Piton de la Fournaise is a basaltic hot spot volcano located in the southeast of La Réunion Island (Indian Ocean). The volcano 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 eruptions 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: Vigilance
(since February 21, 2020)

November 1, 2019 (7h) to February 10, 2020 (12h): Vigilance
February 10, 2020 (12h) to February 10, 2020 (12h): Alert 1
February 10, 2020 (12h) to February 17, 2020 (10h): Alert 2-2
February 17, 2020 (10h) to February 21, 2020 (7h): Sauvegarde

(cf. table in the appendix)
Seismicity

In February 2020, the OVPF recorded at Piton de La Fournaise:

- 249 shallow volcano-tectonic earthquakes (0 to 2 km depth) below the summit craters;
- 11 deep earthquakes (>2 km depth);
- 563 rockfalls (inside the Cratère Dolomieu or along the cliff of the Enclos Fouqué caldera and the Rivière de l’Est rempart).

![Figure 1: Number of shallow volcano-tectonic earthquakes recorded in February 2020 (top panel). Number of deep volcano-tectonic earthquakes recorded in February 2020 (bottom panel) (© OVPF-IPGP).](image1)

![Figure 2: Location map (epicenters) and north-south and east-west cross-sections (hypocenters) of earthquakes at Piton de la Fournaise as recorded by OVPF-IPGP in February 2020. Only localizable earthquakes are shown on the map, while the observatory records more seismic events that are not localizable due to their small magnitude (© OVPF-IPGP).](image2)
In February 2020, the volcano-tectonic activity below the summit of Piton de la Fournaise was predominated by the seismic crisis preceding the February 10-16, 2020 eruption (with 208 earthquakes in about 30 minutes between 10h27 and 10h57 local time on February 10; cf. Figures 1 and 2).

Following the strong seismic activity recorded during the first half of January 2020 (258 shallow volcano-tectonic earthquakes recorded below the summit craters between January 1 and 16, 2020), the seismicity was lower with an average of 1 earthquake per day between January 17 and 31. From February 1 to 9, about 4 earthquakes per day were recorded below the summit, and 10 earthquakes were recorded one day before the onset of the eruption.

The summit volcano-tectonic activity decreased after the end of the eruption, with only two shallow earthquakes recorded between February 17 and 29 (cf. Figure 1). However, 8 deep earthquakes (at > 2 km depth) were recorded between February 17 and 19 underneath the approximate location of Piton de Crac, and on the edge of the deformation field linked to the magma injection that fed the February 10-16 eruption (cf. Figure 10 in section B for the location of the ground deformation field).

**Deformation**

No significant inflation directly preceded the February 10-16, 2020 eruption. On the contrary, the inflation rate that had been observed between late December 2019 and January 18, 2020, had slowed down (cf. Figures 3 and 4). However, upon the end of the October 25-27, 2019 eruption, two significant phases of inflation occurred (one starting at the end of October until mid-November, and a second phase starting at the end of December until mid-January; cf. Figure 3). Those periods of inflation resulted in a cumulative distance elongation of max. 5 cm between GPS stations located at the base of the terminal cone, and about 4 cm between GPS stations located around the summit craters between October 28, 2019 and February 09, 2020 (i.e. one day before the onset of the February eruption).

![Record of ground deformation over the course of February 2020](image)

**Figure 3:** Record of ground deformation over the course of February 2020 (wherein the red bar marks the February 2020 eruption). The time series plots show the changes in distance between pairs of GPS stations located around the Dolomieu summit crater (reference: SNEG; top graph), the terminal cone (reference: FJAG; middle graph) and the Enclos Fouqué caldera (reference: PRAG; bottom graph), from north to south (see location in Figure 5). Increasing distances (or baseline elongation) indicate volcano inflation, while decreasing distances (or baseline contraction) reflect edifice deflation (© OVPF-IPGP).
The magma intrusion that led to the February 2020 eruption was accompanied by rapid inflation of about 20 cm recorded on permanent GPS stations located at the summit of the volcano and of max. 27 cm on the reiteration stations (cf. Figure 3, and Annex B for more detail).

Edifice inflation directly resumed after the end of the eruption at rates similar to those observed upon the end of the October 25-27, 2019 eruption (cf. Figures 3 and 4).

**Figure 4:** Record of ground deformation over the past six months (wherein red and green bars represent eruptions and intrusions, respectively). The time series plots show the changes in distance between pairs of GPS stations located around the Dolomieu summit crater (reference: SNEG; top graph), the terminal cone (reference: FJAG; middle graph) and the Enclos Fouqué caldera (reference: PRAG; bottom graph), from north to south (see location in Figure 5). Increasing distances (or baseline elongation) indicate volcano inflation, while decreasing distances (or baseline contraction) reflect edifice deflation (© OVPF-IPGP).
Gas geochemistry

**CO₂ concentration in the soil**

*In the far field (Plaine des Cafres and Plaine des Palmistes sectors)*: over the course of the year 2019, the soil CO₂ flux remained at low to intermediate levels on distal stations as compared to the signal obtained since the network became operational (corrected data in red on Figure 6).

The period following the eruption of October 25-27, 2019 was marked by a renewed increase of soil CO₂ flux (Figure 6). The last monthly update, marked by the eruption of February 10-16, 2020, indicates that the soil CO₂ flux is reaching the highest values since the network became operational.
Figure 6: Comparison between the normalized average of raw (in blue) and corrected (in red) soil CO₂ flux from distal stations (a) since October 2016 (last station set) and (b) over the course of one year. (© OVPF-IPGP).

* Glossary: CO₂ is the first gas to be released from deep magma (rising 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 obtained by the MultiGas method**

The MultiGas station is currently out of service.

* 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 the C/S ratio (carbon/sulfur). 

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

The NOVAC stations detected the eruption plume produced by the February 10-16 eruption (Figure 7).
Figure 7a: SO$_2$ flux in the air detected by the DOAS method on the "Piton de Bert" station in February 2020 (© OVPF-IPGP).

Figure 7b: SO$_2$ flux in the air detected by the DOAS method on the "Enclos 0" station in February 2020 (© OVPF-IPGP).

Figure 7c: SO$_2$ flux in the air detected by the DOAS method on the "Piton Partage" station in February 2020 (© OVPF-IPGP).

* 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.
Phenomenology

The month of February 2020 was marked by an eruption that occurred on the south and south-eastern slopes of the terminal cone. The eruption lasted 6.1 days, from February 10 and 16 (cf. Appendix B for more detail).

Summary

The new increase of soil CO$_2$ flux following the October 25-27 eruption, together with discontinuous edifice inflation and seismicity, are signs of a deep magma refilling and a pressurization of the shallow magma reservoir. This pressurization led to the February 10-16 eruption, which only partially drained the reservoir. Thus, edifice inflation resumed directly following the end of the February 2020 eruption.
Eruption precursors

In the long term:
The February 10-16, 2020 eruption was not directly preceded by significant eruption precursors, such as significant inflation and/or substantial increased seismicity levels; cf. Figures 1 and 3). Precursors were more evident throughout the first half of January, a time period that was characterized by continuous summit inflation (recorded since the end of December 2019), as well as increased levels of seismicity (including two seismic crises of short duration and low intensity that occurred on January 7 and 12). These increased signs of volcanis unrest are thought to be indicative of refilling and pressurization of the shallow magma reservoir that is located at about 2-2.5 km depth below the Bory and Dolomieu summit craters.

In general, eruptions of Piton de la Fournaise often occur after long periods of deep recharge of the magmatic feeding system. The February 10-16, 2020 eruption was part of a phase of deep magmatic refilling that intermittently continues since the resumption of activity in June 2014. In this respect, soil CO₂ flux increase-decrease cycles along the volcano’s flank are attributed to new inputs of volatile-rich magmatic fluids refilling the deepest part of the system (increase-phase) and the consecutive transfers towards shallower levels (decrease-phase). A significant increase in CO₂ flux was recorded upon the October 25-27 eruption, 2019, culminating in the highest recorded values since the network employment, which were recorded in February 2020 (Figure 6).

In the short term:
A seismic crisis started on February 10, at 10h27 local time (06h27 UTC, Figure 8). This was a sign that the roof of the shallow magma reservoir failed under the pressure, triggering magma propagation towards the surface. A total of 208 shallow volcano-tectonic earthquakes were recorded below the summit between 10h27 and 10h57 local time (between 06h27 and 06h57 UTC). This seismic crisis was accompanied by rapid surface inflation of about 20 cm (cf. Figures 9 and 10).

Figure 8: Seismic signals recorded between 04h00 UTC (08h00 local time) and 09h59 UTC (13h59 local time) on February 10, 2019. For each hour (as indicated by the time step on the y-axis), the time is increasing towards the right. Each red vertical bar represents an earthquake. Note the appearance of the tremor at 06h50 UTC (10h50 local time) (© OVPF-IPGP).
Figure 9: Map of the ground displacements associated with the magma propagation from the shallow reservoir towards the surface that led to the February 10-16, 2020 eruption. The vectors represent the horizontal displacements (max = 0.27 m), while the colored circles represent the vertical displacements (cf. the color bar on the right for the scale, max = 0.27 m). The white lines show the location of the eruptive fissures that opened on February 10 (© OVPF-IPGP).

Figure 10: Interferogram showing the deformation associated with the February 10-16 eruption at Piton de la Fournaise (© OVPF-IPGP). In addition to ground-based GNSS measurements of surface deformation, we also use a satellite-based technique that is referred to as differential Interferometric Synthetic Aperture Radar (dInSAR) in order to monitor patterns of surface inflation or deflation associated with subsurface magma movement. For this measurement, the satellite illuminates an area on the ground actively with an electromagnetic wave and collects the reflected signal from the ground. The comparison of two such measurements taken at different times but of the same area on the ground allows capturing deformation of the surface. A single interferogram (that is calculated from two repeat-pass satellite acquisitions) can be useful to detect faster and significant deformation. The above interferogram, for example, shows the line-of-sight (LOS) surface deformation associated with the February 10-16 2020 eruption of Piton de la Fournaise volcano. Each full color cycle of the interferogram corresponds to 27.8 mm of surface movement towards (red-yellow-blue) or away from (blue-yellow-red) the Sentinel-1 satellite. The black lines show the location of the eruptive fissures that opened on February 10 (©OVPF-IPGP).
The eruption

Volcanic tremor is a sign that magma is close to the surface. This signal appeared on the OVPF seismic monitoring network at around 06h50 UTC (10h50 local time; Figure 8) on February 10. The eruptive activity was characterized by the opening of fissures on the southern and southeastern flank of the terminal cone (Figures 9, 10, 11 and 12).

Figure 11: Location of eruptive fissures that opened on February 10 (photographs taken on February 19 after the end of the eruption) (©OVPF-IPGP).

Figure 12: Map of lava flows emitted during the February 10-16 eruption as derived from SAR satellite data by the OI2 plateform (Université Clermont Auvergne) (©OPGC-LMV).

The three most western fissures were active during the first hours of the eruption only.

The graph below shows the average amplitude of the signals recorded at 6 seismic stations near the eruptive site. The first amplitude peak corresponds to the seismic crisis. At ~06h50 UTC, a first eruptive fissure opened near the SNE station (indicated in blue color in Figure 13). A second fissure opened shortly after 7 am (UTC) in the southwest, near the DSO station (inindicated in grey color in Figure 13), and possibly two more fissures opened between 7h00 and 8h00 UTC. The effusive activity of the latter stopped quite abruptly at ~09h00 am UTC, and the activity resumed on the first fissure before decreasing again.
During the first overflight and 3 hours after the beginning of the eruption, only the lower fissure was visible (Figures 14). At that time, the activity focused at about 2290 m of elevation on the eastern flank of the central cone, where an eruptive cone had built; by that time the lower small fissures that had opened on February 10 on the eastern flank had been covered already by newer lava flows (Figure 15).

**Figure 13**: Average amplitude of the vertical component of 6 seismic stations located near the eruptive site on February 10 between 6h and 12h UTC. The signals are filtered between 0.5 and 1.5Hz and the average amplitude is calculated over one minute (©OVPF-IPGP).

**Figure 14**: Photographs taken on February 10 around 13h15 local time (©OVPF-IPGP).

**Figure 15**: Photographs taken on February 13 around 12h00 local time (©PGHM-SAG).
The lava flow path was modelled using DOWNFLOWGO (LMV-Clermont Auvergne University, Figure 16), which was communicated to the «Etat-Major de Zone et de Protection Civile de l'Océan Indien» for assisting the crisis response operations. Based on the assumption of a maximum mean effusion rate of ~10-15 m$^3$/s during the eruption (estimated by the HOTVOLC (LMV, OPGC, Clermont Auvergne University) and the MIROVA (University of Turin) platforms), this simulation suggested that the flow is likely to stop before reaching the Grandes Pentes area. The final map of lava flows shows that the lava front indeed stopped before entering this area (Figure 12).

![Figure 16: Numerical simulations of the lava flow inundation paths for the lower fissure (following the protocol described in Harris et al. 2019). The inundation area is computed for 10000 iterations from the initial vent location with vertical elevation noise of 2 m via the DOWNFLOW model (Favalli et al. 2005). Yellow to red lines represent the frequency of lava paths from low (yellow) to high (red). The line of steepest descent (LoSD) is shown in red. Green arrows represent the location at which the lava could extend along the LoSD for given effusion rates (numbers are in m$^3$/s) as computed using the FLOWGO model (Harris and Rowland 2001; Chevrel et al. 2018). Blue lines represent the contour of the lava flows on February 12 (©OPGC-LMV-OVPF-IPGP).](image)

References:

The eruption stopped on February, 16 2020 after a rapid decrease of the tremor (on February 15, 2020 around 14h local time), and the end of residual tremor recordings (that were left in the signals of the seismological stations closest to the eruption until 14:12 local time on February 16, 2020; cf. Figure 17).
Figure 17: Spectrogram showing the evolution of the seismic signal between February 15 and 16 (12h00 UTC) on the FLR seismic station that is located on the eastern flank of the central cone (© OVPF-IPGP).
C - Seismic activity on La Réunion and in the Indian Ocean basin

Seismicity

In February 2020, the OVPF recorded:

- 38 local earthquakes (below the island, mainly below the Piton des Neiges edifice, Figure 18);
- 2 regional earthquakes (in the Indian Ocean basin).

![Figure 18: Location map (epicenters) and north-south and east-west cross-sections (hypocenters) of earthquakes below La Réunion Island as recorded by OVPF-IPGP in February 2020. Only localizable earthquakes are shown on the map, while the observatory records more seismic events that are not localizable due to their small magnitude (© OVPF-IPGP).](image)

Seismic-volcano crisis in Mayotte

The « REseau de surveillance VOLcanologique et SIsmologique de MAyotte (REVOSIMA) » is the structure in charge of the volcano and seismic monitoring of Mayotte. IPGP operates this network through the Piton de la Fournaise Volcanological Observatory in La Réunion with the support of the BRGM regional office in Mayotte. REVOSIMA is supported by a scientific and technical partnership including Ifremer, CNRS, BRGM, IPGS and RENASS, IRD, IGN, ENS, Reunion University, Clermont Auvergne University, CNES, Météo France, and SHOM.

All information on the REVOSIMA and the activity in Mayotte can be found on the dedicated webpages:
- [http://www.ipgp.fr/fr/reseau-de-surveillance-volcanologique-sismologique-de-mayotte](http://www.ipgp.fr/fr/reseau-de-surveillance-volcanologique-sismologique-de-mayotte)
- [http://www.ipgp.fr/fr/actualites-reseau](http://www.ipgp.fr/fr/actualites-reseau)
- [https://www.facebook.com/ReseauVolcanoSismoMayotte/](https://www.facebook.com/ReseauVolcanoSismoMayotte/)

March, 3 2020
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.