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# The 1538 Monte Nuovo eruption (Campi Flegrei, Italy)

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**Abstract.** On 29 September 1538 a week-long eruption began in Campi Flegrei forming a new volcano, Monte Nuovo. From contemporary accounts of the eruption, it has been possible to reconstruct the main phases of activity. These phases may be correlated with different depositional units identified in the field. The eruption opened with a hydromagmatic phase, during which a large amount of external water (meteoric or sea water) was able to interact with the magma. The exhaustion of the water supply and decrease in volatile content initiated a change in the dynamic conditions of eruption, which became more purely magmatic in character and less explosive.

## Introduction

Campi Flegrei is an active volcanic district immediately west of Naples in southern Italy. The last eruption occurred in 1538 with the formation of Monte Nuovo. This took place on the western side of a raised marine terrace, la Starza (Fig. 1), in an area that has been strongly affected by tectonic movements over the past 5000 years (Cinque et al. 1985). Before the sixteenth century, at least as far back as Roman times, this movement caused a net subsidence of the ground, modifying the coastline and submerging Roman ruins close to the shore. This phase of subsidence ended sometime before the eruption; precisely when is uncertain, but a clear uplift with the emergence of new land was observed by the inhabitants of Pozzuoli in 1502. A further rapid uplift occurred two days before the eruption in a more localized zone enclosing the immediate vent area and was accompanied by moderate seismic activity.

The first two days of the eruption were characterized by explosive behavior, which produced pyroclastic flow deposits of limited areal extent and led to the growth of the main body of the cone around the vent (Fig. 2).

Four days of relative quiescence with only minor explosive activity followed. The eruption finally ended on 6 October, the seventh day, with a violent explosive phase and the emplacement of a small scoria flow. Twenty-four people, who were climbing up to the vent during this last phase, were killed by a sudden explosion.

This brief reconstruction is based on contemporary accounts of the eruption and on the results of new studies of the Monte Nuovo deposits.

Of particular significance is the change in the style of activity between the opening and closing phases of the eruption, and whether it reflects principally an internal change in the magmatic system or a change in the external, or environmental, conditions of eruption. Here, evidence is presented in support of the latter hypothesis, and it is proposed that a major control on the style of the eruption was the juvenile volatile content and amount of external water which was able to come into contact with the ascending magma.

## Contemporary accounts of the eruption

Several Italian accounts of the eruption were written within a few months of the event (delli Falconi 1538; Marchesino 1538; da Toledo 1539; del Nero 1538; Simone Porzio 1551), of which some English translations have been presented by Hamilton (1776) and Lobley (1889). The following is a

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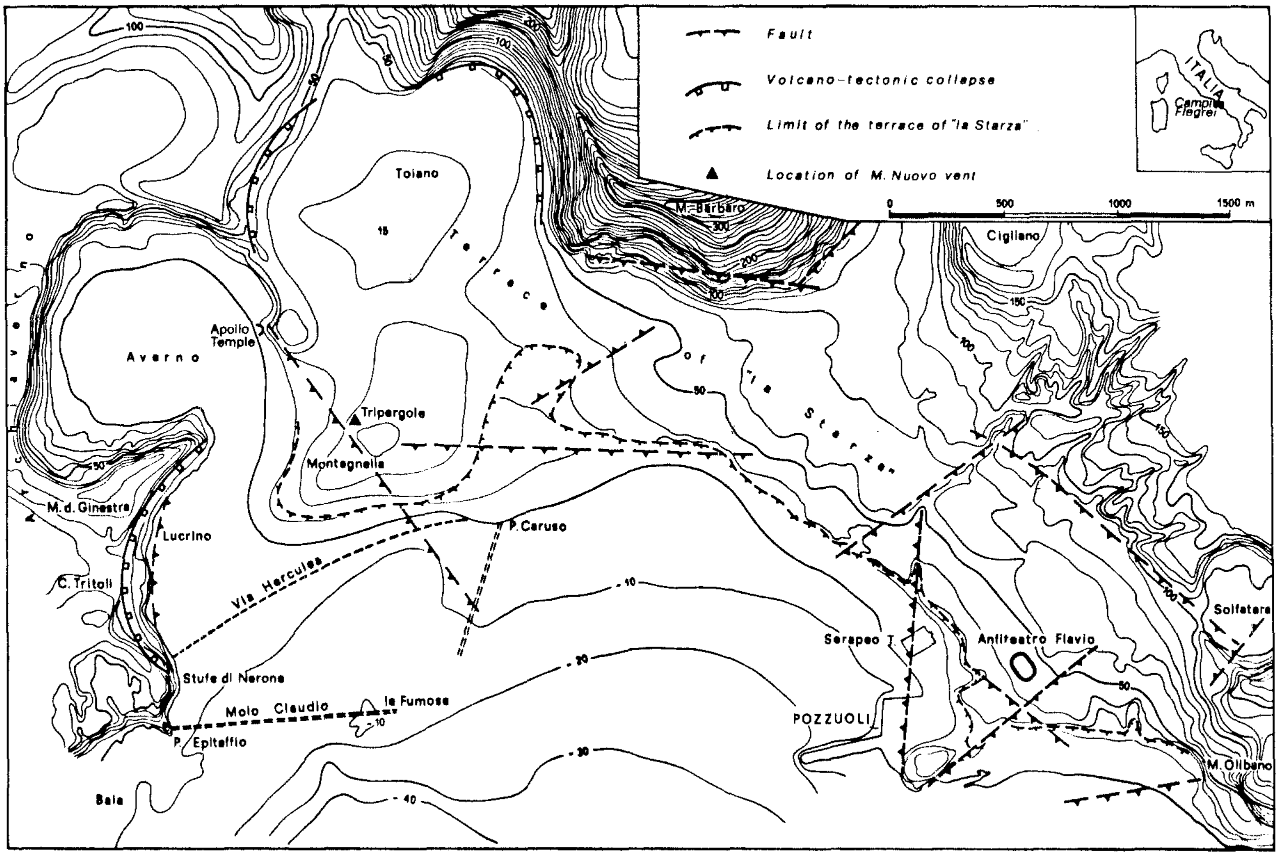


**Fig. 1.** Topographic reconstruction of the central area of Campi Flegrei before the eruption of Monte Nuovo in 1538. Also shown are the probable locations of the Roman Via Herculea and Molo Claudio, which are today under the sea

combined and abridged version of the accounts by Marco Antonio delli Falconi (1538) and Pietro Giacomo da Toledo (1539) as translated by Sir William Hamilton (1776) when he was His Britannic Majesty's Envoy Extraordinary and Plenipotentiary at the Court of Naples; modified forms may be found in Lyell (1872) and Parascandola (1946):

"... It is now two years that there have been frequent earthquakes at Pozzuolo, at Naples and the neighbouring parts; on the day and in the night before the appearance of this eruption, above twenty shocks great and small were felt at the abovementioned places. The eruption made its appearance the 29th of September 1538 ...; it was on a Sunday, about an hour in the night (Fig. 3) and ... between the hot baths or sweating rooms and Tripergoli, flames of fire ... in a short time increased to such a degree that it burst open the earth in this place and threw up so great a quantity of ashes and pumice stones mixed with water, as covered the whole country (MA delli Falconi); the smoke was partly black and partly white; the black was darker than darkness itself, and the white was like the whitest cotton (P da Toledo) ... After the stones and ashes with clouds of thick smoke had been sent up by the impulse of the fire and windy exhalation (as you see in a great cauldron that boils) into the middle region of the air, overcome by their own natural weight when from distance the strength they had received from impulse was spent, rejected likewise by the cold and unfriendly region, you saw them fall thick, and by degrees; the condensed smoke cleared away, raining ashes with water and stones of different sizes according the distance from the place (MA delli Falconi) ... The mud was of the colour of ashes and at first very liquid, then by degrees less so, and in such quantities that in less than twelve hours, with the help of the above-mentioned stones, a mountain was raised of a thousand paces in height ... An infinity of birds and numberless animals of various kinds covered with this sulphureous mud gave themselves up, a prey to man ... The third day the eruption ceased so that the mountain made its appearance uncovered ... On this day ... I saw down into its mouth ... in the middle of which the stones that had fallen were

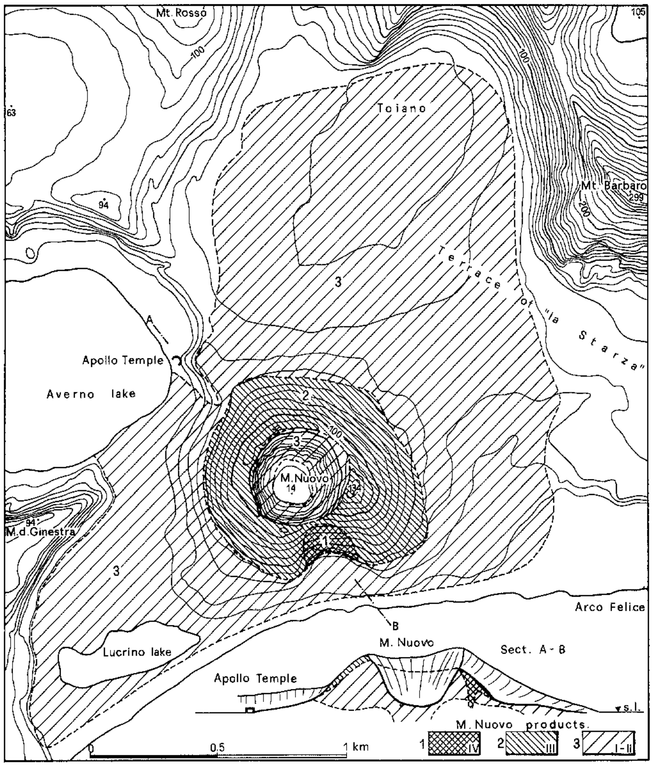


**Fig. 2.** The present day topography of the Monte Nuovo area and a cross section through the volcano. The products of Monte Nuovo eruption have been divided into I—II, pyroclastic flow deposits; III, Strombolian scoria deposits; and IV, scoria-flow deposits

boiling up, just as in a great cauldron of water that boils on the fire. The fourth day it began to throw up again, and the seventh much more, but still with less violence than the first day. (P da Toledo) ... On Sunday following, which was the 6th of October, many people went to see this phenomenon, some having ascended half the mountain, others more. About 22 o'clock there happened so sudden and horrid an eruption with so great smoke that many of these people were stifled, some of which could never be found ... From that time to this nothing remarkable happened ... (MA delli Falconi)." From these descriptions, it is possible to reconstruct a general chronology for the eruption as follows (note that Day 1 in the chronicles refers to 30 September):

| | |
|---|---|
| Day 1 (Sunday, 29 Sept—Monday, 30 Sept): | A violently explosive opening phase |
| Days 2, 3 (Tuesday, 1 Oct.—Wednesday, 2 Oct): | Minor explosivity |
| Day 4 (Thursday, 3 Oct.): | More intense explosivity, but less on Day 1 |
| Days 5, 6 (Friday 4 Oct.—Saturday, 5 Oct.): | Minor explosivity |
| Day 7 (Sunday, 6 Oct.): | More intense activity, but less than on Day 1 |

It is apparent, therefore, that the dynamics of the eruption varied with time, producing explosive activity of differing strengths, and further field and laboratory studies were carried out on the Monte Nuovo deposits to determine the nature of the process, or processes, controlling this variation.

## Field and laboratory data

The deposits from the eruption of Monte Nuovo cover an area of some 3.6 $km^2$ and represent a dense-rock-equivalent volume of about 0.025 $km^3$. They are all fragmental in nature and, on the basis of their setting and appearance in the field, may

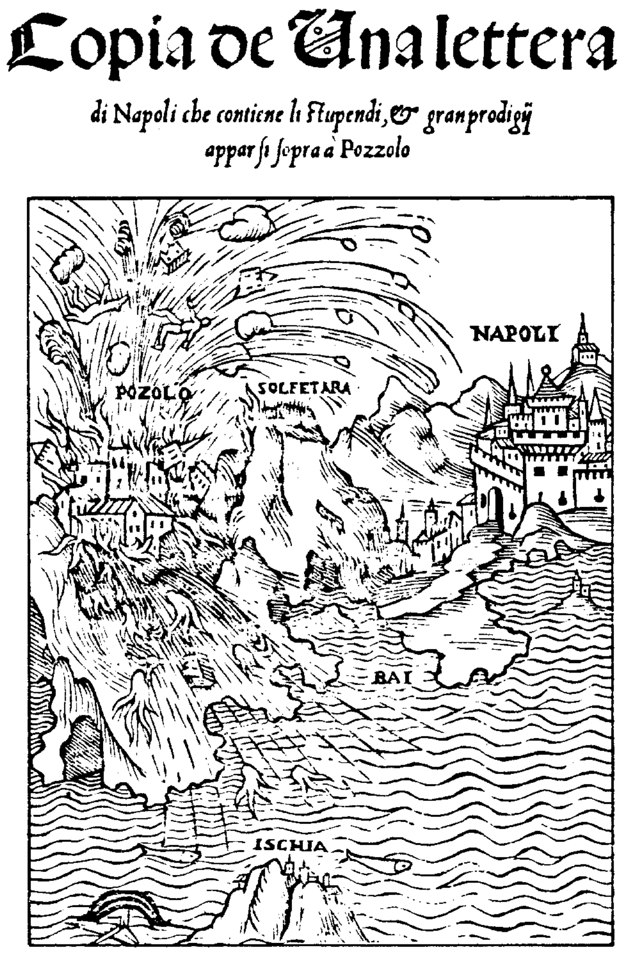


**Fig. 3.** An engraving of the 1538 eruption in the letter by Marchesino (1538) describing the event

be divided into four units (Fig. 2), as summarized below.

The first unit (I) occurs in outcrops around the southern part of the volcano with a maximum thickness of about seven meters. It has a generally chaotic textural appearance with an abundant ashy matrix containing fragments of pumice and nonjuvenile material. The pumice fragments are poorly vesicular, typically subrounded, and commonly about 10 cm across; of these, some of the larger examples (30—50 cm across) occur in sparsely distributed, lens-shaped concentrations, giving the unit a weak apparent stratification. The nonjuvenile fragments of lava and yellow tuff are present only in minor quantities and appear to be evenly distributed in vertical section. Welding, pipe structures, and evidence of plastic deformation are absent from this unit, part of which has been lithified by post-depositonal mineralization (zeolitization).

The second unit (II) outcrops around the whole volcano and with an inferred maximum thickness of 60—70 meters forms the major part of the cone. Largely unlithified, it has a textural appearance similar to unit I. The bulk of the deposit consists of an essentially disordered arrangement of lithic fragments of lava and yellow tuff up to about 10 cm across and rounded pumice set in a matrix of coarse ash. Close to the vent, however, a weak undulatory banding is apparent, owing to the arrangement of zones rich in large pumice fragments 30 cm or less in diameter.

Noteworthy is the distribution of unit II (Fig. 2), which appears to be the most widespread of the Monte Nuovo deposits. It has not only been confined by topographic obstacles to the northeast (Monte Barbaro) and to the southwest (Monte della Ginestra), but has also been flected by a small promontory on the rim of Averno crater to the northwest. As a consequence, the Roman Temple of Apollo apparently survived the eruption unscathed.

The third unit (II) covers most of the outer flanks of the main cone. With a relatively even radial distribution around the vent the deposit thins from about 3—2 meters near the top of the cone to less than one meter toward its base. Three levels may be distinguished, i.e., a massive gray ash bed sandwiched between layers of black scoria containing angular fragments of denser juvenile material and occasional pieces of pale, moderately vesicular pumice.

The fourth unit (IV) is of limited extent and is confined to a small depression on the southern side of the volcano below the rim of the crater. In transverse cross section, it pinches out laterally over a few tens of meters and varies in thickness from a maximum of 25 meters toward its center to only a few meters at its margins (Fig. 2). It consists of two layers of black scoria separated by a thin, irregular layer of ash. The scoria are coarse (50—60 cm across) and angular, and show no signs of having been welded or plastically deformed.

Three obvious features of the field descriptions are the gross similarities of units I and II, on the one hand, and of units III and IV, on the other, and the distinct difference between the two pairs. Evidently the mechanism of eruption underwent a fundamental change at some time between the emplacement of units II and III. The typically chaotic textures of units I and II and the apparent influence exerted by the surrounding topography on their distribution suggest that they were emplaced as pyroclastic flows (in the general sense). In contrast, the dominance of scoria in units III and IV is more indicative of a Strombolian- or Hawaiian-type eruption; as will be discussed later, this, in turn, does not necessarily imply air-fall deposition.

These general inferences are supported by the results of grain-size analyses and SEM studies of the components of the four units. Granulometric data are given in Figs. 4 and 5. In the cases of units I and II, the components display polymodal size-frequency distributions (Fig. 5) and have comparable median sizes and measures of sorting (as defined by the Inman parameters $Md\varphi$ and $\sigma\varphi$ respectively; Fig. 4). Figure 4 shows the $Md\varphi$ and $\sigma\varphi$ values in relation to the fields covering flow and fall deposits as proposed by Walker (1971).

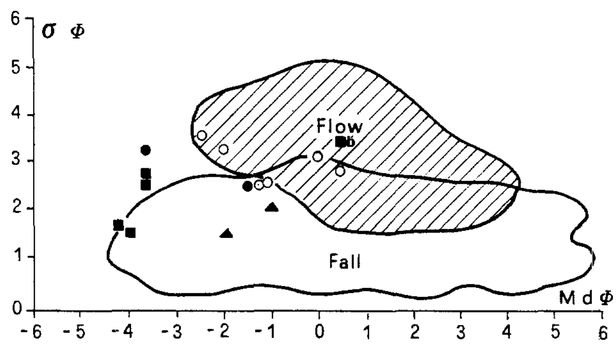


**Fig. 4.** The grain size characteristics of the Monte Nuovo deposits. The Inman parameters $Md\varphi$ and $\sigma\varphi$ are measures of the median size and size range of the components of a sample, respectively. The fields for fall and flow deposits are from Walker (1971), Filled circles, unit I; open circles, unit II; squares unit III; the square labelled "b" refers to the gray ash bed of unit III; triangles, unit IV

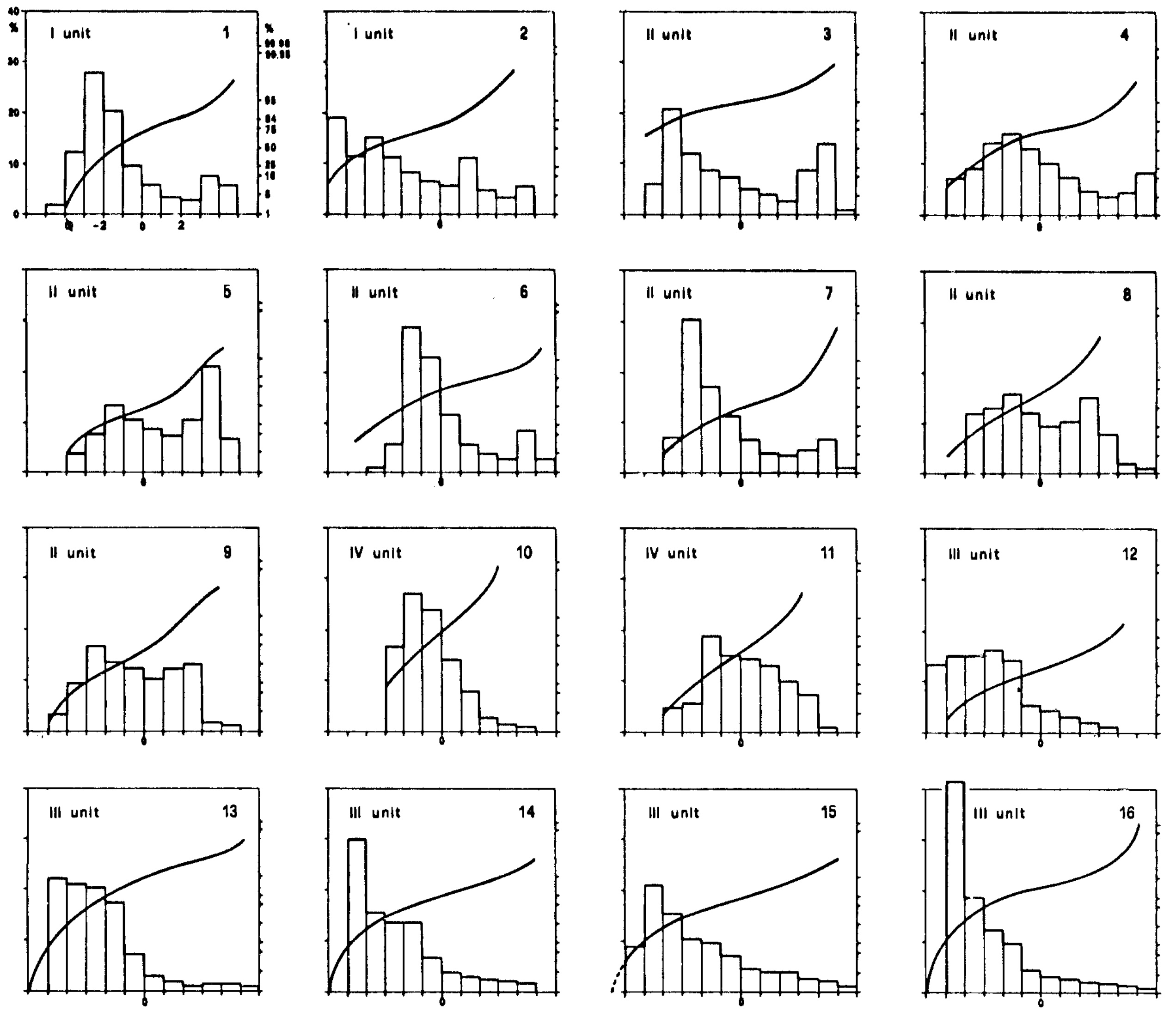


**Fig. 5.** Cumulative frequency curves and histograms of the grain size distributions of the four Monte Nuovo units. Sample 12 refers to III b, the gray ash bed of unit III

They plot either within or close to the margin of the field for deposits produced by flow.

The scoria from the upper and lower black layers of unit III have the grain size characteristics of an air-fall deposit (Figs. 4 and 5). Significantly different, however, are the granulometric features of the middle ash horizon of the unit (Figs. 4 and 5). Although the size frequency distribution is unimodal (Fig. 5), a feature commonly associated with air-fall deposits, the Md$\varphi$ and $\sigma\varphi$ values more closely resemble those of material from unit II, and flow depositon is implied (Fig. 4).

The interpretation of the granulometric data for the scoria from unit IV is also open to ambiguity. Superficially, the unimodal size-frequency distributions of the material (Fig. 5) and their Md$\varphi$ and $\sigma\varphi$ values (Fig. 4) indicate air-fall deposition. However, the boundaries of the air-fall and flow fields shown in Fig. 4 are not rigid, but best approximations, and the Md$\varphi$ and $\sigma\varphi$ values for unit IV (scoria) plot sufficiently close enough to the flow/fall boundary to be consistent with mixed flow and fall depositon. Indeed, the confinement of unit IV to a depression in the cone of Monte Nuovo is most easily explained if the unit was emplaced as a flow; it seems a more remote possibility that directional explosive activity would have fortuitously emplaced the material only into the depression.

An indication of why the style of the Monte Nuovo eruption underwent a fundamental change during its middle stages is provided by SEM data.

Some representative photomicrographs are shown in Fig. 6, from which it can be seen that the products fall into two morphological groups:

a) those which have a high vesicularity and show some conchoidal fracture surfaces, suggesting a significant amount of juvenile volatile components and a significant degree of magma-water interaction upon disruption (units I and II); and b) those which have a relatively lower vesicularity and show evidence of plastic deformation, suggesting that primary magmatic fragmentation was the dominant mode of disruption (units III and IV).

From these features it is inferred that the opening phases of the eruption were markedly hydromagmatic in character, while the final stages were primarily magmatic. Apparently, therefore, the ability of external water to come into contact with the magma played a key role in determining the mechanics of the eruption.

## Discussion and conclusions

From contemporary accounts of the Monte Nuovo eruption, it is evident that the style of activity varied significantly over short periods of time ranging from several hours to days. The changes are reflected by differences in the physical characteristics of the erupted materials, specifically their features in the field and granulometric data, from which it is possible to deduce more precisely the dynamic conditions of eruption.

Considering the first two units together, their generally chaotic textural appearance and the size-frequency distributions of their components suggest that they are flow deposits. Because of the concentrations of large pumice fragments close to the vent, together with the coarse nature of the enclosing matrix, the material feeding these flows must have been, on eruption, a comparatively dense mixture of pyroclastics and gas. The mix-

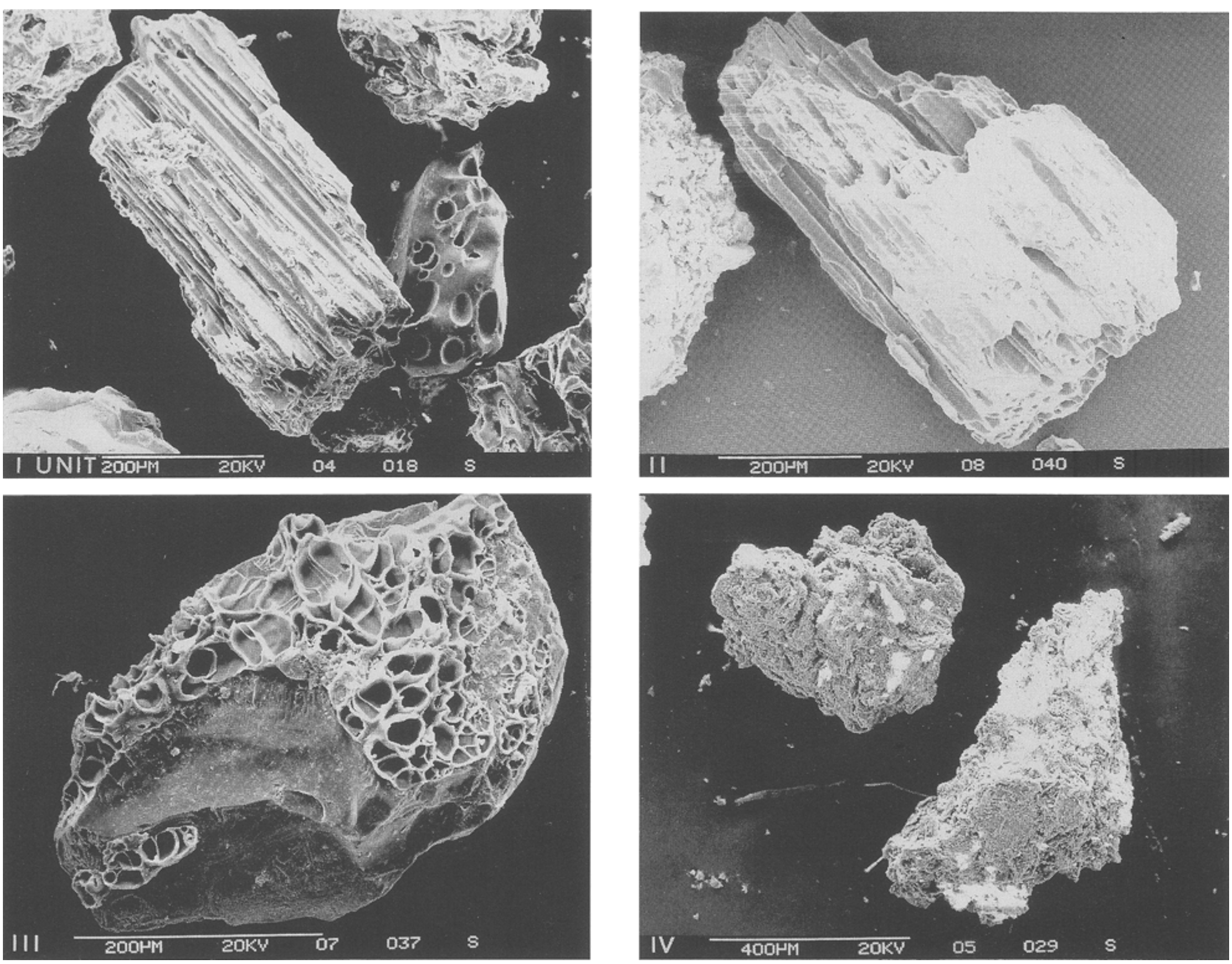


**Fig. 6.** SEM photomicrographs of representative Monte Nuovo samples

ture at this time may also have been relatively cool; this is inducated by the absence of welding features, pipe structures, and signs of plastic deformation, while the lack of graded air-fall deposits implies that a large or sustained eruption column did not develop during this phase of activity. Accordingly, it is likely that substantial cooling in an eruption column before emplacement did not take place, and so the inferred low temperatures of emplacement of units I and II may also be indicative of low temperatures of eruption.

Such conditions would be compatible with hydromagmatic activity, the magma having been chilled by an external water supply shortly before or during eruption. That the opening phases of the Monte Nuovo eruption were indeed hydromagmatic may be inferred directly, as described above, from the fracture patterns of the matrix material, and indirectly from the references in the historical accounts to an initial expulsion of muddy materials. It is worth noting here that, if the line of arguments is reversed and a hydromagmatic eruption assumed, then, given the moderate eruption rate of units I and II of no more than 500 $m^3$/sec (assuming the units were emplaced more or less overnight between 29 and 30 September), the theoretical models of Wilson et al. (1978) indicate that the maximum height of the resulting eruption column would have been only about 4—5 kilometers. The interpretation, therefore, that the opening phases of the Monte Nuovo eruption were hydromagmatic in character and involved the development of only a limited eruption column is internally consistent. Accordingly, it appears that, on eruption, the dominant motion of the pyroclast-gas mixture was in a lateral direction, leading to a comparatively even radial distribution of material around the vent. Such a type of emplacement has been described by Walker (1983) in his discussion on small-scale pyroclastic flows, an may have similarities with that for lahars of direct origin (Crandell 1971).

It would further seem that the flows were not highly fluidized since they were able to travel only short distances of up to a few hundred meters over the gentle topography of the surrounding terrain. Although material entered the sea to the west and, by filling in the coastal inlet (Fig. 1), created the present form of Lake Averno (Fig. 2), it did not disturb the water enough to cause wave damage to the Temple of Apollo on the shore. At this distance from the vent, therefore, the flows must have been cool and slow moving.

The initial phase of the eruption ended on 30 September with the emplacement of unit II. There followed two days of much less vigorous activity, during which the curious endeavored to climb the rim of the new cone. Activity in the vent at this time was linked by da Toledo to that of boiling water, suggesting that the eruption had entered a mild Strombolian phase. The style of activity had therefore become more distinctly magmatic, presumably because the rate at which the external supply of water was able to be recharged was much less than the rate at which water had been consumed at the start of the eruption.

That the external water supply had not been totally exhausted is indicated by the presence of the gray ash with granulometric characteristics similar to material from unit II between the scoria deposits of unit III. The emplacement of this unit is correlated with the increase in the level of activity noted on 3 October. The reason for the increase is uncertain. One possibility is that the Strombolian-type explosions became stronger (possibly evolving to a phase of fire fountaining) due to the arrival of a batch of less-degassed magma at the surface. This may have formed or reopened cracks locally in the surrounding rock, permitting an increased flow of nonmagmatic water toward the conduit and thus initiating a short phase of hydromagmatic activity until the water supply was consumed. Thereafter, the activity returned to its earlier magmatic character, maintaining weak activity until the last stage of the eruption.

The scoria deposits of unit III have an even radial distribution around the vent, indicating the lack of a preferred direction of ejection. In contrast, the scoria deposits of unit IV cover a very limited area on the southern side of the cone, suggesting directional emplacement. This unit was studied by Casertano (1972), who related it to a directed lateral explosion.

However, the morphology and distribution of the unit support the interpretation that it was emplaced as a flow. The fact that the deposit does not extend to the lip of the cone points to a source cutting the flank of the volcano, initiated either by the propagation of a lateral fissure or slumping on the side of the cone.

Hence, unit IV may have been erupted through the flank of Monte Nuovo as a low fountain of material, scoria avalanching down the slope and coming to rest toward the foot of the volcano. In any case the unit must have been emplaced abruptly since it caught twenty-four people by surprise who were climbing the cone on Sunday, 6 October, the last day of the eruption.

In summary, one of the principal factors controlling the eruptive conditions was the degree of volatile content and of interaction between the rising magma and an external water supply.

Consequently, it is important to take into account the local distribution of ground water when considering the hazards of future eruptions in Campi Flegrei.

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