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Quantitative assessment of magmatic refill and overpressure in crustal reservoirs by monitoring He isotope composition from volcanic gases: the case of Mt Etna (Italy)

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There is agreement in recognizing episodes of magma injection into crustal chambers as main triggers of eruptive activity of volcanoes (Caricchi et al., 2014). These events cause in fact a buildup of the internal pressure in magma chamber, which in turn controls outpouring magma amount, possible failure of wall-rocks, dike opening, up to a potential eruption. Assessment of the time-dependent pressurization while occurring in chamber is therefore challenging aim of current volcanological research. Recent advancements in estimating the time-dependent pressurization as long as occurring in chamber come from inverse modeling of ground deformation data, which does not however calculate internal evolution of the magma reservoir (Gregg et al., 2013; Cannavò et al., 2015). On the other hand, the geochemistry of volcanic gases has basically addressed to the pressure(depth) of gas exsolution so far (Caracausi et al., 2003; Aiuppa et al., 2007; Paonita et al., 2012).

We developed an pioneering tool that computes the changes of $^{3}He/^{4}He$ isotope ratio of volcanic gases with respect to a background, as a function of the time-dependent outflow of volatiles from a chamber subjected to evolution of internal pressure through an injection event. Our approach postulates a low-$^{3}He/^{4}He$ gas endmember coming from resident magmas stored in crust, that mixes with a high-$^{3}He/^{4}He$ gas endmember from deep parental magmas refilling the deep chamber. We couple a mass balance between the two gas endmembers to a physical model of the magma chamber. When a deep input pressurizes the chamber, the latter releases large amounts of the high-$^{3}He/^{4}He$ gas endmember, so as to change $^{3}He/^{4}He$ of discharged volcanic gases.

We applied the model to the long-term series of He isotope ratios from geochemical monitoring of some peripheral gas emissions at the base of Mt Etna, fed by magmatic degassing occurring at 200-400 MPa (Paonita et al., 2012). The isotope ratios have in fact displayed phases of increase occurred at all the sampled emissions some months before the onset of eruptions, due to deep magma recharges. This behaviour has been systematic for all the main eruptive phases occurred at Mt Etna since 2001. For most of the events, we quantitatively estimated the rate of magmatic refill during the pre-eruptive recharges of the system, as well as the growth of the overpressure in the deep chamber. Failure of the wall rocks and dike opening is also explained in the case of 2001 eruption, because chamber overpressure overcame the yield strength of rocks.

The results suggest that key parameters as the rate of magma inflow and the volume change in deep chamber can be estimated prior to impending eruptions and directly compared to inferences from geodetic signals.