MT. ETNA 2017: A MULTIDISCIPLINARY INVESTIGATION TO EXPLORE THE RECENT DYNAMICS OF MAGMA ASCENT AND INTERACTION

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Introduction. In the last few decades, several eruptions have taken place at Mt. Etna in relatively short time span, passing from period of entirely effusive activity to strongly explosive (i.e., violent Strombolian to lava fountains). Since 2011, the eruptive behavior was dominantly explosive with two major cycles of paroxysmal eruptions as those of 2011-2013 at New South East Crater (NSEC) and 2015-2016 at the Voragine Crater (VOR). A new drastic change of the eruptive style was observed during the first months of 2017, when the activity turns again to dominantly effusive, giving rise to a short sequence of weak Strombolian explosions and lava flow emissions between February and April. Understanding and forecast such eruptive phenomena at Mt. Etna are of prominent importance due to the high population density on its slopes. In order to enable a better knowledge of the volcanic phenomena in progress, the observation and monitoring systems have been significantly implemented in recent years, and a higher quantity and quality of instrumental data associated to recent eruptions have been collected (Spampinato *et al.,* 2015; Gambino *et al.,* 2016). In particular, the rapid growth of continuously recording geodetic networks enhanced acquiring extensive datasets that largely improved our current knowledge of the magmatic plumbing system. However, in the case of articulated plumbing systems, geodetic data modeling alone are unable to entirely deconvolve complex evolutionary dynamics of magmas or to comprehensively track the ascent paths of magmas and potentially resolve their temporal relationships without relying on compositional information preserved in volcanic minerals and rocks. In this study, we show that geochemistry and diffusion chronometry applied to compositionally-zoned crystals may provide the

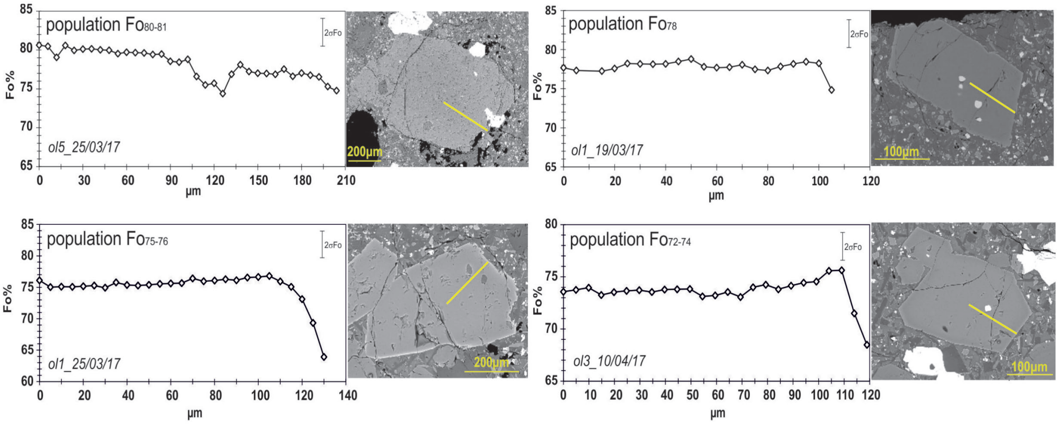

Fig. 1. Representative core-to-rim compositional profiles for the identified olivine populations. Yellow lines in the BSE images indicate the direction of the SEM-EDS/WDS transect.

fundamental framework for the interpretation of geodetic data associated to complex volcanic phenomena. Based on an extensive dataset of concentration and diffusion profiles of olivine crystals combined with geodetic data, we are able to interpret the geodetic evidence of volcanic unrest throughout the 2017 eruptive period in terms of deep and subsurface pre-eruptive processes such as the storage, transport and interactions of magmas. Such approach of investigation allows the spatial localization of active magmatic sources, and also defines their temporal activation before and during each eruptive episode. This enables to address some important changes in the modes of magma supply into the Etnean plumbing system during 2017, which seem to be a direct consequence of the last violent paroxysmal episodes occurred at Voragine Crater on May 2016.

Geochemical and geodetic data elaboration and integration. We elaborated and integrated information preserved in olivine crystals with GPS observations collected from the permanent network and spanning the May 19, 2016 - May 25, 2017 period to explore dynamics of magma ascent and interaction leading to the volcanic activity of 2017. Olivine cores spanning from more basic (Fo_{80-81}) to slightly evolved compositions (Fo_{72-74}) reflect crystal growth in separated magma volumes residing at different depths beneath Mt. Etna, each defined by precise physical and chemical conditions. We have identified four olivine populations which fall in the same range of compositions of olivine groups recognized for past effusive and explosive eruptions of Mt. Etna (Giuffrida and Viccaro, 2017; Cannata *et al.,* 2018; Fig.1). Such observations lead us to infer that the residence and growth of olivine crystals during 2017 occurred within the same magmatic environments (indicated as M_i) that were selectively reactivated during the 2011-2013 eruptive sequence at the NSEC, and later between 2015 and 2016 during the volcanic activity at VOR (Giuffrida and Viccaro, 2017; Cannata *et al.,* 2018). Thus, olivines with Fo_{80-81} cores are representative of the M_0 environment located at pressure of 420-380 MPa; Fo_{78} cores refer to the M_{1a} environment at 290-230 MPa; olivines with Fo_{76} core compositions belong to the M_{1b} environment at 160-120 MPa, whereas the Fo_{72-74} core compositions encompass a compositional range which is intermediate between M_{1b} and M_2 (30-40 MPa). In spite of the complex diversity of zoning patterns, some evolutionary paths are dominant in the history recorded by each olivine population. For instance, the prevalence of normal zoning pattern characterizing more basic crystals (Fo_{80-81} and Fo_{78}) for the eruptions of February 28 and March 19 indicates ascent of basic magmas from deep reservoirs (M_0 and M_{1a}) to shallow crustal levels. Starting from March 25, compositions of olivine cores drop to lower forsteritic concentrations (Fo_{75} to Fo_{72}). Such a compositional change accounts for the reactivation of the shallow magmatic environments M_{1b} and M_2, and therefore the emission of more evolved magmas during the episodes of March 25,

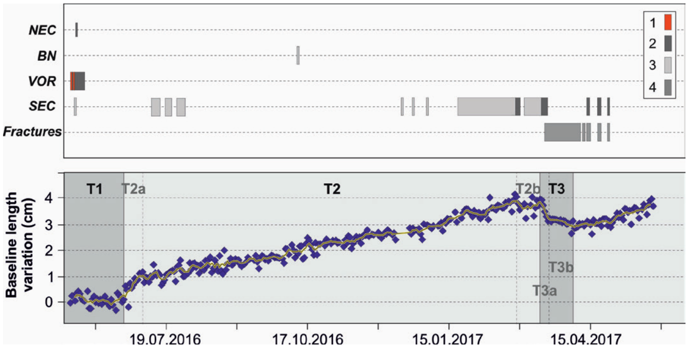

Fig. 2. The upper panel shows the temporal evolution of the volcanic activity at summit area: 1) fire fountain activity, 2) Strombolian activity, 3) ash emission/weak explosive activity, 4) effusive activity. The lower panel displays daily baseline changes of EDAM and EINT stations. The visual inspection of such a baseline allows the detection of main ground deformation stages T1, T2 and T3. Detection of sub-period T2a, T2b, T3a and T3b accounts for changes in the deformation rates within a main deformative stage.

April 11 and April 19. Petrological evidence of multiple magmatic environments beneath the volcano appears strongly connected with geodetic data, through which we inferred the presence of two active magmatic sources associated to two main ground deformation stages, T2 (from June 16, 2016 to March 15, 2017) and T3 (from March 16 to April 1, 2017; Fig. 2). For the deformation stage T2, the magmatic source is located at depth of ~6.3 km bsl and covers the same pressure range of the M_{1a} environment. For the T3 stage, the modeled source is at depth of ~4.6 km bsl, corresponding to that of the M_{1b} environment. Such inferred magmatic sources are connected and they strictly interacted before and during the eruptive events of 2017. We were able to recover the timescales associated to these magmatic interactions by modeling the diffusional smoothing of the Fe-Mg zoning in olivine crystals (Costa *et al.,* 2018; Costa and Morgan, 2010). Final results show a reasonable fit between the observed deformation patterns and inferred transfer dynamics from olivine normal and reverse zoning, allowing to follow the evolution through time of the volcanic activity between February and April 2017. Specifically, at the end of the May 2016 activity at VOR, ground deformation data recorded a new inflation of the volcano edifice (T2) which lasted about 10 months, but had a different deformation rate, which was very high from June 2016 to early February 2017 (T2a) and then changed to low rate from February to mid-March 2017 (T2b; Fig. 2). During T2a, the normal zoning of the Fo_{78} and Fo_{80-81} olivines indicates the ascent of fresh magma that occurred as a consequence of the pressure imbalance between the magmatic reservoir M_{1b} and a deeper one ($M1_a$ or M_0). The diffusive relaxation of such zoning patterns produces, indeed, timescales of about 181-256 days, in accordance with processes of magma movement that started 8-10 months before the beginning of the 2017 eruptive activity. After T2a, the plumbing system pressurized at constant rate, up to the beginning of the vigorous explosive activity in late February. During this period, low-Fo olivine crystals record a new injection of basic magma that occurred 23-44 days before March 25 (i.e., end of February), causing the pressurization of the shallow portion of the plumbing system within the pressure range of M_{1b} and M_2 environments. From the reverse zoning of Fo_{76} to Fo_{78} olivines erupted between April 11 and April 19, 2017 we recovered longer diffusion timescales of 34-54 days associated to episodes of mafic recharge. Such timescales suggest that during T2b (from February 28 to March 15, 2017) the M_{1b} and M_{1a} environments underwent continuous recharge which balanced eruptive phenomena occurring at the surface. After a brief period of volcano flank deflation between mid-March and April 1, due to the intensification of the effusive activity, we have new evidence of ascent of basic magmas (M_0) from depth which rapidly moved throughout the crust during the period T3, reaching the surface in about 1 week.

Conclusions. Combination of all petrological and geodetic observations supports the idea that dynamics of magma transfer driving the eruptive episodes of 2017 were a direct consequence of the violent eruptions occurred at Voragine Crater on May 2016, which greatly enhanced the ascent of fresh magma from deep storage zones and improved the efficiency of the plumbing system to transfer it upward to the surface. We propose a mechanism of self-feeding rejuvenation of the volcano plumbing system during 2017, where fresh recharging magmas ascending from depth progressively pushed away the residual ones stored at shallow crustal levels. Support to this inference is given by the nearly flat deformative pattern observed during the early eruptive episodes of February-March 2017. Indeed, the deflation expected as a consequence of magma extrusion did not occur, probably due to the continuous magma injections from depth that balanced eruptive phenomena at the surface. Similarly, a continuous inflationary deformative pattern was recorded since April 2017 albeit conspicuous magma discharges occurred during the April 11, 19 and 27 eruptions. Such a geodetic-petrological integrated analysis affords a powerful tool to gain insights into the main magmatic processes occurring beneath a complex active volcano like Mt. Etna, therefore yielding important scientific advances, and providing interesting future opportunities for volcanological studies.

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