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SPACE *VS*. TIME: DIFFUSION CHRONOMETRY AS A TOOL FOR INVESTIGATING THE TIMING OF THE MT. ETNA PLUMBING SYSTEM

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INTRODUCTION AND AIMS OF THE PROJECT

Based on the time-dependent diffusion of elements in response to chemical potential gradients formed within phenocrysts during magmatic crystallization, diffusion chronometry is one of the most innovative methods for unravelling the timescales of magmatic processes in volcanoes plumbing systems (Morgan & Blake, 2006; Costa *et al*., 2008; Costa & Morgan, 2011; Dohmen *et al*., 2017). In many active volcanoes, such as Mt. Etna (Sicily, Italy), many questions regarding the geometry and dynamics of the feeding system are still pending, so that the timing and depth of magmatic processes responsible for eruption triggering are yet to be discovered. The present project is designed to build a multi-phase and multi-element diffusion-chronometry model to the main coexisting phenocryst types of Mt. Etna lavas, with the aim of: *i*) ascribing the common chemical/textural patterns of crystals to specific magmatic processes; *ii*) resolving the timescale of magma ascent, ponding, mixing, volatile exsolution and degassing at different levels of the feeding system.

Thanks to this grant*, in-situ* high spatial resolution major/trace element analyses were performed on olivine, clinopyroxene and plagioclase phenocrysts in a large set of well-known products emitted by Mt. Etna during the recent eruptive events. The acquired dataset, consisting of high-quality compositional profiles on olivine, clinopyroxene and plagioclase with specific textures (see Giacomoni *et al*., 2014, 2016), enables us to evaluate the compositional variability of the main crystal phases, and sets the stage for the development of innovative diffusion chronometry models. The application of such an internally consistent set of diffusion chronometers will substantially improve the knowledge of Mt. Etna feeding system, and would have potential implications for the study of the worldwide open-conduit volcanoes.

MT. ETNA

Mt. Etna is one of the most intensively studied volcanoes in Europe, mainly because of its proximity to a densely populated area, the frequent eruptive activity and the articulated structure of its feeding system. The ongoing activity of the volcano occurs from the central open-conduit main system (summit central craters, *i.e.* Bocca Nuova and Voragine, and sub-terminal craters, *i.e.* SE Craters and NE Crater), and subordinately from the tectonics-controlled lateral systems (North-East Rift, S-Rift and W Rift), and the eccentric flank system (randomly dispersed 338 monogenetic cinder-cones). The frequent effusive to strombolian eruptions at Mt. Etna are occasionally interrupted by the onset of paroxysmal events, even though Plinian eruptions have been rarely documented over the last 110 ka (Coltelli *et al*., 2000). In the last decades, textural studies and thermobarometric models on olivine, clinopyroxene and plagioclase phenocrysts in the etnean lavas enabled several authors to speculate about the main chemico-physical parameters driving magma ascent and ponding, as well as on the geometry of the feeding system beneath central conduits, rift-related and eccentric vents (Andronico *et al*., 2005; Ferlito *et al*., 2009; Viccaro *et al*., 2010; Kahl *et al*., 2011, 2013, 2015; Giacomoni *et al*., 2014, 2016, 2018; Ubide & Kamber, 2018). However, many questions regarding the dynamics of Mt. Etna plumbing system are still pending, the most urgent of which is related to the timescale of the magmatic processes occurring at different depths that are ultimately responsible for eruption triggering. A correlation between real-time monitoring data and diffusion chronometry models on single phenocrysts led some authors to hypothesize that the recharge of deep-seated reservoirs takes place in years-time, whereas mixing between evolved magma and hot, mafic, volatile-rich pulses is thought to be capable of triggering eruption in weeks or months (Kahl *et al.*, 2011, 2013, 2015; Viccaro *et al.*, 2016; Giuffrida & Viccaro, 2017; Ubide & Kamber, 2018). Unfortunately, considerable uncertainty in these models is related to the scarce level of representativeness of single-element, single-phase approaches, being an integrated assessment of the chemical zoning of olivine, clinopyroxene and plagioclase (co-precipitating in great parts of the liquid line of descent) still missing.

MATERIAL AND METHODS

For the development of the present project, representative in-situ major/trace element analyses of olivine, clinopyroxene and plagioclase phenocrysts from the products emitted during the 2001; 2002-2003; 2004; 2006; 2011-2012 and 2015 eruptions at Mt. Etna were performed after careful textural characterization by means of optical and Scanning Electronic Microscopy (SEM). High lateral resolution micro-chemical analyses were made by means of a Cameca SXFive Field-Emission Electron Probe Micro Analyser (FE-EPMA) equipped with five wavelength dispersive spectrometers (WDS) and one energy dispersive system (EDS) hosted at the Department of Lithospheric Research of the University of Wien (Austria). Both quantitative point analyses, core-to-rim profiles and 2D element distribution maps were achieved with high lateral resolution (< 3 μm). EPMA trace element (10s to 100s ppm concentration) are less precise than LA-ICP-MS determination, but at the same time are characterized by higher lateral resolution, crucial (and mandatory) factor for developing kinetic modelling from *in-situ* analyses.

The diffusion-chronometry modelling relies on the time-dependent diffusion of elements in response to compositional gradients formed during minerals growth, and by means of the diffusive relaxation of the primary composition patterns enables to extract timing and rates of each process through inverse diffusion modelling (Chakraborty, 2008; Costa *et al.*, 2008; Shea *et al.*, 2015; Dohmen *et al.*, 2017). The diffusion-chronometry approach is thus based on the chemical re-equilibration of a system after perturbation of an initial equilibrium state through externally imposed changes of the physico-chemical parameters, such as T, P, fO_2, fH_2O, or melt composition. On the way towards equilibrium, specific microstructural features may form. This research was focused on the diffusion-mediated degradation of intracrystalline composition zoning in olivine, clinopyroxene and plagioclase phenocrysts.

EXPECTED RESULTS

Results evaluation and related modelling are still in progress. The SEM and EPMA sessions allowed to characterize the core to rim compositional zoning of olivine, clinopyroxene and plagioclase, and link it to a wide span of dissolution-regrowth textures.

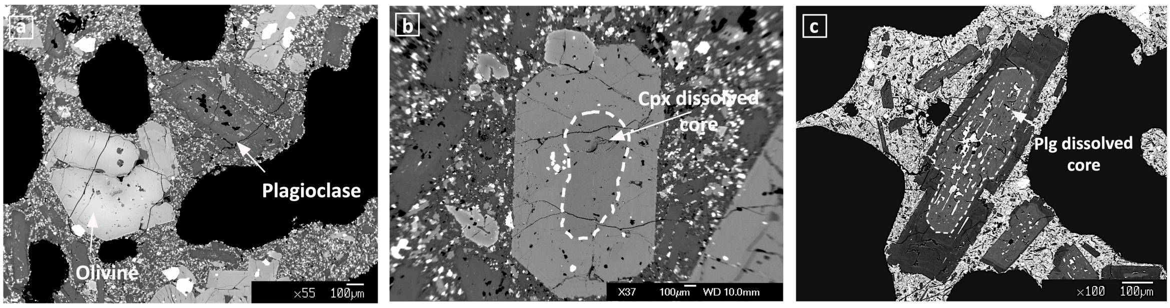

Fig. 1 - BSE images showing some of the identified olivine, clinopyroxene and plagioclase textural types in Mt. Etna recently erupted products. a) Euhedral olivine phenocryst; b) inversely zoned clinopyroxene with rounded dissolved core; c) plagioclase phenocryst with rounded dissolved core surrounded by oscillatory

Olivine phenocrysts are mostly euhedral, ranging in composition from Fo 88 to 62 (Fig. 1a). Clinopyroxene show peculiar textures and associated compositional zoning. Some phenocrysts are directly zoned (Mg# 80-86 core, Mg# 76-78 rim), while others are inversely zoned and have rounded dissolved cores (Mg# 76-78 core; Mg# 79-82 rim; Fig. 1b). Alternatively, dusty rims can occasionally develop. Plagioclase crystals vary in composition from An 88 to 52 and are characterized by a large variety of complex dissolution-regrowth textures at the cores or at the rims, varying in proportions between samples from different eruptive event. As previously described by Giacomoni *et al.* (2014), two main plagioclase groups are present among the studied samples: the first group contains large (up to 2 mm) heavily texturized crystals; the second one is made of smaller (< 1 mm) of mostly euhedral crystals. The most frequent textures recognized in larger plagioclase are: *i*) rounded dissolved cores surrounded by oscillatory overgrowth (Fig. 1c); *ii*) dusty partially resorbed cores followed by oscillatory overgrowth; *iii*) dusty rims. These chemical and textural features will be combined with thermobarometric and hygrometric estimates to evaluate the effect that magmatic processes such as mixing, assimilation, fractional crystallization, volatile exsolution and flushing have on magma crystallization and finally on eruptive dynamics. Parallelly, diffusion-chronometry models will be developed on the most representative phenocrysts to extract timing and rates of such processes.

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