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Volcanic Stratigraphy - State of the art

Gianluca Groppelli[1] & Joan Martì Molist[2]

[1] CNR, Istituto per la Dinamica dei Processi Ambientali, sezione di Milano, Via Mangiagalli 34, 20133 Milano, Italia; gianluca.groppelli@cnr.it

[2] Instituto de Ciencias de la Tierra "Jaume Almera", CSIC, Barcelona, España; joanmartimolist@gmail.com

Summary

The volcanic stratigraphy is a fundament subject of field studies in volcanic areas because it can furnish basic and fundamental data for further and more detailed studies. Nowadays, the volcanologists are discussing the recent application of volcanic stratigraphy to map volcanoes, applying lithostratigraphy and other stratigraphic units, as synthemic units. This application represents a key point because the geological map should be the base for any detailed volcanological research and should represent the warehouse where to store in an objective way the past eruptions and the inter-eruptive phenomena. The volcanic stratigraphy and the stratigraphic mapping methodology provide significant data and constraints for volcanic hazard assessment, volcanological features, physical volcanology, petrographic, geochemical and petrological studies, and geophysical models.

***Keywords*:** Geological map, Tephrostratigraphy, Physical volcanology, Synthemic unit

The volcanic stratigraphy is a fundament subject of field studies in volcanic areas to generate geological maps, to reconstruct the volcanological evolution and eruptive dynamics, to study the physical volcanology and tephrostratigraphy. Detailed log sections for tephrostratigraphic and for eruptive dynamics studies have been used for long time and a common approach is worldwide accepted. Since the pioneering work of Sheridan (1971), Walker (1971) and Sparks *et al.* (1973) the stratigraphic approach allows understanding the different facies, bodies and deposition mechanisms of pyroclastic flow. Recently Wilson & Houghton (2000), Branney & Kokelaar (2002) and Sulpizio & Dellino (2008), based on a detailed stratigraphic study of the pyroclastic deposits, have moved forward in the comprehension of pyroclastic Pyroclastic Density Currents dynamics. In addition, detailed volcanic stratigraphy combined with juvenile texture allows reconstructing the eruptive dynamics of a given eruption (e.g. Polacci *et al.*, 2003; Gurioli *et al.*, 2005; Sable *et al.*, 2006, 2009; Costantini *et al.*, 2010; Vinkler *et al.*, 2012) with strong and evident implications also for the hazard assessment. Also the tephrostratigraphic works have furnished a large contribute to understand the volumes and eruptive styles of the volcanoes (e.g. Coltelli *et al.*, 2000, for Mt. Etna; Sulpizio *et al.*, 2008, for Vesuvius), as well as to identify important marker beds or litho-horizons useful for regional and interregional correlations, using isochronous layer, often easy to date. For this reason in depth studies are ongoing to recognize, to characterize, to attribute and to correlate the tephra layers and to reconstruct as much complete as possible stratigraphic succession including all the achievable events (Sulpizio *et al.*, 2010; Zanchetta *et al.*, 2011).

Nowadays, the most discussed application of volcanic stratigraphy is its use to map volcanic areas, where only recently a stratigraphic approach has been applied. This application represents a key point because the geological map should be the base for any detailed volcanological research and should represent the warehouse where to store in an objective way the past eruptions and the inter-eruptive phenomena. Because of this open discussion, we concentrate this paper on geological mapping and its different aspects.

To map volcanic areas we have not yet established a common mapping approach, opposite to sedimentary terrains, where the stratigraphic practice traces back more than 200 years. In the last 30 years scientists mapping volcanic areas have defined individual beds or successions of beds or bodies as mappable units based on petrographic, geochemical, radiometrical, volcanological or stratigraphic criteria. In the first geological maps in the XIX century the distinction of units were based mainly on petrographic and geochemical composition besides an historical distinction (e.g. recent or ancient lavas). Recently some geological surveys as well use the chemical composition of volcanics to display their color on the map (for example, among many, USGS and BRGM).

In the 1970s, scientists started to apply the volcanic activity units (Fisher & Schmincke, 1984), thus combining stratigraphic and volcanological criteria. The main advantage of this systematic was the direct link to the volcanic activity, the main unit being the individual eruption or a volcanologically uniform set of eruptions. However, the main problem with this approach is that the thus defined unit is not objective as it is genetically defined. Additionally, a single eruptive unit can easily be defined and mapped at active volcanoes, while the distinguishable units are mainly sets of deposits from several individual eruptions when mapping extinct volcanic terrains. Finally, this kind of unit, very useful to understand the eruptive dynamics of a given eruption, does not consider the inter-eruptive phenomena (e.g. debris flow, lahars, etc.), which represent important elements in the life of a volcano and present important implications for the hazard.

At the end of the 1980s, following the guidelines of the International Stratigraphic Codes (Hedberg, 1976; Salvador, 1994), scientists started to apply a stratigraphical approach to mapping volcanoes, using the systematics of stratigraphic units, mainly lithostratigraphic. Some stratigraphic units are also applied to summarize the volcanic succession, as, for example, synthemic and lithosomatic units.

Under the influence of the project for the new geological map of Italy at 1:50 000 scale (Pasquaré *et al.*, 1992) the geological maps realized by most Italian scientists (e.g. Etna, Stromboli, Lipari, Capraia, Vesuvius, Colli Albani, Vulture, El Tatio – Chile, Nevado de Toluca - Mexico) are characterized by the use of different stratigraphic units, often in parallel, with the aim to define the evolution of a volcanic area (e.g. Bellotti *et al.*, 2006; Giannandrea *et al.*, 2006; Funiciello *et al.*, 2008; Lucchi *et al.*, 2009; 2010; Giordano *et al.*, 2010; Tibaldi, 2010; Branca *et al.*, 2011; Forni *et al.*, *in* press; Francalanci *et al.*, *in* press). The basic unit in their projects is the lithostratigraphy, used during the field survey and also in the display of the final map, except for the Vulture map (Giannandrea *et al.*, 2006). These maps document that surveying on the base of lithostratigraphic units is especially helpful in the initial survey phase as during field work the lithologic properties and stratigraphic relationships of rock bodies are the only characteristics immediately recognizable. Laboratory data, e.g. petrographic, geochemical, radiometric analyses, however, only allow a subsequent, more comprehensive definition of an identified lithostratigraphic unit. In addition, a common feature of these papers is the application of lithosomatic and synthemic units (or UBSU) to synthesize the volcanic evolution of the area and to distinguish major phases based on reproducable field ("objective") characteristics. First Chang (1975), later Salvador (1987), and the ISSC (Salvador, 1994) proposed to use synthems as units bounded by discontinuities. In volcanic areas unconformities are due to different causes: a period of quiescence, an erosional phase, a shifting of the feeding system, an abrupt change in eruptive style, or a volcano-tectonic event, such as a caldera or a flank collapse. The relative importance of an unconformity depends on their geographic extension, the duration of an associated hiatus or its volcano-structural significance. However, the application of the UBSU concept to volcanic areas faces problems of scale (temporal and spatial), as usually hiatuses are of short duration (days to 10 000 years), and the limited areal extent of units (e.g. restrictions to individual volcanic bodies or to a volcano). On the other side the synthemic unit, mainly supersynthem in rank, allows to distinguish in objective way the main phases of the volcanism and to relate them with the variation of the regional tectonic regime and other regional events, as eustatic level (Branca *et al.*, 2004; Bellotti *et al.*, 2006; Lucchi *et al.*, 2010). In fact, due to the high sea level during MIS 5, Lucchi *et al.* (2010) and Lucchi (*in* press) recognize two marine platforms as discontinuities bounding supersynthems in the Lipari Island (Lucchi *et al.,* 2010 and references therein). In this way, the authors can correlate these surfaces through the entire Aeolian Archipelago. They thus use a classic feature of sequence stratigraphy to recognize the first-order unconformities of the UBSU, that is a convergence between synthemic units and sequence stratigraphy, as suggested by Murphy & Salvador (1999). Other examples of this convergence are the geological maps along the Tyrrenian Coast, where relationships among volcanic activity, epiclastic deposition, sedimentary processes are controlled by sea level change (e.g. De Rita *et al*., 2002; Funiciello *et al*., 2008; Palladino *et al*., 2010) using also seismo-stratigraphic analyses (Milia, 2010). Moreover, Lucchi *et al.* (2009; 2010) and Lucchi (*in* press) add a fourth level of stratigraphic units by distinguishing volcanic activity units (Epoch) in order to highlight the main constructive phases of the volcanic districts.

Finally, when conducting volcanic stratigraphy it is also very important to establish the time scale of volcanic processes registered in the geological record. Volcanic processes may represent either long or short (even at a human scale) geological events, so a correct time scale needs to be assigned to each of the units included in our stratigraphy. A close collaboration of field geologists and geochronologists during fieldwork and laboratory analyses is essential in order to generate a qualified interpretation of radiometric results and to establish the chronostratigraphy of the volcanic succession. Moreover, it indicates the relevance of radiometric data for the synthemic framework, as they allow to quantify the hiatuses represented by unconformities, as well as to understand their volcanogenic meaning.

Despite the evident hazard posed by active and dormant volcanoes as well as so many casualties due to eruptive or secondary phenomena, no common and international guidelines exist for generating a volcanic hazard map. However, a geological map still represents the main document for an initial hazard assessment in volcanic areas (e.g. Groppelli & Norini, 2005; Gurioli *et al*., 2010; Sheridan *et al*., 2010) as well as modeling of the eruptive phenomena. In fact, geological and volcano-stratigraphic maps allow to define several data, among them, the recurrence time, the magnitude of different phenomena registered in the investigated area, the location of flank eruptions, etc., useful for probabilistic analyses, modeling and hazard zonation.

Concluding, the volcanic stratigraphy represent a fundamental topic in volcanology because it can furnish basic data for further and more detailed studies; the stratigraphy and mainly its application to mapping represent the warehouse where to store past eruptions and inter-eruption phenomena with significant effects on volcanic hazard assessment, volcanological features, petrographic, geochemical and petrological studies, and geophysical models. In addition, the geological maps realized recently mainly by Italian scientists document the applicability of the concept of synthemic units as the main feature to synthesize and map the volcanic evolution of the area. Further discussions and in-depth analyses need to establish a common world methodology mainly for mapping.

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