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GEOLOGY OF MONTE AMIATA VOLCANO (SOUTHERN TUSCANY)

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ABSTRACT: A multidisciplinary approach, comprising lithological, petrochemical, volcanological, structural, geometric, and morphological analyses on the Monte Amiata volcanic rocks and their stratigraphic relationships, has been used to reconstruct the evolutionary history of this Quaternary volcano, located in the southern Tuscany (Italy).

KEYWORDS: Monte Amiata, quaternary volcano, geological mapping, stratigraphy, volcano-tectonics

1. INTRODUCTION

In this multidisciplinary study, we describe the geological evolution of the Monte Amiata volcano based on stratigraphic and volcano-geological methodologies into the framework of a robust field-based work. Mount Amiata is a silicic Quaternary volcano located in the southern Tuscany (Italy). After the first recognition of the volcanic nature of Monte Amiata made by Micheli in 1733 (Principe et al. 2017 cum bib), between the end of the 17th and the 19th centuries, there were numerous reports of naturalistic travels carried out in this territory and descriptions of its rocks. Modern scientific studies, essentially of petrographic and geographical characters, were carried out from the twentieth century. From the 1950s to 1970s, the volcanology of Monte Amiata is marked by the ideas of two great names of Italian volcanology: Alfred Rittmann and Giorgio Marinelli (see Principe et al. 2017 cum bib). Rittmann introduced the term "rheomorphic ignimbrite" to describe the extensive sheet of glassy volcanic rocks that seem to form a single body at the base of the volcanic edifice. Its interpretation is that the large mass of volcanics at the base of Monte Amiata would be the result of the repeated emplacement of pyroclastic flows emitted by a linear fracture and in their entirety constituting a sheet of rheomorphic ignimbrite erupted from a deep laccolithic structure. Marinelli essentially shared this interpretation. The authority of these two scholars made that all the following volcanological studies and geological mapping of Monte Amiata adopted their volcanological interpretation for the genesis of acidic lavas and the stratigraphic subdivision into three units. This tri-fold division of the volcanic activity of Monte Amiata includes: (1) a Basal Trachydacitic Complex (BTC), in turn divided into a lower unit and an upper unit; (2) a Complex of lava domes and flows (DLC), which groups all the domes that make up the summit of the volcano and some lesser lava flows; and (3) the two, basic, lava flows of Macinaie and Ermeta. In this view, the major volcanological arguments debated on Amiata, during the last 55 years, is the occurrence of explosive eruptions and the emplacement of pyroclastic flow deposits during its activity. In particular, the lower unit was considered, into the volcanological and petrochemical literature, as either a unique sheet of ignimbrite and rheoignimbrite deposits, or a sequence of lava flows, or, more recently, the collapse of an endogenous mega-dome. One of the features that previously restricted the distinction of geological units within the volcano was the apparent lithological uniformity that produced the distinction of only two lithological types of rocks and the consequent aggregation of all the outcrops in a few stratigraphic units.

The produced review of the scientific literature on the Monte Amiata volcano (Principe et al. 2017 cum bib) has highlighted the gaps and inaccuracies contained in the past interpretations, as well as numerous insights of investigation and discussion that have been a stimulus for the mass of stratigraphic, geological and petrochemical data collected by the research work carried out for the Tuscany Region project that we summarized in this contribution. Actually, although the Monte Amiata volcano has been the subject of numerous studies, including the production of geological maps at various scales and different details, there was still not a geological model on which to base a reliable reconstruction of its geological structure and volcanological and magmatological evolution.

2. MATERIAL AND METHODS

We performed a detailed field analysis and collected stratigraphic and petrographic data from outcropping deposits and from a continuous deep core drilling named David Lazzaretti that was drilled on the southern flank of Monte Amiata by Regione Toscana in 2010. This deep coring intersected the entire volcano sequence, comprising volcanic units older than the outcropping rocks, and reached the non-volcanic substratum. The stratigraphic analysis has taken into account lithological, petrochemical, volcanological, structural, geometric and morphological characteristics of the volcanic rocks and their stratigraphic relationships. The surficial volcanic units were identified as lithostratigraphic units (more than 30 formations) and grouped into Unconformity Bounded Stratigraphic Units (UBSU) with 2 Synthem and 5 Subsynthem.

3. RESULTS

The pre-volcanic sedimentary substratum of Monte Amiata volcano includes the Ophiolitic Unit and the Santa Fiora Unit of the Ligurian Domain. The proposed geological evolution comprises two main period of activity that correspond to the older Bágnore Synthem and the younger Monte Amiata Synthem. They are separated by a major unconformity corresponding to a surface of erosion, saprolithic weathering and tectonic deformation. Into the Bágnore Synthem, there are two Subsynthem. The lower, the Bagnólo Subsynthem, comprises several great lava flows characterized by a vitrophyric perlitic groundmass. They flowed for very long distances (up to 8 km) in all the directions (e.g. Sorgente del Fiora Fm., Marroneto Fm., Piancastagnaio fm., Abbadia San Salvatore fm., Vivo d'Orcia fm.). A surface of erosion and unconformity separates the Bagnólo Subsynthem from the overlying Montearioso Subsynthem. It is composed of more confined vitrophyric lava flows (e.g. Tre Case Fm., Quaranta Fm., Castel del Piano fm.) and one exogenous lava dome and *coulée* (Poggio Pinzi fm.). All the rocks belonging to the Bágnore Synthem show a well-developed weathering that transformed their uppermost portion in a sandy deposit, yellow and reddish in color. The Monte Amiata Synthem comprises three Subsynthems. The lower Valle Gelata Subsynthem is characterized by exogenous lava domes with thick coulées (e.g. Poggio Lombardo Fm., Pozzaroni Fm.) and by long channelized lava flows (e.g. Leccio fm., Coderino fm.). The intermediate Madonna degli Scout Subsynthem is composed of several exogenous lava domes with short coulées (e.g. Poggio della Pescina Fm., Poggio Falco Fm., Corno di Bellaria Fm., La Vetta fm., Rifugio Cantore fm.), and minor lava flows. All these units are emplaced upon a morphology that has been moulded by tectonic deformations. The final Prato della Contessa Subsynthem comprises several exogenous lava domes (e.g. La Montagnola fm., Pianello fm.) and lava flows (e.g. Ermeta fm., Le Macinaie fm., Cancelle fm, Fosso La Cocca fm.) from the volcano summit area, and the lateral exogenous lava dome and *coulée* of the Trauzzolo Fm.

The main tectonic element affecting the Monte Amiata area is a set of NE-SW-trending faults belonging to the Bágnore and Bagni San Filippo trans-tensional shear zones, located to the south-west and north-east of the volcano, respectively. In addition to these faults, other three sets of lineaments has been recognized on the volcanic area and surrounding sedimentary rocks. They are the older NNE-SSW trend, and the ESE-WNW and SSE-NNW trends that accommodate the stress produced by the NE-SW prevailing trend. All these tectonic regional trends were repeatedly active during the volcano eruptive history. The interaction of these structural elements with the stratigraphic units and the volcanic morphologies, such as domes, *coulées* and lava flows that compose the Monte Amiata edifice, hallowed to assess the presence of several volcano-tectonic graben-like structures that formed at different moments of the volcanic history. The older of these grabens corresponds to a depressed area inside the sedimentary substratum under the south-western portion of the volcanic edifice. This first collapse occurred in relationship with the emplacement of the thick succession of domes and lava flows cored by the David Lazzaretti drilling. During the subsequent episodes of Monte Amiata volcanic activity, other grabens formed. These volcano-tectonic structures repeatedly interested trachidacitic lava flows and domes, generating nested narrow structural strip on the summit portion of the volcanic edifice. From a couple of these fractures, the less evolved lavas were emitted during, and not at the end, of the volcanic history of Monte Amiata. The last emitted volcanics are the exogenous domes of La Montagnola and Poggio Trauzzolo formations, unaffected by graben structures. The presence of these volcano-tectonic collapses gives reason of all the structural elements still visible on the volcano and depicts a new interpretation of the Monte Amiata volcano grown, that is in agreement with morpho -sructural and stratigraphic findings.

Petrographic analyses allowed us to distinguish five different types of lavas on the basis of textural, structural, and mineralogical characteristics. All these five lava types occur at various stratigraphic positions in all the Subsynthems of Montearioso, Valle Gelata, Madonna degli Scout and Prato della Contessa, whereas only lavas of one type are present in the Bagnòlo Subsynthem. All the available whole-rock chemical data of Monte Amiata volcanics have been reprocessed, considering the stratigraphic position of each sample, and focusing on the quantification of mixing processes between mafic and acid magmas, which were recognized in previous studies. Although the chemical composition of meta-sedimentary xenoliths is poorly known, their percentages resulted to be relatively high, from 30 to 45% in lavas and from 35 to 60 % in mafic magmatic inclusions for all the five subsynthems, composing the Monte Amiata stratigraphy. The proportions of both the mafic end-member in acid lavas and the acid end-member in mafic magmatic inclusions were evaluated getting rid of the contribution of meta-sedimentary xenoliths to whole-rock chemistry. In this way, it turned out that the mafic end-member in acid lavas attains maximum values of ~15% in the Bagnòlo Subsynthem, ~17 % in the Montearioso and Valle Gelata Subsynthems, ~36 % in the Madonna, degli Scout Subsynthem, and of ~46 % in the Prato della Contessa Subsynthem. The acid end-member in mafic magmatic inclusions reaches maximum values of ~53 % in the Montearioso Subsynthem, ~34 % in the Valle Gelata Subsynthem (although this figure is affected by the availability of few data), ~57 % in the Madonna degli Scout Subsynthem, and ~64 % in the Prato della Contessa Subsynthem.

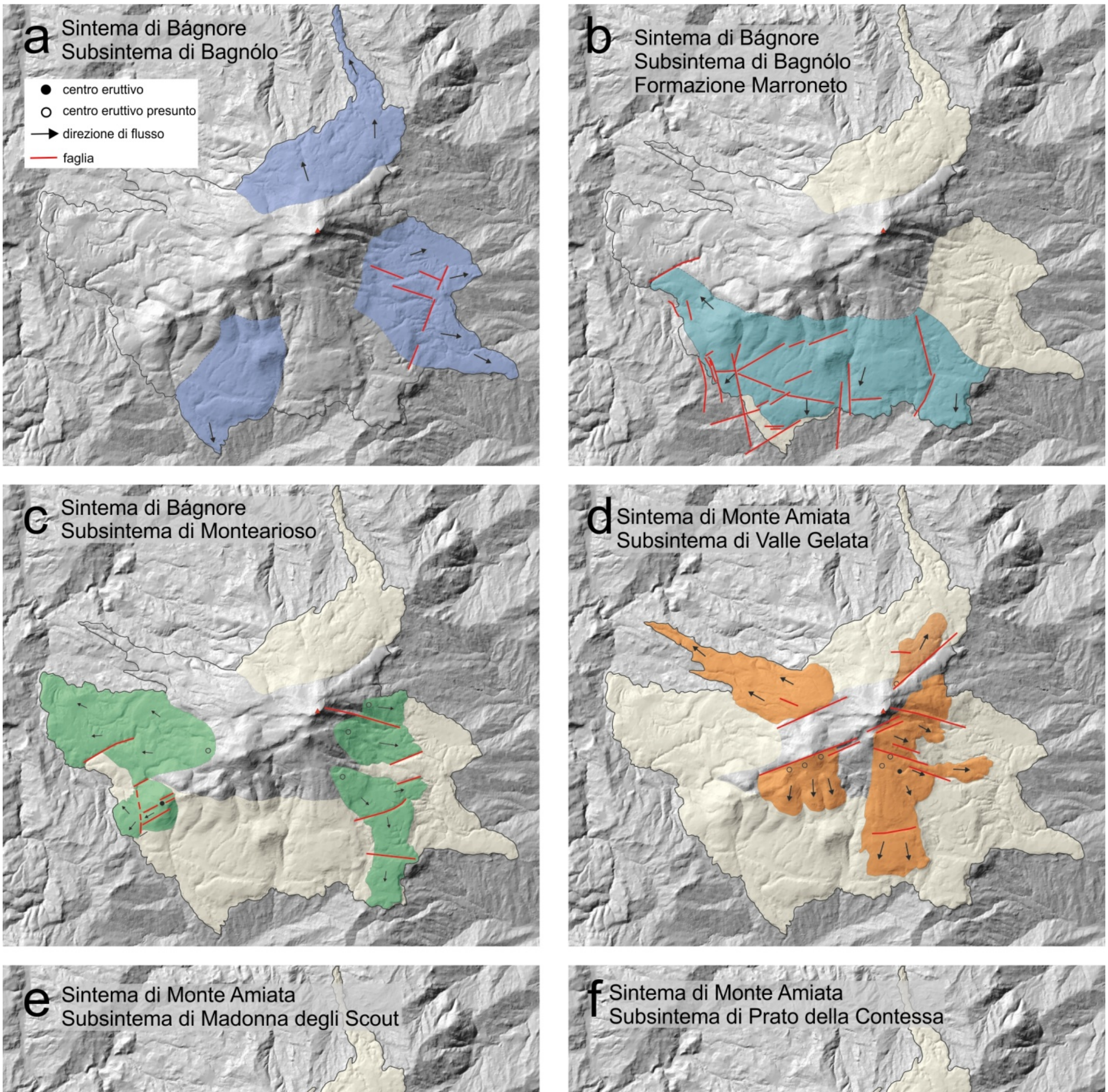

Fig. 1 - Schematic reconstruction of the geological evolution of the Monte Amiata volcano (from Principe et al. 2017, pag.98).

4. DISCUSSION AND CONCLUSIONS

The reconstructed succession is indicative of a rapid aggradation of effusive products and does not evidence pyroclastic deposits or mega-breccia facies. The previously undivided, extensive basal unit comprises different, single, superposed silicic bodies, in which we distinguish structural and morphological features typical of lava flows, such as basal and top autoclastic breccia, front ramp structures and surficial ogive structures. Both at microscopic and macroscopic scale, the rock texture is not fragmental. Individual flow unit does not show evidence of facies variations from proximal near vent (e.g. co-ignimbrite lithic breccia) to distal areas of deposition that is typical of pyroclastic flow deposits. In the individual flow unit, where is not vertical and/or lateral gradation in welding character from non-welded, to medium grade (with sparse welded zones) to pervasively rheomorphic textures. Individual flow units are of small volume and extension, and show channelized lobe geometry. We suggest that the extensive silicic basal (outcropping) unit of Amiata volcano is a sequence of lava flows with a rapid aggradation.

The stratigraphic framework reconstructed in this work, thanks to the accurate geological field survey, has made it possible to accurately define the nature of the various volcanic bodies (lava flow, lava dome, coulée), according to their lithological and outcrop characteristics, and to place them in their proper position within the geologic evolution of the volcano. As a whole, the volcanic deposits of Monte Amiata exclusively consisting of a series of acid lava flows, exogenous domes and associated coulées. Large volumes of lava blocks, dispersed at the periphery of the volcano, and interpreted in the past as blocky lavas, are related to pervasive surface alterations of pressure ridges on top of the major lava flows and to collapse landslides occurred at the margin of the volcanic body in contact with the shaly deposits of the sedimentary substratum.

Despite the apparent homogeneity of mineralogical and chemical composition of Monte Amiata volcanics, invoked in the previous literature as an obstacle to a clear geological and volcanological interpretation of the volcano, we have shown that each identified and mapped stratigraphic unit has petrographic peculiarities that allow its differentiation and recognition, as well as a set of distinguishable lithological and depositional characters. Based on the petrochemical data, the preliminary volcanological framework for the Bagnólo Subsynthem consists of a magma chamber, initially containing a relatively large mass of acid magma, in which a relatively small fraction of mafic magma entered afterwards. During the subsequent periods of volcanic activity, the acid magma batches stationing below the volcano became progressively smaller and the mafic magma venue became consequently more important, originating the abundant mafic magmatic inclusions found in the volcanic deposits. Structures and textures of the volcanic deposits suggest the occurrence of complex mingling and mixing processes during volcanic activity. In particular, the mafic magmatic inclusions abundantly present in the volcanic rocks, especially in the most recent units of the stratigraphic sequence, are characterized by the presence of megacrysts in chemical disequilibrium, that are also consistent with the occurrence of mingling processes.

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