Comparative mineralogy and petrography of the basalts of Vesuvius and Batur volcanoes

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Abstract. In areas of active volcanic activity, sedimentary rocks can form both directly during eruptions and the destruction of effusive rocks. Therefore, the study of effusive parent rocks such as basalts is very important. This work provides information about the history of formation and geological structure of Vesuvius and Batur volcanoes, which are located at different ends of the Mediterranean-Alpine-Himalayan folded belt and have a similar layer-cone structure and they are represented by alkaline (subalkaline) type of magmas. Based on the research and literature data, it is found that modern basaltic samples from these volcanoes are mineralogically close. The basalt of Mount Batur was formed from lavas with higher aluminium content in the melt, higher viscosity, with strong degassing and rapid cooling. The formation of effusive rocks of Vesuvius, on the contrary, is associated with a lower viscosity of lava, a lower content of aluminium and its slower cooling. They underwent more significant secondary changes.

1. Introduction

Vesuvius is one of the most active volcanoes of the Earth, located in a densely populated area of Italy, on the Gulf of Naples, in Campania. It is part of the Apennine mountain system and one of the largest volcanoes of the Romanesque alkaline province, reaching 1,281 m height. Vesuvius is located within the Mediterranean mobile belt, and it lies 15 thousand km along from Western Europe to Indonesia.

Vesuvius is a stratovolcano with a stratified structure, as a result of alternate lava eruptions and spew of detrital materials. It has three inset cones. The oldest of which outlies and it is partially preserved on the northern and eastern slopes only. This large semicircle ridge is called Mount Somma and it is remnants of the prehistoric cone and crater (fig. 1). The bottom of the old crater is 270 m or 360 m below the edge of Somma (about 1200 m above sea level), and the modern much smaller Vesuvius cone (fig. 2), which varies from time to time due to eruptions, rises on it. Its center does not match with the old eruptive focus of the Somma but lies about 3/4 km to the south. Vesuvius, that is 2.5 km in diameter, is much smaller than its predecessor Somma, that was 16 km in diameter and covered an area of 200 km². At the bottom of the crater of Vesuvius, a third temporary cone sometimes appears, which disappears after severe eruptions [1].

In prehistoric times, there was a large caldera on the site of Vesuvius, which, as a result of numerous eruptions, was destroyed, and in its place approximately 25,000 years ago, due to the overlapping of the
African and Eurasian lithospheric plates, the Mount Somma cone appeared. Vesuvius was formed 13 thousand years after that and almost straightway it gave a powerful eruption. It is believed that it happened in the period from 6940 ± 100 B.C. The second powerful eruption of Vesuvius is known a little more: it happened about 3.8 thousand years ago and the territory equal to modern Naples and the surrounding areas was covered by magmatic streams [2].

Strong Plinian eruptions, with powerful explosive magma emissions, accompanied by massive ashy precipitation, are usually interstratified within periods of interplinian weak activity. A typical eruption of Vesuvius was the emission of a large volume of ash and gases[3]. A large eruption, happened in 79 year, destroyed several cities - Pompeii and Stabia were covered with volcanic ash, up to 8 m thick in some places, and Herculaneum was covered with mudflows due to the rain that accompanied the eruption. Evidence of Vesuvius eruptions was dated back in 1631, 1794, 1822, 1872, 1906, and the last time it erupted in March 1944 [4–6]. The Comma-Vesuvius cone has been very stable over the last several decades, with no signs of activity growing [7].

![Figure 1. The Monte-Somma shaft - remains of the outer most ancient cone of Vesuvius that is partially preserved on the northern and eastern slopes](image)

The beginning of the constant activity of Vesuvius after the 1600 year probably correlates with the overlapping of two deformation impulses from Calabria and the Southern Apennines. The tectonic earthquakes of the Calabrian arc happen after some delay as a result of earthquakes in the Sicilian region and the southern Apennines. The volcanic activity of Vesuvius follows a similar way. Major eruptions follow periods of increased seismicity, both in the Calabrian arc and in the Southern Apennines with a longer time delay [8,9].
Several magma chambers were installed under Vesuvius. One of them is near-surface, located at the depth of about 3 km, the second - at the depth of about 10-15 km. The continental crust under Mount Vesuvius consists of thick Triassic dolomites, up to 7 km thick and underlying rocks of the early stages of the Mediterranean belt development, metamorphosed under the conditions of the greenschist facies [10].

Most modern volcanoes erupt lava of basalt or andesite composition. However, Vesuvius is the only volcano that erupts rare types of lavas rich in potassium and containing potassium mineral leucite [2]. The volcanologist Alfred Rittmann [5] developed the theory of the lavas formation of this volcano, characterized by a high content of potassium compounds, got the name of the hypothesis of dolomites assimilation. After studying the fluid and melt components of the volcanic substance, he established both physical and chemical indicators of minerals contained in lava - for example, such as olivine, clinopyroxene and plagioclase.

In the course of the long evolution of the Mount Vesuvius rocks, the content of elements such as calcium, potassium, iron increased and the content of silica and sodium decreased that could be caused by the crystallization differentiation and interaction of the melting with host rocks [11]. Interacting with magma in the underlying Vesuvius volcano, thicker dolomites formed magnesian skarns. When dolomites interact with magma, calcium becomes mobile and transforms from host rocks to magma, while magnesium binds to minerals in skarns.

Gunung-Batur is a volcano, located in the north-east of the Bali island, which is a part of the province with the same name in Indonesia. The island is located near the Sunda trench, which is the result of subduction caused by the dive of the Indo-Australian slab under the Eurasian plate at a rate of 70 mm per year. The trench is seismically active, along its line many active volcanoes are part of the Pacific ring of fire.
Gunung-Batur is a caldera, reaching a height of 1717 meters. In the caldera, there is a lake and volcanic formations, including the cone of Mount Batur, which rises to a height of 700 meters above the surrounding terrain [12]. The appearance of the caldera occurred in several stages [13]. Volcanic activity in this area began about 500 thousand years ago with the formation of stratovolcanoes, included basalts and andesites. Then, secondary volcanic forms were formed, consisting of dacites. The outer caldera was formed 29.3 thousand years ago as a result of volcanic activity on the island and ignimbrite emissions on the surface. The internal caldera, measuring 6.4 × 9.4 km, was formed 21.5 thousand years ago as a result of the next volcanic eruptions and emissions of andesite and dacite ignimbrites. As a result of this volcanic activity, the internal caldera was filled with water - a lake of the same name arose (fig. 3), then the modern third cone of Mount Batur was formed (fig. 4). The Abang volcano arose later in the caldera and it was 2152 meters high [14].

Figure 3. The inner caldera of Gunung-Batur with the lake of the same name and lava fields

Figure 4. Crater of the inner cone of the Batur volcano
Volcanic activity in historical times had a moderate explosive character, lava flows reached the lake's waters. This is evident from the frozen basaltic flows (see fig. 3). During the eruptions of 1963-1964, 16 houses of a nearby village were destroyed. Currently, the volcano is active and from time to time, tremors occur, fumarolic activity is observed. The last significant emission occurred in 1999-2000 [13].

2. Samples and analytical methods

Three samples are taken from the slopes of Mount Vesuvius to study the mineralogical-geochemical features of the rocks. The selected sites are chosen from the areas at the top of the craters covered with effusives, dating from the time of the last eruptions (fig. 5).

![Figure 5. Map of the sampling locations on the Vesuvius](image)

The mineral composition is determined by X-ray diffractometer Shimadzu XRD-7000S. The petrographic analysis was performed on thin sections using a microscope Carl Zeiss AxioImager A2m.

The image of the surface of the high-resolution sample was obtained by scanning electron microscope FEI XL-30 ESEM. Preliminarily fresh chipped side of the sample was coated with a carbon layer of approximately 15 nm. The survey was conducted in low-vacuum mode with an accelerating voltage of 25 keV.

3. Results and Discussions

The study of petrographic features in the sections indicates that the rocks of Vesuvius are mainly represented by tephrites and only one sample can be relative to tephriphonolite (fig. 6A). X-ray diffraction analysis shows that samples include leucite, calcite, augite and calcian albite. Among the Vesuvian rocks, there are no samples with a purely glassy bulk. It is predominantly represented by the mentally large microliths with a disordered arrangement and a small amount of glass (intersertal structure) (see fig. 6A). There are samples with amygdaloidal texture (fig. 6B and 6C). Among the phenocrysts, a greater number of pyroxenes (5-8%) and a few smaller ones - olivine (1-7%) are noted.
Plagioclases are mainly represented by microliths, the fraction of their phenocrysts does not exceed 10% in the total mass. All minerals have signs of secondary changes, the glass present is also affected by the processes of devitrification.

![Micrographs of thin sections of effusive rocks of Vesuvius](image)

**Figure 6.** Micrographs of thin sections of effusive rocks of Vesuvius: at the top - in natural light, below - in polarized. A - andesibasalt with intersertal structure, B - clinopyroxene phenocryst crystal (Cpx) in basalt, C - olivine (Ol) phenocrystal, subjected to secondary changes.

Volcanic rocks of Mount Batur are represented by basalts of vitroporphic (Fig. 7A) and intersertal structures (fig. 7B, 7C), the texture is porous. Porphyritic secretions perform about 15-25% of the total volume of the rock. They are represented by crystals of the main plagioclase (15% and more) (see fig. 7B, 7C) and olivine (1-5%) (see fig. 7A, 7B), as well as individual grains of pyroxenes (see fig. 7B, 7C). The structure of the main mass is hyalopilitic (glass predominates over microlites).

Petrographic study of effusive rocks of the volcano showed that all the studied samples have a porphyry structure. Among the phenocrysts, plagioclase (17-23 vol.%), then olivines (3 vol.%) and pyroxenes (2 vol.%) predominate in number. Almost all samples belong to the subalkaline-alkaline series formed under conditions of island-arc magmatism and vary in composition from basalts to trachyandesibasalts consisting of SiO$_2$ from 49.62 to 54.77 wt. %. The Batur basalts consist of a K$_2$O with values K$_2$O / Na$_2$O within the range from 0.2 to 0.4 (<53 mass% SiO$_2$) in the pre- and post-caldera stages. Within each group, the variation of each oxide forms a curvilinear relation with an increase in the SiO$_2$ content - the content of Al$_2$O$_3$, FeO, MgO and CaO decrease generally, Na$_2$O increases [15].
Figure 7. Micrographs of thin sections of effusive rocks of Batur: at the top - in natural light, below - in a polarized one. A - basalt of vitroporphyrite structure with olivine (Ol) and plagioclase (Plg); B - basalt of intersertal structure with wedge-pyroxene (Cpx); olivine and plagioclase; C - phenocrysts of plagioclase and a single grain of clinopyroxene.

Basalt is characterized by a fibrous microstructure (fig. 8), the formation of which is due to the presence of minerals with chain-building minerals in it. In such minerals, tetrahedra connected by vertices, following the Pauling principle, form elongated infinite chains parallel to each other. They are characterized by the presence of a strong siloxane coherency Si-O-Si, but which do not interfere with the rotation of tetrahedra around the coherency. In addition to the group [SiO4] 4-, there are anions [AlO4] 5- in the chain silicates.

Aluminium-oxygen tetrahedra participate in the construction of complex polymerized structures only in conjunction with the silicon-oxygen tetrahedra, and the aluminium-oxygen tetrahedra in these structures they are weak parts. As a result of the so-called "struggle for oxygen" in the cooling melt, structural groups are formed. If the temperature is sufficiently low, crystals of olivine are formed successively, and then pyroxene, flowing the Bowen series is formed. The crystallization of plagioclases, in this case, depends on the ratio of Si and Al in the melt: with sufficient content of the latter, large crystals of aluminosilicates simultaneously with olivine and pyroxene are formed. With the rapid cooling of the basalt melt, due to the increase of viscosity and the decrease of temperature, the thermal motion of the particles is inhibited and the crystal lattices of minerals, requiring for their construction a certain time and sufficient mobility of the particles, do not have time to be formed and the are solidified in the form of a glass-like substance [16].
4. Conclusions

In comparison with the Vesuvius basalt, samples from Mount Batur are differed by a higher content of plagioclase and glassy base, the phenocrysts are smaller, which may indicate a higher aluminium content in the melt, greater viscosity of the lava and its rapid cooling. The high porosity of the samples is an indicator of the high content of gases in the melt and its strong degassing during cooling. Samples of effusive rocks of Vesuvius, on the contrary, have many large grains of olivine and pyroxene, a smaller content of plagioclases and glassy mass, which is associated with a lower viscosity of lava, a lower content of Al and its slower cooling. In addition, the rocks of Vesuvius were more susceptible to secondary changes due to the longer duration of exposure to exogenous processes since the last eruption.

Acknowledgements

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