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Helium isotopes decipher paroxysmal eruptions inducing caldera collapse

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Among volatiles, helium (He) is a key tracer to characterize Earth's interior reservoirs and track magmatic dynamics due to the primordial origin of 3He with respect to 4He. In addition, the chemical inertness of helium favours the comparison of superficial gases with typical magma-mantle signatures constrained by fluid inclusions (FI) entrapped in minerals. This is crucial for constraining the magmatic signature that we must expect during volcano monitoring in proximity of an unrest phase. In this respect, fast timescale enrichment in primordial helium (3He) have been recently detected in superficial volcanic gases of a few volcanic systems worldwide (Stromboli, Turrialba, Ontake), being due to either a greater contribution of magmatic fluids with respect to crustal ones or the arrival of fresh undegassed magma. Most of these studies have been carried out in subduction-related settings, where long quiescent periods and/or the emission of lavas generally free of gas-rich mafic minerals are common. Despite the potential use of 3He/4He to monitor volcano-tectonic unrest, it remains challenging its synchronous study in both FI and superficial gases for better constraining ongoing dynamics in a volcano plumbing system.

Here, we show the results of this novel approach at Piton de la Fournaise (PdF) volcano, in a hotspot context, where timescale fluctuations of 3He/4He in response to the eruptive activity have never been investigated before. This volcano is characterized by frequent eruptions since at least the 18th century and the emission of basalts containing gas-rich mafic minerals favouring such investigation. We highlight synchronous variations of 3He/4He in surface gases and FI during the last decades of eruptive activity at PdF. The range of 3He/4He values measured during this time lapse (12.5 – 14.4 Ra) overlaps that previously reported during the whole story of the island, with no noticeable relation with strontium (Sr) isotopes. We also document in FI fast 3He/4He fluctuations during the same eruption (August 2015), which are closely related to syn-eruptive magma dynamics change.

Unusual highest 3He/4He signatures (up to 14.4 Ra) were found in magmatic fluids that fed the two most recent caldera collapse eruptions at PdF in 1931 and 2007. We argue that this enrichment in 3He mostly reflects a greater contribution of magmatic fluids from an undegassed component of the mantle plume. This enrichment can fastly footprint superficial gases or be trapped in FI during magma crystallisation. On the contrary, more frequent low 3He/4He signatures (down to 12.5 Ra) are characteristic of "classical" eruptive activity at PdF. They may track the contribution of magmatic fluids from an old degassed buoyancy component of the mantle plume that generates "steady-state" conditions at PdF by gas flushing and/or melt homogenisation.

Our results suggest that the eruptive activity at PdF may respond to fast mantle dynamics change. They emphasize that helium isotopes in volcanic gases may provide early warnings to identify magmatic fluids arrival triggering caldera collapse events. This study open exciting prospects for the monitoring of such paroxysmal eruptive activity as recently documented at PdF (2007) and Kilauea (2018).