Piton de la Fournaise is a basaltic hot spot volcano located in the southeast of La Réunion Island (Indian Ocean). Piton de la Fournaise first erupted about 500,000 years ago. Its volcanic activity is characterized by frequent effusive eruptions (with emissions of lava fountains and lava flows) that occur on average twice a year since 1998. More rarely, larger explosive eruptions (with blocks covering the summit area and ash emissions that can disperse over long distances) have happened in the past with a centennial recurrence rate. Most of the current eruptive activity (97% during the last 300 years) occurs from vents inside the Enclos Fouqué caldera. A few eruptions, however, have occurred from vents outside the caldera (most recently in 1977, 1986, and 1998).

Since late 1979, the activity of Piton de la Fournaise is monitored by the Piton de la Fournaise Volcanological Observatory (Observatoire Volcanologique du Piton de la Fournaise - OVPF), from Institut de Physique du Globe de Paris (IPGP).

### Seismicity

In September 2018, the OVPF recorded at Piton de la Fournaise:

- 1127 shallow volcano-tectonic earthquakes (0 to 2 km depth) below the summit craters and the north flank;
- 1 deep earthquake (>2 km depth);
- 89 rockfalls (inside the Cratère Dolomieu or along the cliff of the Enclos Fouqué caldera).

**Figure 1:** Daily number of shallow volcano-tectonic earthquakes recorded in September 2018 (© OVPF-IPGP).

**Figure 2:** Location map (epicentres) and North-South and East-West cross-sections (hypocentres) of earthquakes Piton de la Fournaise as recorded by OVPF-IPGP in September 2018. Only localizable earthquakes are shown on the map, while the observatory records more seismic events that are not localizable due to their low magnitude (© OVPF-IPGP).

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**Volcano Alert level: Alert 2-2**

(since September 15 – in progress)

From 1 to 15 September 02h30 (local time): Vigilance
From 15 (02h30) to 15 (04h25) September: Alert 1

*(see table in appendix)*
In September 2018, the volcano-tectonic activity below the summit of Piton de la Fournaise has been mainly characterized by the September 14 seismic crisis preceding the September 15, 2018 eruption (with 935 and 122 earthquakes on September 14 and 15, respectively; Figures 1 and 2). From September 1 to 7, the seismicity remained relatively low with only 11 shallow volcano-tectonic earthquakes recorded below the summit. A slight increase was then recorded between September 8 and 13 (35 earthquakes) with a peak on September 8 (15 earthquakes).

Upon the onset of the September 15 eruption, 14 shallow volcano-tectonic earthquakes were recorded on September 16, followed by a mean of 3 earthquakes per day until September 23. Between September 24 and 30 only two shallow events was detected.

Only two deep earthquakes occurred during the eruption (which is still on-going as of the time of writing). They happened on September 21, at a depth of 2.6km below the eastern flank of the volcano (Figure 2), and on September 30 (not locatable).

**Deformation**

Between September 1 and 14, the OVPF deformation network recorded the renewal of a slight summit inflation (< 1cm) (Figures 3 and 4). This inflation phase is thought to be linked to the pressurisation of the shallow magma reservoir located at ~1.5-2 km depth.

This slow inflation was interrupted by the strong ground deformation linked to magma propagation during the intrusive crisis preceding the September 15, 2018 eruption (Figure 3, Appendix B).

After the onset of the eruption, a slight deflation of the edifice was recorded, linked to the magma transfer from the magma storage area below the summit to the eruptive site. Since September 18, no significant deformation is observed, even if a subtle renew of inflation was detected at the end of the month.

* Glossary: The summit GPS signals indicate the influence of a shallow pressure source below the volcano, while distant GPS signals indicate the influence of a deep pressure source below the volcano. Inflation usually means pressurization; and conversely deflation usually means depressurization.

Figure 3: Illustration of the deformation in September 2018 (red shaded areas represent the eruptive periods). The time series plots show the distance changes between pairs of GPS stations crossing the Dolomieu crater, the terminal cone and the Enclos Fouqué caldera, from the north to the south (see location in Figure 5). Increasing distances (or baseline elongation) indicate volcano inflation, while decreasing distances (or baseline contraction) show an edifice deflation (© OVPF-IPGP).

Figure 4: Illustration of the deformation over the last twelve months (red shaded areas represent the eruptive periods). The time series plots show the distance changes between pairs of GPS stations crossing the Dolomieu crater, the terminal cone and the Enclos Fouqué caldera, from the north to the south (see location in Figure 5). Increasing distances (or baseline elongation) indicate volcano inflation, while decreasing distances (or baseline contraction) show an edifice deflation (© OVPF-IPGP).
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Gas geochemistry

**CO₂ concentration in the soil**

*In the near field:*
. from September 1 to 12 (in continuation of the trend observed since August 19): decrease in the CO₂ concentration in the soil,
. from September 12 to 20 (i.e. 3 days before the eruption and during the first days of the eruption): increase in the CO₂ concentration in the soil,
. from September 20 to 27: fluctuations in the CO₂ concentration in the soil accompanied the overall decrease in eruption intensity and the transition from lava flow activity at the surface towards the development of lava tube activity (Figure 6).

* Glossary: CO₂ is the first gas to be released from deep magma (from the mantle), so its detection in the far field often means a deep rise of magma. Its near-field evolution may be related to magmatic transfer in the shallowest part of the feeding system (< 2-4 km below the surface).

**Summit fumaroles composition by MultiGas method**

The OVPF MultiGas station that is located at the summit of the volcano, recorded the same trends as the soil CO₂ station located close to the “Gîte du volcan” (Figure 6), this means specifically:
. from September 1 to 12 (in continuation of the trend observed since August 19): decrease in the CO₂ concentration in the summit emissions,
. from September 12 to 20 (i.e. 3 days before the eruption and during the first days of the eruption): increase in the CO₂ concentration of the summit emissions,
. from September 20 to 27: fluctuations in the CO₂ concentration in the soil accompanied the overall decrease in eruption intensity and the transition from lava flow activity at the surface towards the development of lava tube activity (Figure 6).

* Glossary: The MultiGas method allows measuring the concentrations of H₂O, H₂S, SO₂ and CO₂ in the atmosphere at the summit of the Piton de la Fournaise volcano. Magmatic transfer in the Piton de la Fournaise feeding system can result in an increase in SO₂ concentrations and C / S ratio (carbon / sulfur).

**SO₂ flux in the air by DOAS method**

The NOVAC stations have detected the eruption plume (since September 15) and the decline in SO₂ flux following September 20 (Figure 7).

* Glossary: During rest periods, SO₂ flux at Piton de la Fournaise is below the detection threshold. The SO₂ flux may increase during magma transfer in the shallowest part of the feeding system. During eruptions, it is directly proportional to the amount of lava emitted at the surface.
The month of September 2018 was marked by an eruption that started on September 15 on the south-southwest flank of the terminal cone. This eruption is still on-going at the time of writing (see Appendix B for more detail).

**Summary**

The resumption of the edifice inflation and a low seismicity in early September 2018, which we interpret as a sign of pressurization of the shallow magma reservoir, were linked to a magma transfer from the deep zones towards this reservoir, as evidenced by the decrease in the CO$_2$ concentration (both in the soil and in the summit emissions). This refilling of the shallow reservoir and its pressurization led to the eruption of September 15, which still on-going at the time of this bulletin report.

**Phenomenology**

The month of September 2018 was marked by an eruption that started on September 15 on the south-southwest flank of the terminal cone. This eruption is still on-going at the time of writing (see Appendix B for more detail).
Eruptive precursors

In the long-term:
The eruption that started on September 15, 2018 was preceded by about two weeks of edifice inflation, i.e. a sign of shallow reservoir pressurization (at 1.5-2 km depth) (Figures 3 and 4). During this period, the seismicity remained low with only one peak of seismicity on September 8 (15 earthquakes) before significantly increasing over the course of September 14.

In general, eruptions of the Piton de la Fournaise volcano often occur after long periods of deep recharge of the magmatic feeding system. The September 15, 2018 eruption is part of a phase of deep magmatic refilling that intermittently continues since the resumption of activity in June 2014. The regular monitoring of CO₂ concentration in the soil suggests that these phases of deep magmatic refilling are accompanied by a gradual increase in CO₂ concentration in the soil along the volcano’s flank. A significant increase in CO₂ flux was recorded both in the soil and in the summit emissions (Summit MultiGas) between end of July and mid-August 2018 (Figure 6).

The magmatic transfer to shallower depths leads to the pressurization of the shallow magmatic system (and therefore to edifice inflation phases; Figures 3 and 4), and is accompanied by a decrease of the CO₂ concentration in the soil as observed between the end of August and early September (Figure 6).

In the short-term:
On September 14, 2018, 21h45 UTC (01h45 local time on September 15, Figure 8), a seismic crisis began, indicating that magma had started propagating towards the surface. A total of 995 shallow volcano-tectonic earthquakes (< 2 km depth) were recorded in less than 4 hours. This crisis was accompanied by rapid ground deformation (max: 24 cm; Figure 9).

The eruption

The eruption started between 04:25 (i.e. the beginning of the tremor recorded on the OVPF seismic stations) and 04:39 local time (i.e. the first lava emissions visible on the OVPF’s webcams; Figure 10). Initially, 5 en-echelon fissures opened on the south-southwest flank of the terminal cone (Figure 11), in close proximity to the Cratère Rivals, about 300 m downstream and in continuation of the April 27 – June 1 eruptive fissure.
During the first hours of the eruption, a time-averaged discharge rate of 22.7 and 44.7 m$^3$/s was estimated from satellite data acquired by the MIROVA platform (University of Turin).

The five eruptive fissures remained active simultaneously during the first hours of the eruption with lava fountains of ~30 m height.

Photogrammetric processing of aerial imagery allowed for the 3D reconstruction of the cone growth and its morphological features in high spatio-temporal resolution (Figure 12). While the cone was open towards the south until September 24, it completely closed to form a more or less circular feature thereafter. At the same time, lava flows started to form and travel through lava tubes feeding outbreaks at 150-200 m downstream of the cone (Figure 13).

**Figure 10:** View on the eruptive site on September 15, 2018 at 04h39 local time (00h39 UTC) from the Piton de Bert webcam (©OVPF/IPGP).

**Figure 11:** Photograph of the eruptive vents on September 15, 11h20 local time (© OVPF/IPGP-ImazPress).

**Figure 12:** Morphological evolution of the cone between September 15 and 25, 2018 (© OVPF/IPGP).
Aerial and ground-based photographs were used to accurately map the evolution of the lava flow coverage over time. On September 18, the lavas had travelled as far as 2.8 km with an active flow front at about 500 m from the southern wall of the Enclos Fouqué caldera. As of September 21, lava flows had advanced 150 m eastward. Thereafter lava flow progression had slowed down as a result of the development of lava tubes, which contributed in the vertical growth of the lava field downstream of the cone (Figure 14).

Despite some fluctuations and the usual decrease in intensity following the first hours of the eruption, the intensity of the volcanic tremor (which is an indicator of the eruptive intensity at the surface) remained relatively stable between September 16 and 30 (i.e. the time of writing of this bulletin report; Figure 15). During the same period, no significant deformation was observed, even if a subtle renewal of inflation was detected at the end of the month.

First summary

At the time of writing, the eruption is still on-going, the continuation of this eruption will therefore be discussed in the next monthly bulletin.
Seismic activity is recorded off shore the island of Mayotte since the beginning of May 2018. These earthquakes form a swarm located 50 to 60 km east of the coast of Mayotte. The majority of these earthquakes are of low magnitude, but several events of moderate magnitude (maximum 5.9) were felt by the population and damaged a few buildings. Since July the seismic activity is weaker with only a few events felt by the population.

More information:

- Dedicated webpage on the IPGP website: http://www.ipgp.fr/fr/essaim-simique-a-lest-de-mayotte-mai-juin-2018

- BRGM website: www.ipgp.fr/fr/essaim-simique-a-lest-de-mayotte-mai-juin-2018


- BCSF website: http://www.franceseisme.fr/

- “Préfecture de Mayotte” website: http://www.mayotte.pref.gouv.fr/

On September 28, 2018, 23h51 local time (19h51 UTC), an earthquake was felt by inhabitants of the island.

This earthquake was recorded by the seismometers of the Piton de la Fournaise Volcanological Observatory (OVPF). The earthquake was located at 12 km below sea level in the sector of "Maido" (to the north-west of the island; Figure 16). Its magnitude was measured at 1.8 on the Richter scale.

Events that are felt by the population are recorded several times a year.

This event was isolated and of tectonic origin.
D - Appendix

Definition of Volcanic Alert Levels for Piton de la Fournaise
from: dispositif ORSEC974 – D.S « Volcan du Piton de la Fournaise »
Emergency plan set up by the department responsible for the protection of the population in the event of unrest or activity of the Piton de la Fournaise

• "Vigilance": possible eruption in medium term (a few days or weeks) or presence of risks on the sector (rockfalls, increase of gas emissions, still hot lava flows...).
Access to the Enclos Fouqué caldera and to the summit volcano are allowed with restrictions.

• "Alert 1": probable or imminent.
Access to the Enclos Fouqué caldera and to the summit are closed and prohibited.

• "Alert 2": ongoing eruption.
Alert 2-1: ongoing eruption in the Dolomieu crater.
Alert 2-2: ongoing eruption inside the Enclos Fouqué caldera.
Alert 2-3: ongoing eruption outside the Enclos Fouqué caldera.
Access to the Enclos Fouqué caldera and to the summit are closed and prohibited.

• "Sauvegarde": end of eruption or eruption stabilized.
Evaluation of a partial reopening of the Enclos Fouqué caldera access.
Thank you to organizations, communities and associations for publicly posting this report for the widest dissemination.


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