RECENT VOLCANIC ACTIVITY IN THE VICINITY OF THE BAY OF NAPLES

by

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Summary

The volcanic activity which has taken place in the Phlegraean Fields and at Vesuvius during the last 35,000 years or so are described. The nature of the pyroclastic deposits, which are a dominant feature of this volcanic area, are discussed together with the cyclic nature of the eruptions of Vesuvius. The modification of ideas on the pyroclastic events during the famous large scale eruption of Vesuvius in A.D. 79, generated from the recent study of sections at three important archaeological sites, is evaluated.

Introduction

As a result of the position of the British Isles, well within the aseismic Eurasian plate, we, as geologists, are deprived of the exciting events of earthquake and volcanic activity which occur at plate margins. Our nearest plate margin is the constructive plate margin of the Mid-Atlantic ridge with its associated effusive basaltic volcanic and shallow focus earthquake activity excellently displayed in Iceland. Not much further away is the complex of mini-plates and plate margins of the Mediterranean (fig. 1) with plentiful shallow, medium and deep focus seismic activity, and active and dormant volcanic activity in the Bay of Naples, Sicily and the Aeolian Islands within the zone of convergent plates.

Plate Tectonic Setting

In the vicinity of Italy, the African plate is pushing northwards as it has for around 200 million years, into the Eurasian plate, at a present rate of 2 cm a year. This has resulted in the thick sequences of Mesozoic sediments deposited in Tethys being folded in the Tertiary to produce the fold belts of the Alps, Pyrenees, Apennines, Taurus and Atlas mountains. The arrangement of these mountain chains indicate the quite considerable complexity of the tectonics of the area which has been developed by the presence of a number of mini-plates between the Eurasian and African plates.

Italy is at the hub of this complexity with the eastward moving Iberian Plate overriding the northward moving African plate and westward moving Apulian plate. Not far to the east are the Hellenic and Turkish plates which may indirectly play their parts in this highly complex region.

The junction of the Iberian plate with the Apulian and African plates is along the line of the Appenines in eastern Italy, swings south westwards round the toe of Italy, east to west through Sicily and then along the coastal fringe of north Africa. The greatest subductive activity is taking place near the junction of the three plates off southeast Italy.

The subducting African plate has been located at a depth of around 100 km beneath Etna and Vesuvius, and 200 km beneath the Aeolian Islands. Some authors, Waltham (1985), have suggested that the subducting plate is of part continental origin and this then results in fusion of continental (granitic) crust under the Aeolian

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islands whilst fusion under Etna and Vesuvius takes place beneath the subducting granitic crust in basaltic crust. It is very difficult to accept subduction of low density granitic crust to depths of 200 km. A more realistic explanation may well be that the subduction involves the remnants of the Tethyan oceanic plate material, the different types of magma production and volcanic activity being due to different degrees of partial fusion, together with contamination of magma whilst rising through the crustal rocks.

The Aeolian Islands form a typical island arc from Stromboli to Alicudi with Vulcano and Lipari offset from the island arc, quite possibly related to a major fracture within the African Plate and also related to other fractures in the neighbourhood of Etna. The bay of Naples is situated on the western side of the Apennines above the subducting Apulia plate.

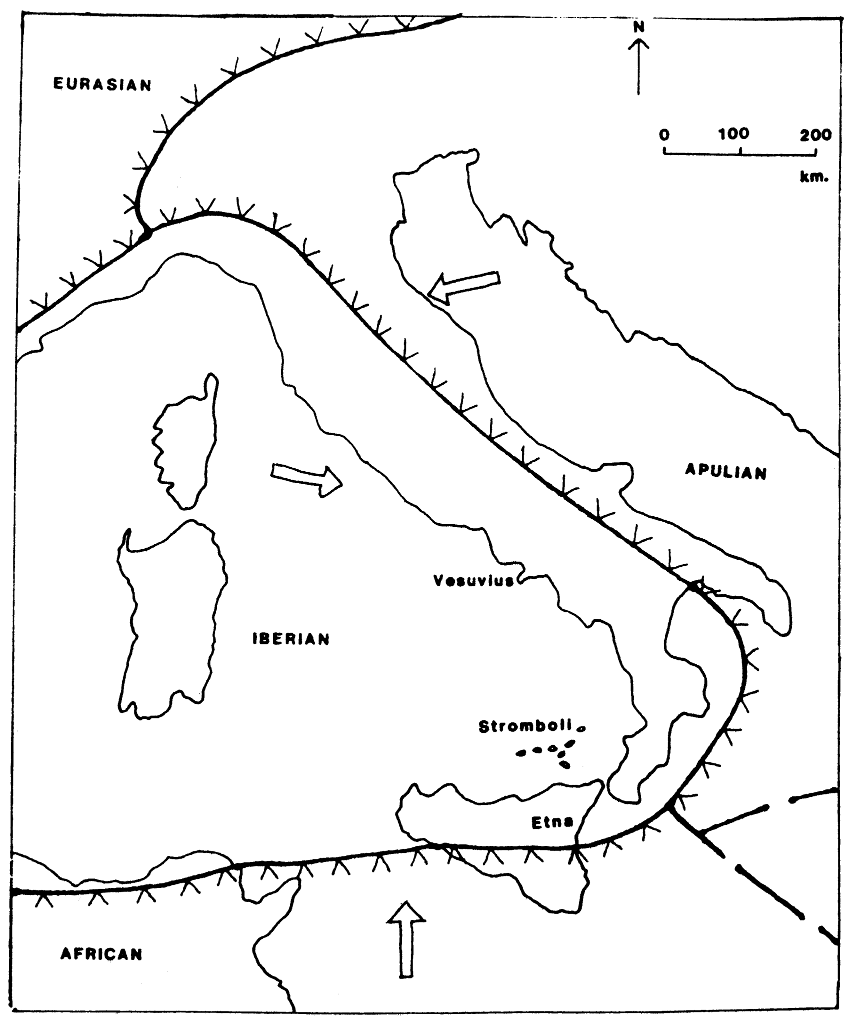

Fig. 1. Plates in the neighbourhood of Italy.

Historical Significance

It is in this area of the Bay of Naples that I will describe the modern volcanic activity. It is here, of course, where Vesuvius is located (fig. 6), and this volcano holds its place amongst the most famous world volcanoes because of the historic eruption of AD 79 which devastated the towns of Pompeii and Herculaneum, and other settlements clustered around its base. Today the area is one of the most highly populated areas of Europe. It was in this area that the first Greek settlements were built around 800 BC and Vesuvius itself had the Vesuvian observatory dedicated in 1845. Because of all these factors, the documentation and history of Vesuvian eruptions is perhaps better known than any.

Vesuvius itself is one of the few remaining 'active' volcanoes on the Italian mainland. It is one of a series of volcanoes located to the west of the Apennines along the Tyrrhenian coast of Italy north of Naples, as far north as Sienna. Very close to Vesuvius on the north side of the Bay of Naples is the famous Phlegraean Fields (Fiery Fields), an area of about 25 square miles containing 19 separate craters which are so closely packed that they tend to overlap (figure 2). The volcanic activity in the Phlegraean Fields is older than that of Vesuvius, going back some 50,000 years. Other than fumarolic activity, this area has been dormant in historic times except for a questionable eruption of Solfatara Volcano in 1198 and the well-known eruption of Monte Nuovo in 1538. In both the Phlegraean Fields and at Vesuvius, explosive volcanic activity has been dominant with only minor effusive eruptions. The various types of explosive eruptions have been classified by many authors according to the intensity of eruptions, ranging from Strombolian eruptions, which consist of almost continuous minor explosions and ejections of frothy volcanic ash and lava, through more explosive Surtseyan type eruptions due to association with water; more isolated but stronger Vulcanian eruptions producing considerable thicknesses of ashfall deposits to Plinian eruptions typified by the eruption of large volumes of ash during a highly explosive eruption. Peleean eruptions are characterised by nuee ardente activity. In both the Phlegraean Fields and at Vesuvius all variations of these type eruptions add to the complexity and interest of this volcanic area.

Mode of Formation of the Pyroclastic Deposits

Fairly recent work on pyroclastic activity has modified our understanding of explosive volcanicity, and Vesuvius and the Phlegraean Fields are not exceptions.

Pyroclastic rocks are now recognised as being conveniently divided into three broad types (cf. Sparks and Walker 1973) viz:–

(1) Fall; (2) Flow; (3) Surge.

1. *Pyroclastic air-fall* deposits are formed by the ejection of particles from a volcanic explosion which are carried by gas streaming from a vent. The eruption column is of two parts, the initial gas thrust and then the convective phase. The convective plume may well be displaced laterally by wind currents. Gravity fall of particles from this eruptive column produces the air-fall deposits. Air-fall deposits show mantle bedding, good internal stratification, and are often fairly well sorted and decrease in thickness from vent outwards. These types of deposits have been very well observed and documented.

2. *Pyroclastic flows* produce deposits (i.e. ignimbrites) which are unstratified and normally badly sorted. They tend to be absent from the steep slopes of volcanic flanks and occupy low lying ground around volcanoes. Unlike fall deposits, their thickness is not a simple function of their distance from source. Pyroclastic flows are often composed largely of pumiceous material and it is widely acknowledged that the flows are in a fluidized state with the gas needed being derived either from air which becomes trapped beneath the advancing flow, or from dissolved magmatic gases escaping from the pumice. Pyroclastic flows are generally recognised as being fairly dense fluidized masses with high concentrations of lava or rock clasts exhibiting laminar flow. Several reasons have been put forward for believing that pyroclastic flows travel as dense fluidised masses (Sparks and Walker 1973). Many ignimbrites, for example, have an inverse grading of pumice clasts with concentrations of coarse pumice clasts towards the top of the unit suggesting that they floated there, which would only be possible if during flowage, the flow itself had a density nearly the same as it has in the non-welded rock. Many non-welded ignimbrites which infill depressions have been recognised as having a level top surface with little down-sagging, which would be expected if the flow was in a highly expanded, less dense state (Sparks and Walker 1973).

Closely related to these flows are lahars which can be defined as a mass of flowing volcanic debris mixed with high proportions of water which may originate by direct or indirect ways from the volcanic eruption.

In its fluidized condition, pyroclastic flows can be considered analagous to mud flows. Mud flows are high density flows which produce homogeneous and poorly sorted deposits. In both, the particulate material is equal to or greater than the gas phase (pyroclastic flow) or water phase (mud flow).

Pyroclastic flows commonly result from the collapse of a Plinian eruption column often preceded by a pyroclastic surge, by an inclined blast from an emerging spine or dome and by boiling over of highly gas charged magma from an open vent.

3. *Pyroclastic surges* are set up by a pulse or series of pulses of volcanic explosive activity. They may result in various ways. Base surges are ring shaped clouds that move outwards at hurricane velocities as a turbulent density current from the base of a vertical eruption column. Surges may result from entrapped phreatomagmatic steam, by gravitational column collapse or by other catastrophic events such as collapse of vent walls into the magma chamber and introduction of water into the magma chamber.

Surges are low concentration flows that are turbulent. They differ from pyroclastic fall deposits in the way in which their thickness is not uniform despite mantling the topography, pinch and swell structures being common. They also have an internal stratification, often showing cross-bedding, and they extend for fairly limited distances, usually not more than 10 km from their source. Surge deposits also differ from pyroclastic flows in a number of other ways. They are generally very thin deposits rarely more than 1 m in thickness whereas ignimbrites are often more than 10 m thick. Surge deposits are well bedded with beds or lamination showing great variations in degrees of sorting and grain size from each other. They occur on quite steep slopes from which flow deposits are missing, and their pinch and swell structures are unrelated to the surface on which they rest.

If we use the analogy of a mud flow for a pyroclastic flow, a similar analogy for pyroclastic surges would be torrents or floods. In surges, the fragments of lava or rock are widely dispersed, ie, they have low concentration and move in a highly turbulent fashion, and compared with pyroclastic flows, have a very low density. Pyroclastic flows, as mentioned above, are the products of comparatively high density flows.

Away from the source, the energy of the surge is dissipated with resultant change in bed-forms.

Sparks and Walker (1973) demonstrated that ground surges are a component of nuées ardente eruptions, for which they described a dual character. They showed that the great bulk of fragmental lava is carried in the lower part of the cloud as a flow, whilst the expanding upper part, is largely a lower density cloud of ash and dust carried turbulently as a surge. In the disastrous nuée ardente eruption of 1902 at Mount Pelée, the pyroclastic flow confined itself and followed the valley of the Riviere Blanche whilst the ash hurricane (surge) proceeded in an undeflected course through to the town of St. Pierre. Thus, there were two components, the ground-hugging flow which for the most part follows valleys and the lower density ground surge which tends to be undeflected by surface topography. The deposits of the two as already described, are quite different.

The Phlegraean Fields

In the small area of the Phlegraean Fields to the west of Naples (figure 6), volcanic activity has been in progress for about 50,000 years. During this period, a number of phases of eruptive activity have takn place, and these changes are due largely to modifications taking place in the magma chamber during its history (figure 3).

The magma chamber is almost certainly at a relatively very shallow depth of about 4 km to 5 km. Evidence for this is produced by the contact metamorphosed rocks ejected in eruptions, and by the very high temperatures found in geothermal wells in the area. The magma chamber shows good evidence of being zoned (Armienti *et al* 1983), with a trachytic top grading down to latite produced by crystal fractionation along the chamber walls. There is plenty of evidence, as will be demonstrated, of a magma chamber gradually reducing in size with progressive cooling.

The volcanic history of the Phlegraean Fields shows a dominance of explosive activity with effusive activity being subordinate. The major volume of material erupted has been trachytic in nature, largely of pumice and ash. The explosive eruptions in the area have varied in type from Plinian to Sub-Plinian and Strombolian with airfall, pyroclastic flow and surge activity and deposits.

The major volcanic event in the history of eruptions in the Phlegraean Fields was the great eruption about 38,000 years ago of the Campanian tuff and formation of the caldera (fig. 2 and 3). Before this eruption, the volcanic history included early submarine volcanicity including both trachytic and latitic material, followed by later sub-aerial eruptions from several vents, some outside the confines of the present limits of the caldera.

The great event of 38,000 years ago involved the eruption of 80 km^3 of trachytic material in the form of largely pyroclastic flows which covered 7000 km^2, producing the Campanian Tuff (figure 3). As a result of this massive eruption, there was a large caldera collapse resulting in the formation of a 12 km diameter caldera, the walls of which can still be recognised in places (fig. 2). Half of the caldera is submerged beneath the sea in the Gulf of Pozzuoli.

After collapse, the caldera depression was invaded by the sea (fig. 3). Volcanic activity which continued was almost completely confined to the caldera. The activity which occurred in the submerged caldera was highly explosive as a result of the interaction of sea water with the magma. At the early stage after the caldera formation, both basic (latitic) and intermediate (trachytic) material was erupted.

Armienti *et al.* (1983) suggest that the eruption of latitic material usually followed major eruptions in the Phlegraean Fields. In normal circumstances, only the less dense trachytic melts would rise towards the surface. However, after caldera collapse, the reduction of lithostatic load enabled more basic latitic materials to reach the surface. These basic volcanic products, together with sediments being deposited on the caldera floor, gradually restored conditions of higher load which only allowed the eruption of light trachytic magma once more. The

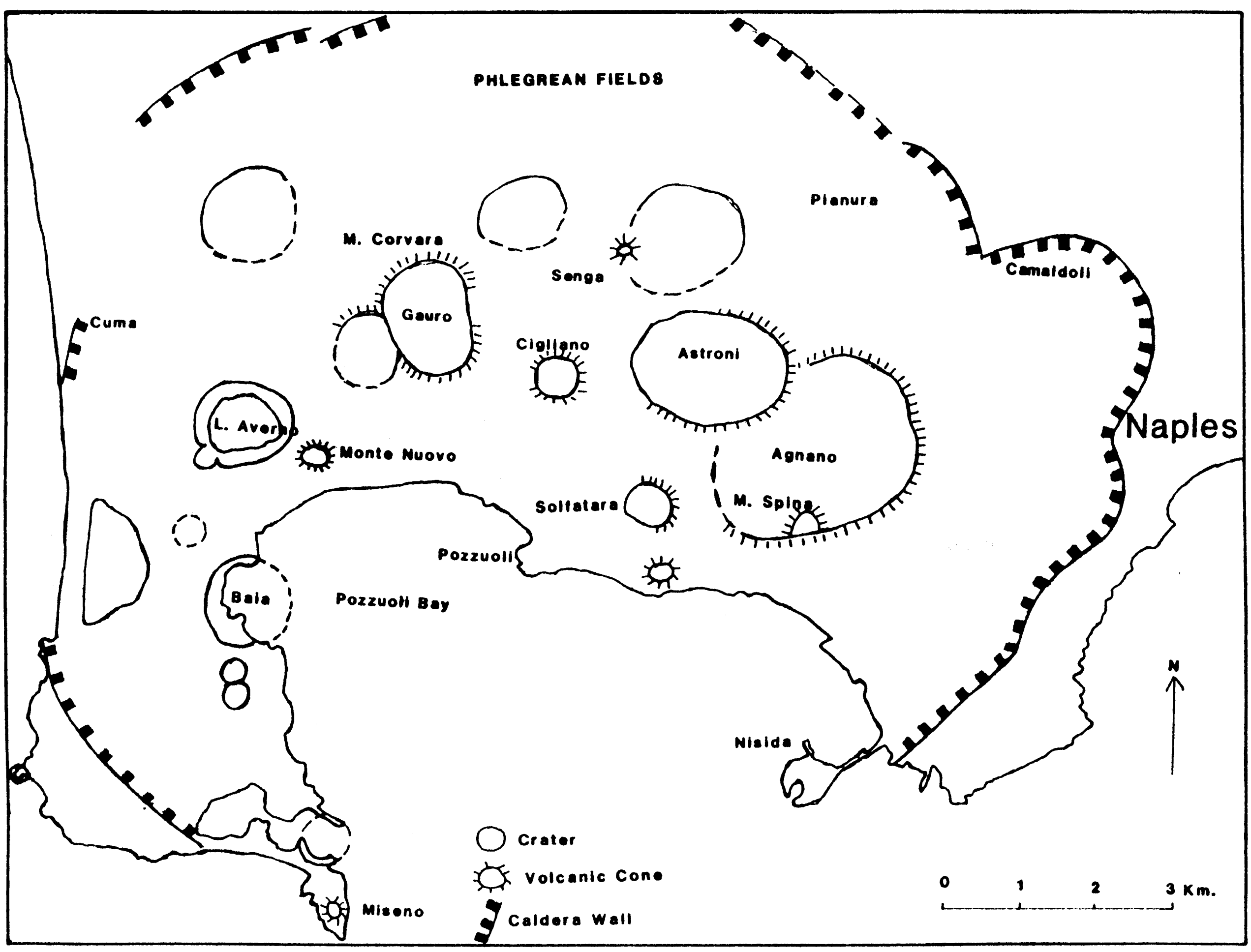

Fig. 2. Important volcanic features in the Phlegraean Fields (after Waltham, 1985).

largest eruption of this submarine phase of the Phlegraean Fields history produced 10 km³ of the famous "Neapolitan Yellow-Tuff" about 11,000 yeas ago (figure 3). Recent work, Rosi, Sibrana and Principe (1983), confirms the view of Rittman (1950) that the yellow tuffs were the products of several vents which were located around the inner rim of the caldera. After the main eruptions of the yellow tuff, there followed a limited collapse of some of the volcanic features to produce plains, such as the plains of San Vito-Toiano Pianura and the plains of Bagnoli.

Following the eruption of the yellow tuff, most of the activity became sub-aerial. The submarine activity had lasted from about 35,000 BP to about 10,5000 BP.

The more recent sub-aerial history of the Phlegraean Fields can be divided into two main phases:

The first was the phase from 10,5000 BP to 8,000 BP (fig. 3). The main event of this period was the Plinian eruption of Agnano which was followed by caldera collapse to produce a caldera of 3 km diameter. During this period, the eruptive centres were becoming more concentrated towards the centre of the caldera in the neighbourhood of Pozzuoli. This is an indication of progressive cooling and reduction in the size of the magma chamber with the consequent concentration of active trachytic events in a smaller internal zone. One or two isolated vents on the rim of the old caldera tapped trachybasalt and latitic magmas at this time.

There now appears to have been a period of quite long repose of about 35,000 years until the most recent phase of sub-aerial activity started about 4,500 BP. The renewed activity was preceded by uplift in the northern part of the Gulf of Pozzuoli which has been attributed to an injection of magma at shallow depth. The volcanic events which followed have been located at or near the uplifted area. Two main centres of eruption now very close to the centre of the caldera occurred (figs. 2 and 3). To the west, one centre is represented by Averno and Monte Nuovo and by Solfatara, Astroni, Agnano and Senga in the east. All material erupted from these vents was trachytic in type. The area of eruptions has been further restricted and the volume of erupted material reduced further indicating progressive cooling and reduction of the magma chamber.

In very recent times, the activity in the Phlegraean Fields has included vertical movements, shallow focus earthquakes, fumarolic and solfataric emissions, and one confirmed volcanic eruption at Monte Nuovo. This eruption in 1538 is well documented and lasted for about eight days, during which a tuff cone of about 150 m in height and about 800 m in diameter was produced by a series of almost continuous eruptive pulses involving air fall, flow and surge activity, finally burying three villages and at distances of around 3 km, trees were uprooted by the effects of surge blast.

Fumarolic and solfataric emissions are perhaps best seen at Solfatara itself, a crater of about 700 m in diameter, with a rim rising to a height of about 100 m, with a flat floor on which occur a variety of geothermal features such as fumaroles, solfataras and mud pools. The mud pools largely dried up after uplift and doming in 1984.

The fishing port of Pozzuoli presents a classic example of vertical movements of the crustal surface which are beautifully recorded at the ancient Roman Temple of Jupiter Serapis. It was probably a public bath and market place rather than a temple, nevertheless, it provides us with evidence of changes of surface level over the last 2,000 years. By about AD 1100, it had subsided like the whole of the Pozzuoli area. The greatest amount of submergence is easily recognised at the Temple of Jupiter Serapis as the three original columns of the temple that exist have been bored by marine organisms to a height of 5 m above the floor. This is really a high water mark and indicates the degree of the greatest subsidence. Since 1100 AD, there has been a gradual rise of land levels so that the base of the temple floor is now just below sea level. However, there have been many fluctuations, and even recently, some spectacular movements. In 1970, a sudden rise in the land surface caused considerable panic, and in 1983 and 1984 quite substantial movements accompanied by extremely shallow earth-quake activity heralded further concern and prophesies of an imminent eruption.

The total uplift during this period was over 2 m, at times as much as 3 cm a day. The effects of the movements and earthquakes were to raise the floor of the fishing harbour, to create problems of access for fishing vessels, and in Pozzuoli, many buildings were seriously damaged by the shallow but low intensity earthquakes, and sewers were tilted so that they had their flowage reversed. By the autumn of 1984, the movements and earthquakes ceased in Pozzuoli, and although magma wash apparently present beneath Pozzuoli, and although it was on the move, no eruption occurred.

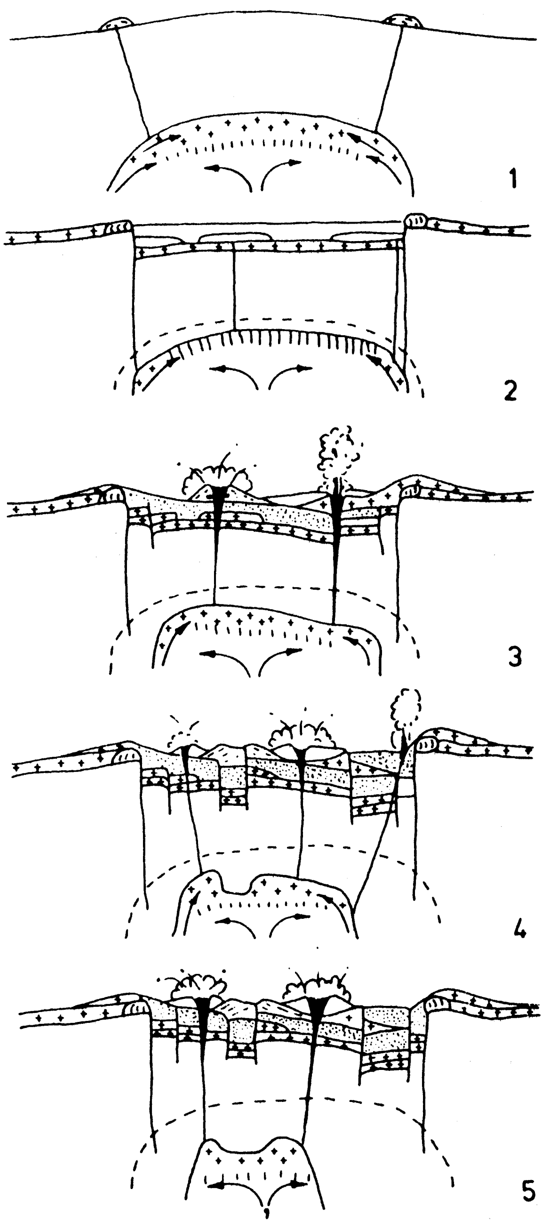

Fig. 3. Evolution of the Phlegraean Fields (after Armienti *et al.*, 1983).

1. Pre-caldera stage, more than 35,000 years ago. Beneath the Phlegraean Fields was a zoned magma chamber with 80 km³ of trachyte magma grading down to latite as a result of fractional crystallisation along the chamber walls.
2. Initial submarine phase following caldera formation about 35,000 years ago after eruption of the Campian Ignimbrite, Caldera about 12 km in diameter. Submarine eruptions of latites, trachytes and sediments gradually filled caldera.
3. Culmination of submarine phase about 11,000 years ago with the eruption of 10 km³ of hydromagnetic trachytic tuffs from several vents (yellow tuffs).
4. The old sub-aerial phase 10,000 to 8,000 years ago Magma Chamber further cooled, reduced in size with eruptive trachytic units concentrated towards the centre of the caldera.
5. Recent sub-aerial phase 4,500 years ago. Magma now concentrated to centre of ancient magma chamber and eruption of small volumes of trachytic material near caldera centre eg. Monte Nuovo 1538.

Vesuvius

The activity at Vesuvius appears to have a shorter history—about 25,000 years during which time it has shown continuous activity. Vesuvius is situated near the centre of the Naples syncline. On the south side of the Bay of Naples, the Sorrento Peninsular and Isle of Capri provide us with the scarp and dip slopes of Mesozoic limestones of the south limb of the syncline. The structure of the Naples syncline indicates that below Vesuvius are Tertiary, Cretaceous and Triassic limestones and dolomites. The depth at which these occur can be estimated from surface dips. During eruptions, blocks from the country rocks have been ejected and they show that the Tertiary rocks have not been altered by any magmatic influence, the Cretaceous rocks show very little change but the Triassic Limestones have been thoroughly altered suggesting that they were in close association with the magma chamber beneath Vesuvius. Rittman (1933) and others have suggested that this relationship suggests a magma at a depth of between 4 km and 5 km below the surface.

The primary magma of Vesuvius today is considered to be a potassium rich basalt. The roofing material of the magma chamber has been shown as Triassic carbonate rocks (see above) and the assimilation of this material has contaminated the original magma. As a result of this contamination, calcium and magnesium silicates have formed. These are largely pyroxenes and the remaining magma is deficient in silica leading to the formation of the felspathoid leucite instead of sanidine. The main lava flows of Vesuvius are described as leucite tephrites. These are under-saturated olivine free basalts.

The history of eruptions at Vesuvius displays a complete range. Its activity can be conveniently divided into three categories.

A. *Small scale eruptions*, mainly effusive activity with cinder cones as in the 1944 eruption. The types of eruption on Vesuvius since 1631 have been of this type. The eruptions are semi-persistent with short repose times between each cycle of eruption. Bullard (1976) has shown the sequence of activity within each cycle (fig. 4).

   (i) A short period of repose with only fumarolic activity with a duration usually of less than seven years;

   (ii) Renewal of activity with minor explosive eruptions forming a cinder cone in the bottom of the crater;

   (iii) Growth of the intracrater cone with lava flows developing a platform within the old crater between the intracrater and the rim of the old crater. This finally fills the old crater and eventually some lava may overflow down the flanks of the volcano. This may continue for twenty-five to thirty years;

   (iv) With the summit crater filled pressure builds up. The magma chamber is at a high level, and the magma is saturated with gas. Eventually, sharp earthquakes and explosions herald new developments which result in fractures splitting the cone from the crater rim to its base, and from these, fissures the magma chamber is tapped and lavas issue out in great floods. This heralds the end of the eruptive cycle, the final events being completed by

   (v) The lava level in the conduit recedes with the eruption of the lava, and with the pressure reduced in the cone area collapse and avalanching of the cone increases the size of the crater and reduces the height of the cone.

   (vi) The crater has now been cleared and is now a basin-shaped depression and the short period of repose commences before the next cycle restarts.

B. *Intermediate-scale eruptions* which are either completely explosive as in the AD 472 eruption, or mixture of explosive and effusive activity as in the 1631 eruption. Prior to one of these eruptions, a long period of repose in the order of one or two centuries occurs.

C. *Large-scale explosive or Plinian eruptions*. During the last 17,000 years at least six of these types of eruption have taken place—Santa-Croce (1983). These highly explosive eruptions are characterised by initial highly explosive paroxysmal ejection of large volumes of pumice (up to 4.0 km^3). These result in characteristic pumice-fall deposits of around 4 m near the vent. They are accompanied by pyroclastic flows and pyroclastic surges which we will discuss in more detail later. The duration of one of these eruptions is only of a few days and it follows a long period of repose, probably of over 1,000 years.

The last Plinian eruption was that of AD 79 and was followed by a sequence of the small-scale eruptions of type (A) above, with the intermediate type (B) eruptions taking place in AD 472 and in 1631. Since 1631, there has been an almost continuous small scale cyclic type eruption sequence (type A), until the 1944 eruption. Following the 1944 eruption, there has been a period of repose of over forty years. During the period from 1631 to 1944, the maximum repose period between eruptions was not more than seven years, and this has led to the speculation that the volcano may have gone into a much longer period of repose either on the scale of a century or two, in which case an eruption of the intermediate (type B) would terminate the period of repose or it may possibly be a much longer period of repose in the order of 1,000 years or so prior to a Plinian eruption or it may be that a small-scale eruption of type (A) is long overdue.

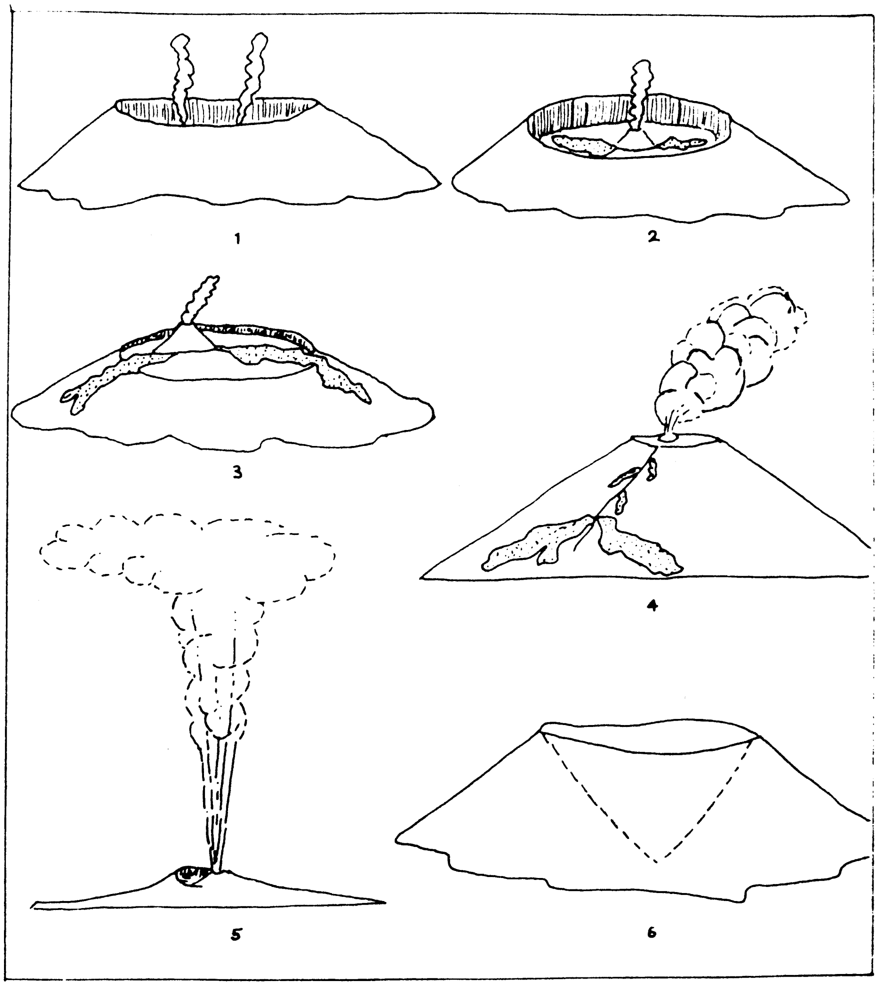

Fig. 4. Small scale eruptive cycle of Vesuvius, type A (after Bullard, 1976).

1. Period of repose lasting seven years on the average.
2. Renewal of activity. Small cinder cone forms in bottom of crater, gradually growing in size.
3. Outflows of lava from cinder cone fills the summit crater, with possibly some overspilling. This phase often lasts for twenty-five to thirty years.
4. Following strong earthquakes, the main cone splits along fractures which taps lava source, which, under great pressure, erupts with large volumes of lava. These fairly large scale eruptions last only for a few weeks.
5. Following outflows of large volumes of lava, the release of pressure allows a strong gas 'blow off' ensue with an eruption cloud many miles in height. This phase lasts a matter of hours. This marks the end of the eruption cycle.
6. Result of eruption in (5) is to clear the crater which forms a basic shaped depression (see dotted line).

The classic AD 79 eruption of Vesuvius has been made famous by the vivid accounts of the eruption by Pliny the younger, hence the term "Plinian type of eruption" for this type of event. The account by Pliny the younger of the eruption has a number of inconsistencies, but his description of the eruption cloud resembling a pine tree is a classic. For a long time, the destruction and burial of Pompeii and Herculaneum were interpreted as being the result of ash-fall and mud flow respectively. By looking carefully at the various deposits of this eruption, it has been possible to propose a more refined and revised story for the events of August AD 79—Sheridan et al (1981). The main sequence of volcanic deposits studied have been from the archaeological excavations of Pompeii, Oplonti and Herculaneum (fig. 5 and 6).

At Pompeii, the 4.5 m of section has a lower white pumice-fall layer which passes upwards into an upper grey pumice-fall bed overlain by interbedded surge and grey pumice-fall. There is an increase of lithic fragments from the white to grey pumice-fall layers. The lower surge beds are of the dry (superheated steam) massive and sandwave bed types whilst the upper surges probably represent emplacement by very wet (condensed steam) phreatomagmatic activity.

At Oplonti, the section is 8.5 m thick with a thin white and thick grey pumice-fall layers. The grey pumice-fall layers are interrupted by three clear cut surge deposits prominent sandwave surge horizons with two overlying pyroclastic flows. Above the pyroclastic flows are further wet surge deposits.

At Herculaneum, the section is 20 m thick. There is no ash-fall horizon. The initial deposits are sandwave surge beds. Above is a pyroclastic flow rich in pumice with fumarolic pipes towards the top. A further sandwave surge is followed by a pyroclastic flow and then a thick lahar sequence to the top.

These different sequences reflect the eruptive behaviour in this great Plinian eruption. The magma chamber of tephritic material was intruded at a shallow depth of 3 km to 5 km within Mesozoic limestones and dolomites. It was present beneath Vesuvius for a sufficiently long time in which reaction skarn formed and a metamorphic halo extended outwards into the limestones. The effect of all this was to seal the magma chamber and allow time for differentiation to take place in the magma and result in an upper portion of evolved magma rich in volatiles with a more basic and homogenous lower part.

On the 24th August AD 79, the eruption began either when the gas pressure in the magma chamber was sufficient to rupture the conduit or less likely when the magma chamber was supplied with an additional injection of hot magma from depth. The eruption started with decompression due to exsolving magmatic gas driving the gas thrust during the opening and widening of the conduit. Above the gas thrust, convective activity carried the column to an estimated height of 17 km.

The initial eruption produced the white pumice fall layers downwind at Pompeii and Oplonti. This was followed by the less fractionated grey pumice which contained a much higher percentage of lithic fragments from the solid magma on the periphery of the magma chamber and from the contact skarn and metamorphic aureole. This effectively removed the solid encasement from around the upper part of the magma chamber. The grey pumice-fall layer has a greater density, larger clasts and greater dispersal than the white pumice indicating an increase in energy. This corresponds to a number of surge units and it has been suggested that with the removal of the encasing layer, water infiltrating into the magma chamber could have increased the explosiveness of the eruptions.

The increase in abundance in the lithic fragments may have been partly due to the cavitation of roof and wall of the magma chamber as the chamber became partly emptied during the early phases of the eruption.

At this stage, the eruptions may have been intermittent but the part played by water appears to have had an increasing influence. The magma level was undoubtedly below the water saturated carbonate rocks above, and as the encasement of the magma chamber had been destroyed, plenty of water would infiltrate the system when the hydrostatic head was higher than the venting pressure in the chamber.

This resulted in very strong hydromagmatic or phreatic explosions with surges of fine ashes, vesiculated tuffs and phreatic breccias. The explosiveness of the eruptions widened the vent, and cooling by vapourization of the water would have led to column collapse.

With increasing water in the system, the initial hot/dry surges and pyroclastic flows were followed by colder, wet surges and lahars, and finally, by phreatic explosion breccias.

In the excavation at Pompeii, the 2,000 or so bodies so far uncovered suggest that the fatalities occurred as a result of the surges. The surges and flows at Herculaneum were much later than the activity at Pompeii and enabled the majority of the population to evacuate. Recently (1982), however, over 150 bodies have been uncovered at Herculaneum in the vicinity of the boat yards and beach, suggesting that even they were attempting to escape having been warned by the ash falls and surges which had buried Pompeii earlier (Gore 1984).

After the eruptions had ceased, Herculaneum was so completely covered by mud that its site was forgotten and it became a lost city. Pompeii was different with the burial being nowhere near so complete with tops of buildings exposed above the pyroclastic debris. Undoubtedly, survivors returned to salvage what they could by excavating into the partially covered buildings but even here search and salvage eventually became too difficult and the city was abandoned. Very few of the buildings, however, escaped the attention of survivors or plunderers. Further volcanic activity and growth of vegetation eventually concealed Pompeii, and in time, recall of its exact location were lost.

Excavations of a canal from the River Sarno to Torre del Annunsiata in 1592 uncovered marble fragments and coins of Emperor Nero at the site of Pompeii, but these finds were not followed up. In the late 1600's, search for water again uncovered stones some of which had inscriptions on them, but no excavations were undertaken, and it was not until 1763 that the site of Pompeii was finally established. From that date onwards, excavations have taken place right up to the present with about half of the old city uncovered.

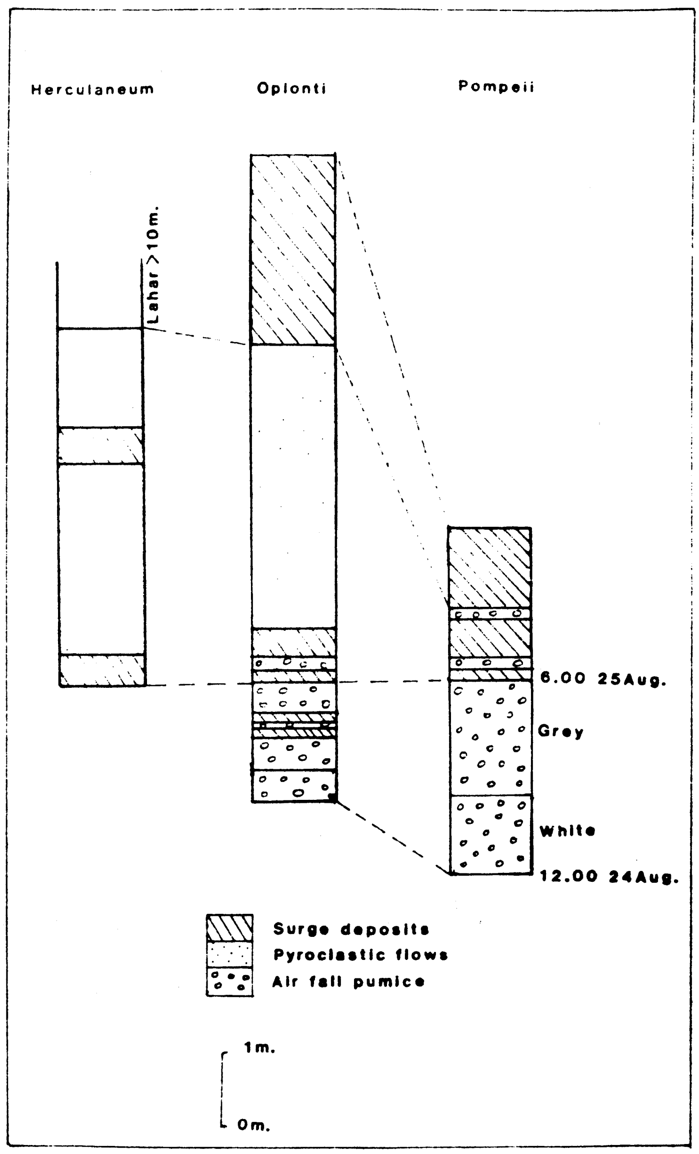

Fig. 5. Comparison of types of pyroclastic deposits from the AD 79 eruption at three archaeological sites (after Sheridan *et al.*, 1981).

Herculaneum was found as a result of well diggings uncovering various marbles at Resina in 1710. For about thirty years, various excavations were carried out before interest turned to the Pompeii site. Excavations on a systematic scale started at Herculaneum in 1927 and continue today, and so far, an area of about 200 m square has been exposed.

Pompeii is, of course, a much larger excavation with an area of about 1,200 m by 1,000 m uncovered. This has exposed hundreds of buildings which are set out in a grid-like fashion. Even as the work goes on, the excavated buildings have been damaged by recent earthquakes in 1980 and scaffolding is needed for support.

Oplonti is a more recent, less known, much smaller excavation of a single villa.

Conclusion

The area around the Bay of Naples has provided us with some of the more recent and spectacular volcanic activity in the Mediterranean. In the Phlegraean Fields where a fine history of Caldera formation followed by varied and largely pyroclastic volcanic activity has been recognised and well documented, all the evidence points to a magma chamber which is cooling and reducing in size, with the concentration of the most recent volcanic activity in a much smaller zone towards the centre of the Phlegraean Fields. In the case of Vesuvius, the long repose since its last eruption in 1944 has led to much speculation about future possible activity. Will Vesuvius after a long period of dormancy erupt with the vigour comparable with the intermediate scale eruption of A.D. 472 and 1631, or is it possible that after a very long period of repose, it may erupt with the violence witnessed by Pliny the younger in A.D. 79? On the other hand, has the volcano finally become extinct? At present, the answer to these questions is not known; further research may lead us towards a more confident prediction.

As far as the Phlegraean Fields is concerned, the alarming events in Pozzuoli over the last decade indicate to us how tenuous our predictions may well be.

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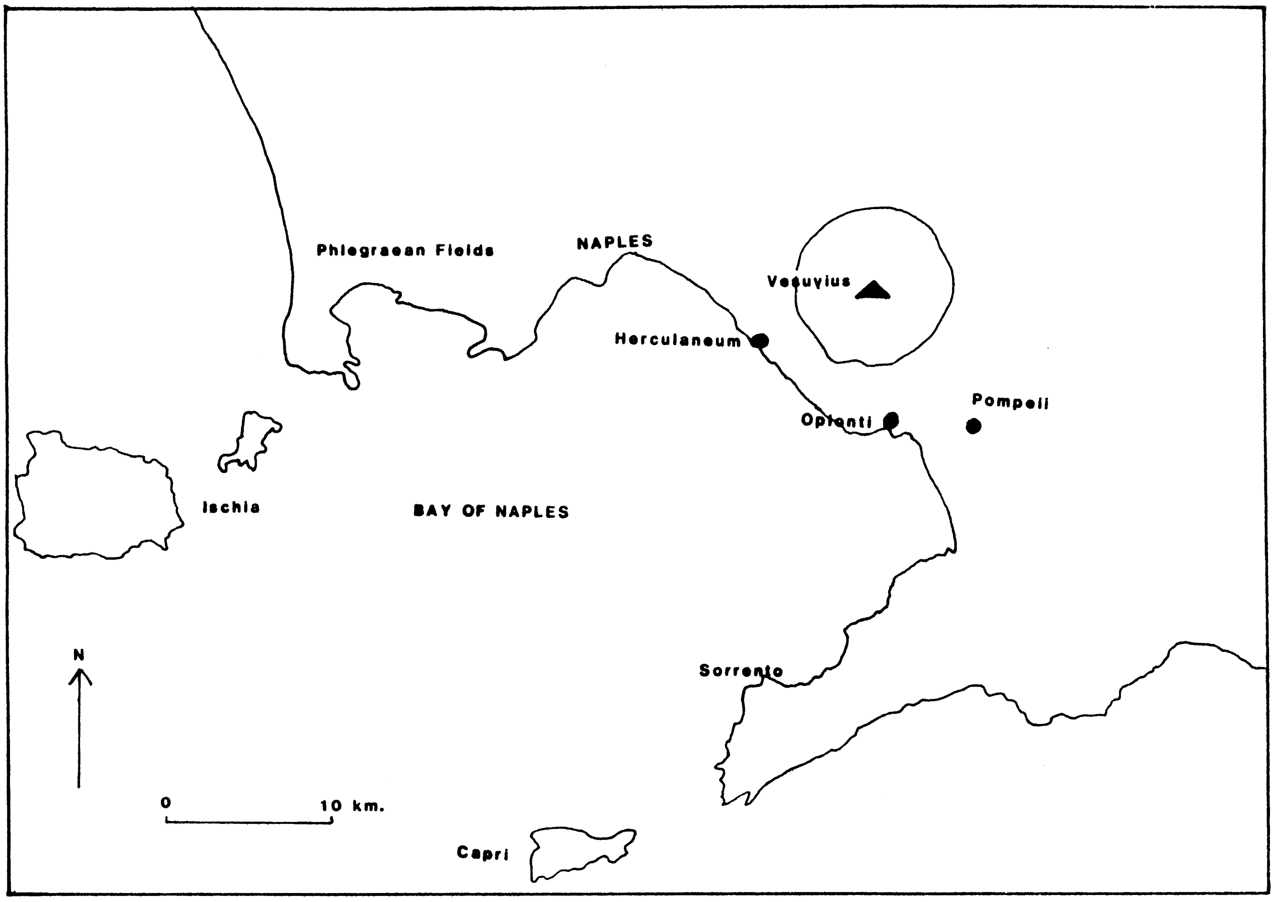

Fig. 6. The Bay of Naples area with Vesuvius and the Phlegraean Fields (after Waltham, 1985).

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