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# The geochemical “crises” at La Fossa crater fumaroles of Vulcano Island (Italy): inferences on the dynamics, structure, and compositions of the magmatic system

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As frequently observed in closed-conduit volcanoes, the fumarolic field of La Fossa crater at Vulcano Islands experiences episodes of rapid and remarkable changes in its geochemical features (referred as “crises”) that normally last no more than a few months. Well documented episodes in literature occurred in 1988 and 1996, characterized by increase in the outlet temperature and steam output from fumarolic vents, marked variations in thermal groundwaters and diffuse $CO_2$ emissions from soils, nevertheless their meaning remains widely debated.

Here we report the chemical and isotopic (C, H, O, and He) compositions of the fumarolic fluids from La Fossa crater in the period 1999-2010. Consistent with records above, our data show that the geochemical features of the fumarole system have experienced several “crises” occurred from November 2004 to January 2005, from October 2005 to January 2006, and from October to November 2009, each lasting no more than a few months. Typical signatures of these short-term anomalies are large increments in $CO_2$, $N_2$, and He concentrations, coupled to increased $^{13}C/^{12}C$ isotopic ratios. Within a model of fumarolic fluids based on mixing between hydrothermal and magmatic endmembers, we have developed a novel approach to constrain chemical ($He/CO_2$ and $N_2/He$) and isotopic ($^{13}C/^{12}C$, D/H, and $^3He/^4He$) ratios of the magmatic endmember during the short-term anomalies. Although much of the geochemical variability in fumaroles results from changes in mixing proportions, the magmatic fluid unquestionably shows significant variations in time. The magmatic $He/CO_2$, $N_2/He$, $^{13}C/^{12}C$, and $^3He/^4He$ values throughout 1988–1996 differed from those feeding the anomaly at the end of 2004. Early clues of the new magmatic fluid appeared in 1998-1999, far from any short-term anomaly, whereas new and old magmatic fluids coexisted after 2004. We quantitatively prove that the detected geochemical changes are consistent with the degassing path of a magma having a latitic composition, and suggest the presence of two magma ponding levels at slightly different pressures, where bubble-melt decoupling can occur. The different He-isotope compositions at these levels suggest low hydraulic connectivity typical of a complex reservoir with dike and sill structures. In this framework, the so-called crises at the fumaroles are probably due to the evolving conditions in the magmatic system, such as gas buildup at the top of magma batches followed by massive discharge, activation of new degassing levels due to reorganization of the magma system, and its interplay with the stress field. These processes probably start years before a crisis. Far from crises, geochemical variations with specific signatures can suggest the onset of changes and reorganization in the magma system, and hence these phases that are apparently “not anomalous” should be evaluated for their implications in volcanic surveillance. Such a scenario explains the observed increases in both fumarole output and shallow high-frequency seismicity (due to increased pore pressure) during the anomalies, while being consistent with the concomitant absence of any deep seismicity or ground deformation.