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Plinian eruptions and their impact in urban context: dynamics and effects on the territory of the fall phases of the 79 A.D. Vesuvian eruption

Eruzioni Pliniane e il loro impatto nei contesti urbani: dinamica ed effetti sul territorio delle fasi da colonna sostenuta dell'eruzione vesuviana del 79 d.C.

PhD Candidate: Dr. ***Giulia Chiominto***

Tutor: ***Prof. Claudio Scarpati***

Co-Tutor: ***Prof. Lorenzo Fedele***

PhD Coordinator: ***Prof.ssa Rosa Di Maio***

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Abstract

Plinian eruptions are particularly dangerous eruptions that often have long-lasting consequences. They produce high eruptive columns that inject considerable volumes of pyroclastic fragments and volcanic gases into the stratosphere. Pyroclastic clasts fall back to the ground forming widespread tephra sheets in which different components are distinguished: juvenile clasts, lithic clasts and crystals. This ‘classical’ behaviour is well represented by the main sustained phase of the AD 79 Vesuvius eruption, which deposited a thick white to gray pumice lapilli fallout deposit. This phase was followed by a post-Plinian, column collapse phase, which mainly emplaced several pyroclastic density currents (PDCs) with minor sustained column pulses that emplaced thin, lithic-rich layers. The current study focuses of the fall deposits recognized within the entire AD 79 stratigraphic sequence (i.e., belonging to both the Plinian and the post-Plinian phases of the eruption) with the aim to estimate their eruptive parameters (e.g., volumes, column height, mass discharge rate, tephra mass etc.), reconstruct a model of withdrawal from the vertically-stratified AD 79 magma chamber, and define the impact of the fall products on some roman towns (Pompeii, Stabiae). Several stratifications were recognised within the Plinian fallout deposit. Stratification is due to granulometric and lithological contrast between successive layers. Based on grain size, component and chemical analyses results eight units have been recognised within white pumice lapilli deposit and six within grey pumice lapilli deposit. All AD 79 fall layers display Plinian dispersal. Variation of grain size with stratigraphic height suggests that the convective plume was far from steady state. During the first white pumice phase, the plume height reached its maximum plume height of 23 km. During the grey pumice phase, the eruption is characterised by the alternation of sustained column phases and partial column collapse phases, with the emplacement of several PDC ash deposits. The maximum height of the plume is 34 km. Mass discharge rates, varies from 6 x 10^7 to 4.3 x 10^8 kg/s. The total volume of the pumice lapilli deposit accumulated during the Plinian fall phase (white + grey) is 6.2 km^3 (1.65 km^3 DRE). Five lithic-rich lapilli fallout layers interstratified with the pyroclastic density current deposits were emplaced after the total collapse of the Plinian column. During this “late” post-Plinian phase, the column resumes heights from 17 to 19 km and mass discharge rates from 1.8 to 4.2 x 10^7 kg/s. These data highlight the oscillating behaviour of the sustained eruptive column of the AD 79 eruption. The duration of the Plinian phase of this eruption is estimated to have been six hours and thirty-six minutes for the white pumice fall deposit, eleven hours for grey pumice fall deposit and several ten minutes for the first three post-Plinian sustained column pulses. The results of the petrochemical analyses provide new insights into the withdrawal of the AD 79 magma chamber. Finally, I present the new timing of the destruction at Pompeii during the Plinian phase of the eruption. During the first phase of the eruption part of the population tried to take shelter inside houses, but after 3 hours from the beginning of the eruption, the roofs begin to collapse under the load of the thick fallout deposit. In addition, several roofing-tiles were recovered up to the highest units of the Plinian fallout

succession. Consequently, roof have continued to collapse. The lack of archaeological evidence led us to suppose that the post-Plinian fallout phases were not dangerous or destructive for the inhabitants.

Introduction

Vesuvius is one of the most studied volcanoes in the world, due to its prolonged history of eruptions, ease of accessibility and the well-documented historical explosive eruption of AD 79. This latter event resulted in the destruction of Pompeii, Herculaneum, Oplontis and Stabiae and caused the death of Pliny the Elder among many other people. The eruption is named directly from its occurrence date and is also referred to as the 'Pompeii eruption'. The main phases of the eruption have been described by Pliny the Younger in two letters written to the historian Tacitus, providing a background for the detailed study of the events that occurred during the eruption. The products of this eruption has been subject to numerous studies in the last fifty years and various interpretations of its dynamics have been proposed (e.g., Lirer et al., 1973; Sigurdsson et al., 1985; Carey and Sigurdsson 1987; Cioni et al., 1990, 1992, 1995, 1996, 2000; Luongo et al., 2003a,b; Scarpati et al., 2020). The eruption lasted at least 19 h, from 1.00 p.m. of August 24 (or October 24) to 8.00 a.m. of August 25 (or October 25).

It began with a weak phreatomagmatic explosion, which covered the proximal area of the volcano with an ash deposit. This was followed by the fall of pumice lapilli from a Plinian column 14 – 32 km high (Carey and Sigurdsson, 1987), which covered a large area to the south and southeast of the volcano (Lirer et al., 1973; Sigurdsson et al., 1985; Doronzo et al., 2022). Pumices are white at the base and grey towards the top of the deposit, indicating a change in density and chemical composition of the tapped magma (Civetta et al., 1991; Mues-Schumacher 1994; Cioni et al., 1995; Redi et al., 2016). The internal structure of the Plinian fallout deposit, a topic of ongoing debate among researchers, has been described as massive or graded (Lirer et al., 1973; Sigurdsson et al., 1985; Cioni et al., 1992; Doronzo et al., 2022). Pyroclastic density currents (PDCs) were produced immediately before, during and after the fallout phase of the grey pumices, flowing radially around the volcano. The role of phreatomagmatism during the eruption is debated. The beginning of magma-water interaction is related to the first PDC after the fallout phase (Barberi et al., 1989; Cioni et al., 1996) or, more probably, to the last stage of the eruption (Sigurdsson et al., 1985), as evidenced by the abundance of accretionary lapilli and the high degree of particles fragmentation. The emplacement of the PDCs during this latter stage was not continuous, as is shown by the presence of four lithic-rich fall layers recognised in the upper part of the sequence (Luongo et al., 2003a,b; Scarpati et al., 2020) interstratified with the PDC ash deposit.

Despite being extensively studied further stratigraphic and analytical investigations of these deposits will provide insight into the timing, intensity, and magnitude of the different phases of this eruption. The Plinian fall deposit has been described as chemically zoned and massive or graded, although some grain-size and component variations have been recognized (Lirer et al., 1973; Sigurdsson et al., 1985; Carey and Sigurdsson 1987; Cioni et al., 1990; Luongo et al., 2003b; Scarpati et al., 2020). No internal subdivisions have been identified, and isopachs are based on the difference in colour between the phonolitic and tephriphonolitic products (Sigurdsson et al., 1985). Recent examinations have revealed that several Plinian deposits, previously described as massive, were in fact stratified. Prominent examples include the Plinian fall deposit of Taupo (Houghton et al., 2014), as well as the Plinian fall deposit of the Campanian Ignimbrite (Scarpati and Perrotta, 2016). Inevitably, these new findings have led to a significant variation in eruptive parameters, distribution and potential impact of this type of eruption. The presence of sustained column pulses during the late, collapsing column phase remains an area of uncertainty. Some lithic-rich layers have been recognised in the upper-part of the stratigraphic sequence. Sometimes they have been associated with fallout layers (Sigurdsson et al., 1985; Cioni et al., 1999; Luongo et al., 2003b; Scarpati et al., 2020) and sometimes with the basal layers of pyroclastic currents (base of EU4 and EU7 units of Cioni et al., 1990) associated with an instability of the conduit, and the expulsion of abundant lithic material which was then taken over by the pyroclastic flow (Barberi et al., 1989b; Cioni et al., 1990). Even recently, despite the recognition of these lithic-rich layers interstratified with the higher pyroclastic current deposits, neither isopleth nor isopach maps have been draw (Scarpati et al., 2020). Finally, although many petrochemical studies on the juvenile component of the 79 AD eruption have been presented in literature (Civetta et al., 1991; Cioni et al., 1992, 1995; Mues-Schumacher et al., 1994; Shea et al., 2002; Redi et al., 2016), a large disagreement still exists about the dynamic of withdrawal from the vertically-stratified magma chamber during the eruption and the interaction between the "white" phonolitic magma and the "grey" tephriphonolitic magma.

The current study focuses of the fall deposits recognized within the entire stratigraphic sequence (i.e., belonging to both the Plinian and the post-Plinian phases of the eruption) with the aim of resolving the most debated topics mentioned above. In particular, the internal structure of the pumice lapilli deposit is being studied in detail to reconstruct the dynamics of the eruptive column during the Plinian fallout phase, with the aim of identifying and defining the presence of sub-units that can be correlated with the use of a multidisciplinary approach (stratigraphic, sedimentological, and petrochemical). In addition, this study presents new stratigraphic and volcanological evidence for the existence of five lithic-rich lapilli fallout layers, interstratified with the pyroclastic density current deposits, emplaced after the total collapse of the 79 AD Plinian column. A total of 434 samples were collected from various stratigraphic sections located around Vesuvius, out of which 363 were selected for grain size analysis and 319 for component analysis. Of these 319 samples, 6 were also selected for density measurements, 5 for crystal enrichment factor estimation and 87 for chemical analyses on the juvenile fraction. The results of the analysis were used to group sub-levels within the white and grey pumice fallout deposit into units, represent the distribution (at the regional scale) of both Plinian and post-Plinian fallout units, estimate their eruptive parameters (e.g., volumes, column height, mass discharge rate, tephra mass etc.) and reconstruct a model of withdrawal from the vertically-stratified 79 AD magma chamber. In addition, thanks to the recent excavations carried out in collaboration with the Archaeological Park of Pompeii, it was possible to make a detailed stratigraphy of the deposit within the archaeological excavation of Pompei (and in the imposing Roman villas) to define the exact stratigraphic position at which the damages were found.

1. The sustained column phases of the 79 AD Vesuvian eruption: a critical review of the volcanological literature

1.1 Plinian eruptions: the case study of the 79 AD Vesuvius eruption

Plinian eruptions are particularly dangerous events that often have long-lasting consequences (Fisher and Schmincke, 1984; Sparks et al., 1997; Cioni et al., 2015). They produce high eruptive columns that inject considerable volumes of pyroclasts and volcanic gases into the stratosphere (Fierstein and Nathenson, 1992; Bonadonna and Philips, 2003; Macedonio et al., 2005; Bonadonna and Costa, 2013; Klawonn et al., 2014). Pyroclastic clasts fall back to the ground forming widespread tephra sheets in which different components are distinguished: juvenile clasts, lithic clasts and crystals. Juvenile clasts, well vesiculated, produced during the magma fragmentation into the volcanic conduit, are typically the main components of these eruptions. This 'classical' behaviour is well represented by the most famous and first documented Plinian eruption that occurred in 79 AD at Vesuvius, which gave the name to this type of activity and whose study has given a strong contribution to the modern volcanology (Sigurdsson et al., 1982; Sigurdsson et al., 1985; Macedonio et al., 1988; Barberi et al., 1989; Barberi et al., 1990; Cioni et al., 1992; Lirer et al., 1993; Cioni et al., 1995; Pyle, 2000; Luongo et al., 2003a, b; Scarpati et al., 2020). The term "Plinian" takes its name from Pliny the Younger, who, in the two letters written to Tacitus (Gigante, 1989), several years after 79 AD, described the eruption in extreme detail and reported the death of his uncle, Pliny the Elder, scientist and admiral of the Roman fleet in Pozzuoli.

The exact date of the eruption is still subject of scientific debate. It is commonly referred to that indicated in a letter from Pliny the Younger to Tacitus, in which it is attested that the eruptive event began *"nonum kal. Semptembers"* that is nine days before the Kalends of September (e.g. August 24th). However, in some manuscripts and older editions, the exact name of the month does not appear, and the reference is truncated.

Based on some archaeological evidence, the archaeologist Carlo Maria Rosini raised doubts about the traditional dating.

During the excavations at Pompeii and Herculaneum, traces of autumn fruits, chestnuts, dried figs, walnuts, and pomegranates were found. In addition, many braziers were found in the lobbies of many houses. This archaeological evidences thus indicates that the texts of Pliny the Younger should likely refer to December, thus proposing to read the date as "nonum kal Decembres" (i.e. November 23rd).

Stefani (2006) reported the discovery of a silver coin belonging to a victim of the eruption, found in the excavations of the House of the Golden Bracelet in Pompeii. This coin shows the image of the emperor Titus (Giove, 2003), which suggests that the coin should be dated after September 7th/8th (date of the fifteen acclamation of Tito). Furthermore, new findings in the archaeological site of Pompeii, such as a charcoal inscription, have made possible to re-evaluate the date of the eruption (Fig. 1.1). The inscription found in Pompeii reports the words: "*XVI (ante) K(alendas) Nov(embres) in[d]ulsit pro masumis esurit[ioni]*" which means: "The sixteenth day before the kalends of November, he indulged in food in an immoderate way". *Kalendes* are the first day of each month, so in this case, the date corresponds to the 17th of October. If we add to all this complementary information the finding of heavy clothes worn by the victims of the eruption and the wine sealed in the "*dolia*", we must necessarily deduce that the eruption took place in late autumn, likely between October 24th and November 1st.

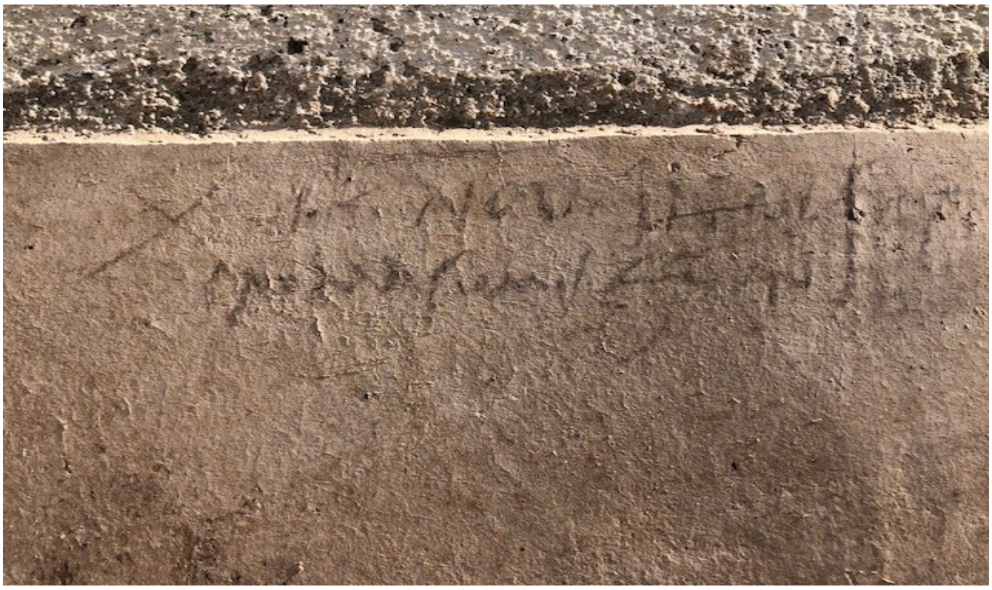

Figure 1.1 Charcoal inscription found during the new excavations carried out in the *Regio V at Pompeii (from http://pompeiisites.org/)*

Rolandi et al. (2007) analysed the meteorological data collected at the Pratica di Mare (Rome) and Brindisi stations, considering the direction and the velocity of the main winds between 2 and 40 km. They observed that these winds blow mainly towards the South – East during in autumn and winter, from East to West in summer, and can change from West-directed to E-directed between May and October . The common dispersions of the 79 AD deposits towards the South-East are thus consistent with the distribution of ashes from high altitude winds from October to June. The dispersion towards the South - East appears to be anomalous– since it is not consistent with the direction of the high-altitude winds from June to August, which blow towards the West. Therefore, further validity is given to the hypothesis that the eruption occurred in the autumn period.

Thanks to these reports and to the chronological references in the two letters it was possible define the chronology of the eruptive phases with moderate precision (Sigurdsson et al., 1985).

Although there are several differing interpretations regarding the depositional and transport processes associated with the 79 AD eruption, there is a substantial agreement in the recognition of four main stages (Sigurdsson et al., 1985; Cioni et al., 1992; Gurioli et al., 2007; Luongo et al., 2003a):

- A phreatomagmatic opening phase related to the interaction between the rising magma and the overlying aquifers. This type of activity resulted in the emplacement of an ash deposit along the volcano slopes (this event began after noon on October 24th).
- A main magmatic phase, with the formation of a high eruptive column, which mainly emplaced a white phonolitic pumice fallout deposit dispersed towards the South of the volcano, and a grey tephriphonolitic pumice fallout deposit dispersed towards the South-East. This variation in the dispersal direction is probably due to a variation of the atmospheric wind direction during this phase of the eruption, which likely lasted about 18-19 h.
- A second magmatic phase related to the eruptive column collapse, which was very energetic and characterized by the formation of pyroclastic density currents (PDC) rich in lithic fragments. Structural variations of the volcanic building, such as calderic collapse and vent widening, are considered the main causes of the increase in the mass eruptive rate registered during this phase, which began in the early hours of October 25th.
- A final phreatomagmatic phase, with the deposition of PDC products rich in accretionary lapilli.

The 79 AD eruption heavily damaged the Roman towns of Pompeii, Herculaneum, Oplontis, Stabiae and a significant part of the peri volcanic area up to 15 km away from the vent (Kent et al., 1981; Sigurdsson et al., 1985; Gurioli et al., 2002, Gurioli et al., 2005; Cioni et al., 2002; Cioni et al., 2004; Zanella et al., 2007; Scarpati et al., 2020; Doronzo et al., 2022), becoming famous since the historical times of Pliny the Younger and today being one of the best studied Plinian eruptions ever occurred. However, as mentioned above, a large disagreement still exists in the scientific community regarding the stratigraphy of the products. Some of the most debated topics include: 1) the first opening phase of the eruption, 2) the internal structure of the Plinian fall deposit and 3) the fallout areal distribution and finally 4) the erupted volumes. Therefore, in the next paragraphs I will synthesise the main outcomes of the various studies carried out on the 79 AD eruption, with a specific focus on the most debated topics.

1.2 Dynamics and stratigraphy of the eruption

The first studies on the 79 AD eruption date back to the XVIII and XIX centuries and are often the result of archaeological finds and volcanic insights.

The first geological study of undoubted scientific value on the Somma-Vesuvius, in which the products of the 79 AD eruption are analysed in a strictly volcanological sense, is due to Johnston-Lavis (1884), who initially did not admit the presence of pyroclastic products on the external slopes of the Somma.

In 1908 Lacroix speculated that most of the outcrops from the AD 79 deposits were produced by phenomena of *nuée ardent* type, eruptive phenomena already observed during the eruption of the Pelée (1902) in Martinique (Lesser Antilles). Merril (1918; 1920) also proposed that Pompeii had been inundated by burning clouds.

In any case, during those years there were many uncertainties related to the different interpretation of the stratigraphic data and many ambiguities related to the origin, transport and deposition of the products emitted by the volcano during the 79 AD eruption.

In the early 1950s, the researchers' interest was essentially directed to the archaeological areas of Pompeii and Herculaneum. In a 1950 article, Ippolito discusses the "burial mechanism" of the two ancient cities.

Ippolito (1950) highlighted the different sedimentological characteristics of the deposits in the two archaeological sites and interpreted them with two different depositional mechanisms: burial by lapilli falling from a volcanic cloud in Pompeii and mudflows for Herculaneum. Rittmann (1950) confirmed the hypothesis of Pompeii and Herculaneum burials and presented a magmatological analysis of the 79 AD eruption, arguing that when Pliny observed the eruptive column around 1 pm, the eruption had probably already begun a few hours earlier. A first mention of this phase is found in the work of Dione Cassius where it is reported that "*stones of extraordinary size were raised to the top of the mountain*" (Rittmann, 1950).

Lirer and Pescatore (1968) presented a sedimentological study on the Somma-Vesuvius pyroclastic deposits, focusing on the different textural aspects of the deposits of the 79 AD eruption, while Di Girolamo (1963, 1968, 1970) recognized the pyroclastic sequence also on the NNE slopes of Monte Somma and mainly focused on the petrology of the juvenile clasts.

In those years, however, there was still a strong limitation regarding the study of eruptive and

emplacement mechanisms of explosive eruptions. The turning point came in the 70s when the first numerical models and the first classifications of the 79 AD deposit were proposed (Walker et al., 1971; McBirney, 1973; Walker, 1973; Blackburn et al., 1976; Sparks e Wilson, 1976; Wilson 1976; Sparks et al., 1977; Nairn e Self, 1978; Self e Sparks, 1978; Wilson et al., 1978; Wilson, 1980; Wilson et al., 1980).

In particular, the first studies on the mechanisms of origin, transport and deposition of pyroclastic flows are carried out, with the recognition and the detailed analysis of those deposits that in previous decades were referred to as mudflows or as reworked (Sparks and Walker, 1973; Sparks, 1976; Sparks et al., 1978; Fisher, 1979; Sheridan, 1979).

A detailed study on the 79 AD products was reported in a paper by Lirer et al. (1973), which will represent a reference for subsequent studies (Fig. 1.2). Notably, Lirer et al. (1973) were the first to make a clear distinction between the products of the 79 AD eruption from those of the previous Avellino eruption, dating back to ca. 3.8 ka.

Figure 1.2 Map of the Vesuvius area. Stippling shows the known extent of the Pompei (A.D. 79) and Avellino Pumice, and the locations of places referred to in the text. S = Monte Somma; V = Vesuvius. (*Lirer et al., 1973*)

The authors interpreted the well-known colour variation of the pumice clasts as the result of the emptying of a zoned magma chamber, with more differentiated magma batches in the uppermost portions and less differentiated batches in the deepest. In agreement with Rittmann (1950), Lirer et al. (1973) suggest that the magma chamber was located at a depth between 5 and 6 km below the sea level, if a cylindrical shape with a vertical height of the order of 5 km and an basal diameter of 350 m were assumed. Finally, they also used Pliny's letters to estimate the timing of the eruption. The conclusions drawn from Lirer et al. (1973) were essentially confirmed by Delibrias et al. (1979).

The first physical model of the 79 AD eruption was proposed by Sheridan et al. (1981), represented in the sketch of Fig. 1.3.

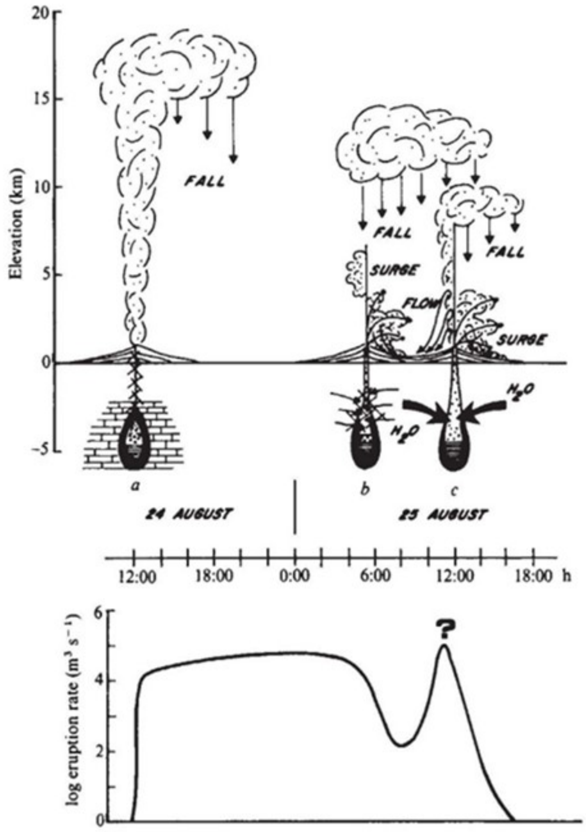

Figure 1.3 Schematic model of the AD 79 AD eruption of Vesuvius related to eruption phenomenology described by Pliny the Younger as proposed by Sheridan et al. (1981). See text for full explanations.

The model presents a classic eruptive sequence consisting of pyroclastic fallout, pyroclastic surges, and flows and lahars. According to the authors, the eruption opened (began/started) with a magmatic phase, with a sustained column of about 17 km, which deposited the white pumice fallout deposits. The progressive emptying of the magma chamber and the rupture of the sedimentary basement caused the i inflow of seawater into the magma chamber. The vaporization of water increased the volatile budget of the magma, thus causing an increment in the explosivity of the eruption and an increase of the eruptive column height. This resulted in the fallout of the grey pumice clasts, denser and larger than the white ones. The surge deposits interstratified with the fallout deposits were described as "hot and dry", massive or "sand-wave", and are interpreted as the results of the so-called "base surge" related to the first processes of interaction between water and magma. This phase represents the most energetic one. The authors suggest that the eruptive rate may have reached a maximum value of the order of 10^5 m^3/s.

As the eruption continued, the activity first became hydromagmatic, with wet surges and pyroclastic flows, then, once the magma was exhausted, became purely phreatic. At the end of the eruption, lahars were also deposited in Herculaneum. Like Sheridan et al. (1981), also Leoni (1980) and Barberi et al. (1981) investigated the 79 AD eruption to better understand the structure of the magma chamber of Somma-Vesuvius. Thanks to the study of the carbonate lithic fragments found within the pumice fallout deposits, the depth of the vertically zoned magma chamber was recalculated and placed at about 2000-4000 m in the sedimentary basement. Furthermore, the shape (cylindrical), the dimensions (h = 2 km; d = 1 km) and the volume of the magma reservoir (2 Km^3) were also modelled. According to these authors, the white pumice clasts would have originated from the differentiation (trough fractional crystallisation) of an original tephritic liquid with a temperature of 850 °C, at the time of the eruption.

Careful examination of Pliny the Younger's letters was also used to relate the eruptive events to the time scale of the facts narrated by Sigurdsson et al. (1982), who also estimated the physical parameters of the eruption such as the eruptive rate during the different phases of the eruption and the sedimentation rate of the pumice lapilli at Pompeii (deposition of more than 280 cm of air-fall pumice over Pompeii with a sedimentation rate of 15 cm per hour during an 18-hour period).

1.2.1 Initial phase of the eruption: fallout or pyroclastic current deposit?

The first topic of debate among the various authors dealing with the 79 AD eruptive sequence was the nature of the first level found in some proximal areas of Vesuvius, at the base of the white pumice lapilli deposit. The proposed models are summarised in Table 1 and described in detail in this section.

Until 1985, an initial hydromagmatic opening phase of the eruption had never been recognized. In fact, Sheridan et al. (1981), argued that the eruption opened with a magmatic phase, with a sustained column from which white pumice clasts were deposited.

Sigurdsson et al. (1985) proposed a detailed work on the stratigraphy of 79 AD eruption, comparing both proximal and distal sequences to reconstruct the eruptive dynamics of the eruption.

These authors suggested that the eruption opened with a phreatomagmatic explosion responsible for the deposition of a thin ash fallout layer (A1) in some areas on the eastern side of the volcano (Fig. 1.4). This is clearly different from the dispersal of the subsequent pumice fallout and was interpreted to indicate that the initial explosion produced a low eruption column, which was dispersed easterly by low-level local winds and was not influenced by stratospheric winds.

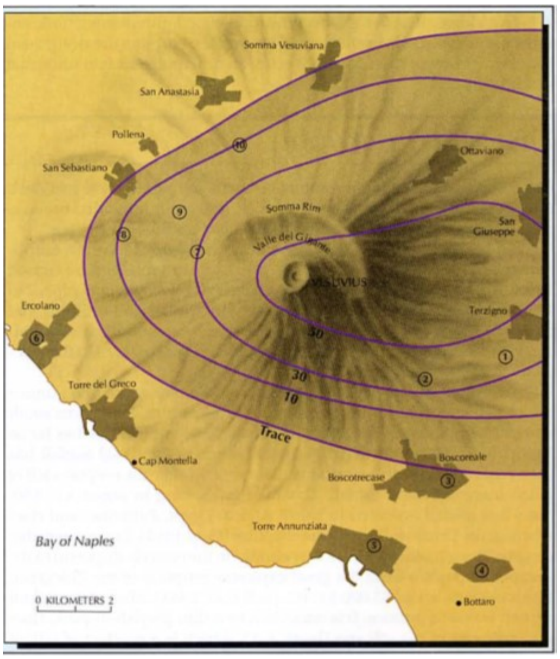

Figure 1.4 Isopach map of the ash- fall layer A1, showing easterly dispersal from the crater (contours in millimeters). (Sigurdsson et al., 1985)

The ash fall layer is at most a few centimetres thick, consisting of light grey, fine ash. The presence of accretionary lapilli and the fine-grained character of this layer indicate that ash fell from a "wet" eruption cloud, and that the explosion induced a high degree of fragmentation. Evidence from the volcanic deposits at the villae rustica in Terzigno indicates that this explosion probably occurred before the main Plinian event.

Barberi et al. (1989) presented both grain-size data and component analysis of pyroclastic deposits, in order to recognise the products of the phreatomagmatic activity and to contribute to the understanding of the condition governing this explosivity style.

At the base of the sequence, directly above a well-developed paleosoil, the authors recognised a thin coarse ash layer of constant thickness, containing accretionary lapilli. This thin layer was found in most proximal outcrops and ascribed to the very initial fallout phase of the eruption, related to the explosive opening of the vent. Lithic ejecta were observed to consist mainly of lava fragments and include relatively abundant carbonate clasts (8 wt.%).

Cioni et al. (1990) studied 20 stratigraphic sections from the area between Ottaviano and the plain south of Pompeii and re-examined the succession of some deposits from archaeological sites around the volcano. The authors adopted a new scheme for the description of the observed stratigraphic sequences based on the concept of Eruptive Unit (EU).

In the entire eastern sector, the basal layer of the eruption is represented by a light grey ash level (EU1). Despite the thickness is variable (from 1 to 7 cm) and scattered accretionary lapilli and rounded pumice lapilli are present, this level was further attributed to a fallout mechanism. Locally, in the basal part of the deposit coarser components were observed in lentiform levels. Abundant footprints of plant remain (rustles and leaves), perfectly preserved due to the fine grain size and the cohesive nature of the ash (which speaks for its phreatomagmatic, low temperature origin), have also been found in this basal layer.

A new approach to the study of the 79 AD eruption was proposed by Lirer et al. (1993; 1997). The authors presented a reconstruction of the various eruption phases based on detailed analysis of grain-size composition, lithological component distribution and chemical composition of 99 juvenile samples, collected along the six stratigraphic sequences of Pompei, Oplontis, Boscoreale, Ercolano, Terzigno and the Pozzelle quarry (see Fig. 4 for site localizations). In the Terzigno and Pozzelle sequences, the thin ash layers cropping out directly above the paleosoil and underlying the white pumice fallout deposits, show a very different component distribution, suggesting that the two deposits, are not correlated, despite both represent an opening eruptive phase. This evidence, together with grain size distribution data, was the first to ever cast some doubts about the fallout origin of this layer, largely proposed by previous workers (Sigurdsson et al., 1985; Barberi et al., 1989; Cioni et al., 1990).

The bimodal grain-size distribution, together with the very limited dispersal of the deposits from this phase would better suggest a depositional mechanism related to a pyroclastic flow. Furthermore, the very high fragmentation of the juvenile fraction, the occurrence of accretionary lapilli and their morphology as observed at the SEM suggest a weak water-magma interaction.

From 1999, an overall agreement has been found (Cioni et al., 1999; Gurioli et al., 1999; Gurioli et al.; Luongo et al., 2003a, b; 2003b; 2005; Doronzo et al., 2022) that the eruption started with a short-lived phreatomagmatic phase, producing an accretionary-lapilli-bearing fallout ash deposit (~0.10 m in thickness), with an eastward dispersal. However, in some sites on the western slopes of the volcano, the EU1 is associated with a fine grained pyroclastic current deposit (Cioni et al. 1999). According to Sigurdsson et al. (1985), EU1 records an initial transient phreatomagmatic phase that marked the opening of the conduit. The exact timing of EU1 deposition is not very clear, but it was suggested that it could have triggered the first plea for help to Pliny the Elder from the Vesuvian area (Sigurdsson et al. 1985).

Below is a summary table (table 1) with the interpretations of the opening phase of the eruption:

Authors	Nomenclature	Fallout/Pyroclastic flow deposit	Magmatic/Phreatomagmatic phase	Description
Sheridan et al., (1981)	-	-	Magmatic	The eruption opened with a magmatic phase that directly deposited the white pumice fall
Sigurdsson et al., (1985)	A1	Fallout	Phreatomagmatic	The ash fall layer is at most a few centimeters of light grey, fine ash. The presence of accretionary lapilli and the fine-grained character of this layer indicate that ash fall from a "wet" eruption cloud, and that the explosion induced a high degree of fragmentation
Barberi et al., (1989)	VS-84 25	Fallout	Phreatomagmatic	Thin coarse ash layer containing accretionary lapilli and having constant thickness, directly overlies a well-developed paleosoil. This thin layer occurs in most proximal sections
Cioni et al., (1990)	EU1	Fallout	Phreatomagmatic	Light-gray ash with variable thickness and although there were scattered accretionary lapilli and rounded pumice lapilli. In these basal ashes have also been found abundant footprints of plant remains (rustles and leaves). The perfect preservation of the plant footprints has been made possible by the fine grain size and the cohesive character of the ash of this level that shows phreatomagmatic and low temperature deposition characters
Lireri et al., (1993; 1997)	-	Pyroclastic flow	Phreatomagmatic	No description provided. They noted however that in the Terzigno and Pozzelle sequences, the thin ash layers displayed a very different component distribution
Cioni et al., (1999)	EU1	both	Phreatomagmatic	No description provided. The authors assume directly that the eruption start with a short-lived phreatomagmatic phase, producing an accretionary-lapilli-bearing fall ash with an eastward dispersal, but, in some sites on the western slopes of the volcano, EU1 is associated with fine grained PDC deposits

Table 1. Summary table with all the interpretations of the different authors regarding the initial phase of the 79 AD Vesuvius eruption

1.2.2 Internal structure of Plinian lapilli fall deposit: massive, graded or stratified?

Another topic of debate regarding the 79 AD eruption is the internal structure of the Plinian fallout deposit that followed the first phreatomagmatic phase.

A relevant support for addressing this issue is provided by studies conducted on the fallout deposit associated with the 186 AD Taupo eruption (Walker et al., 1980; 1981b,c; Wilson et al., 1985; 1987; Houghton et al., 2014).

This eruption is the youngest volcanic event at Taupo volcano, in the central Taupo Volcanic Zone of New Zealand, representing the second largest eruption worldwide in the past 2000 years, probably the most powerful in the past 5000 years (Wilson and Walker, 1985). The eruption is also renowned for its large variability of explosive eruptive styles, and for the extreme mass discharge rates inferred for the unit 5, the Taupo Lapilli Member, and the unit 6, the climactic Taupo ignimbrite (Wilson and Walker, 1985). The eruption products are mapped as seven units, corresponding with seven different eruption phases. The eruption occurred from at least three vents on a 10-km-long northeast-southwest striking fissure, on the eastern shoreline of Lake Taupo (Smith and Houghton, 1995). Unit 5 is a widespread lapilli fallout deposit (5.8 km^3 dense-rock equivalent [DRE]), erupted together with at least 11 small pyroclastic density currents. After phase 5, the explosive volcanism culminated in the generation of unit 6, the 12.1 km^3 (DRE) highly energetically emplaced Taupo ignimbrite (Wilson, 1985).

Walker (1980) used “full-thickness” data to propose that unit 5 represented an extremely high eruption rate for steady eruptions, defining a new end-member class called ultraplinian. According to the author, “full thickness” refers to isopachs drawn from thicknesses measured across the entire unit and isopleths derived from size data for the largest clasts collected over the entire thickness of the deposit at each site. Houghton et al. (2014) recognized and mapped 26 subunits within the Taupo Lapilli member (Fig. 1.5) and showed that previously undetected wind shifts during the eruption resulted in major overestimates of both the deposit thinning and the pyroclasts fining rates, thus resulting in the overestimation of its dispersal power. The characteristics of individual subunits do not meet Walker’s criteria for ultraplinian eruptions, and suggest that the eruption was merely a strong, but not atypical, Plinian event.

The dispersal of a fallout deposit is a function of both eruption column height (a source parameter) and the wind field (a path effect). Estimates of plume height from dispersal data may be influenced by “variations in wind direction which will increase the apparent crosswind range (of a particle) and thus overestimate column height” (Carey and Sparks, 1986). Maximum clast sizes at individual sites reflect the progressive shift in dispersal, that is, the coarsest clasts were sampled from the base of the sequence in the south and at the top of the sequence in the north. In the case of Taupo eruption, the largest clasts used by Walker (1980) to draw the isopleth contours are therefore not strictly time equivalent at each site, since they refer to different subunits for different parts of the dispersal area that were erupted at different times. The new subunit isopleth data by Houghton et al. (2014) show(s) that the footprint of each isopleth contour is much larger for the combined full-thickness data than for data from each subunit. Plume heights for the coarse-grained subunits, calculated after Carey and Sparks (1986), range from 31 to 37 km, consistent with the range of 34–41 km observed or recorded for the strongest historical Plinian eruptions (Williams and Self, 1983; Rosi et al., 2001).

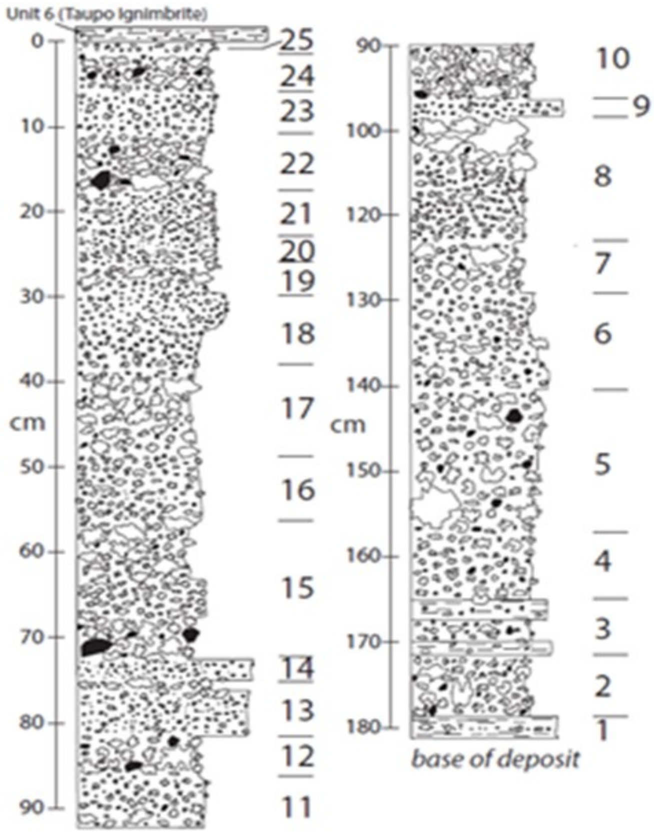

Figure 1.5 Stratigraphic log for unit 5 at site 25 km northeast of vent, showing 25 subunits recognized; Juvenile pumice is in white; wall-rock clasts (mostly older rhyolitic lava) are in black. Note particularly the finer-grained subunits (e.g., 1, 9, 14) interpreted to represent weaker pulses of the sustained eruption column. (From Houghton et al., 2014)

The study by Houghton et al. (2014), carried out over the years, remains an excellent example to understand the importance of the internal structure of a Plinian fallout deposit and its relevance in the classification of an eruption.

Lirer et al. (1973) described the 79 AD fallout deposit (the so-called "Pompei Pumice") as a very coarse deposit with an average diameter of pumice clasts of about one centimeter, that is remarkably homogeneous throughout its thickness. The authors describe three main departures from homogeneity (Fig. 1.6):

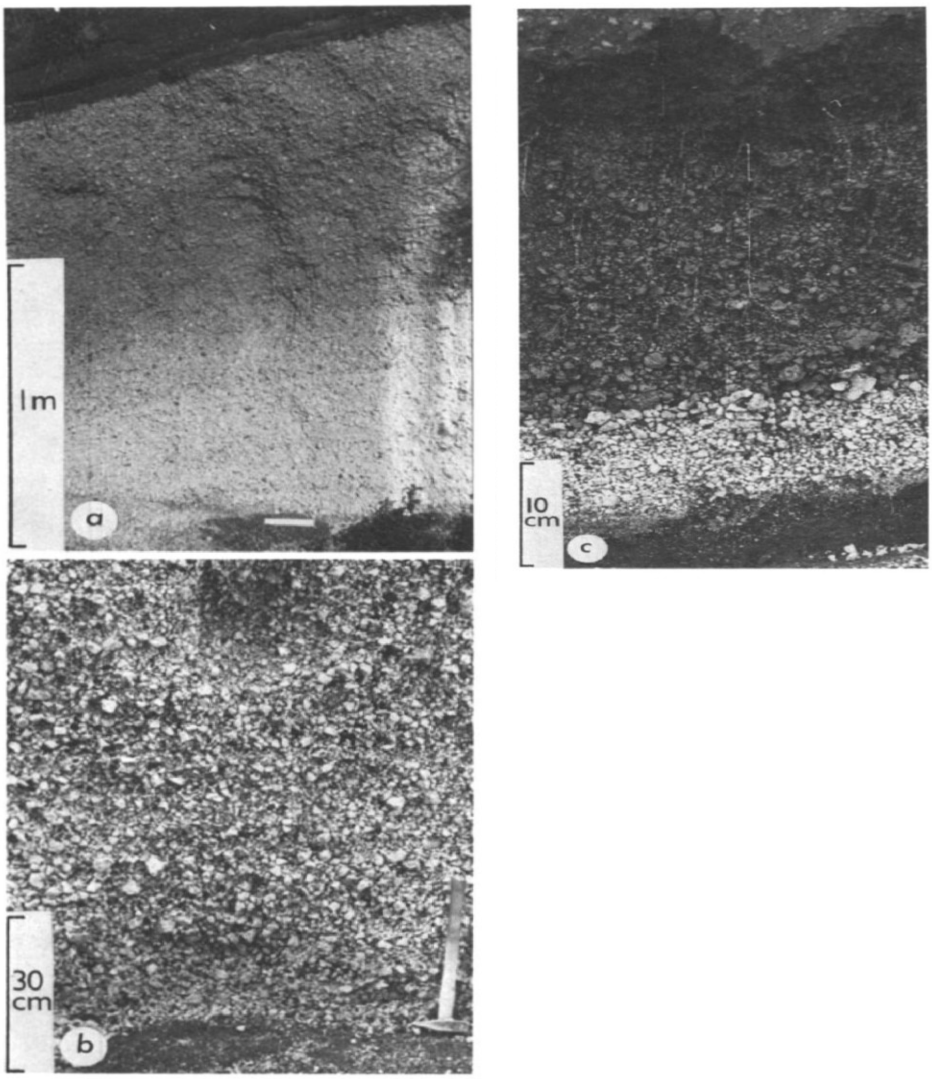

Figure 1.6 The Pompei pumice deposit. a. Part of the Pompei Pumice at Porta Anfiteatro showing the change in colour from white to grey and the overlying dark ashes
b. The lowermost one meter of white pumice at Porta Vesuvio, Pompei, showing the homogeneity of the deposit. c. Section at the site for an autostrada restaurant 3.5 km east-southeast of Nocera showing the abrupt colour change and reverse grading of pumice in the lower part, and the underlying soil. ***(From Lirer et al., 1973)***

One is the rather abrupt upward change in the colour of the pumice clasts, from white to greenish grey roughly halfway up in the deposit; the second is a faint stratification due to minor variations in the grain size and content of lithic fragments; the third is an overall slight but distinct upward increase in the grain size. From here, without specifying what type of values they have been used (maximum deposit thickness for the reconstruction of isopach maps or the maximum diameters calculated for isopleths maps), they reconstruct isopleth and isopach maps.

Regarding the internal structure of the deposit, Sigurdsson et al. (1982) agreed with Lirer et al. (1973). In addition, they observed that "air-fall layer" (term used to describe all the fallout deposit) also contain dense fragments of limestone and older volcanic rocks, ripped off from the walls of the volcanic conduit during the explosive eruption. These rock fragments, rarely exceeding 12 cm in length, make up ca. 12% of the lower half of the pumice deposit, then increased to ca. 20% in the upper grey part. The upward increase of both the size of the pumice clasts and the lithic content, together with the wider dispersal of the grey pumice layer, led Lirer et al. (1973) to propose that the climax of the Plinian phase of the eruption was reached during the emplacement of the grey pumice deposit.

Sigurdsson et al. (1985) used an alphanumeric scheme to identify the various layers making up the 79 AD fallout deposits, which they numbered sequentially from A-1 (the basal fine ash) to A-9. Similarly, the pyroclastic surge layers were numbered from S-1 to S-7, and the pyroclastic flow deposits were labelled F-1 to F-6. The white pumice lapilli deposits correspond to layer A-2, while layers from A-3 to A-9 represent the grey pumice lapilli deposits (Fig. 1.7).

Figure 1.7 The A.D. 79 pumice fallout deposit cropping out near Stabiae, with lower white pumice (A-2) and upper gray pumice layers (A-3 to A-6). ***(From Sigurdsson et al., 1985)***

A gradual increase in clast size is generally observed up to the A-4 layer (in some cases up to A-3 or A-5), reflecting a gradual increase in the eruptive column height. Upwards, the size of pyroclasts systematically decreases, indicating a gradual reduction in the height of the eruptive column. In addition, a change in the abundance of the various components is observed from the A-7 to the A-9 layers, with an increase in the lithic fraction and a decrease in the juvenile content (see Fig. 1.8).

Four episodes of surge and flow generation occurred in association with grey ash and pumice fallout. Field data show that the amount of lithic fragments was increasing with the stratigraphic height and that the height of the eruption column reached a maximum and then began to subside. At this stage of the eruption, the magma evacuation could have led to the collapse of roof-rocks. The increase in lithic fragments thus can be interpreted to represent an increasing disruption of the upper parts of the reservoir and conduit system. After the emplacement of the sixth lithic-rich surge, a new phase of activity began. Lithic-rich, fine ash beds containing abundant accretionary lapilli, are observed above the S-6, indicating a shift to phreatomagmatic activity. A thick sequence of interbedded accretionary lapilli beds and finely stratified, lithic-rich surge deposit was laid down during this final phase.

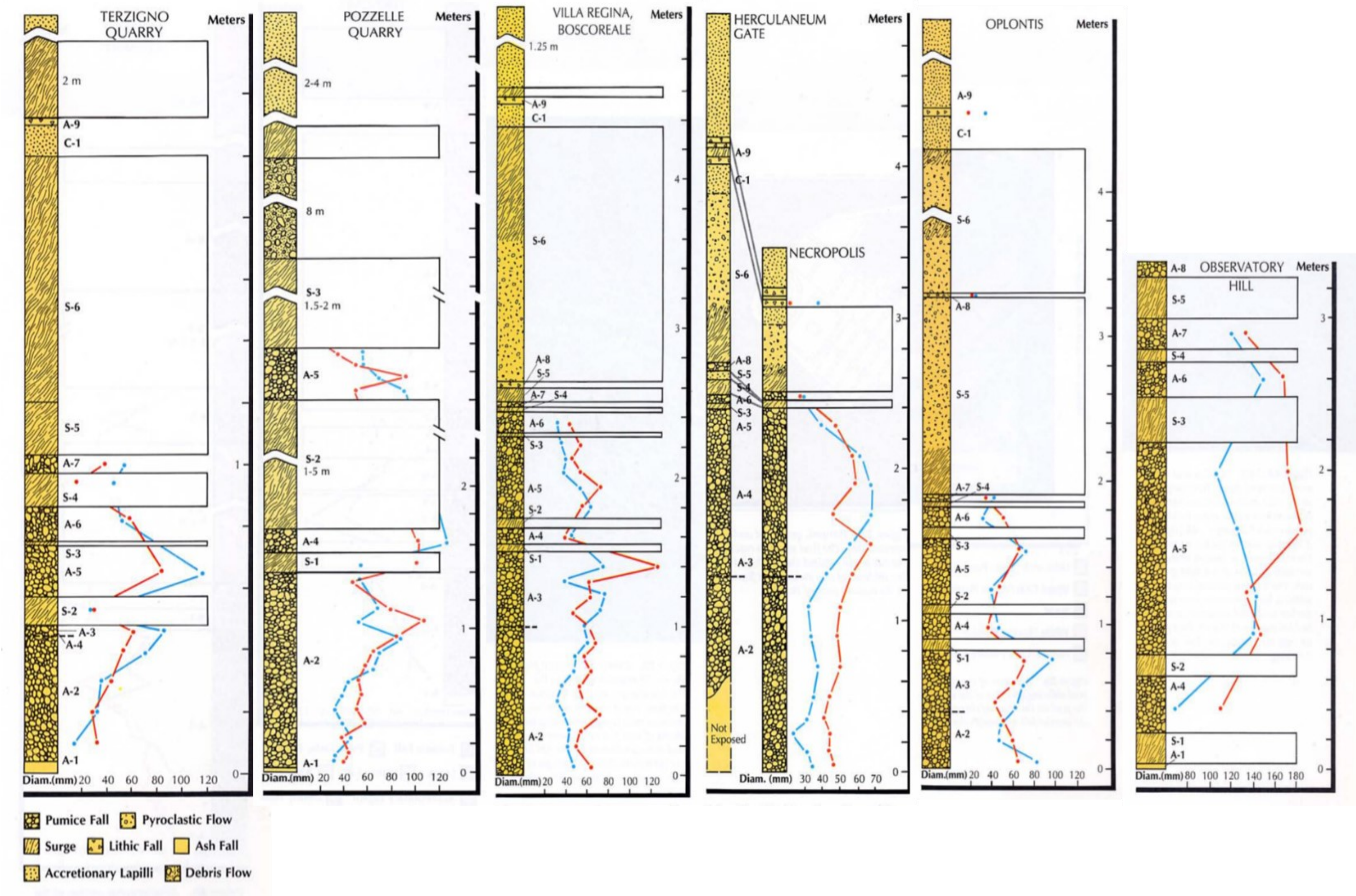

Figure 1.8 The proximal and distal stratigraphic sections of the 79 AD eruption deposits reconstructed by Sigurdsson et al. (1985), showing the variations in the maximum diameter of pumice (red) and lithic clasts (blue).

Barberi et al. (1989) studied the granulometric features and lithological components of the 79 AD deposits in a proximal site (Cava Pozzelle), distinguishing the products related to the magmatic and hydromagmatic phases of the eruption (Fig. 1.9).

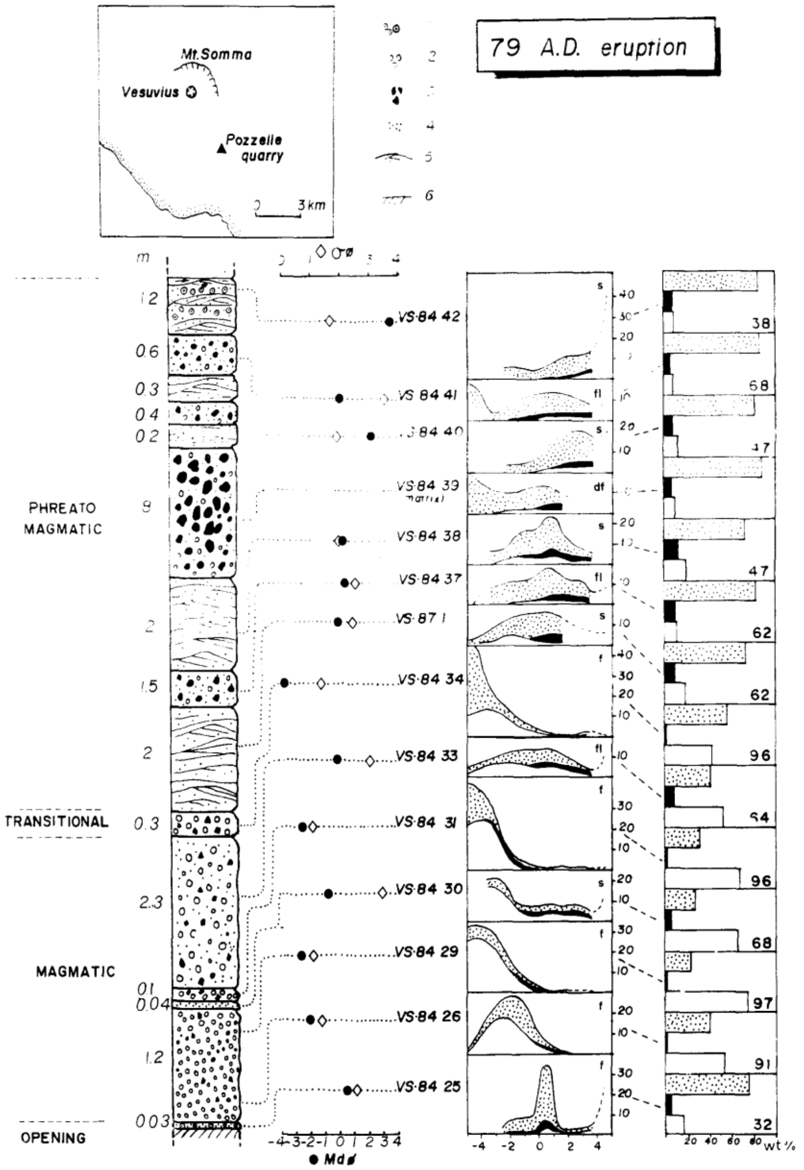

Figure 1.9 79 A.D. eruption: Cava Pozzelle section. From left to right are shown: eruptive phases; stratigraphic column and Inman sorting coefficient (rhombus) values for the samples; grain-size distribution and composition of the total sample (number refers to the analysed percentage; analysed percentage is not reported for sample VS84 39 which represent only the hand-collected matrix of the debris flow): juvenile (unornamented), crystals(solid) and lithics (stippled) ***(from Barberi et al., 1989)***

According to the previous articles (Lirer et al., 1973; Sigurdsson et al., 1985), the Plinian fallout deposit consists of a reversely graded coarse pumice bed, 130 cm thick.

Fallout beds are characterized by juvenile material exceeding 58 wt.% with no systematic preferential concentration in specific grain-size classes (Barberi et al., 1989). Although the grain-size populations and emplacement mechanisms are completely different, the surge (VS-84 30) and the pumice flow (VS-84 33) deposits (see figure 9) related to the magmatic phase of the eruption exhibit very similar component distribution patterns with respect to those of the fallout deposits. This sequence is capped by a ca. 30 cm thick coarse fall bed (VS-84 34), characterized by abundant lithic ejecta of deep provenance (marbles, skarns, cumulates). According to both Lirer et al. (1973) and Sigurdsson et al. (1985), this level marks the beginning of the phreatomagmatic activity. In summary, the Plinian eruptive column was formed, and its height increased progressively, following an increase in the mass eruption rate (Wilson et al., 1980), as suggested by the observed reverse grading. The grain-size polymodality of the ash cloud deposit (VS-84 30) reflects contamination by fallout products, confirming the hypothesis of a partial column collapse proposed by Sigurdsson et al. (1985). The pumice flow deposits overlying the fallout beds closed the magmatic phase and possibly mark the total collapse of the eruptive column. Finally, the prevalence of limestone lithics, with respect to lavas, observed in the final phreatomagmatic deposits, confirms that the magma-water interaction occurred at the level of the Mesozoic limestones (located at a depth of 8-10 km; Zollo et al., 1996). In addition, the increase in the lithic clasts of deeper provenance compared to the initial phreatomagmatic episode, is suggestive of a deepening of the fragmentation level in the conduit.

The reverse grading of the white pumice lapilli deposit, which continues at the base of the grey pumice lapilli deposit, and the normal grading in the remaining uppermost part of the grey pumice lapilli deposit, testifying for the eruptive column first increasing and then decreasing in height, is also reported in later literature (Carey and Sigurdsson 1987; Cioni et al., 1990; Lirer et al., 1997; Luongo et al., 2003a).

Scarpati et al. (2020) proposed a new composite stratigraphy of the deposits of the 79 AD eruption at Pompeii. The authors revised the sequence reported by Sigurdsson et al. (1985), Cioni et al. (1992) and Luongo et al. (2003a) on the basis of new data from outcrops located around or inside the Pompeii archaeological excavations (Fig. 1.10).

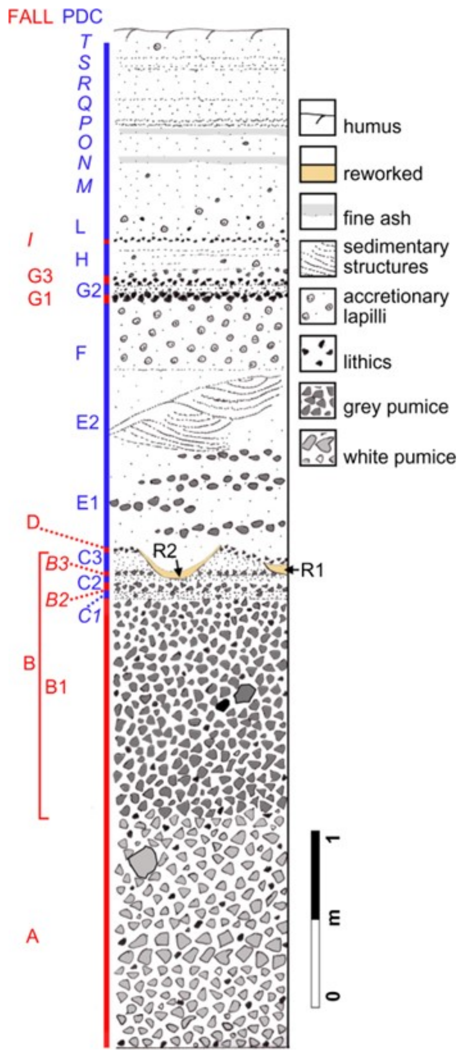

Figure 1.10 Composite stratigraphic section showing the maximum thickness of the units of the 79 AD deposit at Pompeii (Scarpati et al., 2020).

The deposit consists of a lower white to grey pumice lapilli bed intercalated with ash deposits, overlain by stratified ash and pumice layers with minor, thin, lithic-rich, horizons. All layers, except the first ash layer of the opening phase of the eruption, are dispersed across the entire Pompeii area, although some of them are locally missing due to the erosive action of the following PDC. According to Luongo et al. (2003a), the lower white to grey pumice lapilli fallout bed (units A and B) is massive and is interrupted by two PDC ash layers (units C1 and C2), interstratified at the top of unit B (locally split into the layers B1, B2 and B3). Within unit B, C1 is massive and poorly sorted. The occurrence of this bed outside the northern wall of

Pompeii had been previously reported by Sigurdsson et al. (1985). The second ash layer (C2) is a very fine, massive ash deposit that is interstratified at the very top of the grey lapilli bed. The uppermost grey lapilli deposit, B3, is a moderately to poorly sorted fine to very fine pumice lapilli deposit. Where thicker, the B3 better sorted and includes subangular fine pumice lapilli clasts. C3 is a massive ash layer showing a stratified, lateral facies variation where it thickens. The basal contact is erosive. The upper part of the exposed sequence shows poorly sorted, PDC ash deposits (units E, F, G2, H, L, M, N, O, P, Q, R, S and T) often with erosive bases interstratified with four well-sorted, thin lithic-rich layers (units D, G1, G3 and I). Layers from M to T were recognized by Scarpati et al., (2020) for the first time because of the new excavations that locally exposed the undisturbed upper part of the 79 AD sequence, usually missing because of hundreds of years of ploughing.

1.2.3 Distribution maps of the Plinian fallout deposit

The 79 AD Plinian fallout deposit was one of the first to be investigated to quantitatively define the volume of the erupted products and the height of the eruptive column using the isopach and isopleth method (Lirer et al., 1973).

Lirer et al. (1973) identified a dispersion area in the south-eastern sector of the volcano by drawing isopach maps (Fig. 1.11) from which they calculated a minimum volume on land of 0.8 km^3, an extrapolated a total volume of 2.6 km^3 and a DRE (dense rock equivalent) volume of 0.53 km^3.

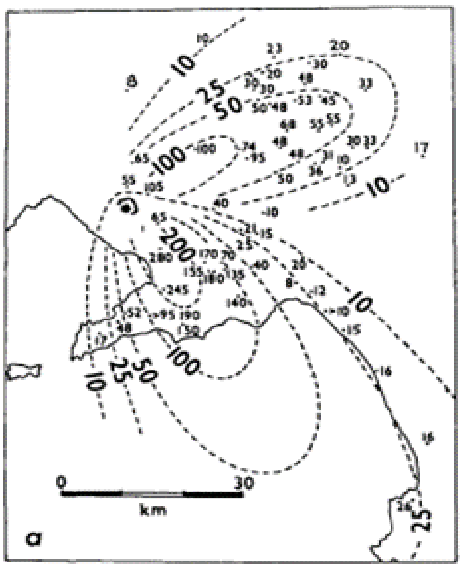

Figure 1.11 Isopach maps showing the thickness, in centimetres, of the Pompeii (Southeast trending) and Avellino (northeast trending) fallout deposits. a. White and grey components combined, b. Lower white component only. c. Upper grey component only (*Lirer et al., 1973*).

A few years later, Sigurdsson et al. (1985) added new data points (Fig. 1.12) to better describe the distribution of the white and grey pumice lapilli deposits.

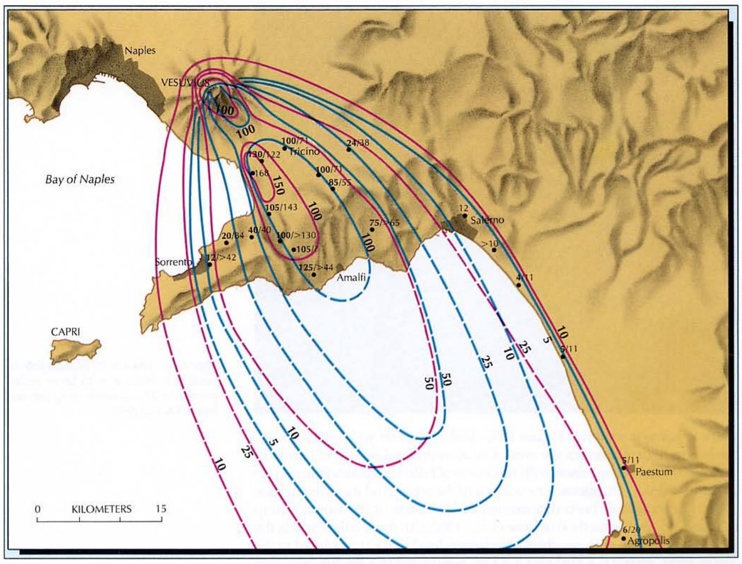

Figure 1.12 Isopach map for the 79 AD fallout deposits. The isopaches for the gray pumice fallout are in red, those for the white pumice fallout in blue. (From Sigurdsson et al.,1985)

The dispersal axis of both the white and the grey pumice layers is to the southeast, with axes trending 140° for the first and 155° for the second. According to Lirer et al. (1973), this may indicate a slight shift of the stratospheric wind direction during the eruption.

The volume of the white and the grey pumice fallout deposit has been determined based on the isopach map by Rose et al. (1983). They obtained 2.5 km^3 and 6.4 km^3 of tephra volume for the white and the grey pumice layers, respectively, corresponding to 1 km^3 and 2.6 km^3 of dense rock equivalent volume. For these calculations they assume a density of 1 g/cm^3 for the deposit and 2.5 g/cm^3 for the magma. Noteworthy, the total volume is more than three times the earlier estimate of Lirer et al. (1973).

The maximum diameter of pumice and lithics fragments has been determined for the white and grey fallout deposits at many localities. The results, shown with the isopleth maps of Fig. 1.13, are based on the average of the maximum diameters of the five largest pumice and lithics fragments found at each locality. Lithic clasts are more representative of transport dynamics, rather than of eruptive processes, since they do not break upon impact. The height of the eruption column has been calculated from the plume equation of Morton et al. (1956) as modified for volcanic eruptions (Wilson et al., 1978). The eruption column reached a maximum of 27 km during the ejection of the white pumice layer, 33 km during the ejection of the grey pumice layer.

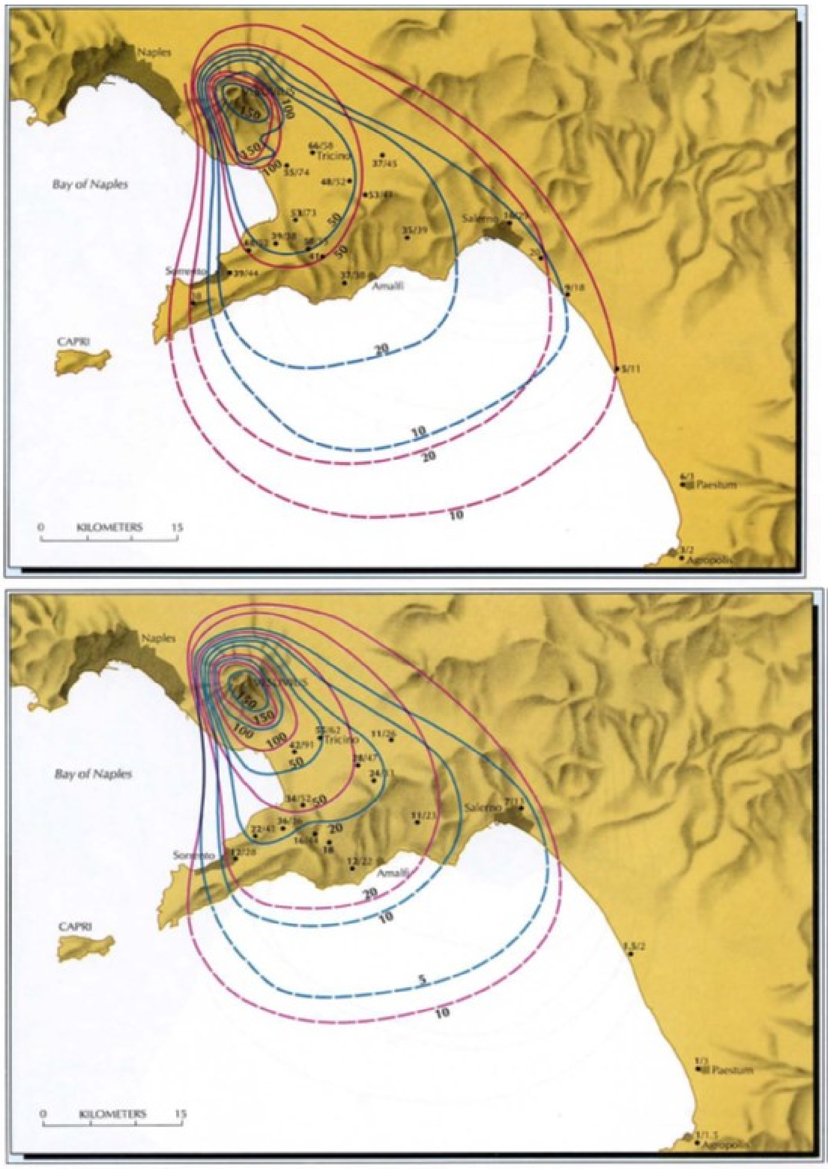

Figure 1.13 Isopleth map (in millimeters) for the 79 AD fallout deposit (red for grey and blue for white pumice-fallout). Above the isopleth map of the pumice and below of the lithics. Sigurdsson et al., (1985)

Carey and Sigurdsson (1987), based on the models by Sparks (1986) and Carey and Sparks (1986) for the dynamics of eruptive columns, and using the stratigraphic data from Sigurdsson et al. (1985), calculated the height of the eruptive column using the isopleth maps for pumice and lithic clasts and different wind speed values. In order to correlate grain-size data from site to site, they normalized the height of the stratigraphic sections of the fallout deposit by assuming proportionally equivalent accumulation at each site. Maximum lithic size data were plotted in sections normalized from 0 at the base to 1.0 at the white-grey boundary, thus assuming that data from equivalent normalized levels (for example 0.5) at different sites represent a given chronostratigraphic level.

This technique is not used for the grey pumice fallout deposit due to erosion by the following pyroclastic surges and flows, so some sites do not contain the complete grey-pumice sequence. The surge strata, however, define an additional series of chronostratigraphic levels, as surge emplacement was almost instantaneous compared to the duration of the eruption. Figure 1.14 shows the position of the six surge layers at Boscoreale, normalized to the total thickness of the grey pumice fallout deposit at this site.

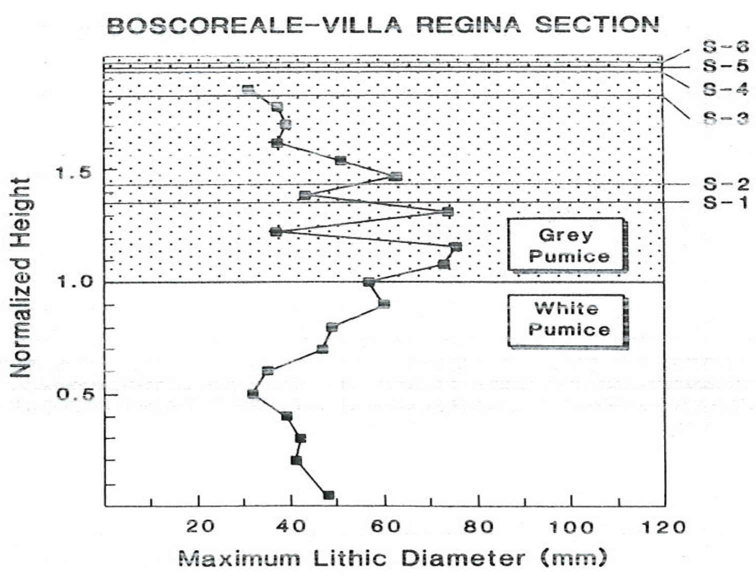

Figure 1.1 Normalized white and grey fall sequence at Boscoreale (Villa Regina) showing the relative position of the six correlated surges and the variation of the five largest lithic clasts as a function of height in the fallout deposit. ***(From Carey and Sigurdsson 1987)***

It should be noted that this method did not take into account the internal structures of the deposit (gradations/stratifications) to implement the correlations. In addition, the use of surges deposits as stratigraphic markers is controversial due to their variability of facies and lateral discontinuity.

Using this technique, maximum lithic isopleth maps have been constructed (Carey and Sigurdsson 198) eight chronostratigraphic levels in the white and grey pumice layers to investigate the temporal evolution of pyroclastic dispersal. The white pumice deposit was subdivided into four chronostratigraphic levels (Fig. 1.15) based on data from ten sites.

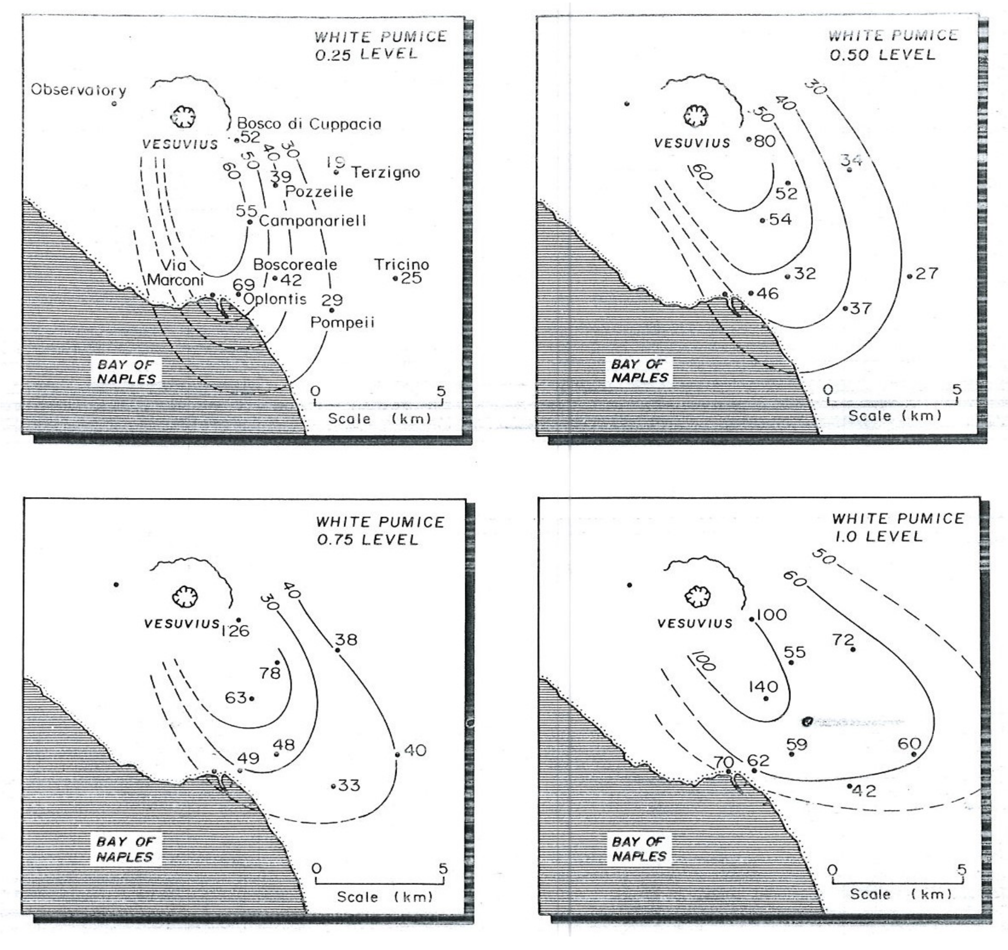

Figure 1.15 Maximum lithic isopleth maps of the 0.25, 0.50, 0.75 and 1.0 chronostratigraphic levels within the 79 AD white pumice fallout deposit. ***(From Carey and Sigurdsson 1987)***

The first part of the eruption (0.25 level) was marked by a south trending fallout axis. As the eruption progressed, the fallout axis rotated (due to a slight shift of the stratospheric wind direction during the eruption) to southeast, accompanied by an increase in the area encompassed by a specific size isopleth (Pompeii is initially enclosed inside the 30 mm isopleth and then inside the 60 mm isopleth). With the onset of the grey pumice fallout, the lithic clast size continued to increase (Fig. 1.16).

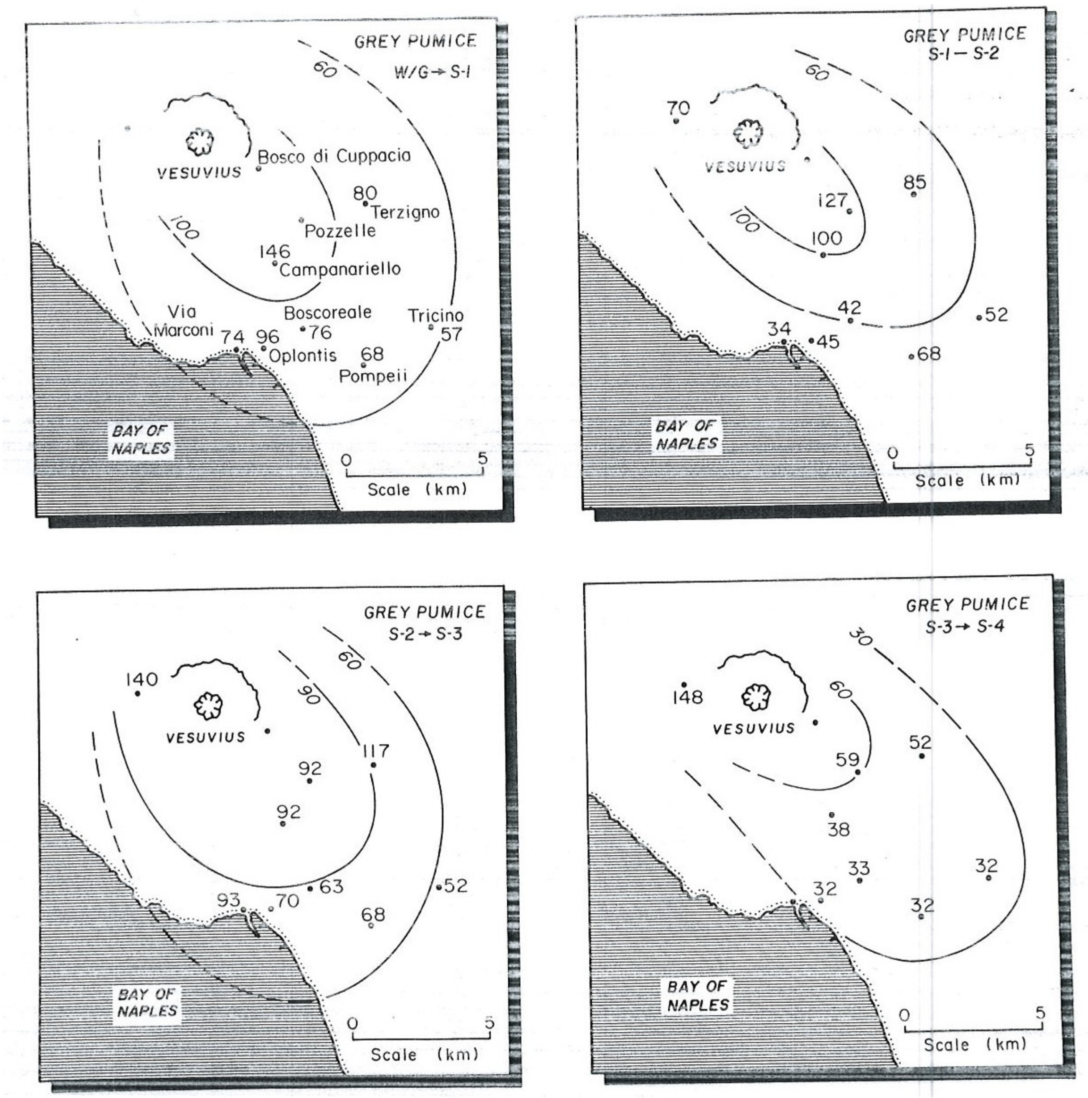

Figure 1.16 Maximum lithic isopleth maps of inter-surge fallout units from the white/gray pumice boundary (W/G) to S-1 surge, from S1 to S-2, from S2 to S3, and from S3 to S4 withing the 79 A.D. gray pumice fallout sequence (From Carey and Sigurdsson 1987)

Grading patterns withing inter surge fallout units are generally consistent, although exceptions occur. Carey and Sigurdsson (1987) adopted the most frequently occurring grading patterns at localities with the densest sampling profiles and best-preserved data.

The reverse grading trend observed in the white pumice fallout deposit was observed to continue without apparent discontinuity in the grey pumice deposit, up to the first surge (S-1). Prior to the emplacement of the second surge, a thin unit of pumice fallout was deposited with a reduction in dispersal area and showing a reverse grading. The thickest fallout unit in the grey sequence is recognised between the S-2 and the S-3 surge deposits. This unit is normally graded, indicating maximum dispersal of lithic clasts after the emplacement of the S-2, followed by a gradual reduction in the dispersal up to the S-3. After the emplacement of the third surge, a very thin pumice fallout layer was deposited, characterised by the narrowest dispersal of the lithic fraction. The limited number of data points for fallout units from S-4 to S6 layers prevented the authors from reconstructing additional isopleth maps.

The isopleth data yield an average column height of 26 km for the white pumice and 32 km for the grey pumice deposits. In addition, magma discharge rates were calculated from the column heights, with estimated magma temperature of 800 °C (lower than the temperatures estimated by Cioni et al., 1995 of 860° for the "white" phonolitic magma and 1050° for the "grey" tephriphonolitic magma) and the discharge curves of Sparks (1986). During the emission of white pumice fallout, the magma discharge rate was 7×10^7 kg/s. During this phase the axis of dispersal migrated from south to southeast at the white-gray boundary. The column continued to increase in height and reached 32 km just before the emplacement of the first pyroclastic surge (S-1). This was the time of maximum discharge rate, estimated at 1.5×10^8 kg/s.

Cioni et al. (1999), in a study on the pyroclastic deposits as a guide for reconstructing the multi-stage evolution of the Somma-Vesuvius caldera, reported a total volume for the 79 AD Plinian deposit of 3 km^3 (1.5 km^3 DRE), much lower than previous estimates. These values were reported without specifying which isopach maps were used and which method was employed to calculate the volumes.

Recently, Doronzo et al. (2022) reviewed the eruption stratigraphy using the detailed stratigraphic and sedimentological data of Cioni et al. (1990). The database was integrated with new findings from Naples, Pollino, Velia, Sicily and offshore data, for a total of 346 sites. With these new data, they reconstructed the distribution area of the fallout units (Fig. 1.17).

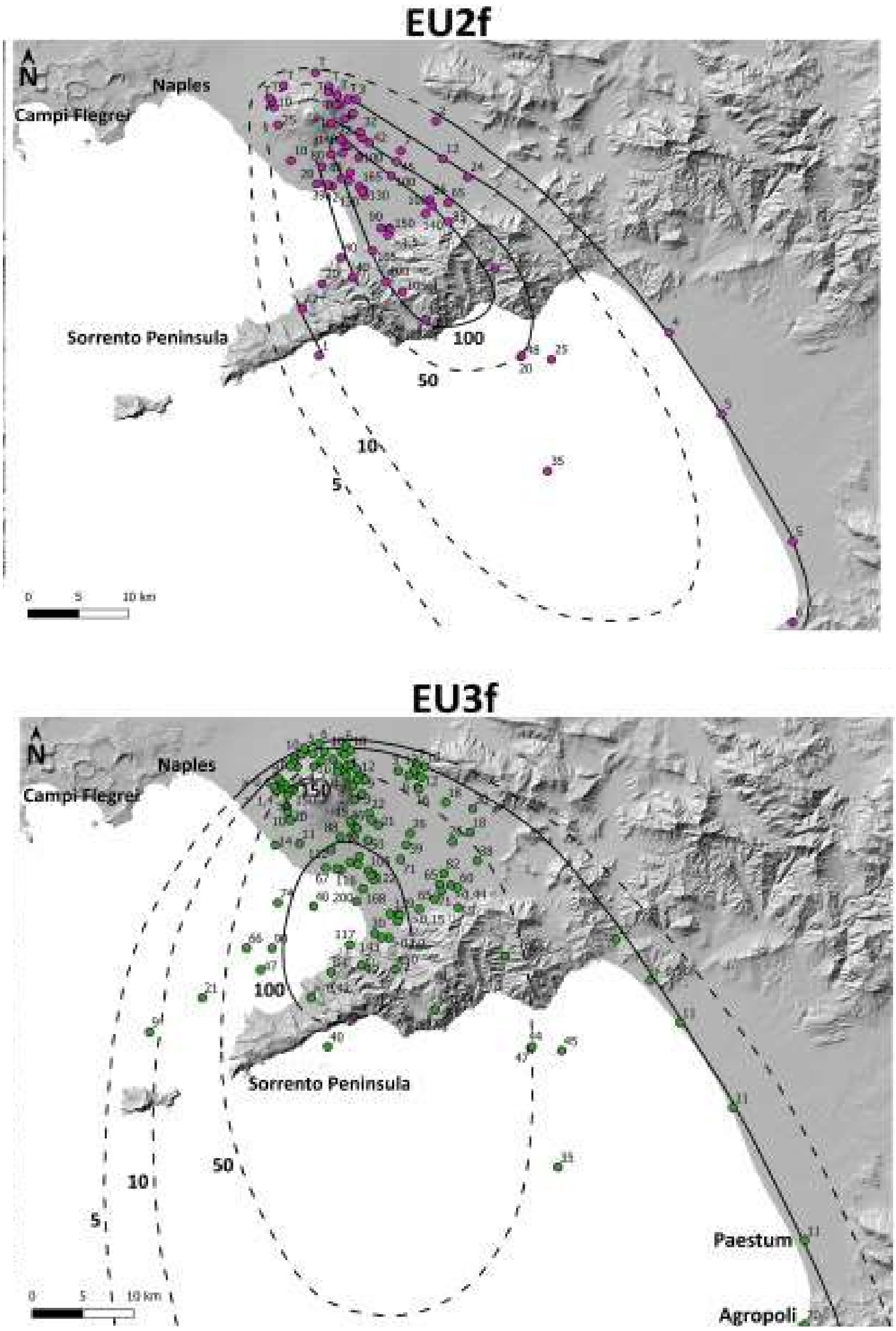

Figure 1.17 Local thickness (in cm) of the EU2f and EU3f deposits and related isopachs. (Doronzo et al., 2022)

The pyroclastic fallout deposits have been also found offshore in marine cores west of Calabria, in the Policastro Bay, in the Adriatic Sea, in the Ionian Sea up to offshore Greece and Crete. At these localities, the deposit occurs as thin primary tephra layers or cryptotephra. In figure 1.18 the 5 cm and 2 cm isopachs and the trace area (T area) are reported.

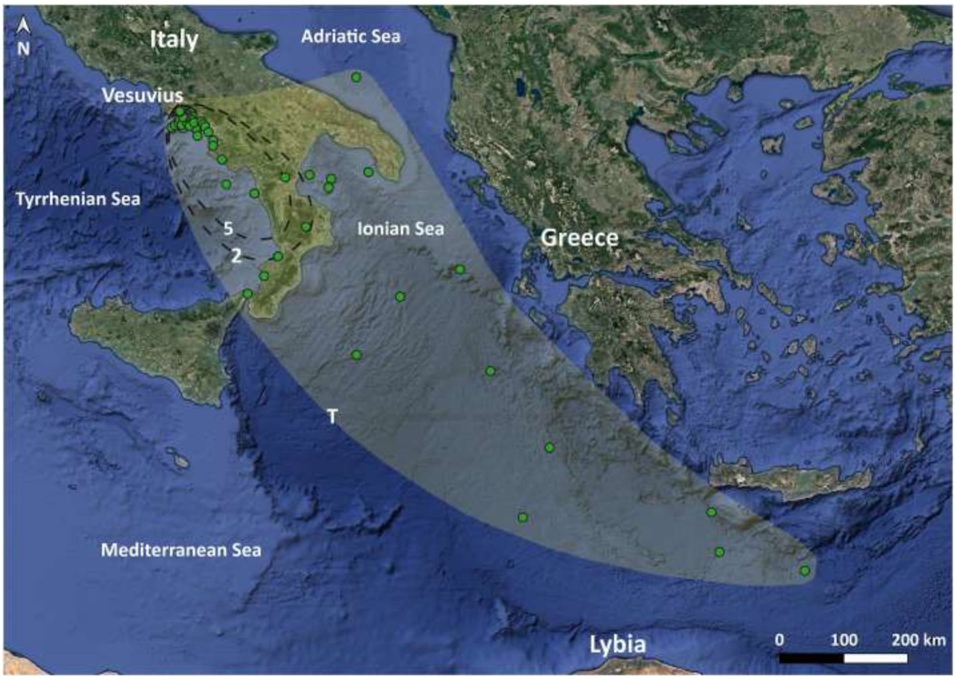

Figure 1.18 Distribution of the EU3f deposit from proximal to ultra-distal areas miming the volcanic cloud dispersal that occurred during the 79 AD eruption of Vesuvius. The 5 cm and 2 cm isopachs, and trace area (T) are also shown (from Doronzo et al., 2022).

The authors recalculated the erupted volume for such pumice deposits by adding the volumes relative to the areas between the 5 cm and 2 cm isopachs, and between the 2 cm isopach and the T area.

The new calculation gives a minimum extra volume of erupted magma of 0.5 km^3, approximately 20% more than volume estimates previously reported in the literature.

The estimated values for the volumes and height of the eruptive column in the existing literature are summarised in Table 2:

	White pumice fall			Grey pumice fall			
	Vdep(km³)	VDRE (km³)	Col. height (km)	Vdep (km³)	VDRE (km³)	Col. height (km)	Vtot (DRE)
Lirer et al., (1973)	1.09	0.2	-	1.51	0.33	-	0.55
Carey and Sigurdsson (1987)	2.5	1	27	6.4	2.6	33	3.6
Cioni et al., (1999)	-	-	-	-	-	-	1.5
D'Oronzo et al., (2022)	2.5	1	-	7.7	3.1	-	4.1

Table 2. Summary table with the estimated values for the volumes of the deposits (Vdep), volumes of dense rock equivalent (VDRE) and the height of the eruptive column for both the white pumice and the grey pumice fallout deposits of the 79 AD eruption.

1.2.4 The presence of a secondary maximum thickness: fact or fiction?

Plinian fallout deposits typically thicken toward the source. In the case of the 79 AD eruption, Sigurdsson et al. (1985) found a sort of "anomaly" in this sense, as both the grey and the white pumice deposits bulge just south of Pompeii. Consequently, the pumice deposits become thinner northwards, from a maximum of about 280 cm in Pompeii to about 180 cm in the saddle north of Pompeii. The maximum thickness of the pumice fallout was thus attained 10 to 15 km from the source. This type of distribution had already been observed for the Taupo eruption by Walker (1980), who observed a maximum thickness of the pumice fallout deposits 20 km from the source. However, the "anomaly" was then ruled out by Houghton et al. (2014), who drew a more elongated and narrower isopach that opens from the source and closes 20 km away.

1.2.5 Sustained column pulses during the late, collapsing column phase of the eruption

Some fallout layers were also recognised in the upper part of the stratigraphic sequence of the 79 AD eruption deposits.

In Boscoreale, Terzigno, Pompeii, Oplontis and on the Observatory Hill (see Fig. 8) Sigurdsson et al. (1985) recognized three lithic-rich fall layers (named from A8 to A10) with abundant lava and carbonate fragments, interstratified with the highest flow deposits.

The authors argued that eruptive column partially collapsed during such events (characterised by the emplacement of S-4, S-5, and S-6 surges), while the column continued to rise with the emplacement of the three lithic rich layers (Sigurdsson et al., 1985). This oscillation was interpreted to reflect variations in the eruptive parameters, such as the column height, the emitted volume during this phase, the mass discharge rate etc. After the emplacement of the sixth, lithic-rich surge, the magma ascent rate was probably very low, and ground water poured into the open conduit, reaching the stagnant magma. This led to a series of vulcanian explosions, which generated small water-rich eruption clouds.

Barberi et al. (1987) recognized only one lithic-rich layer (VS-84 34) at the base of two surge deposits with large wavelength dunes. They interpreted the emplacement of the pumice flow deposit occurring above the fallout beds (corresponding to the end of the magmatic phase) as indicating the total collapse of the eruptive column.

Cioni et al. (1990) defined two marker units (EU4 and EU7), associated with phreatomagmatic activity (Fig. 1.19):

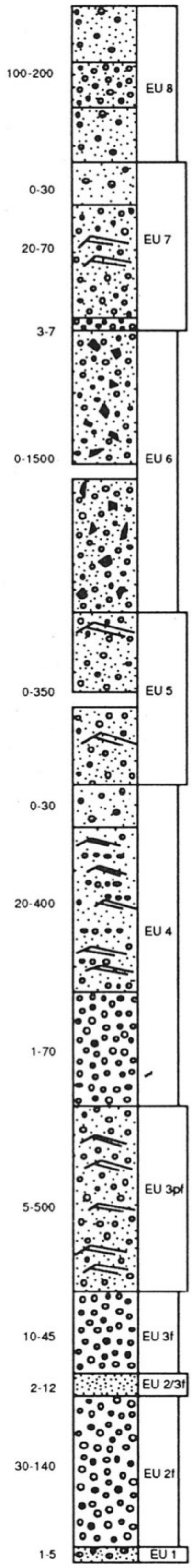

Figure 1.19 Composite stratigraphic section for the 79 AD eruption deposits. (Cioni et al., 1990)

EU4. Complex pyroclastic flow unit, characterized by a clear subdivision into three levels with a general normal gradation. The basal level, always present in the proximal outcorps of the south-eastern sector, consists of grey pumice lapilli with clinopyroxene and biotite phenocrysts, and abundant lithic lapilli and blocks (lavas, limestones, marbles, cumulitic and metasomatic rocks); it shows a clear normal gradation, no cineritic matrix, and contains numerous charred plants remains. Towards the roof, the level shows frequent crossed laminations that fade into the upper bank, consisting of a coarse ash deposit with crossed stratifications and dune structures, marked by lentiform alignments, with normal gradation, of rounded white and grey pumice lapilli and lithic clasts. The topmost level is represented by a few centimeters of light pisolitic ash layers cropping out discontinuously. The unit lies in clear angular (erosive) discordance on the substrate.

EU7. The unit is observed in the final phreatomagmatic deposits, consisting of a set of layers with a basal level rich in lapilli, containing porphyritic gray pumice clasts and numerous lithic fragments (marble and cumulate rocks), overlain by a thick ashy layer with accretionary lapilli, massive or stratified with dunes. The unit is similar to EU4 but with a less regular development of the base, probably related to the lower energy. In fact, the lowest part of the level is massive with abundant lithic fragments consisting mainly of lava and limestone clast. The lithological characteristics of this unit suggest a deposition mechanism from a dilute and turbulent pyroclastic flow.

At the base of these two marker units, some lithic-rich layers with no matrix have been recognized. These are associated with an instability of the conduit, with the expulsion of abundant lithic material which was then taken over by the pyroclastic flow.

This opened a scientific debate as if the deposit of the basal part of EU4 should be interpreted as a fallout or a pyroclastic flow deposit. After few years, Cioni et al. (1999) revised what previously proposed and defined the basal lithic-rich layer of EU4 as a fallout unit due to a resumption of a short-lived Plinian column that ended with the generation of a pyroclastic flow. So, for the first time, the presence of a short-lived Plinian column was identified.

Luongo et al. (2003a; 2003b) and Scarpati et al. (2020) reconstructed the stratigraphy of the 79 AD eruption based on several sections located inside the Pompeii excavations and adopted a new nomenclature for the various units (Fig. 1.20). They recognised four lithic-rich layers (D, G1, G3 and I), interstratified with ash deposits, and consider them to be of fallout origin.

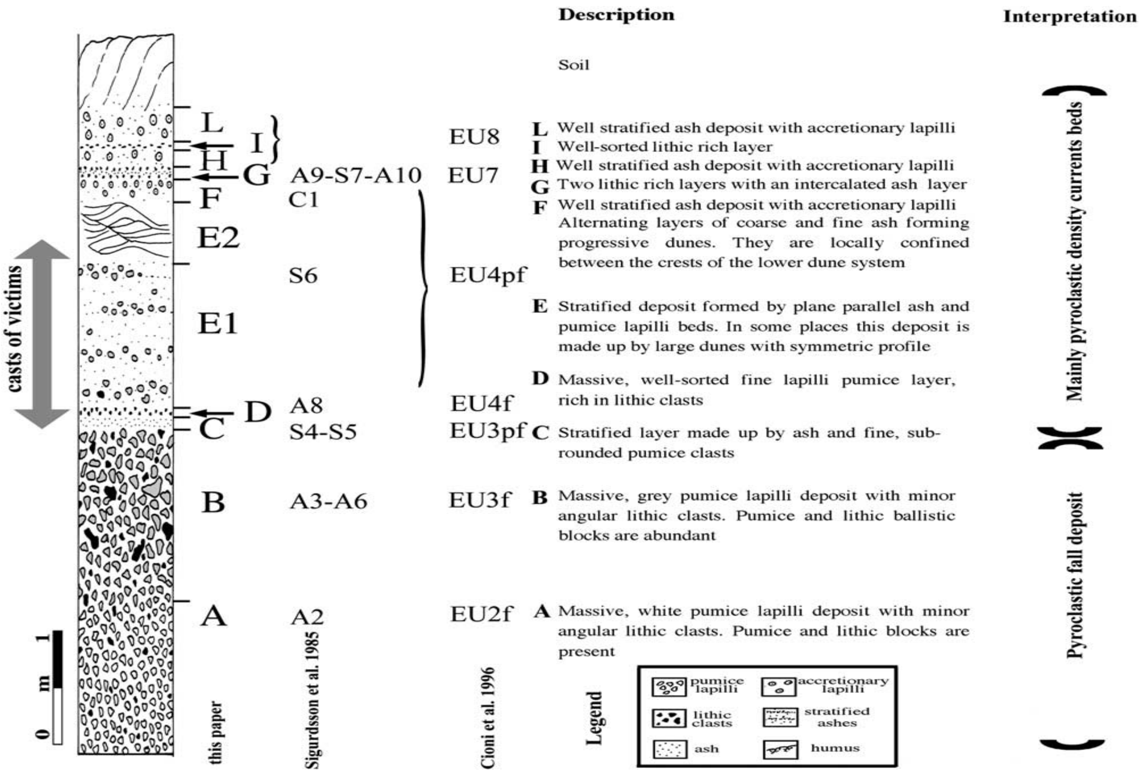

Figure 1.20 Stratigraphic scheme for the units making up the sequence of the 79 AD deposits as proposed by Luongo et al. (2003b). Comparisons with the layers previously identified by Sigurdsson et al. (1985) and by Cioni et al. (1996) are highlighted.

This interpretation has been carried out over the years (Luongo et al., 2003b; Scarpati et al., 2020) without however going into detail about the dynamics of these short-lived eruptive events. So, despite the recognition of these "new" lithic rich layers interstratified with the higher pyroclastic current deposit, neither isopleth nor isopach maps have been draw, useful for the calculation of the emitted volumes and the height of the eruptive column.

1.3 Geochemical variations in the eruptive sequence of the 79 AD eruption

Di Girolamo (1963, 1968) was one of the first authors to deal with the petrography and chemical composition of the juvenile components of the 79 AD deposits. He studied a sequence located inside Pompeii excavations (Regio II and Regio III), in areas poorly disturbed by archaeological remains. The author concluded that the white pumice clasts are leucitic phonolites while the darker pumice clasts are also leucitic phonolites but richer in clinopyroxene, biotite, and with traces of olivine. The upper grey pumice deposit shows a more uniform and less evolved composition.

After these pioneering studies, new, more detailed petrological investigations of the juvenile clasts of the 79 AD eruption were performed by Barberi et al. (1981) and Joron et al. (1987). These authors interpreted the overall compositional variation observed throughout the depositional sequence as (to be) related to the fractional crystallisation of a tephritic magma which entered the magma chamber at a temperature of 1200 °C. During a long period of rest lasted for several centuries at least, the magma experienced significant crystal fractionation and a residual phonolitic liquid was formed in the upper part of the chamber, after removal of about 70% of solid phases that accumulated in the lower part of the reservoir. Interactions with the calcareous country rocks also occurred, producing contact reaction skarns which also variably contaminated the phonolitic melt.

Based on petrographic, geochemical, and isotopic data (Fig. 1.21), Sigurdsson et al. (1990) and Civetta et al. (1991) suggested a synergic mixing and mingling between a zoned phonolitic magma and a homogeneous mafic magma. The process assumes that a significant amount of relatively mafic (tephritic-phonolitic), crystal-rich and volatile-poor magma had remained within the Vesuvius magma chamber after previous eruptive events. As new batches of magmas with different isotopic ratios enter the chamber, these would mix with the residual less-differentiated magma. The mixed magma would be subjected to magma chamber processes (sidewall crystallization, upward volatile concentration, etc.) and form a highly differentiated "white" portion capping and a lower convective "grey" portion. In the first stages of the process, the isotopic ratio of the white cap would be strongly affected by the $^{87}Sr/^{86}Sr$ ratio of the residual magma, which would thus significantly differ from that of the grey magma.

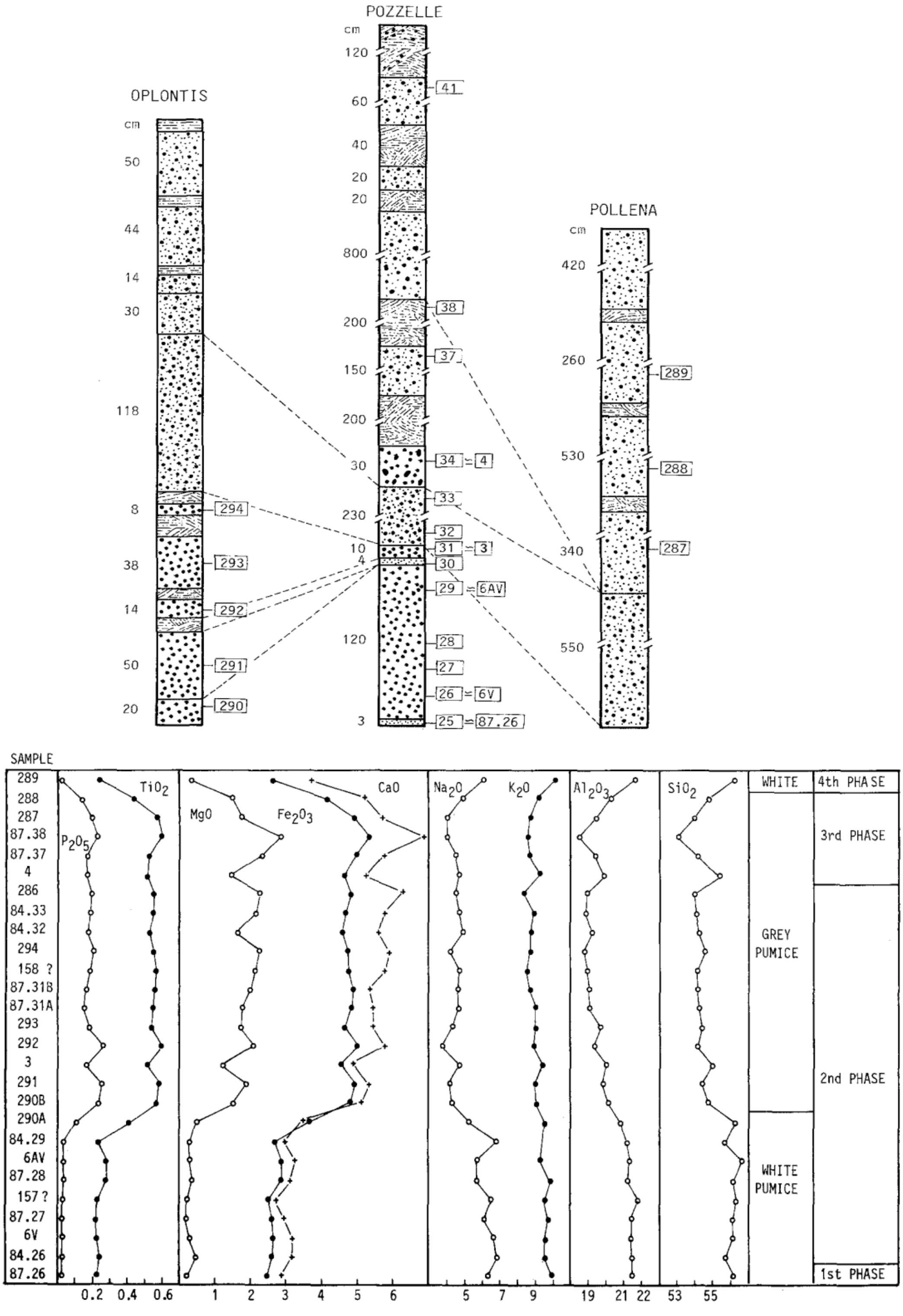

Figure 1.21 Vertical chemical variations for the juvenile fraction in an idealized section of the 79 AD eruption deposit. Sample locations and numbers are reported in the stratigraphic columns on the left. (Civetta et al., 1991).

Lirer et al. (1993) recognised two different compositional fields within the fallout deposits of 79 AD, well observable in the total alkali diagram vs. D.I. (differentiation index, calculated as) diagram (Fig. 1.22).

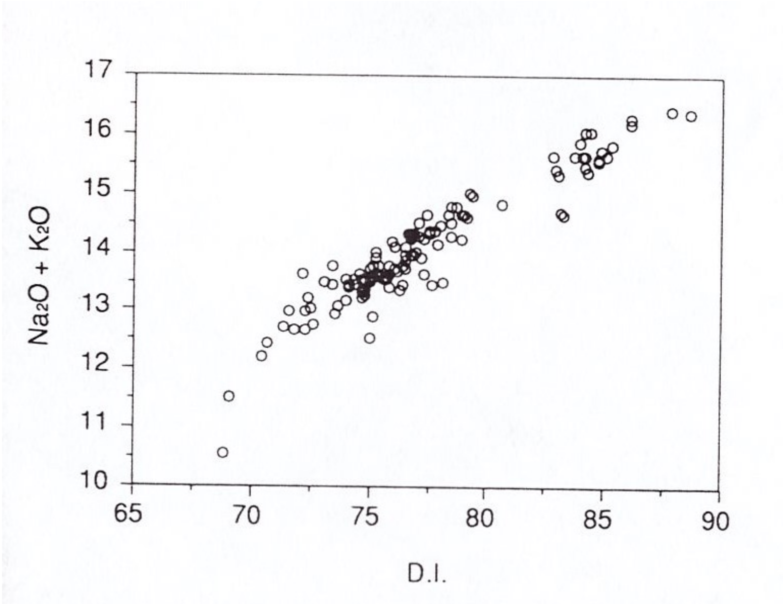

Figure 1.22. Total alkalis vs D.I. diagram (Lirer et al., 1993)

The D.I. was observed to range between 70 and 79 in the grey pumice clast (from tephritic phonolites to mafic phonolites), whilst it varies from 83 to 80 (80 to 83) in the salic phonolite white pumice ones. Vertical variations of the CaO content in the pumice fragments (Fig. 1.23) show three distinctive compositional fields. One is represented in the white pumice clasts only (with CaO < 3.00 wt.%) and the other two representing variations of the grey pumice compositions, characterised by CaO in the range of 4.00-4.50 wt.% and 5.00-5.5 wt.%. In some instances, the two are even recognised in a single pumice fragment as two distinctive, compositionally different portions.

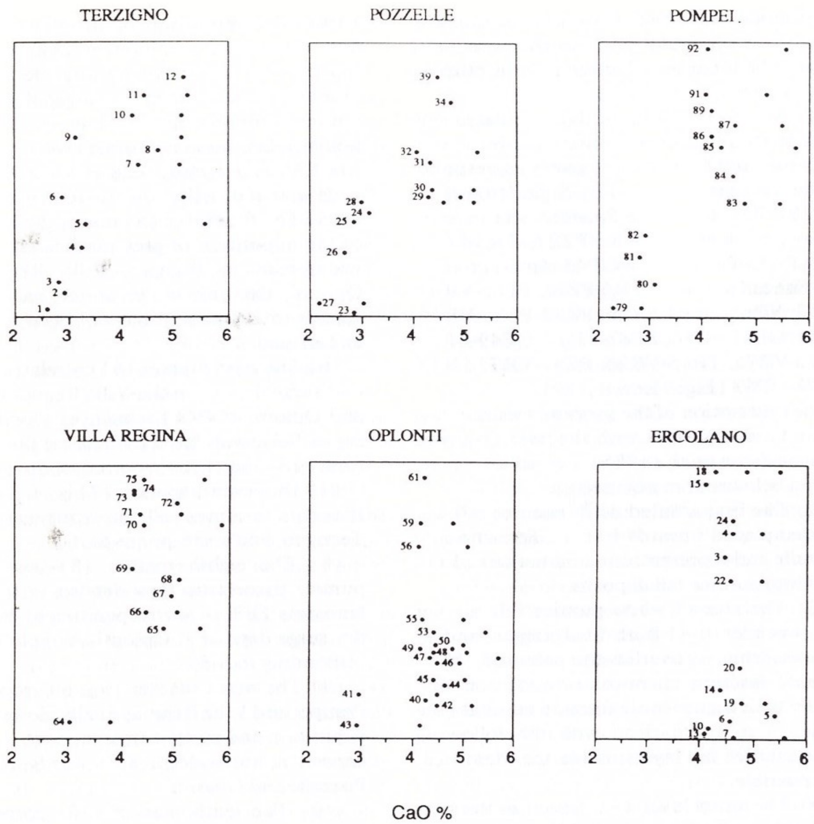

Figure 1.23 Vertical variations of CaO content along the six investigated sequences (Lirer et al., 1993)

Grey pumice clasts from the fallout and surge deposits overlying the white pumice fallout have both phonolitic and tephriphonolitic compositions. Products from the upper part of the sequences show two grey compositions, with CaO contents of ca. 4.00 and 5.00 wt.%, respectively. These variations were argued to represent the result of the mixing between a salic phonolitic magma and a tephritic phonolite one. The occasional coexistence of the two grey composition within the same pumice clast could be explained by the syneruptive mingling between the tephritic phonolite and the intermediate end-member [in accordance with Sigurdsson et al. (1990) and Civetta et al. (1991)].

Cioni et al. (1992) observed some clear vertical compositional variations in the 79 AD juveniles for several major oxides and trace elements (Fig. 1.24). The white pumice clasts of the EU2 fallout deposit define a faint though systematic trend towards slightly less evolved compositions with increasing stratigraphic height. On the other hand, the grey pumice clasts overall display more homogeneous compositions, with some slightly less evolved compositions generally occurring in the central part of the fallout deposit, immediately before the deposition of the EU3pf unit.

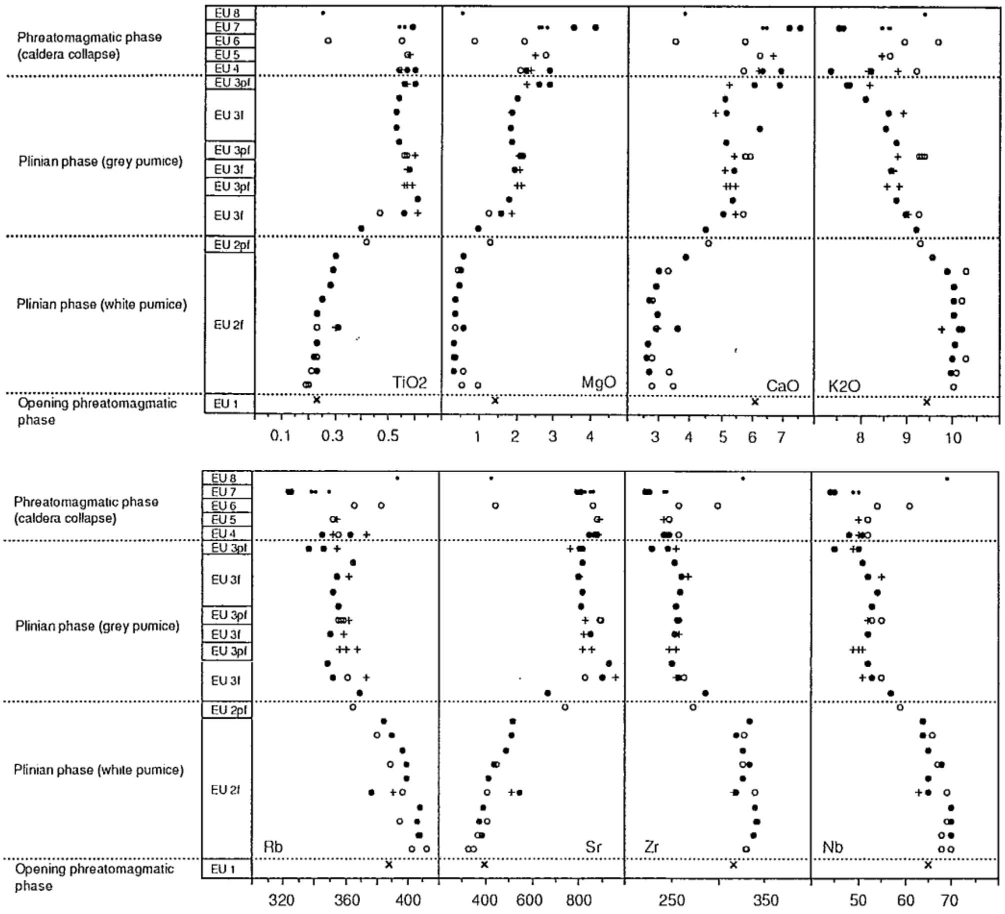

Figure 1.24 Variations of some major oxides and trace elements along the stratigraphic succession. O, Pozzelle Quarry, •, Necropolis, ˙,Terzigno Quarry, †, Oplontis, x, Villa Telesi (Cioni et al., 1992)

The least evolved juvenile compositions were recovered in the products of the phreatomagmatic phase (more specifically in the EU7), immediately after the caldera collapse. In addition, the authors observed that the pumice clasts from the pyroclastic flow deposits of the magmatic phase of the eruption (i.e. EU2pf and EU3pf) generally show a homogeneous composition that is consistent with that of the coeval pumice fallout layers. On the other hand, pumice clasts from pyroclastic flow deposits of the phreatomagmatic phase are generally more heterogeneous in composition (EU4, EU6, EU7). Cioni et al. (1992) interpreted these compositional trends as related to a regular withdrawal from a zoned magma body during the Plinian phase, and the extraction from a chaotically destabilized magma chamber during and after the caldera collapse event.

Cioni et al. (1992) also correlated the variations in the Sr content of the juvenile fraction with the Median of the corresponding layer (Fig. 1.25). Two subparallel vertical variation trends were observed in the white pumice, with the less-evolved "more mafic" spike corresponding to the minimum grain-size. This was interpreted to rule out a syneruptive mixing process, rather pointing to a model of regular extraction from a stratified magma body [similar to what proposed by Civetta et al. (1991)].

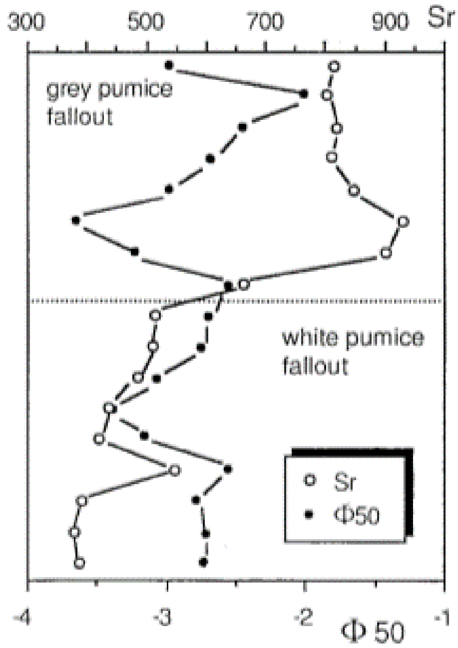

Figure 1.25 Sr content (ppm) and Median (Φ50) vs. stratigraphic height for the pumice fallout deposit (Cioni et al., 1992)

Mues-Shumacher et al. (1994) focussed on the differences between the white and grey pumice clasts and recognised a third pumice component, which they called "*the boundary pumice"* as it was found at the transition from the white to the grey pumice fallout deposits. This transitional zone includes both the white and grey pumice clasts, as well as the "boundary pumice", which is light grey in colour, internally homogeneous (i.e. without evidence of physical mingling), and displays and intermediate composition between the grey and white pumice (especially in terms of MgO, K_2O and Ba contents). According to the author, the tephriphonolitic grey pumice clasts do not display a distinct vertical geochemical gradient like those observed for the white pumice clast, indicating stable layering of the upper phonolitic part of the magma chamber due to diffusion and liquid-state-differentiation. On the other hand, within the tephriphonolitic magma batches, convection was maintained and agitated by periodic influx of hotter juvenile magma. The “boundary pumice” would testify for the existence of an interface magma layer, resulting from mixing and diffusion processes, likely occurring prior to, rather than during the eruption.

A very detailed alternative model of magma withdrawal dynamics was proposed by Cioni et al. (1995) in order to explain the overall change from the “white” phonolite to the “gray” tephriphonolitic magma composition in the 79 AD eruption sequence. In this framework, the phonolitic endmember would represent a remaining portion of the tephriphonolitic magma from the Avellino eruption, subsequently fractionated to form the uppermost, compositionally layered “white” cap of the 79 AD magma chamber. On the other hand, the “gray” tephriphonolite magma is considered a mixture between a tephritic magma, periodically injected into the chamber, with the residual phonolitic one. The early-erupted white pumice clasts of the EU1 and EU2 fall layers (separated by proximal, locally dispersed PDC deposits) are chemically homogeneous, with slightly higher SiO_2, MgO and CaO and lower Al_2O_3, Na_2O, and K_2O in EU2. Notwithstanding the chemical differences, the two main pumice types were reported (have been considered) to be largely similar by Cioni et al. (1995). Indeed, both the white and grey pumice clasts have phenocrysts of kfs and cpx (plus lesser bt, lc, grt, amph and minor pl and sporadic ol, ap and ne), set into a glassy groundmass with microlites of lc, kfs, cpx, amph and bt. However, the authors report a lower density (600-700 kg/cm^3 vs. 800-1200 kg/cm^3) for the white pumice clasts, whose groundmass includes colourless glass and abundant lc grains (plus lesser kfs, cpx, amph and bt), as opposed to the brownish glass and the higher crystal load (and larger crystals) consisting of lc cpx and bt, of the grey pumice clasts.

Cioni et al. (1995) also focused on the ejecta hosted in the 79 AD deposits (summing up to 1-5 wt.%), consisting of skarn and crystalline silicate rocks, especially abundant in the coarse-grained basal bed of the EU4. The first are classically considered as the product of the thermal metamorphism/metasomatism occurring at the contact between the magma and the carbonate country rocks. The crystalline silicate rocks instead include both cumulitic rocks and metasomatic cumulitic ejecta, interpreted as an intermediate “assimilation zone” between the skarn shell developed in the carbonate country rocks and the cumulate rocks of the inner walls of the magma chamber. More recent studies on such skarn xenoliths also highlighted the possible role of magma-wall rock interaction(s) on the eruptive style (Jolis et al., 2015).

In the following years, several other authors continued to study the petrology of the 79 AD products and the chemostratigraphic variations in the juvenile components (e.g. Ayuso et al., 1998; Cioni et al., 2000; Morgan et al., 2006; Redi et al., 2016; Melluso et al., 2022).

All these articles led to the following overall model of magma withdrawal during the eruption (according with Cioni et al., 1995):

During the white pumice fallout, the eruption tapped progressively deeper magma, and the deposits reversed the chemical gradients in the upper portion of the chamber. After the withdrawal of ~20% of original magma, the column destabilized as a consequence of a turbulent mixing within the chamber between white and grey magmas. When the Plinian column resumed, the erupted products had drastically changed composition to the mixed grey tephri-phonolitic pumice, containing a significant number of mafic crystals scraped off the walls of the chamber. During this phase the magma discharge rate fluctuated, drawing up mixed magma from different depths in the chamber. Initially, the amount of white magma physically mixed in the grey pumice was decreasing with increasing depth of tapping, but, after a few hours, the mixing was complete, and erupted products consisted of hybrid pumice clasts. As the eruption proceeded, the decreasing amount of magma within the chamber became less able to compensate, by vesiculation, for the loss of mass through volume increase, until 18-19 h after the beginning of the eruption, when the magma chamber wholly collapsed forming a circular caldera. Following activity was significantly different, with the emplacement of turbulent, highly diluted pyroclastic flows and surges (EU 4, EU 5 and EU 7) and a lithic-clast rich debris flow (EU 6). The pumice clasts from the post-Plinian stages are relatively heterogeneous in composition because of the highly variable content of cognate material from the collapsing walls of the chamber, as well as of the tapping of nearly pristine white magma trapped under the roof in the chamber and not involved in the turbulent mixing.

Additional petrological investigations on the 79 AD eruption were carried out by means of fluid (FI) and melt inclusion (MI) studies (Marianelli et al., 1995; Cioni et al., 1998; Fulignati et al., 2004, 2011; Balcone-Boissard et al. 2008, 2011) and experimental investigations (Scaillet et al. 2008; Shea et al., 2009, 2014).
The MI studies provided significant insights to the understanding of the processes of volatile accumulation and degassing in the different portions of the magma chamber and to shed light on the factors that governed the transition from an initial phase of steady state sustained column to a following phase of oscillatory eruptive column, characterized by several collapse events.

Large variations in both residual volatile contents and textural features were observed between the different eruptive units and pumice types, suggesting that degassing processes were highly heterogeneous. Balcone-Boissard et al. (2011) proposed that pre-eruptive conditions (i.e., H_2O saturation, magma temperature and viscosity) strongly influenced the variability of the syn-eruptive degassing processes and hence the eruptive dynamics. More in detail, only the white and the upper part of the grey magmas were H_2O saturated prior to eruption. The eruptive units characterized by white pumice clast were thus interpreted as indicating a typical closed-system degassing evolution, whereas the first grey pumice clasts, though stored under similar pre-eruptive conditions, followed an open-system degassing evolution, as suggested by their textural features indicating that the exsolved volatile phase was heterogeneously distributed before fragmentation. The oscillatory regime that dominated the grey magma eruptive phase would be linked to pre-eruptive water undersaturation of most of the magma, and the associated time delays necessary for H_2O exsolution. In addition, the high residual H_2O content of the batches of the grey magma that were deposited after the renewal of Plinian activity following the first column collapse event, are considered to be related with the syn-eruptive saturation and reduced H_2O exsolution efficiency.

The decompression experiments performed by Shea et al. (2009) failed to reproduce the textural features (in terms of both shapes and average size) of lc crystals from the 79 AD white pumice clasts, which were on the contrary well reproduced by equilibrium crystallization experiments (i.e., in line of principle approaching magma chamber, rather than magma conduit conditions). This allowed the authors to propose that lc crystallisation did not occur during rapid magma ascent at average rates typical of Plinian eruptions (i.e., during decompression), but rather they grew over timescales of days at lower degrees of undercooling. In addition, the authors proposed that the magma from which the white pumice clasts derived was not only faintly compositionally zoned (see above), but also thermally zoned, with pumice clasts from the EU1 equilibrated at 830-840 °C, whereas those of the EU2 formed in the 850-925 °C range (both at P around 100 MPa. Such differences in T could be due to the late arrival of a tephritic melt batch that successively mixed within the magma chamber to form the tephriphonolitic "grey" magma. This is also in line with the results from Cioni et al. (1998), who found two distinct populations of homogenization temperatures in MI for the white pumice clasts, one between 800 and 850 °C (in agreement with those for EU1), the other between 900 and 950 °C (roughly in line with those for EU2).

Finally, as regards the crystallisation experiments performed by Scaillet et al. (2008), these were conducted at variable T, P and H_2O content in the fluid phase within the melt, allowing the authors to explore the intensive parameters characterizing not only the 79 AD eruption, but also those of other recent Vesuvian Plinian/subplinian eruptions such as Mercato, Avellino and Pollena. The best match between the experimental runs and the natural samples point to pre-eruptive conditions of 200 MPa, 815 °C and 6 wt.% of dissolved H_2O (and at relatively high oxygen fugacity, around the Nickel-Nickel oxide NNO buffer) for the magmas of the 79 AD eruption. The results showed that magma reservoirs seem to have migrated upwards through time, from 7-8 km for the three oldest events (including the Pompeii eruption) to 3-4 km for the more recent Pollena eruption. Considering also geothermobarometric and melt inclusion data from older (the Pomici di Base Plinian eruption) and younger (AD 1631, 1906 and 1944 eruptions), the authors observed a trend not only towards shallower depths of magma storage, but also towards MgO-richer, hotter magmas.

1.4 The impact of the 79 AD explosive eruption: causes of death during the fall phases

Estimates of people killed by volcanic eruptions are usually incomplete and often not linked to specific causes (Francis, 1976; Simkin and Fiske, 1983; Blong, 1984). This is generally due to the lack, especially for the past centuries, of complete and accurate reports. The role of the different eruptive hazards as agents of death can be better ascertained with an improved knowledge of the effects of past eruptions, based on evidence from the resulting volcanic deposits (Blong, 1984; Tanguy et al., 1998).

One excellent case is the 79 AD eruption of Vesuvius that buried the roman cities of Pompeii and Herculaneum as well as many countryside villas. These archaeological sites are excellent natural laboratories for understanding the relationship between the various styles of eruptive events, the mechanical behaviour of the buildings and the number and location of the victims.

The first discovery of four skeletons in Pompeii dates to 1748, during the excavation of the Portico dei Teatri. In April 1768, 34 victims came to light. In December 1772, while a large building was being explored outside the walls of Pompeii, 20 skeletons were found in a corridor near the entrance to a cryptoporticus. In the second half of the nineteenth century, Giuseppe Fiorelli, director of the Pompeii archaeological site, developed an innovative technique to obtain the casts of the victims found inside ash deposit, simply by pouring plaster into the voids left by the bodies following the decomposition of the organic matter. This method was first used in February 1863.

The exact number of inhabitants of Pompeii is still subject of scientific debate. The estimates vary from 6400 to 20000 (Fiorelli, 1873; La Torre, 1988). Conversely, the number of victims, is considered to be of about 2000 (Sigurdsson et al., 1985; Cioni et al., 1995; Luongo et al., 2003b). According to Sigurdsson et al. (1985), all the victims were killed during the first pyroclastic current (S4-S5). In a study by Luongo et al. (2003b), the exact position of each victim in the city is reported.

To fully understand the location where the victims have been found, it is useful to summarise what was the urban framework of the ancient city. Pompeii was located at an average elevation of 25-30 m above the sea level, upon an ancient hill formed by a lava flow. The city has been conventionally subdivided into nine zones ('regiones', from I to IX) by longitudinal arteries ('decumans') and transversal arteries ('cardini') (Fig. 1.26). Every 'regio' has been subdivided into 'insulae', made up by blocks of houses. Around the town seven gates dissected a 10-m-tall wall.

Of the 394 skeletons found within the fallout levels, 200 were found isolated and 194 in groups. Most were found inside a building (345), whereas only 49 were in open locations (table 3).

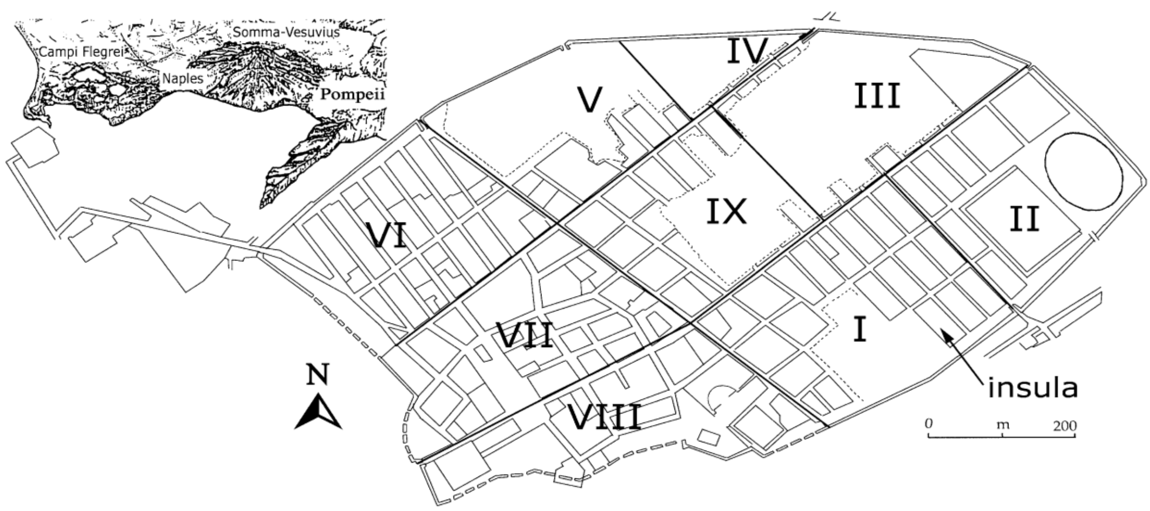

Figure 1.26 Map of Pompeii excavations showing the location of the "regiones". Unornamented areas represent unexcavated "regiones". (Luongo et al., 2003)

	Indoor areas (a)	Outdoor places (b)	Individual finds (c)	Multiple finds (d)	Total (a)+(b) or (c)+(d)
External areas	17	17	12	22	34
Regio I	66	9	38	37	75
Regio II	12	7	5	14	19
Regio III	9	–	1	8	9
Regio IV	1	1	2	–	2
Regio V	40	–	16	24	40
Regio VI	41	2	29	14	43
Regio VII	59	5	39	25	64
Regio VIII	21	5	16	10	26
Regio IX	69	1	39	31	70
Unknown location	10	2	3	9	12
Total	345	49	200	194	394

Table 3. Total numbers of skeletons found in the fallout deposit . (Luongo et al., 2003)

On the other hand, the victims found in the deposits from pyroclastic currents are distributed evenly between internal and external areas. During the first phase of the eruption, the population tried to take shelter inside houses and buildings. In fact, the fractured skulls of some skeletons probably testify that death occurred following the collapse of roofs under the load of the fallout deposit. The small percentage of victims found outdoors was likely killed by collapsing roof tiles or by larger lithic fragments following ballistic paths. According to Thomas and Sparks (1992) particles smaller than 1.6 cm are deposited already cold, while clasts larger than 25 cm have a smaller heat loss. Therefore, considering the size of the clasts found in Pompeii, the deposit was likely cold at the time of deposition. During the PDC phase the victims were killed by the pyroclastic currents. Luongo et al. (2003a; 2003b) reported that victims were found several centimeters above the base of unit E (S6 for Sigurdsson et al., 1985). Furthermore, most of the tiles and demolished walls were found above the casts of the victims, suggesting that the pyroclastic currents with greater kinetic energy reached the city when the victims had been already buried (and thus shielded) by a previous pyroclastic impulse.

There are only few studies regarding the gender and the age of the inhabitants of Pompeii. Hennerberg et al. (1999) suggests that among the 210 victims founds, 45 are men, 80 women and 85 children. During the eruption, the healthiest and strongest people left the city before the disaster, while women and children were abandoned in the city. According to Capasso (2000), the same happened in Herculaneum.

In addition to Pompeii, numerous other areas have been excavated in the proximity of Vesuvius.

Herculaneum was discovered in 1709 and excavated by the Bourbons through tunnels and passages until 1795. Subsequently, the excavations resumed in 1828, with the complete removal of the volcanic material. The city centre, now completely exposed, is surrounded by vertical sequences of pyroclastic current deposits from 10 to 23 meters thick, which thus represent a remarkable outcrop of the volcanic succession. The Plinian fallout succession is almost totally absent in Herculaneum, given that the direction of dispersion of the products is towards the south-east. The origin of the 79 AD pyroclastic current deposits has been controversial for several years. Corti (1964) and Maiuri (1977) attributed these deposits to mudflows, Sheridan et al. (1981) described basal flows and surges and summit lahars. Since the 2000s, thanks to the new classification by Branney and Kokelaar (2002), authors (Luongo et al., 2002; Scarpati et al., 2020; Doronzo et al., 2022) started to correlate these deposits with pyroclastic currents.

In 1977 in Boscoreale, during the excavations for the foundations of a building, Villa Regina was brought to light. This rustic villa consists of several rooms arranged on three sides of an open courtyard. The villa, which was built in the 1st century BC and expanded over time (Jacobelli et al., 2020) is in an open excavation of about 8 meters below the level of the surrounding soil. The main entrance on the west side of the property opens onto a small vestibule. Plaster casts of the original doors are visible on the sides of the entrance. The room immediately to the left is likely a former warehouse, where a large amount of pottery and agricultural tools were found under the load of the thick layer of the fallout deposit.

Villa Regina is best known for the discovery of the famous curved "tree", which has a paramount importance for volcanologists. Indeed, the cast of the trunk provides a complete set of information regarding the pyroclastic flow and the dynamics of the 79 AD eruption. The tree shows how the eruption first filled with “light” material (ash and pumice) the environment around the tree and then, after hours, the pyroclastic flow invaded the whole area and bent the tree, charring it instantly. The discovery has also made possible to trace more precisely the amount of material that fell in the area, its precise direction, and the power of the pyroclastic flow.

In 1967 a large Roman villa was discovered in Torre Annunziata (Petrosino et al., 2004), the ancient city of Oplontis. The city of Oplontis first appeared in the Tabula Peutingeriana (a copy of an ancient Roman map showing the roads of the Roman Empire) in the third century AD. Numerous amphorae were found in the villa (buried under the load of pumice lapilli fallout deposit) containing the inscription "Poppaea Libertus", referring to Poppaea Sabina, wife of the emperor Nerone. The stratigraphic succession in the area is generally very similar to that found in Boscoreale. The excavation of the portico of the Oplontis villa showed that the colonnade and roof over the portico collapsed during the deposition of the grey pumice fallout, which could have triggered the evacuation of the villa. Near the villa a large outdoor swimming pool is also present. The Oplontis pool is 17 m wide and about 50 m long, and between 135 and 142 cm deep (Sigurdsson et al., 1985). During the excavations in 1984, the volcanic stratigraphy in the pool was well exposed: some details are strikingly different from the stratigraphy elsewhere in Oplontis, although these differences can be attributed to the presence of water in the pool during the eruption.

Moving towards the proximal areas, in the spring of 1981 a new Roman archaeological site was discovered in a large quarry south of Terzigno, only 6 km east of the crater of Vesuvius. Shortly thereafter, another site was discovered in an adjacent quarry, 1 km to the north. The 79 AD deposit, which can be traced throughout the Terzigno quarries, overlies a rich brown soil with the characteristic hummock of the Roman vineyards. Evidence from the excavation of the northern villa rustica in the Terzigno quarry indicates that the pumice fallout could have rapidly followed the deposition of the A-1 ash layer (Sigurdsson et al., 1985). There the fine ash layers lied in the doorway and courtyard of the villa where skeletons were found. Following the deposition of layer A-1, continuous fallout of coarse pumice emplaced layers A-2, A-3 and A-4. Fallout of pumice was interrupted by the emplacement of the first surge (S-2). This damaged the *villae rusticae* as evidenced by the occurrence of minor building fragments within the deposit.

Moving towards the south, the 79 AD succession is well exposed within the archaeological area of Stabiae, which is located on the Varano plateau, a terrace of volcanic and alluvial formation at an altitude of 50 m, one of the numerous flat hilly terraces that slope down from the Lattari Mountains towards the sea (Ruffo, 2011).

Villa San Marco was the first villa to be explored in Stabia during the Bourbons period, between 1750 and 1754. The villa was stripped of the best-preserved frescoes and furnishings and then reburied after its structures were drawn up by the engineer Karl Weber. It falls into the category of urban residential villas as it presents the main characteristics of city domus (Fig. 1.27) and luxurious holiday homes.

Thanks to the testimonies left by Libero D'Orsi it was possible to associate the damages caused by the eruption on the villas to the different eruptive phases.

For example, the fragments of tiles and decorations belonging to the ceiling found in the fallout deposits suggest that in some rooms the collapse of the roofs occurred during the sustained column phase of the eruption. On the other hand, the presence of fragments of wall and ceiling decoration inside the ash deposit, and the discovery of columns and truncated walls, testify for the impact produced by the pyroclastic currents generated by the collapse of the eruptive column.

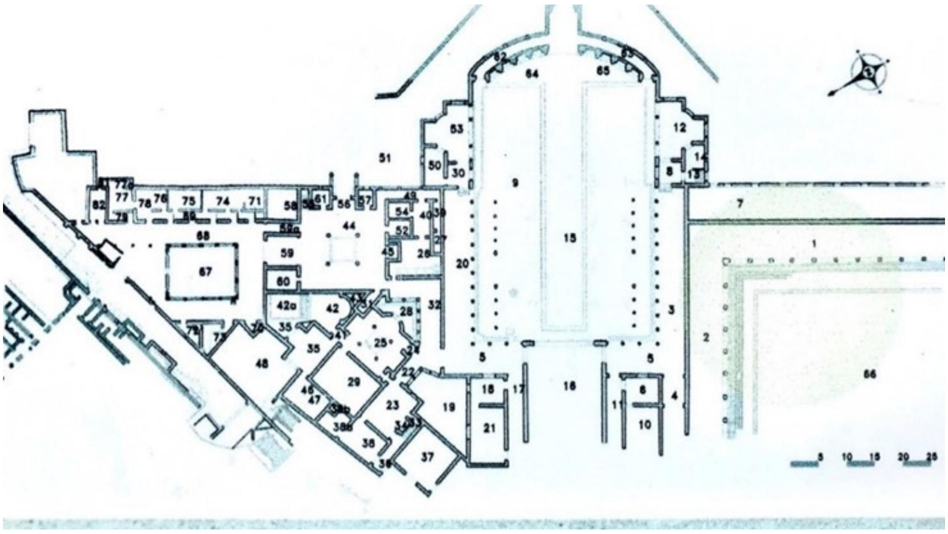

Figure 1.27 Planimetry of Villa San Marco (Stabiae)
(https://it.m.wikipedia.org/wiki/File:Mappa_Villa_San_Marco.jpg)

Conclusions

The dynamics of the Plinian and post-Plinian sustained column phases of the 79 AD eruption has been reconstructed on the basis of a detailed field work and laboratory analysis of 368 samples (grain size, component, density measurements, crystal enrichment factor estimation and chemical analyses of the juvenile fraction). The field work was aimed at the reconstruction of the stratigraphy and distribution of fallout deposits through the detailed study of 32 stratigraphic sections located at distances between 3 and 25 km from the vent. Both Plinian and the post-Plinian fallout deposits have been studied in detail. Several stratifications were recognised within the Plinian fallout deposit. Stratification is due to granulometric and lithological contrast between successive layers. A key factor is the relative abundance of lithic and juvenile clasts. Based on grain size, component and chemical analyses results it was possible to group sub-levels identified within white and grey pumice fallout deposits into single units that best represent the common characteristics of each layer. Eight units have been recognised within white pumice lapilli deposit (A-LR1, A-PR1, A-PR2, A-LR2, A-PR3, A-LR3, A-PR4 and A-LR4) and six within grey pumice lapilli deposit (B-LR1, B-PR1, B-LR2, B-LR3, B-PR2 and B-LR4). They differ mainly for lithic content (that highlight an instability in the conduit system) and the size of clasts with the stratigraphic height. All units also show a well-defined decrease in lithic content and an increase in the juvenile fraction with distance. More in detail, they show a strong reduction of deep lithics with the distance because the ability to support them decrease toward the edges of the eruptive cloud. Post-Plinian lithic-rich layers show a low mean juvenile content (22 wt. % in layer D, 6.7 wt. % in layer G1, 2.3 wt. % in layer G3 and less than 0.50 wt. % in layer I), even if this parameter increases with the distance from the source, testifying that the finer and lightest juvenile fraction has been transported to distal sections. Resulting isopach and isopleth maps for white pumice units show that the azimuth of the dispersal axis varies from 133° to 150°, with a southward shift of about 15° during the settling of the first five units. The grey lapilli units have a more constant dispersion axis showing a slight oscillation of less than 10° for only two units. These results highlight how the simplified shape of the total Plinian (white and grey) deposit isopach maps obscures the distribution shown in the isopach maps of the individual fall units, emphasizing that more eruption details can be documented with an accurate stratigraphy. The distribution of the post-Plinian lithic-rich layers is comparable to that of some Plinian units (e.g. A-LR3 and A-PR4), suggesting the rise of considerable eruptive columns even during the final stages of the AD 79 eruption. The total volume of the pumice lapilli deposit accumulated during the Plinian fall phase (white + grey) is 6.2 km^3 (1.65 km^3 DRE). Tephra mass for the single units is on the order of 10^{11} kg. The maximum plume height during the first white pumice phase was reached during the emplacement of unit A-LR4, with a height of 23 km. Mass discharge rates range from 5.2 x 10^6 to 9.0 x 10^7 kg/s. During the grey pumice phase, the eruption is characterized by the alternation of sustained column phases and partial column collapse phases, with the emplacement of several PDC ash deposits. The maximum height of the plume is reached with the emplacement of unit B-LR3, with a height of 34 km. Mass discharge rates, varies from 6 x 10^7 to 4.3 x 10^8 kg/s. During the late, post-Plinian fallout phase, the column resumes heights from 17 to 19 km and mass discharge rates from 1.8 to 4.2 x 10^7 kg/s. These data highlight the oscillating behaviour of the sustained eruptive column of the 79 AD eruption. The determination of magma discharge rate and total mass of each unit within the white and grey deposits, which are based entirely on field evidence, provide a new detailed chronology of the eruption. The eight phases occurred during the emplacement of the white pumice fall deposit last from few minutes (A-LR2, 3 minutes) to about two hours (A-PR4, 110 minutes). In total, this phase lasts six hours and thirty-six minutes. The six phases occurred during the emplacement of the grey pumice fall deposit, which is estimated including the distal isopachs in the total volume, lasts eleven hours. The duration of the first three post-Plinian sustained column pulses last several tens of minutes; the first, the longest, lasts an impressive 44 minutes. The detailed stratigraphy of the fallout deposits, and the new chronology of the eruption, have been useful tools to define the timing of the destruction during the Plinian phase of the eruption. During the first phase of the eruption part of the population tried to take shelter inside houses and buildings, but after 3 hours from the beginning of the eruption (around 3 pm), the roofs begin to collapse under the load of the thick fallout deposit. Victims found indoors were probably killed during the white pumice fallout phase, from the beginning of A-PR2 phase (which deposition started around 3 pm) onwards. The small number of victims found outdoors was likely killed by collapsing roof tiles or by larger lithic fragments. In the section of Pompei, many ballistics were found within B-LR1 and B-PR1 units, testifying that the victims found outdoors were probably killed between 7.36 and 8.33 pm. In addition, several roofing-tiles were recovered up to the highest units of the Plinian fallout succession, within B-PR2 and B-LR4 units. Consequently, roof have continued to collapse from 3 pm to 4 am, with the beginning of B-LR4 phase. The lack of archaeological evidence led us to suppose that the post-Plinian fallout phases were not dangerous or destructive for the inhabitants.

Finally, the results of the petrochemical analyses provide new insights into the withdrawal of the 79 AD magma chamber. The first Plinian fallout phase, corresponding to the emplacement of the white pumice lapilli deposits, is characterised by relatively homogeneous strongly evolved composition of the juvenile fraction. A slight decrease in the degree of evolution of the juvenile clasts is recorded in topmost levels of the white pumice lapilli fallout sequence interpreted as reflecting the withdrawal from a vertically stratified phonolitic "white" magma batch capping the 79 AD reservoir which included also a lower tephriphonolitic "grey" body. The relationships linking the "white" and "grey" is evident in the final stages of the white pumice lapilli fallout, as testified by the sporadic occurrences of grey pumice clasts with intermediate chemical composition in the uppermost levels of the sequence. The second Plinian fallout phase is characterised by the "grey" magma which is generally considered the product of three end-members: 1) a phonolitic "white" magma 2) a crystal-poor phono-tephritic magma that was never erupted unmixed and 3) a crystal mush from the magma chamber. The juvenile clasts from the grey fallout deposits show some compositional variability but no systematic vertical trend is observed. The variable degree of evolution that is observed in the grey pumice clasts would thus mainly reflect varying proportions of the involved end-members. An overall progression to decreasing degrees of evolution (high MgO content) is observed when the post-Plinian fallout deposits are erupted. Such gradient is not so linear and continuous like in the case of the white pumice lapilli fallout. MgO-rich compositions, never reported before for the 79 AD products, might represent the MEM end-member, likely deriving from the near-primitive melts periodically refilling the reservoir.

References

Andronico D., Cioni R., 2002. Contrasting styles of Mt. Vesuvius activity in the period between the Avellino and Pompeii Plinian eruptions, and some implications for assessment of future hazards. Bull. Volcanol. 64, 372-391.

Aravena A., Cioni R., de' Michieli Vitturi, Neri A., 2019. The Lithic Component of Pyroclastic Deposits as a Proxy for the Reconstruction of the Syneruptive Evolution of Volcanic Conduits: The CE 79 Eruption of Vesuvius. JGR Solid Earth. 124, 11022-11037.

Aravena A., Cioni R., Bevilacqua A., de' Michieli Vitturi M., Esposti Ongaro T., Neri A., 2020. Tree-branching based enhancement of kinetic energy models for reproducing channelization processes of pyroclastic density currents. JGR Solid Earth.

Ayuso R.A., De Vivo B., Rolandi G., Seal R.R., Paone A., 1998. Geochemical and isotopic (Nd-Pb-Sr-O) variations bearing on the genesis of volcanic rocks from Vesuvius, Italy. J. Volcanol. Geoth. Res. 82, 53-78.

Balcone-Boissard H., Villemant B., Boudon G., Michel A., 2008. Non-volatile vs volatile behaviours of halogens during the AD 79 Plinian eruption of Mt. Vesuvius, Italy. Earth and Planetary Science Letters. 269, 66-79.

Balcone-Boissards H., Boudon G., Villemant B., 2011. Textural and geochemical constraints on eruptive style of the 79 AD eruption at Vesuvius. Bull. Volcanol. 73, 279-294.

Barberi F., Leoni L., 1980. Metamorphic Carbonate Ejecta from Vesuvius Plinian Eruptions. Evidence of the occurrence of shallow magma chambers. Bull. Volcanol. 43, 107-120.

Barberi F., Cioni R., Rosi M., Santacroce R., Sbrana A., Vecci R., 1989b. Magmatic and phreatomagmatic phases in explosive eruptions of Vesuvius as deduced by grain-size and compositional analysis of pyroclastic deposits. J. Volcanol. Geoth. Res. 38, 287-307.

Barberi F., Macedonio G., Pareschi M.T., Santacroce R., 1990. Mapping the tephra fallout risk: an example from Vesuvius Italy. Nature 344, 142-144.

Blackburn E., Wilson L., Sparks R.S.J., 1976. Mechanisms and dynamics of strombolian activity. J. Geol. Soc. Lond. 132, 429-440.

Blong R.J., 1984. Volcanic Hazards. Academic Press, New York, 411,1-424

Bonadonna C., Phillips J.C., 2003 Sedimentation from strong volcanic plumes. J. Geophys. Res. 108, 2340–2368

Bonadonna, C., Costa A., 2013. Modeling tephra sedimentation from volcanic plume. Modeling Volcanic Processes: The Physics and Mathematics of Volcanism, Chapter 9.

Branney M.J., Kokelaar B.P., 2002. Pyroclastic density currents and the sedimentation of ignimbrites, Geol. Soc. Lond. Mem., 27, 51–58.

Bursik M., 1993. Subplinian eruption mechanism inferred from volatile and clast dispersal data. J. Volcanol. Geoth. R. 57, 57-70.

Calder E.S., Sparks R.S.J., Gardeweg M.C., 2000. Erosion, transport and segregation of pumice and lithic clasts in pyroclastic flow inferred from ignimbrite at Lascar Volcano, Chile. J. Volcanol. Geoth. Res. 104, 201-235.

Carey S., Sparks R.S.J., 1986. Quantitative models of the fallout and dispersal of tephra from volcanic eruption columns, Bull. Volcanol. 48, 109–125.

Cioni R., Marinelli P., Sbrana A., 1990. L'eruzione del 79 d.C.: stratigrafia dei depositi ed impatto sugli insediamenti romani nel settore orientale e meridionale del Somma-Vesuvio. Rivista di Studi Pompeiani IV (1990). 179-198.

Cioni R., Marinelli P., Sbrana A., 1992. Dynamics of the AD 79 eruption: stratigraphic, sedimentologic and geochemical data on the successions of the Somma-Vesuvius southern and eastern sector. Acta Vulcanol. 2, 109-124.

Cioni R., Civetta L., Marinelli P., Metrich N., Santacroce R., Sbrana A., 1995. Compositional layering and syneruptive mixing of a periodically refilled shallow magma chamber: the AD 79 Plinian eruption of Vesuvius. J. Petrol. 36, 739-776.

Cioni R., Sbrana A., Gurioli L., 1996. The deposits of AD 79 eruption. In Vesuvius Decade Volcano Workshop Handbook (eds R Santacroce, M Rosi, A Sbrana, R Cioni and L Civetta), pp. 17–23. CEV-CMVD workshop on Vesuvius. Rome, Italy: Consiglio Nazionale delle Ricerche.

Cioni R., Marianelli P., Santacroce R., 1998. Thermal and compositional evolution of the shallow magma chambers of Vesuvius: evidence from pyroxene phenocrysts and melt inclusions. J. Geophys. Res. 103, 18277-18294.

Cioni R., Santacroce R., Sbrana A., 1999. Pyroclastic deposits as guide for reconstructing the multi-stage evolution of the Somma-Vesuvius caldera. Bull. Volcanol. 60, 207-222.

Cioni R., Longo A., Macedonio G., Santacroce R., Sbrana A., Sulpizio R., Andronico D., 2003. Assessing pyroclastic fall hazard through field data and numerical simulations: example from Vesuvius. J. Geophys. Res. 108, B22063

Cioni R., Gurioli L., Lanza R., Zanella E., 2004. Temperature of the AD 79 pyroclastic density current deposits (Vesuvius, Italy). J. Geophys. Res. 109, 1-18

Cioni R., Tadini A., Gurioli L., Bertagnini A., Mulas M., Bevilacqua A., Neri A., 2020. Estimating eruptive parameters and related uncertainties for pyroclastic density currents deposits: worked examples from Somma-Vesuvio (Italy). Bull. Volcanol. 82, 1-20

Civetta L., Galati R., Santacroce R., 1990. Magma mixing and convective compositional layering within the Vesuvius magma chamber. Bull. Volcanol. 53, 287-300.

Civetta L., Galati R., Santacroce R., 1991. Magma mixing and convective compositional layering within the Vesuvius magma chamber. Bull. Volcanol. 53, 287-300.

Corti E., 1957. Ercolano e Pompei. Torino, 243.

Costa A., Melnik O., Sparks R.S.J., 2007. Controls of conduit geometry and wall-rock elasticity on lava dome eruptions. Earth and Planetary Science Letters. 260, 137-151.

Delibrias G., Di Paola G.M., Rosi M., Santacroce R., 1979. La storia eruttiva del complesso vulcanico Somma-Vesuvio ricostruita dalle successioni piroclastiche del Somma. Rend. Soc. It. Mineral. Petrol. 35, 411-438.

Di Girolamo P., 1963. La serie piroclastica dell'eruzione di Pompei. Ann. Osserv. Vesuv. 6,5, 1-81.

Di Girolamo P., 1968. Petrografia del Somma-Vesuvio: le serie piroclastiche. Rend. Acc. Sc. Fis. Mat. 4-36, 1-68.

Di Girolamo P., 1970. Rilevamento petrografico-stratigrafico lungo il margine SW del Vesuvio. Rend. Soc. It. Mineral. Petrol. 26, 77-108.

Doronzo M., Di Vito M.A., Arienzo I., Bini M., Calusi B., Cerminara M., Corradini S., De Vita S., Giaccio B., Gurioli L., Mannella G., Ricciardi G.P., Rucco I., Sparice D., Tedesco M., Trasatti E., Zanchetta G., 2022. The 79 CE eruption of Vesuvius: a lesson from the past and the need of multidisciplinary approach for developments in volcanology. Earth Sci. Rev. 231, 104072

Gurioli L., Cioni R., Bertagna C., 1999. I depositi di flusso piroclastico dell'eruzione del 79 d.C.: caratterizzazione stratigrafica, sedimentologica e modelli di trasporto e deposizione. Proceedings Società Toscana Scienze Naturali, Memorie, Ser. A. 106, 61-72.

Fierstein J., Nathenson M., 1992. Another look at the calculation of fallout tephra volumes. Bull. Volcanol. 54, 156–167.

Fiorelli G., 1873. Gli scavi di Pompei dal 1861 al l872. Napoli, 12-14.

Fisher R.V., 1979. Models for pyroclastic surges and pyroclastic flows. J. Volcanol. Geoth. Res. 6, 305-318.

Fisher R.V., 1990. Transport and deposition of a pyroclastic surge across an area of high relief: The 18 May 1980 eruption of Mount St. Helens, Washington. Geol. Soc. Am. Bull. 102, 1038-1054.

Francis P., 1976. Volcanoes. Penguin, Harmondsworth.

Fulignati P., Marianelli P., Santacroce R., Sbrana A., 2004. Probing the Vesuvius magma chamber-host rock interface through xenoliths. Geological Magazine. 141, 417-428.

Gigante M., 1989. "Il fungo sul Vesuvio secondo Plinio il Giovane". Ed. Luccarini, Roma.

Giove T., 2003. Scheda IV. 754 in Storie da un'eruzione Pompei Ercolano Oplontis, a cura di Antonio d'Ambrosio, Pier Giovanni Guzzo, Marisa Mastro Roberto, catalogo mostra Napoli 20 marzo, 31 agosto 2003, Milano, p. 420.

Gurioli L., Cioni R., Sbrana A., Zanella E., 2002. Transport and deposition from pyroclastic flow over densely inhabited areas: Herculaneum (Italy). Sedimentology, 49, 929-953

Gurioli L., Houghton B.F., Cashman KV., Cioni R., 2005. Complex changes in eruption dynamics during the 79 AD eruption of Vesuvius. Bull. Volcanol. 67, 144-159.

Gurioli L., Zanella E., Pareschi MT., Lanza R., 2007. Influences of urban fabric on pyroclastic density currents at Pompeii (Italy): flow direction and deposition (part I). J. Geophys. Res., 112 (B5).

Guzzo PG., Fergola L.. 2000. Oplontis, la villa di Poppea.

Henneberg M., Henneberg R.J., 1999. Primi risultati di uno studio ad ampio raggio e ancora in corso sul materiale scheletrico umano di Pompei. Catalogo della mostra Homo Faber, Electa Ed., 51-53.

Houghton B.F., Carey R.J., Rosenberg M.D., 2014. The 1800a Taputo eruption: "III wind" blows the ultraplinian type event down to Plinian. Geology, 42, 459-461.

Ippolito F., 1950. Sul meccanismo di seppellimento di Pompei e di Ercolano. Pompeiana, 387-395.

Jacobelli L., Pensabene P., 2020. La decorazione architettonica del Tempio di Venere a Pompei: contributo allo studio e alla ricostruzione del Santuario. Rivista di studi Pompeiani: VII, 45-75.

Jashemski W.F., 1979. The Natural History of Pompeii

Johnston-Lavis H.J., 1884. The geology of Monte Somma and Vesuvius, being a study in Vulcanology. Quart J. Geolo. Soc. 40, 35-119.

Jolis E.M., Troll V.R., Harris C., Freda C., Gaeta M., Orsi G., Siebe C., 2015. Skarn xenolith record crustal CO_2 liberation during Pompeii and Pollena eruptions, Vesuvius volcanic system, central Italy. Chemical Geology. 415, 17-36.

Kennedy B., Spieler O., Scheu B., Kueppers U., Taddeucci J., Dingwell D.B., 2005. Conduit implosion during Vulcanian eruptions. Geology. 581-584.

Klawonn M., Wolfe C.J., Frazer L.N., Houghton B.F. 2014. Novel inversion approach to constrain plume sedimentation from tephra deposit data: Application to the 17 June 1996 eruption of Ruapehu volcano, New Zealand. JGR Volume 117, Issue B5

Kent DV., Ninkovich D., Pescatore T., Sparks RSJ., 1981. Paleomagnetic determination of emplacement temperature of Vesuvius AD 79 pyroclastic deposits. Nature. 290, 393-396.

Kiyaguchi T., Yujiro J., Kozono T., 2010. Effects of the crater on eruption column dynamics. J. Geophys. Res. Volume 115, issue B7.

Krumbein W.C., 1936. Application of logarithmic moments to size-frequency distributions of sediments. J. Sedim. Res. 6 (1), 35-47.

La Spina G., Burton M., de' Michieli Vitturi, 2015. Temperature evolution during magma ascent in basaltic effusive eruptions: A numerical application to Stromboli volcano. Earth and Planetary Science Letters. 426, 89-100.

La Torre G.F., 1988. Gli impianti commerciali ed artigianali nel tessuto urbano di Pompei. In: Pompei l'informatica al servizio di una città antica Roma. 73-102.

Lirer L., Pescatore T., 1968. Studio sedimentologico delle piroclastiti del Somma-Vesuvio. Acc. Sc. Fis. Mat. 7, 139-187.

Lirer L., Pescatore T., Booth B., Walker G.P.L., 1973. Two Plinian pumice-fall deposits from Somma-Vesuvius, Italy. Geol. Soc. Am. Bull., 84, 759-772.

Lirer R., Munno R., Petrosino P., Vinci A., 1993. Tephrostratigraphy of the A.D. 79 pyroclastic deposits in peri-volcanic area of Mt. Vesuvio (Italy). J. Volcanol. Geotherm. Res. 58, 133-139.

Lirer L., Munno R., Postiglione I., Vinci A., Vitelli L., 1997. The A.D. 79 eruption as a future explosive scenario in the Vesuvian area: evaluation of associated risk. Bull. Volcanol. 59, 112-124

Luongo G., Perrotta A, Scarpati C., 2003a. Impact of AD 79 explosive eruption on Pompeii I: relations amongst the depositional mechanism of the pyroclastic products, the framework of the buildings and the associated destructive events. J. Volcanol. Geoth. Res. 126, 201-223.

Luongo G., Perrotta A., Scarpati C., De Carolis E., Patricelli G., Ciarallo A., 2003b. Impact of the AD 79 explosive eruption on Pompeii II: causes of death of the inhabitants inferred by stratigraphical and areal distribution of the human corpses. J. Volcanol. Geoth. Res. 126, 169-200.

Macedonio G., Pareschi M.T., Santacroce R., 1988. A numerical simulation of the Plinian fall phase of 79 A.D. eruption of Vesuvius. J. Geophys. Res. 93, 14817 - 14827

Macedonio G., Costa A., Longo A., 2005. A computer model for volcanic ash fallout and assessment of subsequent hazard. Comput. Geosc. 31, 837-845.

Maeno F., Taniguchi H., 2009. Sedimentation and welding processes of dilute pyroclastic density currents and fallout during a large-scale silicic eruption, Kikai caldera, Japan. Sedimentary Geology. 220, 227-242.

Maiuri A., 1983. Pompei ed Ercolano fra case e abitanti. Firenze. 34-38.

Marianelli P., Métrich N., Santacroce R., Sbrana A., 1995. Mafic magma batches at Vesuvius: a glass inclusion approach to the modalities of feeding stratovolcanoes. Mineralogy and Petrology. 120, 159-165.

McBirney A.R., 1973. Factors governing the intensity of explosive andesitic eruptions. Bull. Volcanol. 37, 443-453.

Melluso L., Scarpati C., Zanetti A., Sparice D., De Gennaro R., 2022. The petrogenesis of chemically zoned, phonolitic, Plinian and sub-Plinian eruptions of Somma-Vesuvius, Italy: Role of accessory phase removal, independently filled magma reservoirs with time, and transition from slightly to highly silica undersaturated magmatic series in an ultrapotassic stratovolcano. Lithos. 430-431, 106854.

Merril E.T., 1918. "Notes on the eruption of Vesuvius in 79 AD.". AJA 22, 304-309

Merril E.T., 1920. "Further Note on the Eruption of Vesuvius in 79 A.D.,". AJA 24, 262-68.

Morgan D.J., Blake S., Rogers N.W., De Vivo B., Rolandi G., Davidson J.P., 2006. Magma chamber recharge at Vesuvius in the century prior to the eruption of A.D. 79. Geology (2006) 34 (10), 845-848.

Morton N.E., Crow J.F., Muller H.J., 1956. An estimate of the mutational damage in man from data on consanguineous marriages. PNAS, 42, 855-863.

Mues-Schumacher U., 1994. Chemical variations of the AD 79 pumice deposits of Vesuvius. European Journal of Mineralogy 6, 387-395.

Nairn I.A., Self S., 1978. Explosive eruptions and pyroclastic avalanches from Ngauruhoe in February 1975. J. Volcanol. Geoth. Res. 3, 39-60.

Perrotta A., Scarpati, C., 2003. Volume partition between the Plinian and co-ignimbrite airfall deposits of the Campanian Ignimbrite eruption: Mineralogy and Petrology. 79, 67–78.

Pioli L., Harris J.L., 2019. Real-time geophysical monitoring of particle size distribution during volcanic explosions at Stromboli Volcano (Italy). Earth Science. Volume 7, article 52.

Pyle DM., 1989. The thickness volume and grain-size of tephra fall deposits. Bull. Volcanol. 51, 1-15.

Redi D., Cannatelli C., Esposito R., Lima A., Petrosino P., De Vivo B., 2016. Somma-Vesuvius activity: a mineral chemistry database. Miner. Petrol. 111, 43-67.

Rittman A., 1950. L'eruzione vesuviana del 79 d.C.: studio magmatologico e vulcanologico. Pompeiana. 456-474.

Rolandi G., Paone A., Di Lascio M., Stefani G., 2007. The 79 AD eruption of Somma: the relationship between the date of the eruption and the southeast tephra dispersion. J. Volcanol. Geoth. Res., 169 (2007), 87-98.

Rosi M., Vezzoli L., Castelmenzano A., Grieco G., 1999. Plinian pumice fall deposit of the Campanian Ignimbrite eruption (Phlegrean Fields, Italy): J.Volcan. and Geoth. Res. 91,179–198,

Rosi M., Paladio-Melosantos M., Di Muro A., Leoni R., Bacolcol T., 2001. Fall vs flow activity during the 1991 climatic eruption of Pinatubo Volcano (Philippines). Bull. Volcanol. 62, 549-566.

Ruffo F., 2011. Alcune riflessioni su Stabiae: STABIAE, SAN MARCO: LA VILLA, LE TERME, NARCISSO. Rivista di Studi Pompeiani. 25, 174-178.

Ruggiero M., 1888. Degli scavi di antichità nelle province di terraferma dell'antico regno di Napoli dal 1743 al 1876.

Santacroce R., 1987. Somma-Vesuvius. Quaderni de "La Ricerca Scientifica". CNR, Roma (1987).

Santangelo I., 2023. "Plinian eruption and their impact in urban contests: dynamics and effects on the territory of the pyroclastic currents of the 79 A.D. Vesuvian eruption". PhD thesis 1-330

Scaillet B., Pichavant M., Cioni R., 2008. Upward migration of Vesuvius magma chamber over the past 20,000 years. Nature. 455, 216-219.

Scandone R., Cashman K.V., Malone S.D., 2007. Magma supply, magma ascent and the style of volcanic eruptions. Earth and Planetary Science Letters. 235, 513-529.

Scandone R., Giacomelli L., Rosi M., 2019. Death, survival and damage during the 79 AD eruption of Vesuvius which destroyed Pompeii and Herculaneum. J. of Res. and Didactics in Geography.

Scarpati C., Perrotta A., De Simone F.G., 2016. Impact of explosive volcanic eruptions around Vesuvius: a story of resilience in Roman time. Bull. Volcanol. 78, 1147-1159.

Scarpati C., Perrotta A., Martellone A., Osanna M., 2020. Pompeian hiatuses: new stratigraphic data highlight pauses in the course of the AD 79 eruption at Pompeii. Geo. Megaz. 157, 695-700.

Self S., Sparks R.S.J., 1978. Characteristics of widespread pyroclastic deposits formed by the interaction of silicic magma and water. Bull. Volcanol. 41, 196-212.

Shea T., Larsen J., Gurioli L., Houghton B., Hammer J., Cioni R., 2009. Leucite crystals: surviving witnesses of the pre-eruptive magma chamber of the 79 AD eruption at Vesuvius, Italy. Eart Sci. Planet. Lett. 281, 88.98.

Shea E., Hellebrand E., Gurioli L., Hugh T., 2014. Conduit- to localized-scale degassing during Plinian eruptions: insights from major element and volatile (Cl and H2O) analysis within Vesuvius AD 79 pumice. J. Petrol. 55, 315-344.

Sheridan M.F., 1979. Emplacement of pyroclastic flows: a review. In Chapin & Elston. 125-136.

Sheridan M.F., Barberi F., Rosi M., Santacroce R., 1981. A model for Plinian eruptions of Vesuvius. Nature. 289, 282-285.

Sigurdsson H., Cashdollar S., Sparks R.S.J., 1982. The eruption of Vesuvius in AD 79: reconstruction from historical and volcanological evidence. American J. Archaeol. 86, 39-51

Sigurdsson H., Carey S., Cornell W., Pescatore T., 1985. The eruption of Vesuvius in 79 AD. National Geographic Res. 1, 332-387.

Sigurdsson H., Cornell W., Carey S., 1990. Influence of magma withdrawal on compositional gradients durinf the 79 A.D. Vesuvius eruption. Nature, 345, 519-521.

Simkin T., Fiske R.S., 1983. Krakatau: The volcanic eruption and its e¡ects. Smithsonian Institution Press, Washington, DC.

Smith R.T., Houghton B.F., 1995. Vent migration and changing eruptive style during the 1800a Taupo eruption: new evidence from the Hatepe and Rotongaio phreatoplinian ashes. Bull. Volcanol. 57, 432-439.

Sohn Y.K., Chough S.K., 1989. “Depositional processes of the Suwolbong Tuff Ring, Cheju Island (Korea)”. Sedimentology, vol. 36, 837-855.

Sparks R.S.J., Walker G.P.L., 1973. The ground surge deposit: a third type of pyroclastic rock. Nature Phys. Sc. 241, 62-64.

Sparks R.S.J., Wilson G.P.L., 1976. A model for the formation of ignimbrite by gravitational column collapse. J. Geol. Soc. Lond. 132, 441-452.

Sparks R.S.J., Sigurdsson H., Wilson L., 1977. Magma mixing: a mechanism of triggering acid explosive eruptions. Nature 267, 315-318.

Sparks R.S.J., Wilson L., Hulme G., 1978. Theoretical modelling of the generation, movement, and emplacement of pyroclastic flows by column collapse. J. Geophys. Res. 83, 1727-1739.

Stefani G., 2006. La vera data dell'eruzione. Archeo. Attualità del passato XXII, 10, 10–13.

Sparks R.S.J., Wilson L., 1976. A model for the formation of ignimbrite by gravitational column collapse. J. Geol. Soc. Lond. 132, 441-452.

Sparks R.S.J., Bursik M.I., Thomas R.M.E., Carey S.N., 1992. Sedimentation of tephra by volcanic plumes. Part 2: controls on thickness and grain-size variations of tephra fall deposits. Bull. Volcanol. 54, 685-695.

Tanguy J.C., Ribièr C., Scarth A., Tjetjep W., 1998. Victims from volcanic eruptions: A revised database. Bull. Volcanol. 60, 137-144.

Thomas R.M.E., Sparks R.S.J., 1992. Cooling of tephra during fallout from eruption columns. Bull. Volcanol. 54, 542-553.

Walker G.P.L., Wilson L., Bowell E.L.G., 1971. Explosive volcanic eruptions. The rate of fall pyroclastics. J. Geophys. Res. Astr. Soc. 22, 377-383.

Walker G.P.L., 1973. Explosive volcanic eruptions – a new classification scheme. Geol. Rundsch. 62, 431- 446.

Walker G.P.L., 1980. The Taupo pumice: Product of the most powerful known (ultraplinian) eruption? Journal of Volcanology and Geothermal Research, 8, 69–94.

Walker G.P.L., 1981b. Plinian eruptions and their products. Bull. Volcanol. 44, 223-240.

Walker G.P.L., 1981c. Generation and dispersal of fine ash and dust by volcanic eruptions. Journal of Volcanology and Geothermal Research, volume 11. 81-92

Walker G.P.L., 1983. Ignimbrite types and ignimbrite problems. J. Volcanol. Geoth. Res. 17, 65-88.

Williams S.N., Self S., 1983. The October 1902 Plinian eruption of Santa Maria volcano, Guatemala. J. Volcanol. Geoth. Res. 16, 33-56.

Wilson L., 1976. Explosive volcanic eruptions – III. Plinian eruption columns. J. Geophys. Res. Astr. Soc. 45, 543-556.

Wilson L., Sparks R.S.J., Huang T.C., Watkins N.D., 1978. The control of eruption column heights by eruption energetics and dynamics. J. Geophys. Res. 83, 1829-1836.

Wilson L., Sparks R.S.J., Walker G.P.L., 1980. Explosive volcanic eruptions – IV. The control of magma properties and conduit geometry on eruption column behaviour. J. Geophys. Res. Astr. Soc. 63, 117-148.

Wilson C.J.N., 1985. The Taupo eruption, New Zealand II. The Taupo ignimbrite: Philosophical Transactions of the Royal Society of London, 314, 229–310.

Wilson C.J.N., Walker, G.P.L., 1985. The Taupo eruption, New Zealand I. General aspects: Philosophical Transactions of the Royal Society of London. 314, 199–228.

Zanella E., Gurioli L., Pareschi M.T., Lanza R., 2007. Urban fabric influences on pyroclastic density currents at Pompei (Italy): deposit temperature (part II). J. Geophys. Res. 112 (B5).

Zimanowski B., Wohlet K.H., Dellino P., Büttner R., 2003. The volcanic ash problem: Journal of Volcanology and Geothermal Research. 122, 1–5.

Zollo A., Gasparini P., Virieux J., Le Meur H., De Natale G., Biella G., Boschi E., Captano P.,De Franco R., Dell'Aversana P., De Matteis R., Guerra I., Iannaccone G., Mirabile L., Vilardo G. 1996. Seismic evidence for a low-velocity zone in the upper crust beneath Mount Vesuvius. Science. 274, 592-594.

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