Monthly bulletin of the Piton de la Fournaise
Volcanological Observatory

A - Piton de la Fournaise activity

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). Such eruption can potentially threaten communities.

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), which belongs to the Institut de Physique du Globe de Paris (IPGP).

Volcano Alert level: Alert 2-2 (since February 19, 2019)

Seismicity

In February 2019, the OVPF recorded at Piton de la Fournaise:

- 740 shallow volcano-tectonic earthquakes (0 to 2 km depth) below the summit craters;
- 521 deep earthquakes (>2 km depth);
- 101 rockfalls (inside the Cratère Dolomieu or along the cliff of the Enclos Fouqué caldera).

In February 2019, the volcano-tectonic activity below Piton de la Fournaise was mainly characterized by three seismic crises (February 16, 18 and 19) preceding an intrusion (16) and two surface eruptive phases (18 and 19, see section B for more details) with 379 and 208 earthquakes on February 16 and 18, and 511 deep earthquakes under the east flank (at sea level, about 2.5 km deep) on February 19, respectively (Figures 1 and 2).

These seismic crises were preceded by a slight renew of summit seismicity in early February (1-3 earthquakes per day), which intensified since February 11 (with a peak of 29 earthquakes on February 14).

The first seismic crisis of February 16 (started at 3:21 pm local time), accompanied by deformation, did not lead to surface activity but was the sign of a first magma intrusion towards the surface. Following this crisis, the seismicity remained high prefiguring the crisis of February 18 (09h16 local time). This...
second crisis accompanied by deformation much larger than those of February 16 (see next section) was followed, 32 minutes after its beginning, by the appearance of an eruptive tremor (9:48 am local time), synonymous with the arrival of magma close to the surface.

This first eruptive phase lasted 12 hours and 12 minutes on the eastern slope of the Dolomieu crater. Following the end of this eruptive phase, the seismicity persisted until the third seismic crisis (February 19 at 15h local time) with events located below the East flank (at sea level, about 2.5 km depth), highlighting the magma propagation under this flank. At 17:10 the eruptive tremor appeared again on the observatory recordings, but the first gas plumes and the first lava projections in surface were observed at 5:50 pm and 7:12 pm, respectively.

It should be noted that the third seismic crisis was not accompanied by deformation of the summit zone but only by deformation on the East flank, showing the magma propagation under this flank (see section B for more details).

After the beginning of the first eruptive phase (February 18), a slight edifice deflation was recorded due to the magma transfer from the reservoir under the summit area to the eruptive site (Figure 3). Since February 20, no significant deformation is observed.

Deformation

In early February 2019, the OVPF deformation measurement networks recorded the renewal of the summit inflation (about 1 cm of elongation of the summit zone in 15 days; 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 phase of inflation preceded the intrusion of February 16 and the two eruptive phases that started on February 18 and 19, respectively. The intrusion of February 16 was accompanied by very slight rapid deformation (<1cm). The most intense deformation (10 cm of elongation of the summit zone) was associated with the 2nd seismic crisis (February 18) which led to the first eruptive phase on the eastern slope of the Dolomieu crater.

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Gas geochemistry

**CO₂ concentration in the soil**

In the far field (Plaine des Cafres and Plaine des Palmistes sectors): increase in CO₂ concentrations in the soil since the end of January (Figure 6). The onset of the eruption (February 18) was marked by a sudden drop in CO₂ fluxes that have since stabilized.

In the near field (Gîte du Volcan): increases in CO₂ concentrations in the soil since December 2018. The concentrations remain high since the beginning of the eruption.

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

The NOVAC stations have detected the eruption plumes emitted during the eruptive stages started on February 18 and 19 (Figure 7).
The month of February 2019 was marked by an eruption that started on February 18 with the opening of 3 eruptive fissures on the external and eastern slope of the Dolomieu crater. The activity on these 3 fissures ceased after only 12 hours and 12 minutes, before resuming on February 19 on another fissure located further downstream on the East flank at 1800 m of elevation. Given the absence of deformation and seismicity on the summit zone during the seismic crisis preceding the second phase of activity, the preferred hypothesis is a continuity between these two events with only one and unique magma injection from the reservoir, leading first to the opening of fissures near the Dolomieu crater on February 18 and then a propagation eastward on February 19. This eruption is still ongoing at the time of writing (see Appendix B for more detail).

Summary

The resumption of the edifice inflation and a low seismicity in early February 2019, 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 increase in the CO$_2$ concentrations in the far-field soil (Plaine des Cafres and Plaine des Palmistes areas) since the end of January. This refilling of the shallow reservoir and its pressurization led to the eruption of February 18 whose activity ceased after 12 hours and 12 minutes before resuming on a new fissure located further downstream on the East flank on February 19; eruption still on-going at the time of writing.

* Glossary: During rest periods, SO$_2$ flux at Piton de la Fournaise is below the detection threshold. The SO$_2$ 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.
**Eruptive precursors**

*In the long-term:*  
The eruption that started on February 18, 2019 was preceded by 20 days of edifice inflation, i.e. a sign of shallow reservoir pressurization (at 1.5-2 km depth; Figure 8).

![Figure 8: Map of the ground displacements recorded between February 1 and 17, 2019 (© OVPF-IPGP).](image)

During this period, a slight summit seismicity renewed in early February (1-3 earthquakes per day) and intensified from February 11 and 15 (with a peak of 29 earthquakes on February 14).

In general, eruptions of the Piton de la Fournaise volcano often occur after long periods of deep recharge of the magmatic feeding system. This 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 end of January 2019 in the soil in far field (Figure 6).

*In the short-term:*  
On February 16, 2019, 11h21 UTC (15h21 local time, Figure 9a), a first seismic crisis began, indicating that magma had started propagating towards the surface. This crisis did not lead to an eruption but small (but signification) ground deformation (< 1 cm) show that magma propagated below the Dolomieu crater and stopped in depth. Following this crisis, the seismicity remained high prefiguring the crisis of February 18 (09h16 local time). This second crisis accompanied by deformation much larger than those of February 16 (see next section) was followed, 32 minutes after its beginning, by the appearance of an eruptive tremor (9:48 am local time), synonymous with the arrival of magma close to the surface.

This first eruptive phase lasted 12 hours and 12 minutes on the eastern slope of the Dolomieu crater. Following the end of this eruptive phase, the seismicity persisted until the third seismic crisis (February 19 at 15h local time) with events located below the East flank (at sea level, about 2.5 km depth), highlighting the magma propagation under this flank. At 17:10 the eruptive tremor appeared again on the observatory recordings, but the first gas plumes and the first lava projections in surface were observed at 5:50 pm and 7:12 pm, respectively.

![Figure 9a: Seismic signals recorded between 09h00 UTC (13h00 local time) and 14h59 UTC (18h59 local time) on February 16, 2019. For each hour (as indicated by the time step on the y-axis), the time is increasing to the right. Each red vertical bar represents an earthquake (© OVPF-IPGP).](image)

For each hour (as indicated by the time step on the y-axis), the time is increasing to the right. Each red vertical bar represents an earthquake. Note the appearance of the tremor starting at 05h48 UTC (09h48 local time). (© OVPF-IPGP).

![Figure 9b: Seismic signals recorded between 02h00 UTC (06h00 local time) and 07h59 UTC (11h59 local time) on February 18, 2019. For each hour (as indicated by the time step on the y-axis), the time is increasing to the right. Each red vertical bar represents an earthquake. Note the appearance of the tremor starting at 05h48 UTC (09h48 local time). (© OVPF-IPGP).](image)
Figure 9c: Seismic signals recorded between 09h00 UTC (13h00 local time) and 15h59 UTC (19h59 local time) on February 19, 2019. For each hour (as indicated by the time step on the y-axis), the time is increasing to the right. Each red vertical bar represents an earthquake. Note the appearance of the tremor starting at 13h00 UTC (19h00 local time). (© OVPF-IPGP).

Figure 10: Map of the ground displacements associated with the magma propagation from the shallow reservoir towards the surface leading to the February 18, 2019 eruption. The vectors represent the horizontal displacements (max=0.28 m), while the coloured circles represent the vertical displacements (cf. the colour bar on the right for the scale, max=0.27 m).

Figure 11: Slope variations (in microradians) recorded by the tiltmeters located in the Enclos Fouqué caldera. In blue: tilt variations recorded on February 18. In red: tilt variations recorded on February 19. The blue star represents the location of the pressure source on February 18, and the red one the pressure source on February 19 (© OVPF-IPGP).

The eruption

Given the absence of deformation and seismicity on the summit zone during the seismic crisis preceding the second phase of activity, the preferred hypothesis is a continuity between these two events with only one and unique magma injection from the reservoir, leading first to the opening of fissures near the Dolomieu crater on February 18 and then a propagation eastward on February 19.

The first eruptive stage began on February 18, 09h48 local time with the opening of 3 eruptive fissures on the external and eastern slope of the Dolomieu crater (Figure 12).

Figure 12: Fissures and lava flows map on February 18, 2019 deduced from aerial images (© OVPF/IPGP).
During the first hours of the eruption, a time-averaged discharge rate of 25 and 40 m³/s was estimated from satellite data acquired by the MIROVA (University of Turin) and HOTVOLC (OPGC - université d’Auvergne) platforms. This eruptive phase of short duration (12 hours and 12 minutes) was marked by the flood of the touristic path by lava flows over a distance of 150-200 m and the lost for the observatory of two benchmarks used during GPS campaigns.

The second eruptive stage began on February 19, 19h12 local time (first observations of lava flows in surface) with the opening of an eruptive fissure at 1800 m of elevation on the eastern flank (Figure 13).

Aerial and ground-based photographs were used to accurately map the evolution of the lava flow coverage over time. On February 28, the lavas had travelled as far as 2.2 km with a front at about 1200 m of elevation (Figure 13). Between February 22 and 28, the progression of the lava front was slow with 300 m in 6 days. On February 28, only the norther branch was active.

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 February 19 and March 1 (i.e. the time of writing of this bulletin report ; Figure 15). During the same period, no significant deformation was observed.

The NOVAC stations have detected the eruption plumes emitted during the eruptive stages started on February 18 and 19 (Figure 7).

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 on La Réunion and in the Indian Ocean basin

Seismicity

In February 2019, the OVPF recorded:
- 27 local earthquakes (below the island, mainly in the Piton des Neiges area, Figure 7);
- 9 regional earthquakes (in the Indian Ocean basin).

Figure 16: Location map (epicentres) and north-south and east-west cross-sections (hypocentres) of earthquakes below La Réunion Island as recorded by OVPF-IPGP in February 2019. 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).

Seismic crisis in Mayotte

Seismic activity is recorded off shore the island of Mayotte since the beginning of May 2018. These earthquakes form a swarm located 30 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 M5.9) were felt by the population and damaged a few buildings. Since July the seismic activity is weaker but remains with a few events felt by the population. The month of February was particularly active with notably 129 earthquakes of magnitude >= M3.5. Data from the Teria GPS network installed on Mayotte, and distributed by the RGP of the Institut Géographique National (IGN), and data from the Diego Suarez station in Madagascar were obtained by LACy (Université de la Réunion) under the INTERREG-5 Indian Ocean 2014-2020 project "ReNooRisk Cyclones and Climate Change", funded by Europe, the Region of La Réunion and the State. Post-processing of this data by OVPF-IPGP (©OVPF-IPGP).

Figure 17: Displacements (in m) recorded on 4 GPS stations located in Mayotte (BDRL, GAMO, KAVE, MAYG) and one station north of Madagascar to Diego Suarez (DSUA), on the east (top), north (middle) and vertical (bottom) components, between April 2018 and January 2019. The data from the 4 Mayotte stations come from the Teria network and are distributed by the RGP of the Institut Géographique National (IGN), and data from the Diego Suarez station in Madagascar were obtained by LACy (Université de la Réunion) under the INTERREG-5 Indian Ocean 2014-2020 project "ReNooRisk Cyclones and Climate Change", funded by Europe, the Region of La Réunion and the State. Post-processing of this data by OVPF-IPGP (©OVPF-IPGP).

deforation (via the Gipsy software), as well as the source at its origin. Thus for the last 3 months, the source of "depressurization" at the origin of these displacements could be located about thirty km east of Mayotte and about 35-45 km deep (Figure 19). This suggests that fluid transfers in the crust are still on-going.
Figure 18: Ground displacements recorded around the seismic swarm on the GPS stations of Mayotte and Madagascar in February 2019. The data from the 4 Mayotte stations come from the Teria network and are distributed by the RGP of the Institut Géographique National (IGN), and data from the Diego Suarez station in Madagascar were obtained by LACy (Université de la Réunion) under the INTERREG-5 Indian Ocean 2014-2020 project “ReNonRiC Cyclones and Climate Change”, funded by Europe, the Region of La Réunion and the State. Post-processing of this data by OVPF-IPGP (©OVPF-IPGP).

Figure 19: Location of the source (best model resulting from a "Mogi" source) at the origin of the displacements recorded during the last 3 months on the GPS stations of Mayotte (© F. Beauducel (IPGP/IRD) and OVPF-IPGP).

For a better follow-up of this crisis the CNRS launches a campaign of observation in Mayotte, in which the Institut de Physique du Globe de Paris and in particular the Observatoire Volcanologique du Piton de la Fournaise are involved. More information on this link:
http://www.cnrs.fr/fr/le-cnrs-lance-une-campagne-dobservation-de-lactivite-sismique-mayotte

More information:
- Dedicated webpage on the IPGP website:
  http://www.ipgp.fr/fr/essaim-sismique-a-est-de-mayotte-mai-juin-2018
- BRGM website:
  www.ipgp.fr/fr/essaim-sismique-a-est-de-mayotte-mai-juin-2018
- ENS website:
  http://volcano.terre.fr/mayotte-seismo-volcanic-crisis
- BCSF website:
  http://www.franceseisme.fr/
- "Préfecture de Mayotte" website:
  http://www.mayotte.pref.gouv.fr/
- GEOSCOPE website:
- NEIC / USGS website:
  https://earthquake.usgs.gov/earthquakes

March, 1 2019
OVPF-IPGP Director
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.

All information on the Piton de la Fournaise activity can be found on the OVPF-IPGP media:
- website (http://www.ipgp.fr/fr/ovpf/actualites-ovpf)
- Twitter (https://twitter.com/obsfournaise?lang=fr)
- Facebook (https://www.facebook.com/ObsVolcanoPitonFournaise/)

The information in this document may not be used without explicit reference.