Vesuvius, the Plinian eruption style and the Phlegraean Fields caldera
By Raffaello Lena (text and images) and Guy Heinen (mineral microscopy and iconographic plates)

Introduction

In a previous work I have described the Strombolian eruptions, which may have formed the largest dark mantle deposits on the Moon.

Another eruptive style of volcanism in the earth is called Plinian.
Plinian eruptions typify the terrestrial eruptions that produce plumes of ash ascending up to 45 kilometers. These spectacularly explosive eruptions are associated with volatile-rich dacitic to rhyolitic lava, which typically erupts from stratovolcanoes. These explosive eruption types are named after Pliny the Younger. He gave an excellent account of the catastrophe occurred in 79 A.D. in two letters to the historian Tacitus. This eruption of the Vesuvius volcano caused the destruction of the cities of Herculaneum, Pompeii, Oplontis and Stabiae, whose ruins, buried under layers of pumice and also lahars, were brought to light from the 18th century.
Lahars are volcanic mudflows created when water (from rain or melt water from glaciers) and ash mix. Pyroclastic flows are avalanches containing hot volcanic gases, ash and volcanic bombs.

Lunar volcanic eruptions

Lunar volcanic eruptions created lava flows, pyroclastic deposits and domes (similar to terrestrial shield volcanoes). Lunar domes formed during the later stages of volcanic episode on the Moon, characterized by a decreasing rate of lava extrusion and a comparably low eruption temperature, resulting in the formation of effusive domes. Most lunar domes are hemispherical and have summit pits and are formed by outpouring of magma from a central vent (effusive eruption). Factors governing the morphological development of volcanic edifices are interrelated, including the viscosity of the erupted material, its temperature, its composition, the duration of the eruption process, the eruption rate, and the number of repeated eruptions from the vent. The viscosity of the magma depends on its temperature and composition. Thus, the steeper domes represent the result of cooler, more viscous lavas with high crystalline content (Lena et al., 2013).
Among the volcanic edifices on the Moon, the highland domes Gruithuisen γ and δ, the nearby Northwest Dome, situated at the border of Mare Imbrium, are described as volcanic edifices originated from highly silicic, more viscous, non-mare lavas, likely dacitic or rhyolitic lavas. For this reason these highland domes are characterized by steep flank slopes, high volumes, and red

spectral signatures, giving rise to the assumption that they have been formed by lava of significantly different composition and erupted over a long period of time (Lena et al., 2013).

Overview of Somma-Vesuvius and Plinian eruption

The Somma-Vesuvius, located at the SE of Naples, is one of the most dangerous volcanoes in the world (Fig. 1). The Somma-Vesuvius volcano is formed by the superimposition of two volcanic edifices. Monte Somma, subsequently collapsed into an elliptical caldera, and the cone of Vesuvius grew inside the depression (height of 1280 meters).

Figure 1: Somma-Vesuvius volcano as seen from Naples (photo of Lena).

The stratovolcano consists of the old edifice of Mt. Somma, featured by a summit caldera structure occupied in its centre by the younger Vesuvius cone, whose last eruption occurred in 1944, during the *Second World War*.

A document of the eruption in 1944 is also visible in internet (see video clip below)

Eruption of Vesuvius 1944 (see historical document below)
https://www.youtube.com/watch?v=1bsmv6PyKs0

The summit crater has a diameter of 450 m and a depth of 300 m (Fig. 2). At the base of the crater and inside the Somma caldera there are several eruptive vents, from which many of the lava flows of historical times have come out, starting from between 1631 and the last eruption in 1944.

Figure 2: Summit crater of the actual cone (photo of Lena).

The summit crater of the cone is plugged with solidified material (Fig. 2) as visible in this video made by Lena.

(https://www.facebook.com/1348598626/videos/10217835040171537/)

The volcanism in Mt. Somma started with an early (and ancient) period of effusive and slightly explosive activity, interrupted and followed by a period characterized by at least four Plinian eruptions (Pumici di Base, Mercato Pumice, Avellino Pumice, Pompeii Pumice) staggered with minor events covering a large range of magnitude and intensity.
A summary geologic map is reported here:
https://www.nature.com/articles/s41598-017-07496-y/figures/1

After 79 A.D. (Pompeii Pumice) eruption, the Vesuvius cone began to form during periods of open conduit activity, the last of which manifested in 1631-1944, ended with the current (and apparent) quiescent state.

Vesuvius is currently characterized by the presence of a hydrothermal system, which feeds a field of fumaroles inside the crater (Fig. 3), and is the site of a modest seismicity represented by a few hundred small earthquakes per year.

Figure 3: active fumaroles inside the summit crater (photo of Lena).

Minerals from Vesuvius-Somma volcano

Minerals produced by explosive eruptions are represented by blocks torn from the eruptive duct and from the magma chamber and ejected on the surface by paroxysmal eruptive events. They are generally made up of carbonate rocks, sometimes strongly metamorphosed (sanidinites), and fragments of lava.

The numerous minerals crystallized in the geodes of the limestone blocks are Vesuvianite, Thomsonite, Meionite, Spinel, Sodalite, Nepheline, Lazurite (Lapislazuli), Biotite, Olivine, Hauyne, Pyroxenes (Augite and Diopside) and others.

Minerals produced by effusive eruptions are those present in lava flows (Augite, Leucite, Olivine and others).

The most abundant lavas of the Monte Somma-Vesuvius volcanic complex are the Leucitic Tephrites characterized by the presence of Leucite in phenocrysts, Augite and Olivine.

Figs. 4-19 provide some different volcanic products, originated during major eruptions (see also the history of Vesuvius https://www.vesuvioinrete.it/e_storia.htm), that can be observed and identified in the Somma-Vesuvius.

Images of high quality taken by Guy Heinen with a microscope (from his minerals private collection) are shown in Figs. 12-19 and presented in the section mineral microscopy.

Figure 4: Siderazot (**Fe_5N_2*****) was found for the first time by Arcangelo Scacchi (1887) at Vesuvius, on the slag of the lava of 1884-85. The Siderazot which is presented in iridescent patinas with metallic reflections has also been found on the dross of other eruptions (1858, 1898, 1900, 1913, 1917, 1929 and 1944). It is probable that this mineral is formed by sublimation on high temperature slags (Lena private collection).***

Figure 5: Vesuvianite from Vesuvius (Lena private collection).

At Vesuvius other than Augite (black, green-black) and Diopside (greenish), some phenocrysts of Olivine (forsterite) are found (Fig. 6).

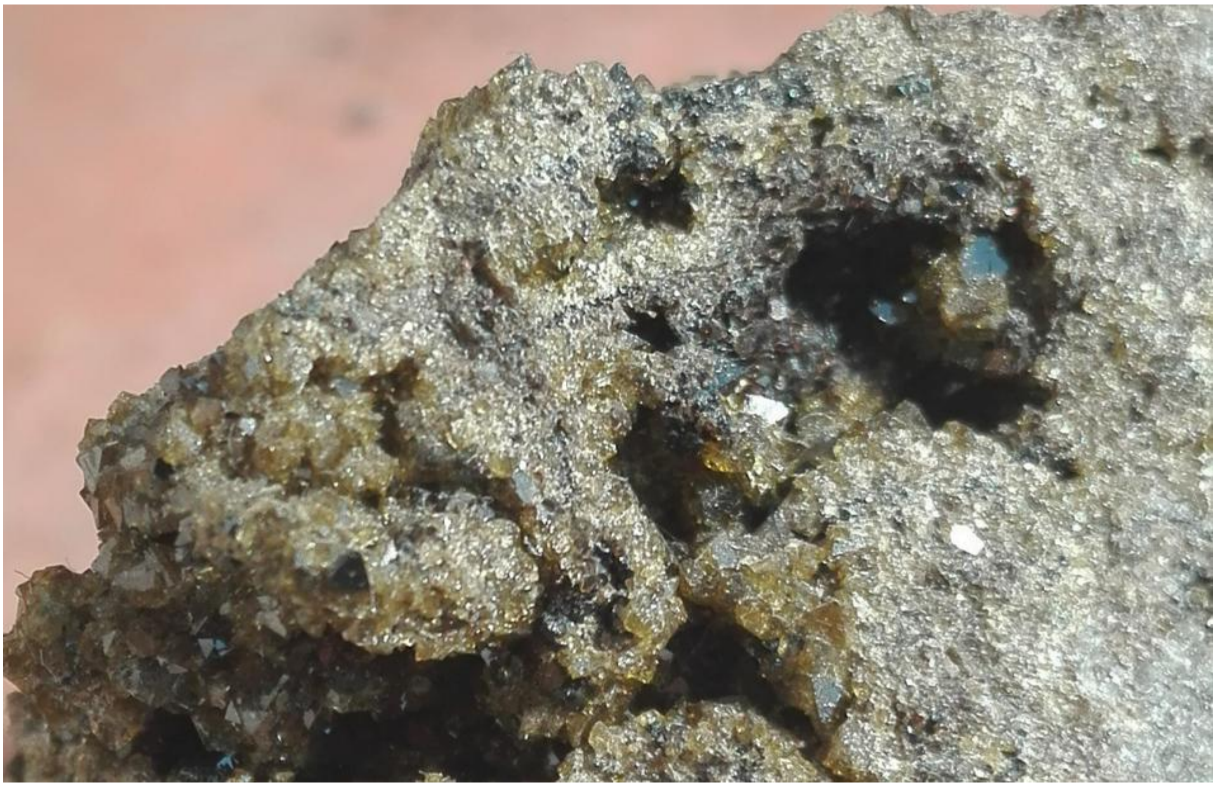

Figure 6: Olivine from Vesuvius (Lena, private collection).

At Somma-Vesuvius, Thomsonite is another common species of zeolitized shells (Fig. 7).

Figure 7: Thomsonite and Leucite (Lena, private collection).

Olivine (essentially forsteritic) is frequent in the products of the last eruption of 1944: in reality they are cumulitic screeds ejected during the eruption and enveloped by fresh lava.
One of the mineralogical constituents of the lavas of Vesuvius and Mount Somma is Augite (Fig. 8), a characteristic inosilicate of the pyroxene group, frequently found in isolated black crystals.

Figure 8: Augite a characteristic inosilicate of the pyroxene group (Lena, private collection).

Figure 9: Meionite, Spinels (black) and Pyroxenes (Lena, private collection).

Very interesting are the minerals found in the metamorphosed blocks of Mount Somma: these may contain Meionite (Fig. 9), Sodalite, Nepheline and Vesuvianite (Fig. 10).

Figure 10: Meionite and Nepheline (Lena, private collection).

Figure 11 shows a sample of the flow of mud that covered Herculaneum in the eruption occurred in 79 A.D.

When the magma that reaches the surface is very viscous and rich in gas, explosive eruptions are generated: the products deriving from this type of activity are called "pyroclastic" and the associated deposits are called "pyroclastic deposits". They consist of ashes, pumice, lapilli, bombs and fragments of the volcanic duct, in thicknesses from a few centimeters to a few meters, up to distances of a few kilometers from the volcano. The major pyroclastic deposits produced by the eruptions of Vesuvius are found in the southern and south-eastern sector, in Herculaneum and between Terzigno and Boscoreale, and date back to the eruption of 79 A.D. during which immense clouds of gas and incandescent ashes poured down the slopes of the volcano, up to the villages of Herculaneum, Pompeii, Stabiae and Oplontis.

Figure 11: flow of mud that covered Herculaneum in the eruption occurred in 79 A.D. (Lena private collection).

Mineral microscopy

As reported above, the numerous minerals crystallized in the geodes of the limestone blocks are Vesuvianite, Thomsonite, Meionite, Spinel, Sodalite, Nepheline, Lazurite (Lapislazuli), Biotite, Olivine, Hauyne, Pyroxenes (Augite and Diopside) and others.

Minerals produced by effusive eruptions are those present in lava flows (Augite, Leucite, Olivine and others).

In the following Figures (Figs. 12-21) are shown some images taken by Heinen using the mineral microscopy (his private collection). A 9Si Leica microscope was used. It has a built-in camera of 10 Mpix. Magnification is from 6,3 to 55 X, but can be extended to 110X. Heinen stacks 10 to 40 images using the software HeliconFocus. Images are treated with Lightroom, Sharpen projects pro and Photoshop Elements.

Figures 20-21 display mineral microscopy on a lava sample (25 x 15 cm) found around the crater rim of the Vesuvius (1990).

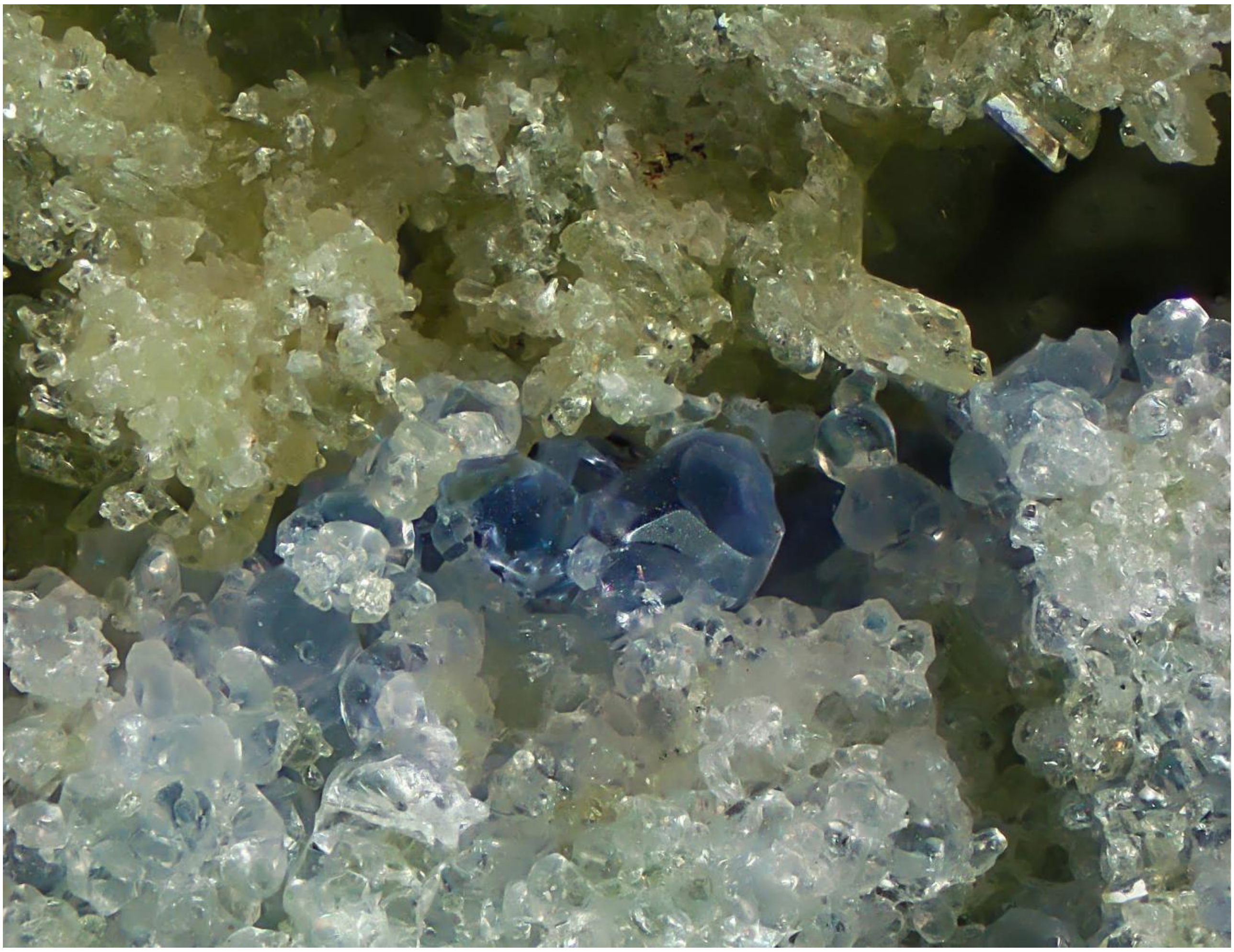

Figure 12: Hauyne, Cava San Vito 40X, image taken by Heinen from his private collection.

Figure 13: Lazurite, Magnetite, Diopside, Monte Somma 30X, image taken by Heinen from his private collection. Lazurite is a feldspathoid belonging to the sodalite group and is generally found in granular, massive form and, although rarely, in octahedral crystals. The Sodalite group includes four minerals: Sodalite, Noseana, Hauyne and Lazurite.

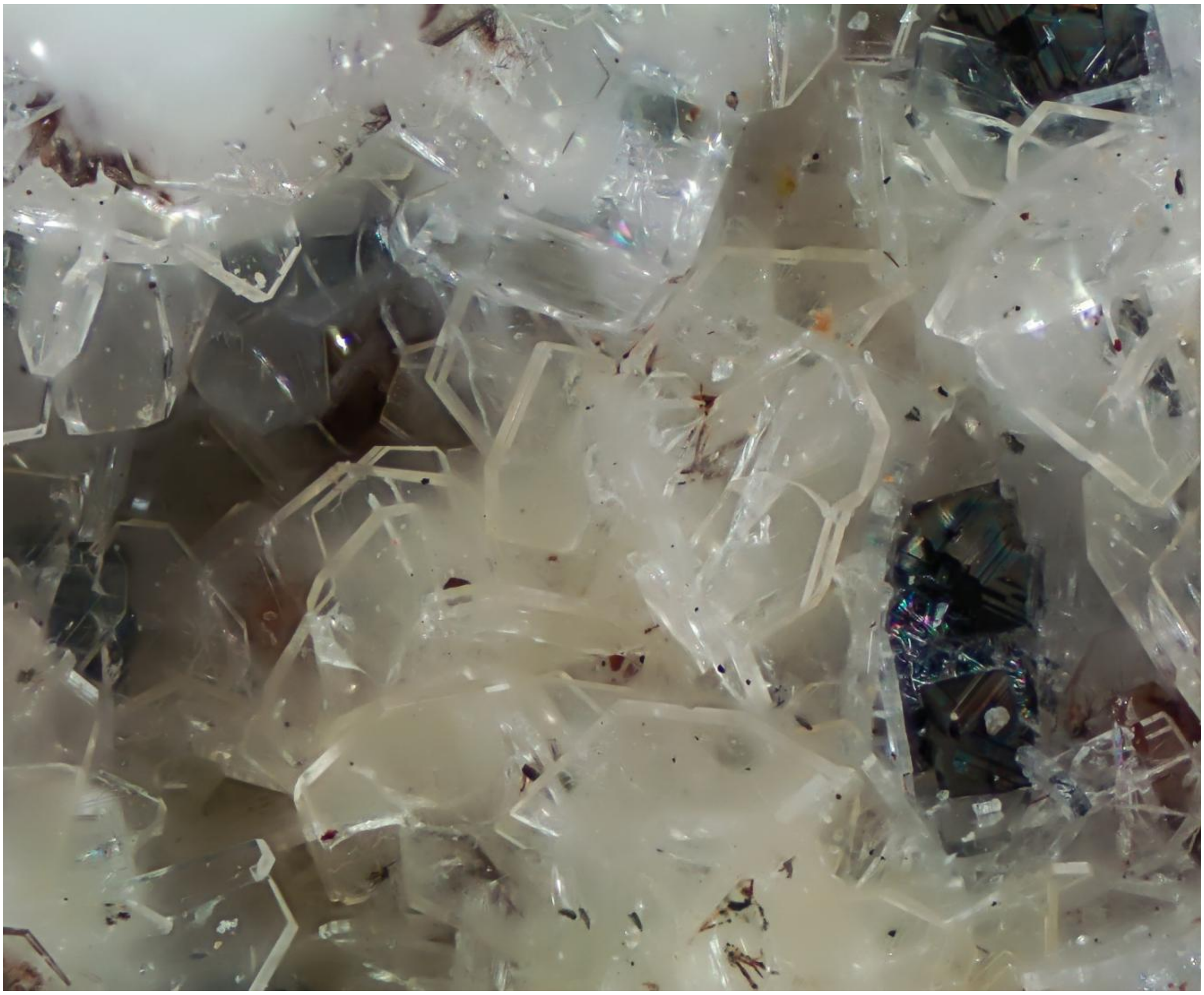

Figure 14: Nepheline, 40X, Cava San Vito, image taken by Heinen from his private collection. Nepheline is present in the sanidinitic blocks in beautiful clear crystals. In such matrices can be in paragenesis with all the other minerals typical of this location. It was found as a product of pneumatolysis on the lavas of the last eruption of 1944.

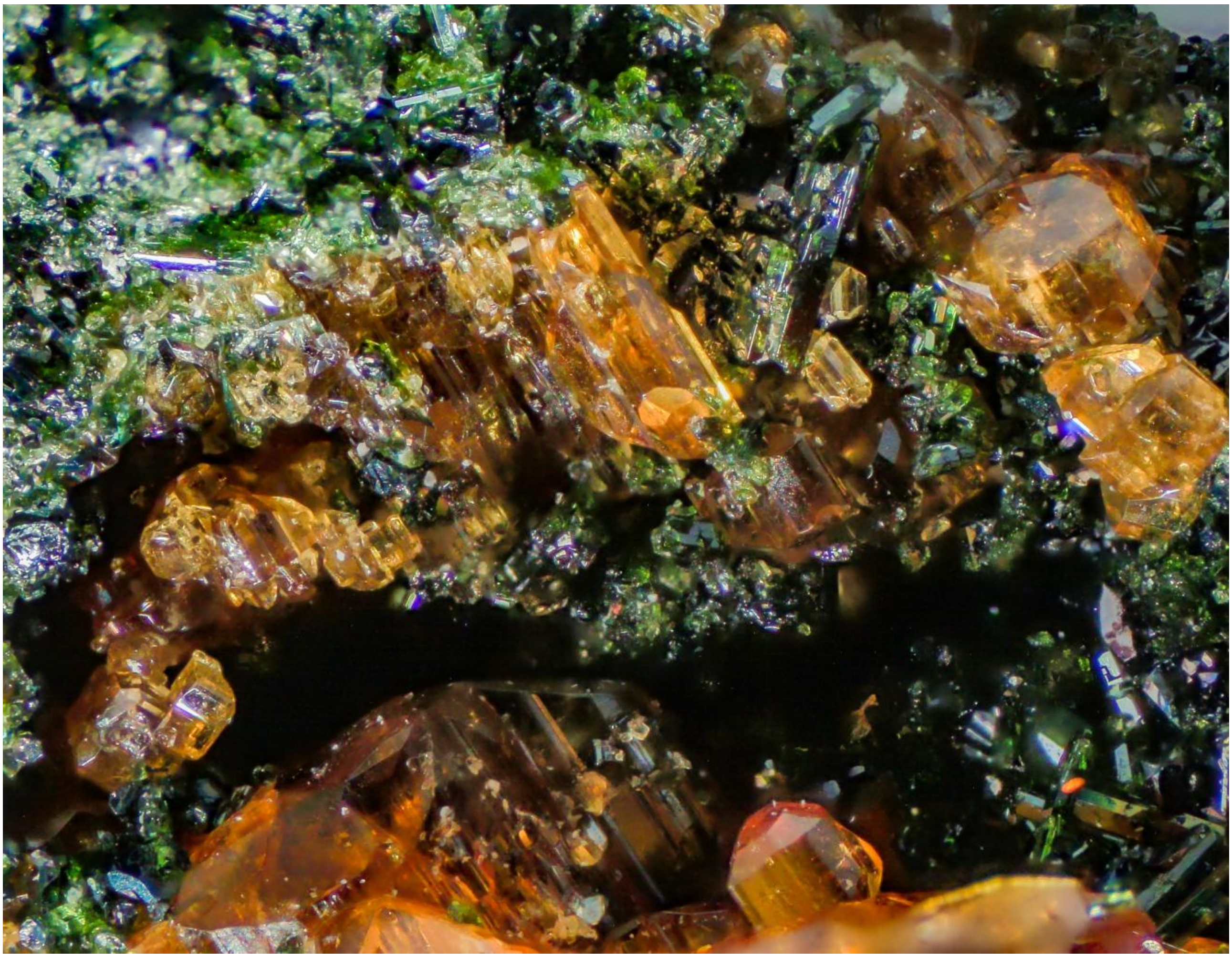

Figure 15: Vesuvianite and Diopside, 30X, Cava San Vito, image taken by Heinen from his private collection.

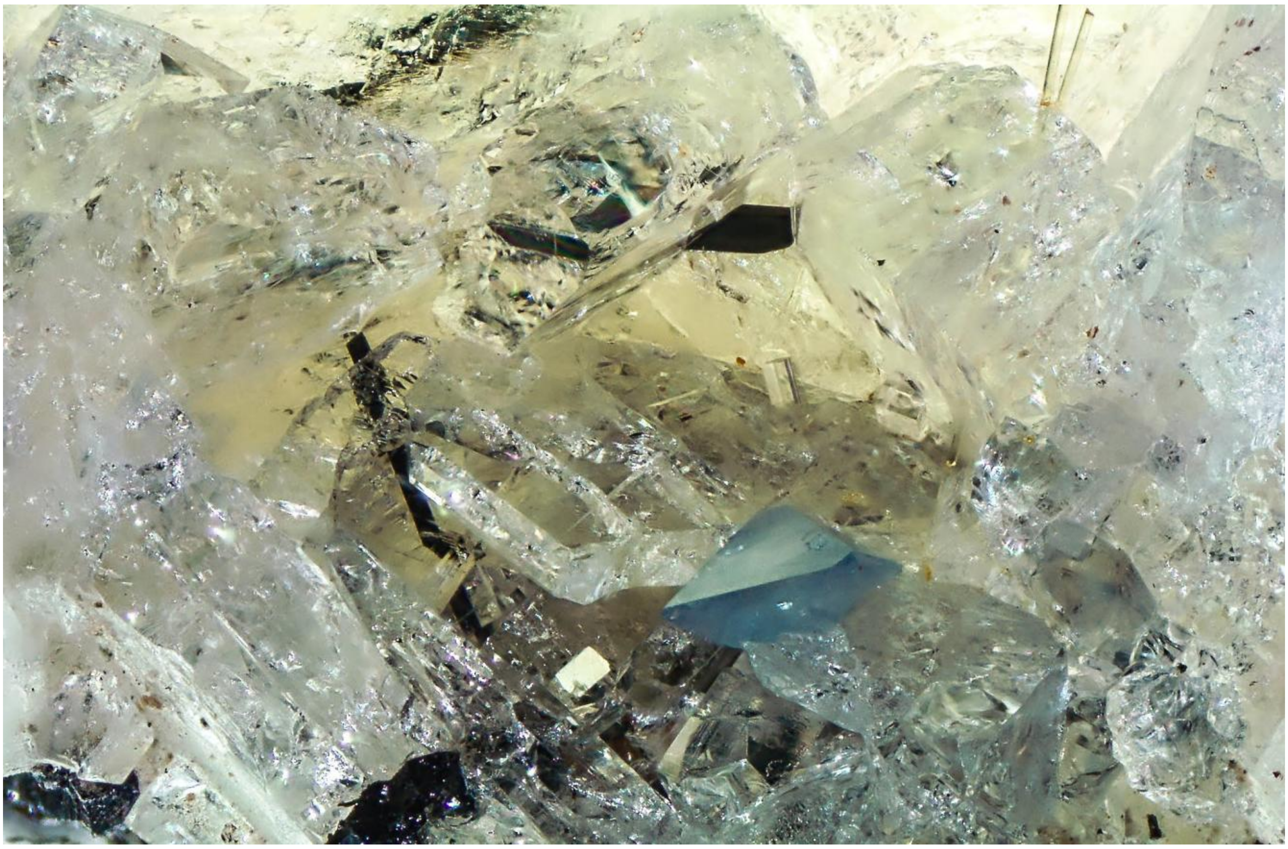

Figure 16: Zircon, 20X, Cava San Vito, image taken by Heinen from his private collection. The most common color is blue, from clear to more intense.

Figure 17: Scolecite (Tektosilicates with zeolitic H_2O) and Analcime, Cava San Vito, 20X, image taken by Heinen from his private collection.

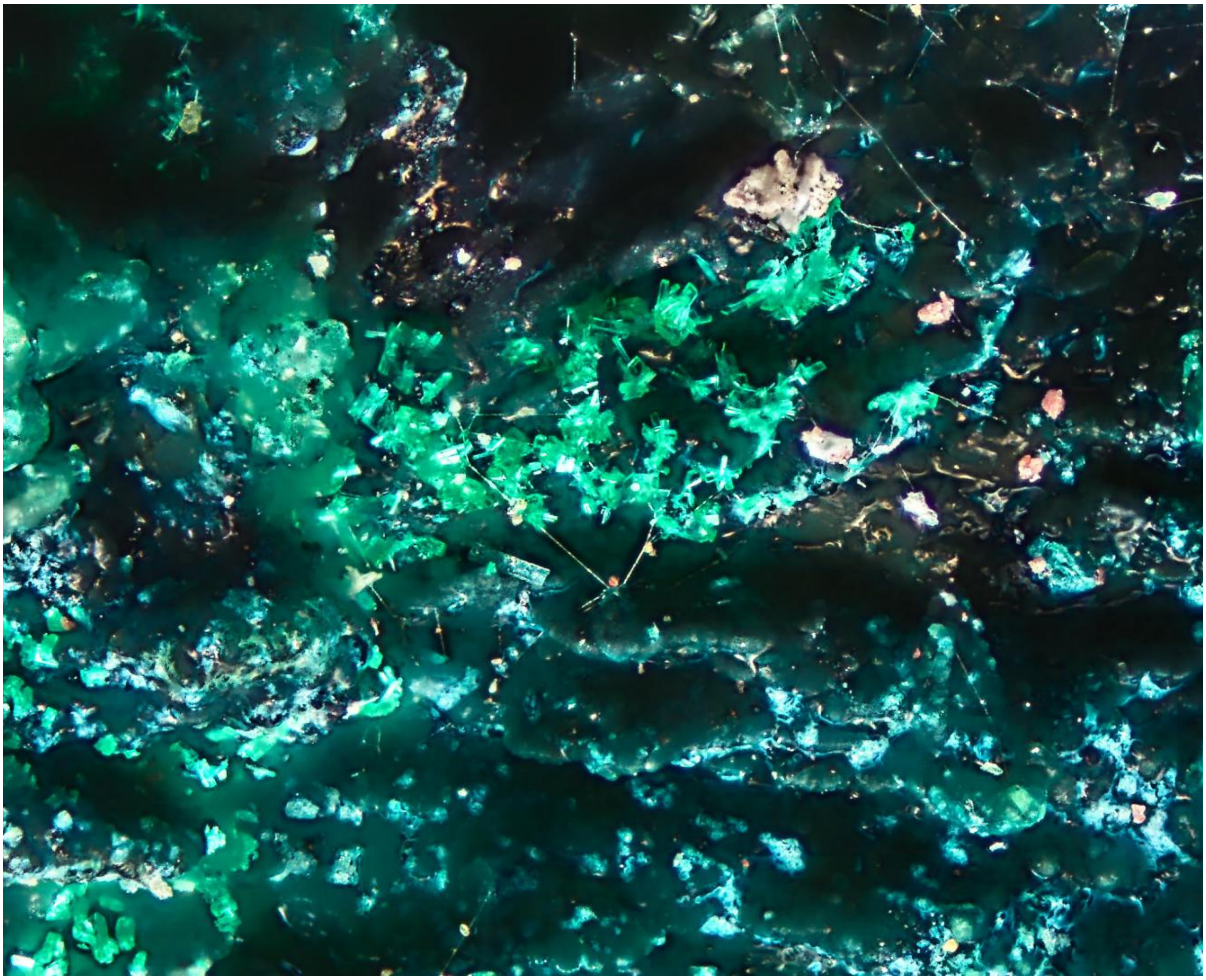

Figure 18: Antlerite from the 1944 eruption, 50X, image taken by Heinen from his private collection. It is a rare greenish hydrous copper sulfate mineral, with the formula $Cu_3(SO_4)(OH)_4$.

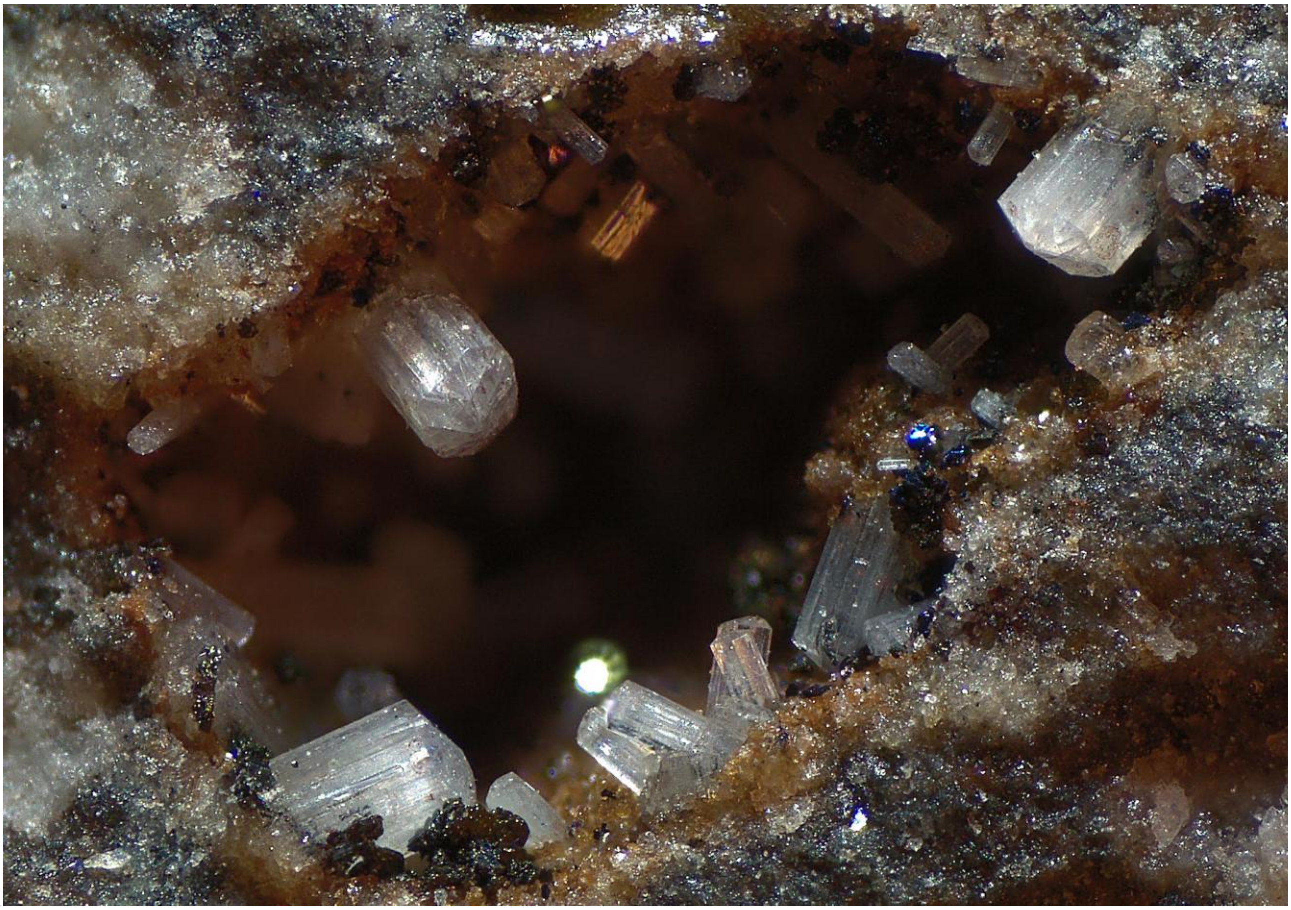

Figure 19: Prismatic colorless crystals of Microsommite in a metamorphosed conglomerate, Cava San Vito, 30X, image taken by Heinen from his private collection. ***Microsommite*** $Na_4K_2Ca_2(Al_6Si_6O_{24})(SO_4)Cl_2$ ***is a tectosilicate belonging to the Cancrinite group, feldspathoids belonging to the subclass of tectosilicates and crystallize in alkaline or peralkaline igneous rocks, with compositions ranging from slightly to strongly undersaturated in silica.***

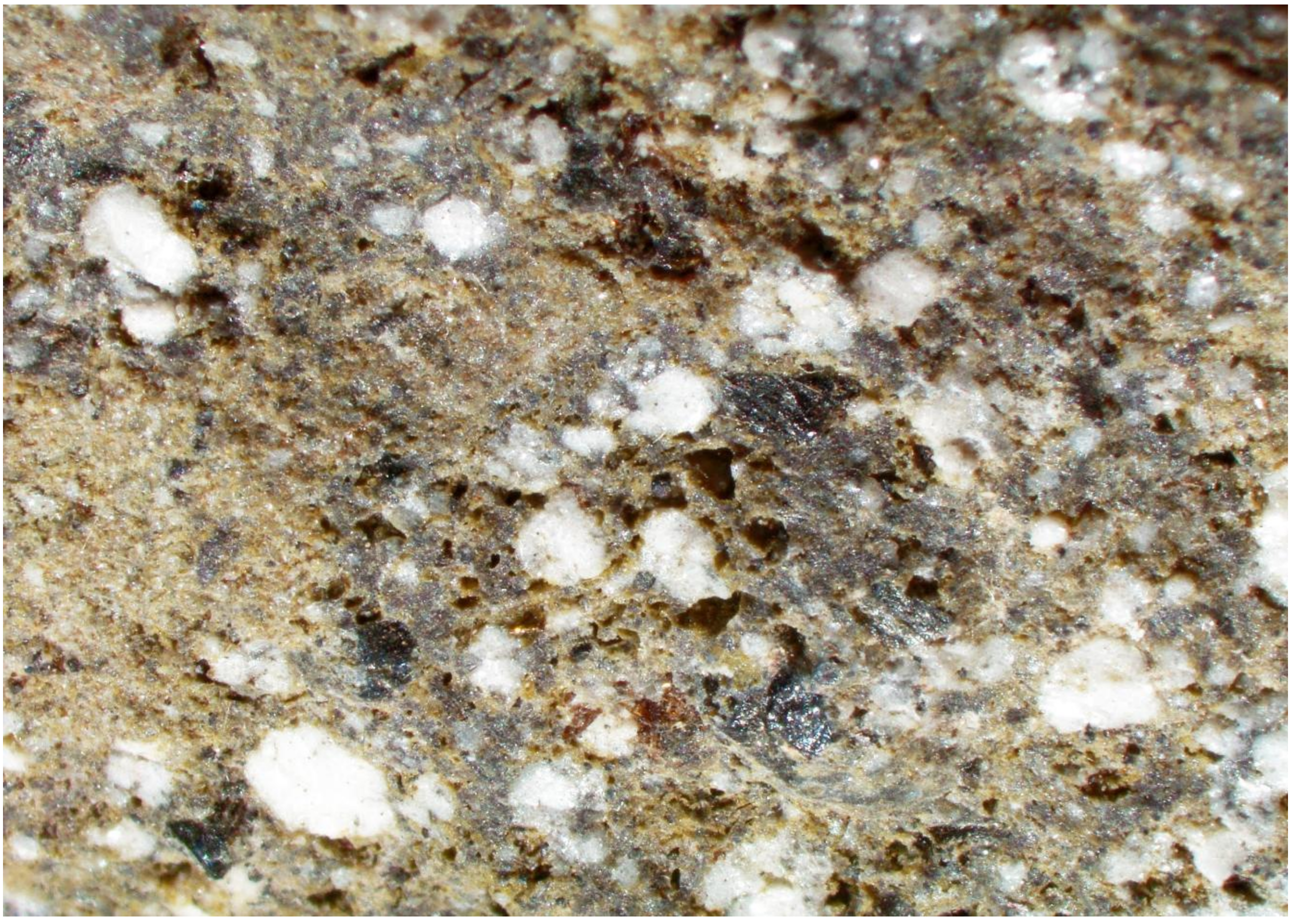

Figure 20: Leucite on lava from the 1944 eruption, 6X, image taken by Heinen from his private collection.

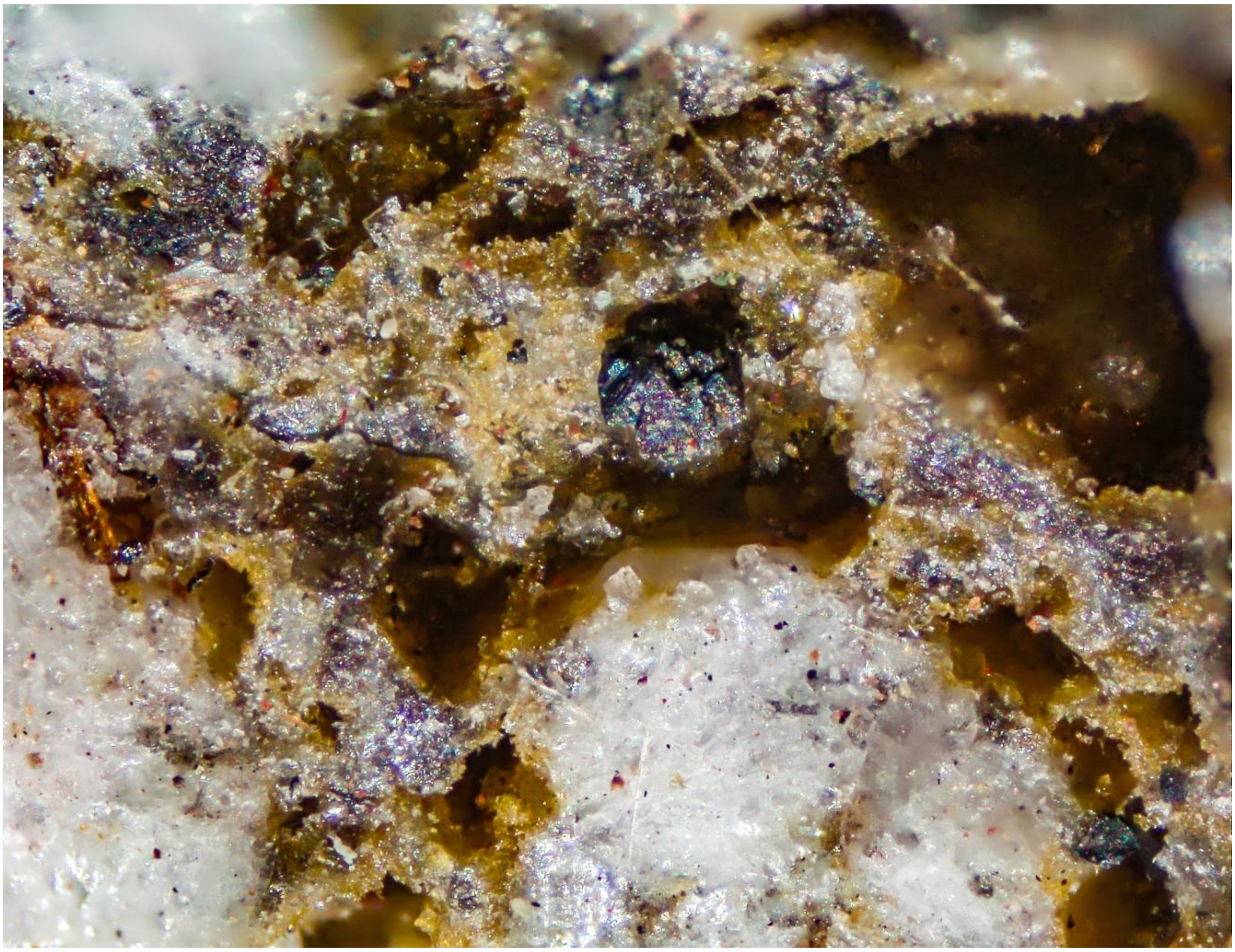

Figure 21: Magnetite xx with some Antlerite xx on lava from the 1944 eruption, 50X, image taken by Heinen from his private collection.

Campi Flegrei volcanic caldera (Phlegraean Fields)

The Phlegraean Fields (Campi Flegrei) is a large area of volcanic origin located in the north-west of the city of Naples. It is an area with a singular structure: not a truncated cone-shaped volcano but a vast depression or caldera, about 12x15 km wide.

The eruptive history is dominated by the eruptions of Ignimbrite Campana and Neapolitan Yellow Tuff (see also https://en.wikipedia.org/wiki/Ignimbrite). These events were so violent that the volumes of magma produced and the speed with which they were emitted caused collapse and originated calderas. For this reason, the shape of the area is that of a semicircle bordered by numerous volcanic cones and craters.

In 1538 the last eruption occurred which, despite being among the minor ones in the entire eruptive history of Phlegraean Fields, interrupted a period of quiescence of about 3,000 years and gave rise to the cone of Monte Nuovo, about 130 m high. Since then, the activity in the Phlegraean Fields is endowed with phenomena of bradyseism, fumarolic activity and hydrothermal activity localized in the Solfatara area.

Solfatara of Pozzuoli

The solfatara of Pozzuoli is one of the forty volcanoes that make up the Phlegraean Fields; it is located about three kilometers from the city of Pozzuoli. It is an ancient volcanic crater still active but in a quiescent state that for about two millennia has retained an activity of sulfur dioxide fumaroles. The Solfatara today represents a relief valve of the magma present under the Phlegraean Fields (Figs. 22-23), thanks to which it is possible to maintain a constant pressure of the underground gases.

Figure 22: Solfatara di Pozzuoli (photo made by Lena).

The Bocca Grande is the main fumarole of the Solfatara with steam, with the characteristic smell of sulfur and H_2S, which reaches temperatures of about 160°. Named by the ancient Forum Volcanoes, in its vapors there are salts such as Realgar and Orpiment which, resting on the surrounding rocks, give a yellow-reddish color (Figs. 23-26).

Figure 23: Solfatara of Pozzuoli. Bocca Grande is the main fumarole of the Solfatara (photo made by Lena).

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Figure 24: Solfatara of Pozzuoli. Realgar and Orpiment, two arsenic sulfide minerals (photo made by Lena).

Figure 25: Solfatara of Pozzuoli. Bocca Grande is the main fumarole of the Solfatara (photo made by Lena).

Realgar, As_4S_4, is an arsenic sulfide mineral, also known as "ruby sulphur". It is found in granular or powdery form, in association with the related mineral Orpiment (As_2S_3) yellow in color (Fig. 24). Realgar is orange-red in color (Fig. 26).

Figure 26: Realgar found in the Solfatara of Pozzuoli (Lena private collection).

Sulfur (Fig. 27) is found in paragenesis with Realgar, Alunogen (Fig. 26), Gypsum and Alotrichite.

Figure 27: Sulfur found in the Solfatara of Pozzuoli (Lena, private collection).

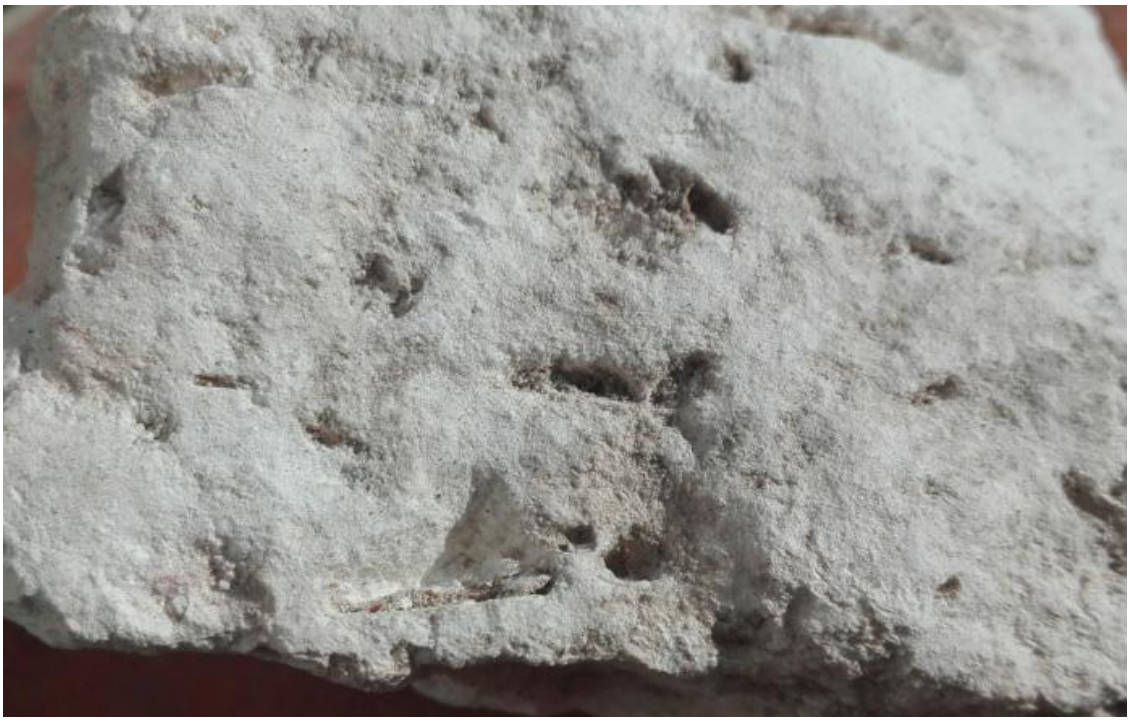

Figure 28: Alunogen found in the Solfatara of Pozzuoli (Lena, private collection). Alunogen is an Aluminium sulfate mineral $Al_2 (SO_4)_3{\cdot}17H_2O$.

Iconographic plates

Iconographic plates from Heinen's private collection, with drawings from Somma-Vesuvius and Phlegraean Fields (Campi Flegrei), are shown in the following figures (Figs. 29-31).

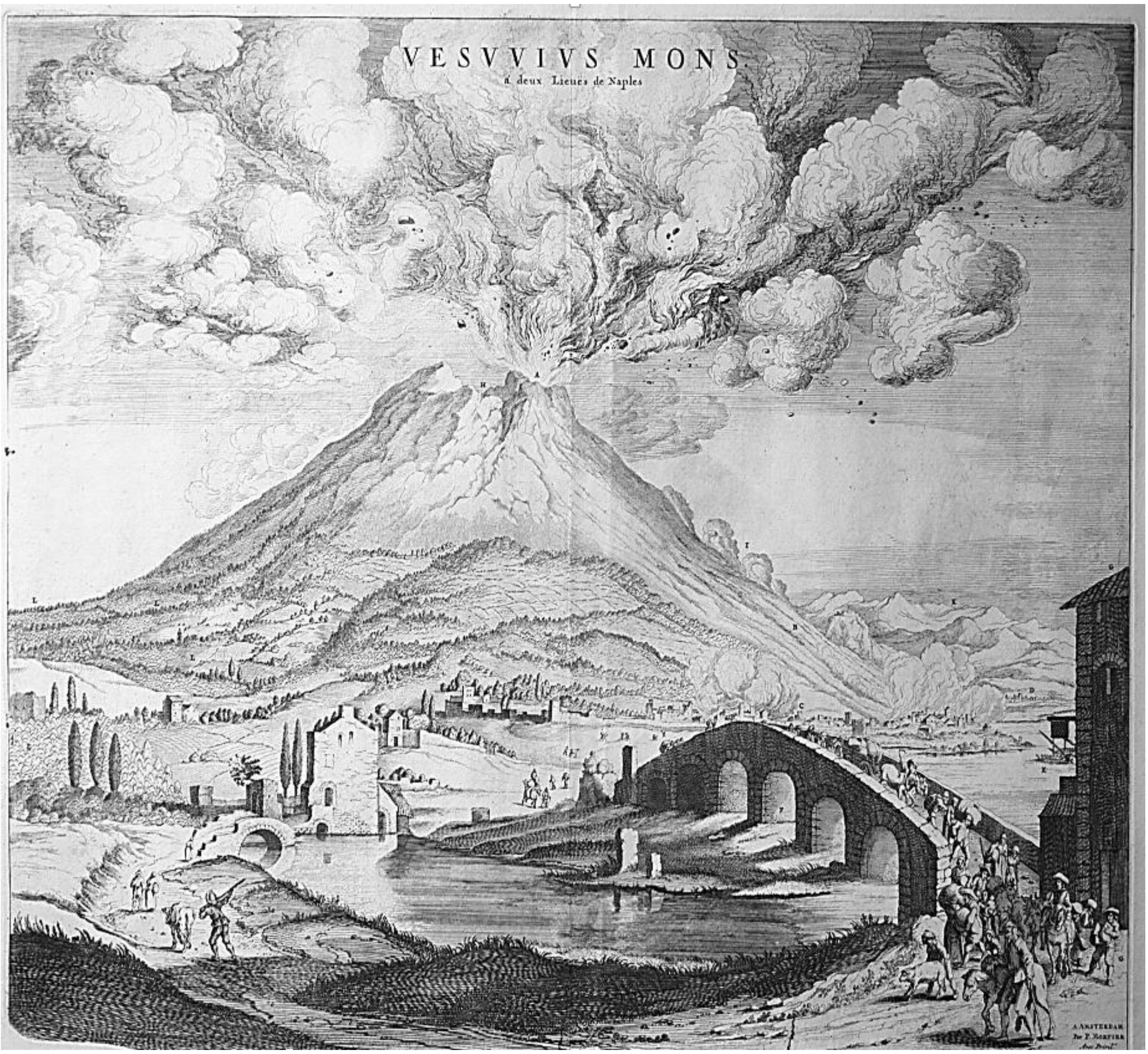

Figure 29: Vesuvius from Mortier (1663) -private collection of Heinen.

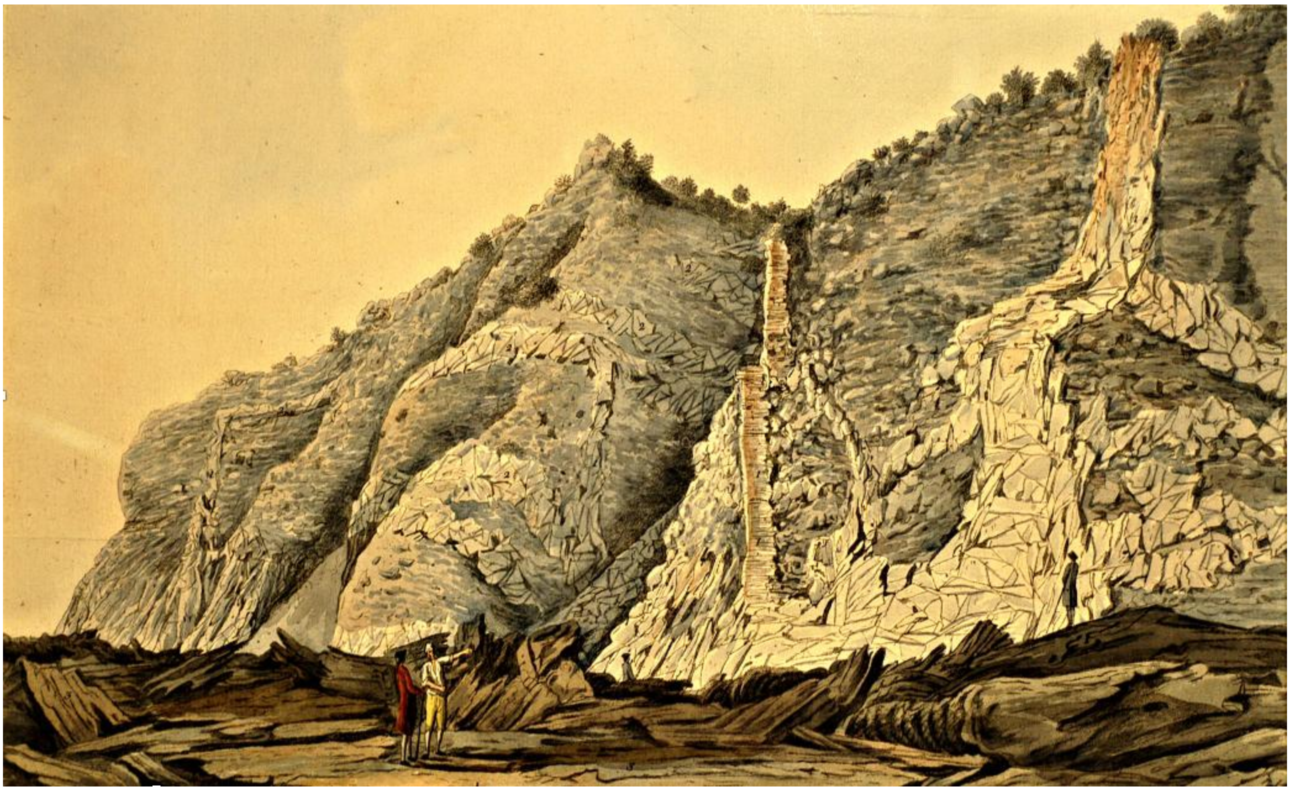

Figure 29: Vesuvius drawing by Lord Hamilton (1776)-private collection of Heinen.

Figure 30: Phlegraean Fields (Campi Flegrei), drawing by Lord Hamilton (1776)-private collection of Heinen.

Conclusion

Vesuvius is a particularly interesting volcano for its history and the frequency of its eruptions. It is a mainly explosive volcano.

Furthermore, the characteristics of the volcanic products associated with the eruptions of Vesuvius, one of the most dangerous terrestrial volcanoes, have been described.

Several studies (e.g. Pappalardo and Marstrolorenzo, 2012) suggest a relation between Vesuvius and the Phlegraean Fields (Campi Flegrei): there might be a unique long-lived magma pool beneath the whole Neapolitan area.

Stratovolcanoes/Composite cones are steep sided due to more viscous lava and are explosive. These volcanoes have a higher proportion of silica minerals and more gas in the magma.

In comparison the shield volcanoes, and also the lunar domes, have moderate or gentle slopes caused by highly fluid lava flows of basalt.

Stratovolcanoes are not known on the Moon. Lunar domes originated by lava of basaltic composition. The highland lunar domes (e.g. Gruithuisen domes) originated from highly silicic, more viscous, non-mare lavas, likely dacitic or rhyolitic in composition. Thus the highland domes are similar, both in terms of slope and height, to the volcanic complex of Mount Amiata, an ancient volcanic complex in Italy (Tuscany Region). The description of the volcanic activity in the Amiata complex will be the object of an ongoing next note.

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