994). Confidence circles associated with the analyses performed in this work (*P*) are also plotted. **(b)** Enlarged section of the previous plot for the medieval period. **(c)** Data set for lavas from A.D. 79 to 1631 from Carracedo et al. (1993) (*V*) and **(d)** from Gialanella et al. (1993 and 1998) (*G*) and Hoye (1981)

event. The data obtained for the lavas attributed to the 1631 eruption suggested that these lavas were the result, not of a single eruptive event, but of several different eruptions, with a palaeomagnetic correlation with the medieval curve (Carracedo *et al*., 1993). Most of these lavas have been newly analysed in the framework of the present work (Table 8).

There is evidence that substantial differences exist between this classical paleomagnetic method and the “big sample” dating procedure (Tanguy *et al*., 2003), mainly due to rotation of the steel, diamond-tipped corer used for traditional palaeomagnetic sampling which induces secondary magnetisation in lavas (Lauer, 1978; Audunsson & Levi, 1989). In spite of this fact, a number of authors have extracted samples of Vesuvius’ lavas by coring and performed paleomagnetic analyses by spinner (Hoye, 1981; Carracedo *et al*., 1993; Gialanella *et al*., 1993 and 1998). Figures 8c and 8d report the results obtained by these authors, as well as the curves of secular geomagnetic variation drawn in Figures 8a and 8b. Table 8 shows the correspondence between the various analysed sites.

Another source of error lies in the fact that Hoye (1981) based his attribution of the lava he analysed to the 1631 eruption on the thesis of Principe (1979), wherein lava sample PFSV 200 was erroneously described as a lava from the 1631 eruption on the basis of the Le Hon (1866) map of Vesuvius’ lavas. This site corresponds (Table 8) to site V19 of Carracedo *et al*. (1993) and site P29 of this work, which obviously belongs to medieval times (1139 eruption, see below). Consequently, Hoye (1981) constructed an unreliable secular curve, of which the 1300–1600 part was confused with the medieval one (compare Hoye, 1981 and Tanguy *et al*., 1999 and 2003).

Figures 8c and 8d show the fact that the results obtained with classical methods present a much larger spread on the secular variation curve with respect to our samples (Figures 8a and 8b). Moreover, the literature data have α_{95} values higher than our data and their analytical results are not always conform with the stratigraphic order of the samples. The best results with traditional methods were obtained by Carracedo *et al*. (1993) on the juvenile fraction of the 1631 pyroclastic flow, the circle of confidence of which is compatible with the first “direct” measurements of the Earth magnetic field (Cafarella *et al.*, 1992). Such a good analytical result may be due to the fact that “tender” samples, such as scoriae, are drilled

Table 8 Correspondence between the ages given by Vittozzi & Gasparini (1965), Di Girolamo (1970), Burri & Di Girolamo (1975), Carracedo et al. (1993), Gialanella et al. (1993 and 1998), and Hoye (1981) and those obtained in this work for the same lavas. Sample codes are in brackets. MA = Middle Ages

Sampling locality	*This paper*	*Di Girolamo (1970) Burri & Di Girolamo (1975)*	*Lirer et al. (2001)*	*Rolandi & Russo (1989)*	*Hoye (1981)*	*Gialanella et al. (1998) Incoronato (1996)*	*Carracedo et al. (1993)*
San Vincenzo Postiglione	**9th century (P16)**					1631 (GA8)	MA (V8)
Masseria Donna Chiara	**?9th century? (P27)**			1631		1631 (GA9)	
Calastro	**10th century (P10)**	1631				1631 (GA10)	MA (V15)
Scogli della Scala	**10th century (P18)**	1631					MA (V14)
Granatello	**10th century (P25)**	1631					MA (V16)
Torre Annunziata soccer	**10th century (P12)**					1631(GA1)	
Palazzo Monteleone/La Perla	**10th century (P28)**		1631	1631		1631(GA2)	MA (V27)
NA-SA Portici Bellavista	**10th century (P30)**					1631 (GA12)	
Scogli di Prota/Oncino	**1006/7 (P14)**		13th-14th century	MA		pre-1301 (GA3)	MA (V12)
Torre Bassano	**968 (P15)**	1631	MA	MA		pre-1301 (GA13)	MA (V22)
Villa Inglese, lower lava	**999 (P02)**	1480		MA		pre-1301 (GA6)	MA (V3, V9)
Torre Scassata	**999 (P03)**			MA			MA (V11)
Villa Inglese, upper lava	**1037 (P01, P20)**	1631		MA		pre-1301 (GA4, 5)	MA (V2, V4, V10)
NA-SA Ercolano	**1139 (P11)**						MA (V20)
Cupa dei Monti	**1139 (P29)**				1631 (PFSV200)	1631 (GA11)	MA (V19)

very quickly and consequently acquire less secondary magnetisation during mechanical core sampling than "hard" samples, such as lavas. Finally, we must point out that some authors (Gialanella *et al.*, 1993, 1998; Incoronato, 1996, 1999; Incoronato *et al.*, 2002) were led to incorrect conclusions on medieval lavas (Table 8) because they also used the wrong reference curve defined by Hoye (1981).

The interpretation of new archaeomagnetic data

The geographical distribution of the main lavas dated in this work and their stratigraphical relationships are sketched in Fig. 9, on the basis of both field evidence gathered during sampling and the cartography of lava outcrops given in the detailed geological map of Johnston-Lavis (1891a). In Appendix 2 the ages we obtained via the archaeomagnetic method are discussed in the framework of geological and archaeological constraints, for each of the geographical sectors defined in Figure 1.

Unnoticed events

As suggested by the comparison of historical (Table 1) and archaeomagnetic data (Table 7), several effusive eruptions occurred between the second half of the 9th century and the first half of the 10th century that were not documented in the surviving historical sources (Table 9). This fact may be explained by the limited circulation of documents in a historical period dominated first by the repeated invasions of the Longobards and Franks, and then by the conflicts between the Byzantines and Saracens for the domination of the Dukedom of Naples (Girelli, 1994). It is possible that some of these effusive eruptions also involved an explosive phase, which might be responsible for the minor tephra layers of this time span. Apart from these eruptions, all the historically documented eruptions are corroborated by the archaeomagnetic evidence, confirming both the validity of the historical information, when available, and the power of archaeomagnetism as dating tool of young volcanic units.

Mixed eruptions

The current stratigraphic and geochronological findings confirm the attribution of the "ochraceous" lapilli fallout that lies between the 1037 lava and the deposits of the 1631 eruption in the *Villa Inglese* area (Fig. 6 and 7c) to the 1139 eruption, as already recognised by Principe *et al.* (1987) and Rolandi *et al.* (1998). A number of eruptions are of mixed (effusive and explosive) type, such as those of A.D. 787, 999, 1006–07, and 1139 (Table 9), based on existing radiocarbon ages, historical data, and our new archaeomagnetic data. Moreover, in the case of the eruptions of 1006/7 and 1139, archaeomagnetic age determination support a phase of lava discharge for which documentation was lacking in the historical chronicles (Principe, 2003).

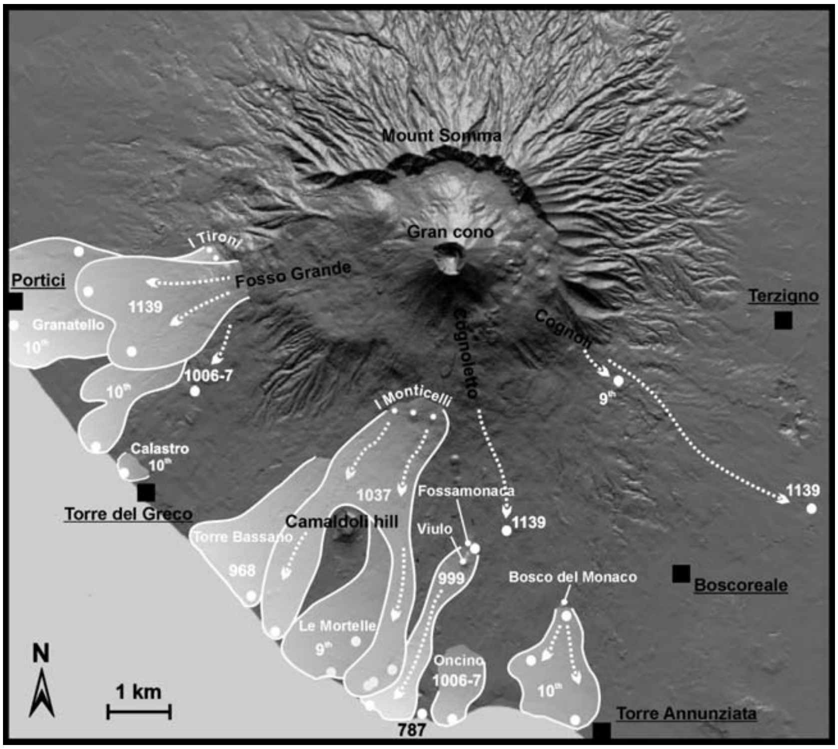
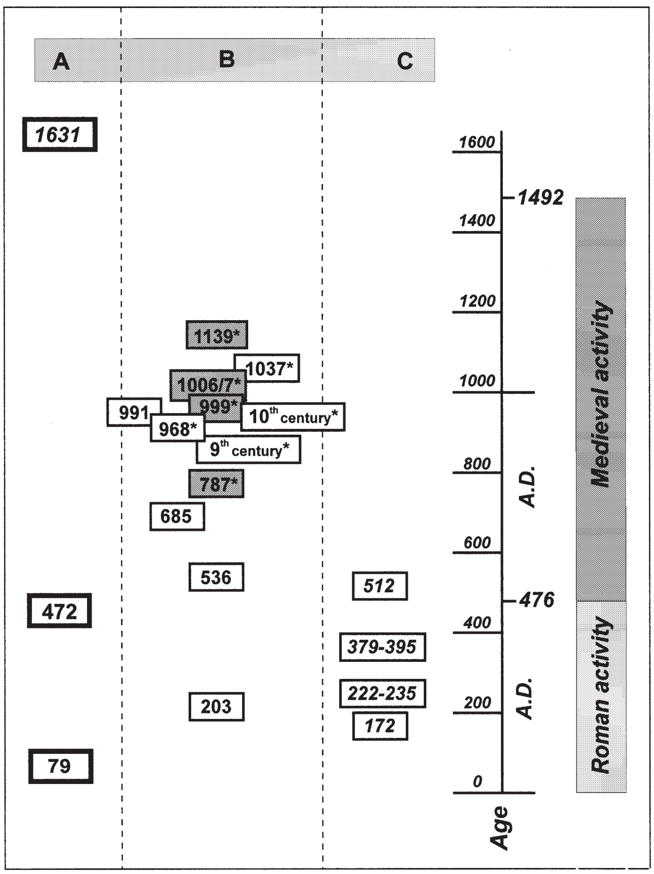


Fig. 9 Sketch map, flow directions and ages of the medieval lavas dated in this work (topography as in Fig. 1).Bold dots refer to the sampling sites listed in Figure 1 and Table 3

Table 9 Mineralogy of selected lava samples. The presence of each mineral phase has been qualitatively estimated (Scarce = <5%, present =5–10%, quite abundant=10–15%; abundant >15%)



Effusions from central vent and intracaldera activity

The lavas of the 1139 eruption are distributed at relatively high elevation on the western and southeastern slopes of the volcano, downstream from the *Fosso Grande, Cognoli,* and *Cognoletto* valleys (Fig. 9), which channelled the numerous post-1631 lavas (Arrighi *et al.,* 2001). Contrary to the parasitic activity that generated lavas sometimes more than 10 m thick and several hundred meters across, the 1139 lavas have fronts which never exceed 2–3 m in thickness. Hence, the 1139 lavas were probably erupted from the main crater. In addition to the lavas of the 1139 event, few other lavas between A.D. 79 and 1631 (e.g., samples P06 and P29) were able to surpass the *Mount Somma* caldera rim. Overflow probably occurred when the *Gran cono* attained sufficient development inside the *Mount Somma* caldera, as testified by historical sources (see discussion above). To appreciate this fact it must be recalled that the *Mount Somma* caldera was an amphitheatre-shaped depression without any inner cone after the A.D. 79 eruption. Subsequent eruptive events determined the gradual growth of the *Gran cono* and, consequently, the progressive decrease in the caldera storage capacity for the lavas which erupted both from the top of the *Gran cono* and from fractures cutting its flanks. Finally, probably in the 9th century, lavas started to be dicharged from the caldera rim, which locally did not act as a morphological barrier anymore.

A similar phenomenon occurred after the 1631 eruption that brought about the total destruction of the *Gran cono*. Again, lavas were able to surpass the caldera rim only after a century of activity when the *Gran cono* is documented to have been fully reconstructed (Melilli, 1996; Arrighi *et al*., 2001).

Parasitic vents

The most evident of the Vesuvius' parasitic cones is the *Camaldoli* hill (Fig. 9), which is covered by the deposits from the the A.D. 79 eruption (CNR, 1986) and by those of the medieval activity, as described in detail by historical sources (Sorrentino, 1734) and confirmed by the stratigraphic surveys of Rolandi *et al.* (1998). Since the Camaldoli cone predates the A.D. 79 event, it is beyond the focus of the present work and, for this reason, archaeomagnetic sampling was not carried out.

As already mentioned, the considerable thickness and morphological prominence of many "medieval" lavas cropping out along the coast depend on their emission from parasitic vents, thus suggesting activation or reactivation in this time interval of significant tectonic elements. Four possible sources for the eccentric lavas have been identified in this investigation on the basis of historical and field data (Fig. 9): *Tironi, I Monticelli, Viulo-Fossamonaca,* and *Masseria Bosco del Monaco*. Based on the archaeomagnetic analyses, it is reasonable to attribute the lower lava of *Villa Inglese-Torre Scassata* to the A.D. 999 eruption and set its discharge vent at *Fossamonaca*. The lava widely outcropping at *Torre Annunziata* along the coastline was discharged from the vent of *Masseria Bosco del Monaco* in the early 10^{th} century. Another vent (possibly opened during the same eruption or another eruption occurring within±40 years of the *Masseria Bosco del Monaco* event) was also responsible for the large lava of *Granatello*, the vents for which are very likely the two *Tironi* cones described by Sorrentino (1734). On the basis of both their position and the persistence of the related morphological anomaly, even beneath the lavas discharged on this slope after 1631, the three vents at *I Monticelli* may tentatively be attributed to the 1037 eruption, though this is by no means certain. The source vents of the *Torre Bassano, Oncino* and *Le Mortelle* lavas are still unknown.

Timing of volcanic activity

Based on our new archaeomagnetic data, the critical reading of historical sources, and taking into account the Vesuvius' literature for the post-A.D.-79 activity, the A.D. 79–1631 period of activity can be divided into two phases by the small-scale A.D. 472 plinian eruption.

The first phase from A.D. 79 to 472 includes a main explosive event occurring in A.D. 203 and a number of minor eruptions and periods of activity, tentatively classified as strombolian to violent strombolian based on historical and available stratigraphical data. During this period, there is no evidence of lava effusions outside the *Mount Somma* caldera, although effusive intracaldera activity cannot be ruled out.

The second phase, from A.D. 472 to 1631, was initially characterised by a number of explosive eruptions as documented by available historical and stratigraphical data. However, a new kind of activity began in A.D. 787, with the occurrence of several mixed, explosive and effusive, eruptions. Lavas were erupted from the main cone and fractures situated outside the *Mount Somma* caldera, invading the southern flanks of Vesuvius' and shaping the coastal morphology. These products are relatively primitive, with a MgO content of generally between 3.5 and 6.5 wt% (Joron *et al*., 1987; Belkin et al., 1998; Raia *et al.*, 2000; Paiotti, 2000). This activity lasted for about 360 years and ended with the 1139 eruption which preceded a 5-century-long period of quiescence.

A number of features of the post-A.D. 472 phase, such as the initial occurrence of intracaldera events, the mixed style of eruptions suggesting an open-conduit system, and the MgO concentrations of the erupted products, are similar to the post-1631 behaviour of the volcano (Joron *et al*., 1987; Belkin *et al*., 1993).

By assuming that the post-1631 period mimics the post-472 period, and that the last eruptive stage ended with the 1944 eruption (Principe, 1979; Carta et al., 1981), we are tempted to compare the long quiescence following the 1139 eruption and preceding the 1631 event with the present state of inactivity. However, we must point out that a repose period of less than one century preceded the A.D. 472 eruption, which is similar to the 1631 event, although the pre-A.D. 472 eruptive history is poorly known. It is clear that the present level of knowledge of the volcano behaviour during the A.D. 79–1631 period is not yet sufficient to draw sound extrapolations on its future state.

Conclusions

The archaeomagnetic method has resolved the ages of Vesuvius' eruptions in the time period from A.D. 79 to 1631. The method affords high reliability and an analytical error which is generally less than ±40 years.

Archaeomagnetic dating highlights several lavas, erupted between the second half of the 9^{th} and the first half of the 10^{th} century, that have been unnoticed by the historians of that rather dull period. Conversely, historically documented ages of eruptions are consistent with archaeomagnetic and geological data.

All the medieval lavas cropping out along the southern slopes of Vesuvius' at low altitudes were erupted in ~360 years, from A.D. 787 to 1139. The large lavas that shaped the morphology of the Vesuvius' coast were largely discharged from parasitic vents situated outside the *Mount Somma* caldera. A number of these eruptions were also characterised by an explosive component, recorded by radiocarbon-dated tephra deposits (A.D. 787, 999, 1006–07, and 1139). The dated lavas include all those attributed by various authors to the eruption of 1631, often on the basis of questionable data and misinterpretations. The chronology of the lavas and tephra younger than the A.D.

79 eruption confirms that the violent 1631 eruption was preceded by a long period of repose (lasting probably almost 500 years). In the early centuries of the first millennium A.D., Vesuvius' activity was dominated by explosive eruptions, the last of which was the cataclysmic event of A.D. 472. Then, as in the case of the post-1631 activity (Rosi *et al.*, 1993; Arrighi *et al.*, 2001), intra-caldera lava effusion recommenced, after apparently no rest at all. Then, from 787 to 1139 (~360 years), at least nine eruptions of mixed kind, effusive and explosive, took place, and lava fronts moved outside the *Mount Somma* caldera rim. These lavas were mostly discharged from vents placed low on the volcano slopes, invading the coastal strip and shaping the present coastline. The last centuries before the violent explosive paroxysm of 1631 were quiet.

On one hand, such a picture is somewhat reassuring, given the long period of quiescence that followed the 1139 eruption and similarities with the current situation following the 1944 eruption. On the other hand, a rest period of less than one century preceded the A.D. 472 eruption, which is very similar to the 1631 event. In addition, the presence of such recent eccentric lavas underlying all the main inhabited land along the Vesuvius' coast cannot but arouse a certain degree of apprehension.

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Appendix 1: New radiocarbon dating

For internal control of the consistency of the archaeomagnetic data, the charcoal sample OZF467 found within the scoria fallout underlying P23 (Fig. 7c), was radiocarbon-dated at the Accelerator Mass Spectrometry (AMS) facility at ANSTO (Lawson *et al.*, 2000). AMS makes use of a nuclear particle accelerator to detect single ^{14}C atoms in the overwhelming presence of stable ^{12}C and ^{13}C atoms. Compared to the traditional counting technique, an AMS measurement requires smaller mass samples (typically 1 mg of carbon is sufficient) and shorter measurement times. The standard AAA method (Mook & Streurman, 1983) was employed to remove contamination. The pre-treated sample was converted to CO_2 by combustion and graphitised (Hua et al, 2001). The graphite was loaded into an aluminium sample holder for the AMS measurement. The $^{14}C/^{13}C$ isotopic ratio was measured relative to the internationally accepted HOxI standard material (Stuiver, 1983). Then corrections were applied for spectrometer background, the contamination during preparation of the graphite target and isotopic fractionation. Using the corrected radioisotope ratio, the conventional radiocarbon age of 1370±40 BP was calculated. A calibration performed using the CALIBETH software (Niklaus *et al.*, 1992) and the tree ring data set from Stuiver *et al.* (1998) provided us with a (cumulative probability) age range of 639–687 A.D. This result, compared with historical data, suggests that the deposit belongs to the A.D. 685 eruption, confirming the presence of an explosive phase in such an eruption.

Appendix 2: Geological and archaeological framework

Sector I

The geomorphology of this coastline is dominated (Fig. 2) by the small promontory of *Villa D'Elboeuf*, the seaward front of the *Granatello* lava (P25), and the two rockcliffs known as *Scogli della Favorita* and *Scogli della Scala* (Fig. 3, P18). Construction of the Royal Palace of *Portici* and its surrounding park, on the *Granatello* lava, started in 1738 in an area that was famous before 1631 for its marvellous pomegranate gardens (whence the name), which were completely destroyed by the 1631 eruption (Mormile, 1632).

A lava tentatively correlated by various authors with the *Granatello* lava (Di Vito *et al.*, 1998; Bellucci, 1998) lies above the pyroclastic flow and lahar deposits of the A.D. 79 eruption which are found into numerous wells drilled in the immediate surroundings of *Portici* and also in outcrops along the coast below and immediately west of *Villa D'Elboeuf* (Fig. 2, n.1).

The coast to the south of *Granatello* maintains a low flat profile, partially filled by the 1631 *nuées ardentes* deposits up to *Scogli della Favorita*, and then rises to the promontory of the *Scogli della Scala* (now called *Punta Quattro Venti*), where a single large lava crops out (P18) in an over 150 m long sea cliff .

Archaeomagnetic dating indicates that the *Granatello* and *Scogli della Scala* lavas are a single huge lava ("*Granatello*" lava), which was erupted between the 9th and 10th century. A lava attributable to the 1139 eruption (P11, P29) overlies the inland portion (P30) of the *Granatello lava* (Fig. 9). Both these lavas are intersected by the Naples-Salerno highway.

Sector II

The lava (P10) forms the promontory called Calastro, from which the breakwater of the port of *Torre del Greco* (Fig. 4) extends outwards. This lava crops out on a long stretch of coastline (around 250 m), with a mean thickness of 7–8 m. The locality name *Calastro* is of Greek origin and the *Calastro* settlement precedes the founding of *Torre del Greco* which occurred in the 14^{th} century on the site of one of the coastal towers built to defend the coast during the domination of the Suevians, in the 13^{th} century (Orlandi, 1631). Since this tower was situated at eight Roman miles from Naples, the settlement was initially called *Turris Octava*. During their first extensive development, the two villages of *Sola* (south of the residential area, where the cemetery is now located) and *Calastro* were reported to be damaged by the eruption of 1037 (De Seta *et al.*, 1980). In the 16^{th} century, first a fortress, and then a mill were built on this lava because of the presence of a fresh water spring nearby. In spite of the very ancient origin of the name, the lava of Calastro is attributed to the 10^{th} century based on our archaeomagnetic result.

Sample P26 from this sector comes from a lava attributed on the CNR (1986) geological map to modern activity but, in fact, pertains to the 1006–07 eruption, based on our archaeomagnetic data.

Sector III

An outcrop (P15) of the same lava exposed on the seacliff under the tower (Fig. 5) is located in the stretch of the coastal road leading from *Torre del Greco* towards *Torre Annunziata*, just inland of *Torre Bassano*. Based on our archaeomagnetic measurements, the lava under *Torre Bassano* is attributed to the A.D. 968 eruption.

Sector IV

Near the coast, a few kilometers west of *Torre Annunziata*, two directly overlapping lavas (P01, P02) crop out in the large quarry of *Villa Inglese* (Fig. 6). On the northeastern side of the quarry they are overlaid by the pyroclastic flow and lahar deposits of the 1631 eruption. These, in turn, are covered by the 1760 lava. A third sample (P20) was collected from the uppermost of these two lavas, on the northwestern side of the quarry. Here, the upper lava is divided into two lobes, giving the false impression of the existence of a third lava, as erroneously stated by Gialanella *et al.* (1998).

The "medieval", stratigraphically highest lava is of whitish colour due to weathering, very compact, and, because of its good physical and mechanical characteristics, has been quarried widely since the early 19^{th} century. It is locally known as *"il Villa Inglese"* lava (Formicola *et al.*, 1990; Penta & Del Vecchio, 1963). The *"il Villa Inglese"* lava is located directly below the second "medieval" lava, which was correlated by Rolandi & Russo (1989) with the seaward lava on which the *Torre Scassata* tower was constructed (Fig. 6, n.5). Archaeomagnetic data (P03) confirm such a correlation. There is no geologic evidence supporting Rolandi & Russo's (1989) contention that both medieval lavas cropping out in the quarry are present under the *Torre Scassata,* as only one lava crops out widely below the tower and along the broad beach beyond.

The two lavas of the *Villa Inglese* occupy an important position in the stratigraphy of the pre-1631 deposits, particularly in the so-called "medieval" lavas. The *Villa Inglese* lavas have been taken into account in practically all the studies on the Vesuvius' eruptive history between A.D. 79 and 1631 (Burri & Di Girolamo, 1975; Delibrias *et al.*, 1979; Principe *et al.*, 1987; Rolandi & Russo, 1989). We found that the two *Villa Inglese* lavas are archaeomagnetically attributable to the A.D. 999 and 1037 eruptions. This last eruption also produced the lava sampled at Lido Incantesimo (P19).

In the quarry of *Villa Inglese*, below the two aforesaid lavas, another lava is present, though it is not visible at the present time (Principe *et al.*, 1987; Rolandi & Russo, 1989; Formicola *et al*., 1990). On the basis of the previous discussion, the coastline morphology, the precise cartography by Johnston-Lavis (1891a) of the lava units cropping out at that time and their stratigraphic relationship, we can hypothesize that this third and oldest lava is the easternmost edge of the large lava that formed *Le Mortelle* promontory (P16, n.4 in Fig. 6). It is attributed to the 9^{th} century based on the archaeomagnetic datum. The two *Villa Inglese* lavas extend along the coastline to the south, overlying the southern border of this large lava. Subsequently, the 1631 *nuée ardentes* deposits filled the topography, leaving the upper surface of the *Le Mortelle* lava exposed in some morphological windows, on which the foundations of *Masseria Donna Chiara* and *Villa Prota* were laid (n.2 and n.3 in Fig. 7a, respectively). Rolandi & Russo (1989) attribute the lava of *Masseria Donna Chiara* to the eruption of 1631 and insert it between the 1631 pyroclastic deposits and the 1760 lava in the stratigraphy of the *Villa Inglese* quarry. The *Masseria Donna Chiara* lava is not present in the quarry, but occurs west of the quarry area, beneath the farm of the same name, the existence of which is documented since at least 1645 (Raimondo, 1985 and 1994). This lava (P27) is overlain by a characteristic bed of normally graded ochreous lapilli belonging to the "middle-age" tephra sequence (Principe *et al.*, 1987). The territory surrounding the *Masseria Donna Chiara* was widely, though not entirely, covered by the 1631 *nuées ardentes* (Rosi *et al.*, 1993), which spared the nearby *Villa Prota* of which the construction dates back to the 16^{th} century (De Seta *et al.*, 1980). Although we did not obtain a reliable archaeomagnetic age for the lava of *Masseria Donna Chiara*, it is older than 1631 and might probably belong to *Le Mortelle* lava (9^{th} century, see above).

The two scoria cones of *Viulo* and *Fossamonaca* are located in the northernmost portion of this sector.The *Fossamonaca* cone (P09) is a scoria cone open seaward, from where lava was seen to escape (Sorrentino, 1734). *Viulo* is another, smaller-sized scoria cone located just south of *Fossamonaca* and that was probably constructed soon thereafter. Due to the thick undergrowth covering the *Viulo* vent, only the *Fossamonaca* cone has been suitable for archaeomagnetic sampling. Archaeomagnetic dating allows us to attribute it to the eruption of A.D. 999, as is the lower *Villa Inglese* lava (Fig. 9).

Sector V

About 1.5 km north of *Torre Annunziata,* the top of a small hill (Fig. 7a) emerges from the 1631 pyroclastic deposits surrounding it. This is all that remains of the vent (*Masseria Bosco del Monaco* cone) for a large lava flow that expands towards the sea (Johnston-Lavis, 1891a), and the eastern edge of which crops out in the construction site for the new hospital of *Torre Annunziata* (P23). The 1631 eruption deposits are located above this lava (Fig. 7c), which is intercepted by a series of small quarries (Fig. 7a), up to the port area of *Torre Annunziata*, where it crops out extensively along the *Litoranea Marconi* road, between the thermal baths of *Terme Nunziante* and *Palazzo Monteleone* (Fig. 7a and 7b). The lava outcrops along the Naples-Salerno highway, near the *Torre Annunziata*-Nord exit, also belong to this lava flow, and were sampled for this work at the soccer stadium of *Torre Annunziata* (P12). The westernmost branch of this lava crops out opposite of the seaside garden of *Villa Filangeri* (n.3 in Fig. 7). The age of the large *Masseria Bosco del Monaco* lava is early 10th century, as indicated by our archaeomagnetic measurements. This is one of the eruptions which was unnoticed by historians.

Another large lava dominates the morphology of the Vesuvius' coastline near *Torre Annunziata*. This is the rock-cliff lava of *Scogli di Prota* (P14, n.1 in Fig. 7a), known in the literature as the *Oncino* lava because of the 16th-century fortress called *Forte dell'Oncino* situated on the eastern side of the *Scogli di Prota* promontory (n.2 in Fig. 7a). In the stratigraphy proposed by Rolandi & Russo (1989), the *Oncino* lava is positioned below the lava of the *Litoranea Marconi*, which is attributed by these authors to 1631. However, no relation is recognizable in the field between these two lavas, just as there is no basis for attributing the *Litoranea Marconi* lavas to 1631. In the stratigraphic section of *Cantiere La Perla* (near *Terme Nunziante*), this lava merely occurs at the top of the succession. Based on our archaeomagnetic measurements the *Oncino* lava is attributable to the 1006–7 eruption (Table 7).

Sector VI

Two lavas, situated stratigraphically between the deposits of the A.D. 472 and the 1631 eruptions, were sampled in this sector at *Terrioni* quarry (P06) and at the village of *Passanti* (P17). They are attributed to the eruption of the 9th century (P06) and to the 1139 event (P17), based on our archaeomagnetic measurements. These lava flows have first been channelled into the narrow gorges of the easternmost, low-lying sector of *Mount Somma*, and have expanded downhill. As this area is outside the main populated areas, no historical information is available for these lavas.

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