THE DECEMBER 2015 AND MAY 2016 ERUPTIONS AT MT. ETNA: INSIGHT ON VOLCANO PLUMBING SYSTEM STRUCTURE AND GEOMETRY BY A MULTIDISCIPLINARY APPROACH

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Introduction. The enhancement of our knowledge on volcano plumbing system structure and geometry, as well as on magma dynamics and timescales, requires a multidisciplinary approach (e.g. Pallister and McNutt, 2015).

Mt. Etna volcano is monitored by a multiparametric permanent network (Fig. 1), continuously producing streaming of variegated data (i.e. GPS, seismic, infrasonic, tiltmetric, video, thermal data and so on). Therefore, it can be considered a perfect natural laboratory to perform multidisciplinary studies (e.g. Cannata *et al*., 2015; Viccaro *et al*., 2016). In the period January 2011 - December 2014, the New South-East Crater (NSEC) produced more than 50 paroxysmal episodes, while the South-East Crater (SEC), Bocca Nuova (BN) and North-East Cater (NEC), experienced a mild activity. During 2015-2016, paroxysmal eruptions, affected the Voragine Crater (VOR), marking important changes in the eruptive behavior of Mt. Etna. In particular, during 3-5 December four powerful paroxysmal eruptions with columns up to 10-14 km asl took place at VOR. Again, on 18 and 19 May 2016 two lava fountain episodes occurred at VOR, accompanied by the emplacement of short-living lava flows (Corsaro *et al.*, 2017).

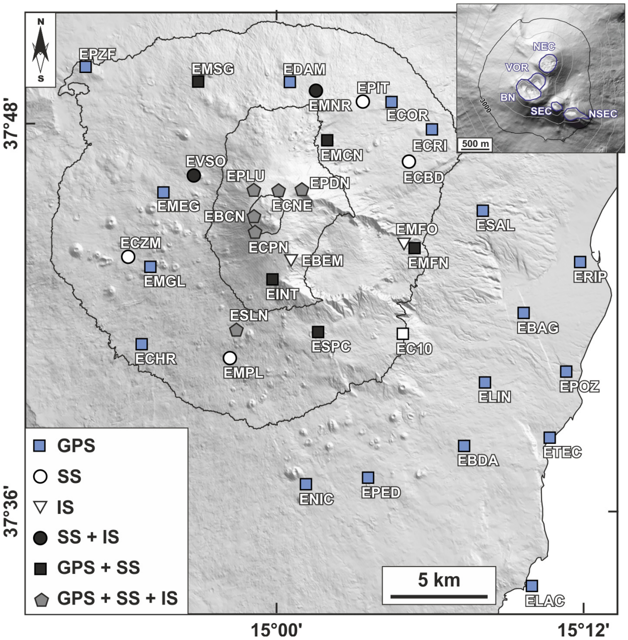

Fig. 1 - Map of Mount Etna volcano with the location of the seismic (SS), infrasound (IS) and geodetic (GPS) stations. Note that in the upper portion of the volcano, many of the stations are co-located (see the map legend). The inset shows a zoom.

Here, we have integrated ground deformation, seismic, infrasonic and petrological data, collected during June 2015 - August 2016 to investigate the volcano internal processes that led to these VOR's eruptions, casting lights on the modern Etna plumbing system structure and dynamics.

Data analysis. *Geodetic data.* Raw data collected from the permanent GPS network and spanning the 1 June 2015 - 31 August 2016 interval were analyzed by using the GAMIT/GLOBK software and adopting the methodology described in Gonzalez and Palano (2014). By analyzing the daily baseline changes for some selected sites crossing the summit area, we recognized four major ground deformation stages, defining two inflation/deflation cycles. Modelling of each recognized stage allowed us to infer the presence of a magmatic reservoir located at a depth of ~5.5 km.

Seismic and infrasonic data. The following parameters were investigated: i) variation over time of amplitude and source location of volcanic tremor; ii) daily occurrence rate and amplitudes of LP events; iii) daily number of infrasonic events located on each summit crater.

The centroids of volcanic tremor were located at depth ranging from the sea level up to the volcano summit, while the infrasonic sources coincided with VOR, NSEC and NEC. Furthermore, on the basis of the evolution in time of volcanic tremor, LP and infrasonic events, variations in the state of the feeding system were inferred. In particular, increases in amplitude of both volcanic tremor and LP events were observed at the same time as inflation cycles, defined by GPS data, suggesting pressurization phenomena of the upper portion of plumbing system, as already observed during 2013 (Cannata *et al.*, 2015).

Petrological data. Air-quenched rheomorphic lava and tephra samples were taken at the end of each paroxysmal eruption occurred at VOR (Fig. 1). They were investigated for whole rock major and trace elements, together with textural and in situ compositions of plagioclase and olivine crystals. Volcanic rocks erupted during the activity of December 2015 and May 2016 at VOR are porphyritic K-trachybasalts with composition very similar in terms of major and trace elements to the products erupted at NSEC during the 2011-2013 paroxysmal eruptions (Giuffrida and Viccaro, 2017). Textural and compositional characteristics of the observed mineral phases resemble those of crystals previously emitted in historical and recent eruptions at Mt. Etna, particularly during the 2011-2013 activity at NSEC (e.g. Giuffrida and Viccaro, 2017). Plagioclase crystals in lava rocks emitted at VOR show at least 5 main textural types: a) oscillatory zoning (Type 1); b) pervasive dissolution/resorption textures (Type 2); rare patchy textures (Type 3); c) coarse-sieve textures at the plagioclase core (Type 4); d) sieve textures at the crystal rim (Type 5). Olivine crystals found in lavas and tephra emitted at VOR exhibit various types of zoning from core to rim as other recent crystals of the 2011-2013 period (Giuffrida and Viccaro, 2017). Based on the olivine core composition, we have grouped into five olivine populations (OP) the recognized crystal types: OP1) coresat Fo83-84; OP2) Fo80-82; OP3) Fo78; OP4) Fo75-76; OP5) Fo70-73.

Discussion and concluding remarks. The integration of ground deformation, seismic and infrasonic data allows reconstructing the magma dynamics within the plumbing system from a few km bsl up to the shallowest portions, corresponding with the summit craters. Modelling of ground deformation for each recognized stage allowed us to infer the presence of a magmatic reservoir located at a depth of ~5.5 km bsl. Such a reservoir can be considered as a permanent zone of magma storage at Mt. Etna given its recurrent activity over the last decade (see Viccaro

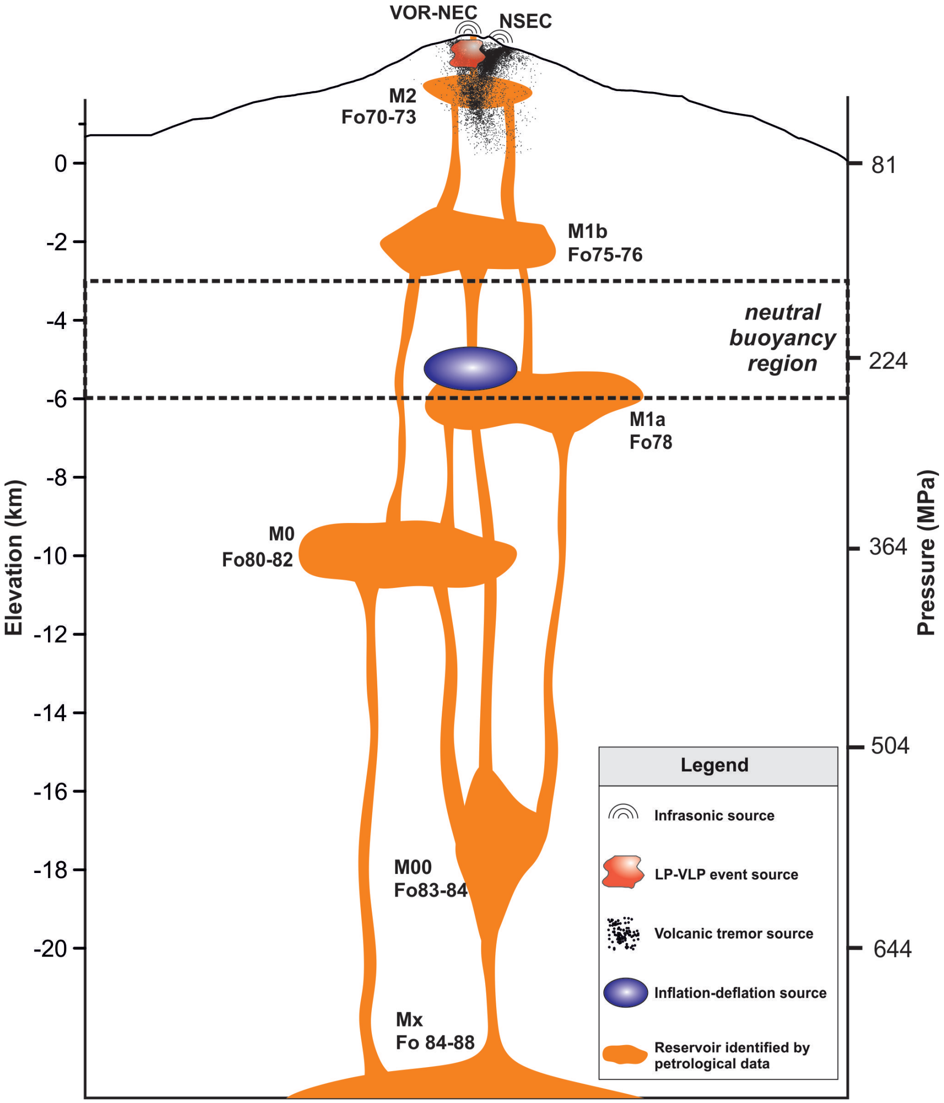

Fig. 2 - Simplified sketch model of the different portions of Mt. Etna plumbing system, highlighted by geophysical and petrological data.

et al., 2016 and reference therein for details). We interpreted this reservoir as the main magma chamber feeding both the December 2015 and May 2016 volcanic activity that involved three of the summit craters (VOR, NSEC and NEC). Volcanic tremor sources were located below the summit craters at depth ranging from ~1 to 3 km asl. Most of the shallowest centroid locations (~3 km asl) fall within VOR/BN and NSEC areas, and are associated with degassing and eruptive activities of these craters, while the deeper locations (down to 1 km asl) are likely to be related to magma migration in this portion of plumbing system. Infrasonic data provided insights into the shallowest portions of the plumbing system, corresponding with the degassing/eruptive vents, and their variations over time (Cannata *et al.*, 2013). The infrasonic sources active during the investigated period were NSEC, NEC and VOR. The infrasound emission from NSEC accompanied only Strombolian activity and lava fountains, while infrasonic activity of NEC and VOR was associated with both explosive eruptions and simple degassing.

The compositional and textural observations for plagioclase crystals of the 2015-2016 activity at Mt. Etna have provided preliminary evidence that crystals experienced complex and variegate histories from nucleation to eruption, as crystals show a combination of growth and resorption features reflecting changing chemical/physical conditions (fast decompression, recharge, etc.) of the magmatic system. Chemical zoning of olivine crystals also gives us the opportunity to constrain timescales of magmatic processes before the eruptions at VOR. Combining geochemical data with thermodynamic modeling, we fixed 5 main magma environments, distributed across a wide pressure range (from >650 to 30 MPa), which were variously reactivated during the eruptive episodes occurred at VOR. Routes of connection between these different environments and processes of intrusion and mixing Etnean magmas underwent during ascent have been also inferred through the chemical zoning observed at the olivine rims, i.e. the reverse zoning which indicate that crystals were involved in hybrid magmas originated by mafic recharge and mixing, and the normal zoning that are expression of magma transfer and subsequent diffusive relaxation of the olivine zoning after intrusion into a more differentiated melt. Time constraints to magma dynamics preceding eruptions of December 2015 and May 2016 at VOR have been also derived modelling the diffusive relaxation through time of these olivine normal and reverse zoning patterns, which are both the expression of changed initial thermodynamic conditions. The spectrum of timescales determined by diffusion modelling covers a time span from a few days up to about 8 months, with the majority of the recorded timescales confined within 3 months before eruption.

In conclusion, the integrated analysis of geodetic, seismic, infrasonic and petrological data proved a powerful tool to investigate the volcano structure and dynamics. In particular, a multilayered plumbing system was highlighted, with a complex spatial and temporal history of magma transfer and recharge beneath the volcano (Fig. 2).

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