Monthly report on the volcanic activity of *La Soufrière de Guadeloupe* and on the regional seismicity

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**Synopsis** - La Soufrière de Guadeloupe is an explosive-type active volcano that has experienced many magmatic and phreatic eruptions in the past. Since 1992, its seismic, fumarolic and thermal activity shows a fluctuating but generally increasing regime, which results in a strong activity of the hydrothermal system (circulation and interaction of gas, steam and water under pressure within the porous and fractured rock).

Since the beginning of 2018, we have remarked a cyclic process of deep magmatic gas injection at the base of the hydrothermal system, at a depth between 2 and 3 km below the summit. This generates a recurring process of heating and pressurisation of the hydrothermal system that results in: 1) disturbances in hydrothermal fluid circulation; 2) evolution in the activity of the summit fumaroles, one of which shows evidence of projections of hot and acid mud over a range of several metres; 3) an increase of seismic swarms of volcanic origins; 4) some volcanic earthquakes being felt by the surrounding population (four between February and April 2018) including the M4.1 on 27 April 2018, the strongest since 1976; 5) low-amplitude ground deformation limited to the La Soufrière dome, on the order of 3-7 mm/year, as well as the continued opening of summit fractures; 6) fluctuations in fumarolic gas flow rates emitted from an overpressured hydrothermal reservoir; 7) propagation of the ground thermal anomalies on the summit and dome of La Soufrière.

Though these phenomena incite the observatory to exert extra vigilance, they are currently not clearly accompanied by anomalies in other monitoring parameters related to a possible rise of magma. These could include, though not in every case the occurrence of increased deep and/or felt seismicity, large scale deformations, and sulphuric gas emissions at high temperature (> 150 °C).

On the basis of the observations recorded by the OVSG-IPGP during the month of January 2019 and summarised in this bulletin, and in accordance with the provisions laid down by the authorities, the current level of volcanic activity (see table in annex) remains:

**VIGILANCE (= YELLOW)**

The short-term probability of eruptive activity remains low. However, given the increase in seismic and fumarolic activity recorded since February 2018, a change of the volcano regime has been observed such that we can not exclude an intensification of phenomena in the future. As a result, the OVSG-IPGP is in a state of increased vigilance.

The gaseous emissions in the vicinity and leeward of the main summit fumaroles (in particular Cratère Sud, Cratère Tarissan and Gouffre 1956) have, since 1998, proven risks of irritation and burns (eyes, skin, respiratory tract).

Given the evolution described above and the other observations on the activity the OVSG-IPGP considers important to keep a distance of at least 50 m radius from the main centers of fumarolic gas emissions (Cratère Sud Sud, Cratère Sud central, Cratère Sud Nord, Napoleon Nord, Napoleon Est, Gouffre 1956, Gouffre Tarissan) as a precautionary measure.

Considering the evolution of the anomaly zone at the summit (with the ground heat propagation, the recrudescence of fumarolic activity, accompanied by the appearance in time of new centers of emission and projection of mud and fragments, the signs of the impact of sulfur and acid gases on the ground and on the vegetation) and therefore of a general increase in areas of instability, the Préfecture de Guadeloupe with the decree n°2019/001 CAB SIDPC of 14 January 2019 instituted regulated access to the top of the Soufrière volcano, based on the identification of a security perimeter and the prohibition of any unauthorized person crossing it.

### Volcano seismicity

During the month of January the observatory recorded **1230** earthquakes of volcanic origin, located mainly under and around the dome of Soufrière (Figure 1), between 0.1 and 3.9 km deep under the summit. A large part of the activity is grouped around two swarms, recorded from 8th January to 16th January (621 earthquakes) and from 18th January to 23rd January (501 earthquakes).

1227 of these earthquakes are of the volcano-tectonic type (so-called VT) and 3 of the long-period type or low-frequency (so-called LP). A large proportion of these VT earthquakes have a low frequency (or long-period, LP) component in the coda of the signals which is diagnostic of their "hybrid" type behaviour. This behaviour is characteristic of hydrofracturing processes generated by the migration of fluids into the volcano.

The aforementioned activity is typified by micro-earthquakes of weak magnitude (M < 1). VT earthquakes correspond to small-size rupturing of the volcano fractures. LP earthquakes are associated with pressurised fluid resonance phenomena (water, gas) in the fractures of the volcanic building.

The entire seismic activity released a total energy of the order of **4.7 MJ (4°)**. The energy released by the seismic activity of January 2019 represents < 0.01% of the seismic energy released during the last 12 months (Figure 2)
The recorded and very localised earthquakes testify to: 1) the typical dynamics of a highly-developed hydrothermal system, whose activity is marked by the interaction between the gases that rise from the depth and the water circulating in the shallow fractures; 2) releasing of tensional stresses that affect the deeper roots of the La Soufrière hydrothermal and magmatic system, which are related to the complexity of the numerous faults of tectonic origin that intersect the dome and the volcanic complex of Soufrière-Grande Découverte.

Figure 1. Location map (epicentres) and NS and EO sections showing the localization in depth (hypocentres) of volcanic earthquakes recorded and located by the OVSG-IPGP in January 2019 under la Soufrière dome and the volcanic complex around the dome (maximum depth shown: 10 km below sea level).

Figure 2. Semi-logarithmic diagram of seismic energy accumulated and released, on a daily basis, by volcanic activity during the last 12 months (since February 1st, 2018). The seismic energy released in this period is dominated by the end-April 2018 contribution.

Since early 2017 the OVSG-IPGP has improved its networks, which now acquire seismic data at unprecedented instrumental sensitivities. In conjunction with an improved data treatment, these changes allow for the detection of a greater number of earthquakes, especially those of very small magnitude. Nevertheless, since the beginning of 2018, the OVSG-IPGP has also recorded an increase in seismic activity. During the first half of the last year, such an increase culminated in the highly-energetic crisis recorded at the end of April (Figures 2 and 3). In addition, since 4th August 2018, OVSG-IPGP has recorded an increase in the number of very low energy seismic swarms (many earthquake events closely spaced in time). As of January 31st, 2019, the OVSG-IPGP has detected 13 swarms with a total of 14 seismic activity peaks of at least 50 earthquakes per day (Figure 3). This increase recorded since August can not be solely attributed to the aforesaid improvements to the seismic network.

The OVSG-IPGP has therefore established a new communication protocol for these low-energy phenomena related to La Soufrière’s activity. Since November 12th, 2018, we report daily regarding scientific observations when we detect a seismic swarm, during, and at its end.

We consider that it is important to communicate on this increased seismic activity that is associated with the rock fracturing in the hydrothermal reservoir. Although the events remain of very low energy, this increased seismicity nevertheless marks a change in the behaviour of La Soufrière over the past few months as it implies the involvement of other processes related to hydrothermal fluid circulation. If this trend intensifies, this could have implications for the evolution of the activity at the summit, including sudden and highly localized phenomena such as: geysering with emission of hot and acidic sludge, projection of ash and fragments over few meters, rapid “steam flashing”, and the opening of new fumaroles.

Figure 3. Number of earthquakes per day since the beginning of the year (upper panel) and since August (lower panel). Thirteen seismic swarms of very low magnitude can be counted that comprise 14 activity peaks of 50 quakes per day, at least.

Deformations

Ground deformations are measured by GNSS (1) and extensometry. The GNSS network extends over the entire south Basse-Terre and highlights movements at different scales: a) in southern Basse-Terre, far from the La Soufrière dome, to detect possible mass migrations from deeper roots of the magmatic system; b) around the dome, at the level of the hydrothermal system; c) at the level of the dome, in addition to the extensometry on the fractures.

In the south of Basse-Terre, we do not observe movements that show any significant contribution of mass arrival at depth. At the dome scale, the movements are globally more important at the top of the volcanic edifice, where we measure among the strongest horizontal and vertical deformations since the onset of the network in 1995. On the dome, the deformation signal is globally radial (3 to 7 mm / year).
The fracture extensometry measurements, since the onset of the network in 1995, show a general tendency of opening of the faults and fractures in the active fumarolic zones as well as along the “Faille de 30 August”. This signal is observable mainly at the top of the dome, in the active zone and particularly at the Napoleon crater where the deformations have always been more marked. These opening movements can be partially compensated locally by closing of other fractures.

A clear opening trend in active fumarolic zones was observed on the basis of the last measurements in January, in line with the general opening rate observed during the last two years (Figure 4).

**Figure 4:** Radial spacing in millimeters measured at Crater Napoléon during the last 10 years. Located at the top of the dome, the Crater Napoléon is the site where we generally record the largest deformations as well as the appearance of new fumaroles very active and the progression of a thermal anomaly in the soil with temperatures that oscillate between 50 and 92 °C.

### Fluid Geochemistry

#### Fumarolic activity

Fumarolic activity and gas emission velocities at Cratère Sud had remained at a very high level until 19-20 April 2018 after reaching their highest values on 23 March 2018. However, we observed, as of 23-25 April 2018 and thus just prior the 27-28 April 2018 seismic swarm and the magnitude M4.1 volcanic earthquake, a significant decrease of gas emission velocities and therefore of gas flow rates. Since September 2018 gas flow rates have shown a continuous increase reaching since December 2018 a level similar to that observed on 19-20 April 2018. This past month, we observed a very high flow rate from Cratère Sud fumaroles (Cratère Sud Sud, CSS, Cratère Sud Central, CSC, Cratère Sud Nord, CSN), same as December 2018. Fumarolic activity at Cratère Sud is still characterized by extensive deposits of crystalline yellow sulphur.

The temperature at the Central South Crater (CSC) was measured when sampling the fumarole, and has a value of 100 °C, which is higher than the liquid-vapour equilibrium temperature for the water at the local atmospheric pressure.

The pH of 2.30 in fumarole condensates and the persistence of hydrochloric acid droplets mixed with volcanic gases testify to the acidity of the fumarole plume.

Since late 2017 we have improved the fumarole sampling involving “Giggenbach” type soda bottles. The volume concentrations of the main gases of the fumarole CSC are (averaged over two measurements): H₂O = 97.58%, CO₂ = 1.99%, S₂₂ = 0.41% (1 <CH₄/SO₂<10).

The fumarole temperature of the Crater Napoleon Nord is stable (95°C), at the liquid-vapour equilibrium temperature for water at the local atmospheric pressure. The condensate pH remains acidic and the fumarole flow rate appears stable if compared to observations of the previous months.

The other active zones, indicated on the map of Annex C (Gouffre Tarissan, Cratère Napoleon, Gouffre 1956, Lacroix fractures, Cratère Breislack, Route de la Citerne, Ravine Matyli, denoted by yellow stars on the map) show a marked tendency to flow rates increasing, locally accompanied by the degradation of the nearby vegetation. The observation of the terrain around the fumarole known as Napoleon East shows signs of mud splashing over a few meters, which explains the enlargement of the fumarole vent, formed between 8-10 February 2016. This month, we sampled the acid lake at the bottom of the Tarissan crater, showing a pH of 0.25. The lake water table is at 100.8 m below the rim.

Figure 5 shows the temporal evolution of the chemical composition of the fumarole CSC. For this fumarole, the most representative for the monitoring and study of the hydrothermal system, the molar ratios gas/steam, C/S, CO₂/CH₄ and CO/CO₂ (¹) are shown.

It should be noted that the ratio gas/steam, stable since 11/2017, rose considerably on 2nd June (up to 0.1), before falling on 21st June to around 0.03, reaching 0.05 in October and getting back to 0.03 since November 2018. The C/S ratio fluctuates about an average value of 4 and shows, in particular, values that after the end of March minimum (3) rise to 6 in September and decrease to a value of 4.7 in November. The two measures for December 2018 cover the range of 5 to 6 shown since September 2018. In January 2019 the ratio has a value of 5. The CO₂/CH₄ ratio shows a general upward trend, with values rising sharply at the end of April and beginning of May (200 000 to 250 000). This ratio reaches a peak of the same value as late April at the beginning of June and in September. Same as in early June 2018, this ratio has an average value of around 150,000 since October 2018, ranging between 140,000 (December 2018) and 170,000 (November 2018 and January 2019) and which as a whole indicates a new baseline.

Overall, the behaviour of these indicators is related to the increase of the deep magmatic gas component in the hydrothermal system, which seems to be recurrent when comparing the C/S and CO₂/CH₄ values recorded in September and early June.

The progressive infiltration of magmatic deep gas was responsible for the rise in the CO₂/CO ratio, which peaked at the end of April - beginning of May, typically in response to a process of deep heating of the hydrothermal system. As of June, this indicator has returned to a baseline value that has been identified since November 2017, which fluctuates between 0.000005 and 0.00001 with a minimum (0.000004) in July. From July to November, the CO₂/CO ratio showed a rising trend (up to 0.000006). In December 2018 and January 2019 it shows values of about 0.000005.

The infiltration of deep magmatic gases caused an increase in temperature and pressure inside the hydrothermal system, at depths of 2-3 km, compatible with the hypocentres of the seismic swarms recorded between February and April 2018. The latest data show that the Soufrière volcanic system is governed by the cyclically dynamics of energy recharge and discharge due to the infiltration of deep magmatic gases into the hydrothermal system. This generates a recurring process of overheating and overpressuring of the boiling hydrothermal fluids whose...
pressure and temperature conditions approach those of the critical point of water. Also the accumulation and energy release has for the moment reached its peak with the strong seismic and fumarolic activity of March-April 2018. Given the clear infiltration of magmatic gases into the hydrothermal system, as well as the high temperatures and pressures inside the hydrothermal system, we estimate that the volcanic system is currently recharging energy.

**Thermal springs**
The physico-chemical characteristics of spring waters (pH, conductivity, cations and anions) are for the most stable. Source temperatures are mostly stable: Bains Jaunes 29.1°C, Habitation Revel 32.9°C, Pas du Roy 35.1°C, 2ème Chute du Carbet 40.6°C, Ravine Marchand 44.1°C, Tarade 45.0°C, Galion 49.5°C, Bains Chauds Matouba 58.4°C.

**Phenomenology**
Acidic emissions carried by the wind continue the destruction of vegetation on the southern part of the summit and on the south-western and western flanks of the volcano.

We recall here that last month (December 2018) we observed the decline of vegetation in two areas of the upper Ravine Matylis, as well as the presence of white sublimates in different points in the soil. In addition, we have identified a thermal flux released from the fracture located at the bottom of the Gouffre Breislack. This low flux was associated with the presence of white sublimates on the wall in the fracture, the emission of CO$_2$ and H$_2$S and an area without vegetation, or with declining vegetation in the immediate proximity of the wall below the chasm.

The summit fumarolic zone has continued to evolve in recent years with the appearance in July 2014 of a new diffuse active zone (with a low flow rate) north of the crater Napoleon associated with the progression of a thermal anomaly (> 50°C in the ground). A new fumarole was identified in early February 2016, east of Crater Napoléon (in the no-go zone). Its temperature is about 95°C. Around the fumarolic mouth, which has grown since March 2018, there have been signs of past mud ejection and splashes a few meters away. The flow rate of the 1956 Gouffre has increased sharply since September 2015. These evolutions confirm that the increase in the activity of the hydrothermal system, observed since 1992, has become more important in the last period.

**Other information**
**Weather conditions at the volcano summit**
The anemometer has failed. Cumulative monthly rainfall was 414 mm. Average temperature was 17.4°C.

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*Figure 5. Molar ratios of gases from the CSC fumarole (CSN for the month of May 2018) since November 2017.*
**Synopsis** - The insular arc of the Lesser Antilles results from the subduction of the America plate under the Caribbean plate. This active subduction has a convergence speed of 2 cm/year. It causes deformation in the contact zone of these plates, making our archipelago a region characterised by strong volcanic and seismic hazards. Some earthquakes are directly related to sliding processes between the two plates. Others, more superficial, result from the deformation of the Caribbean plate. During the historical period, several earthquakes caused damage/victims in Guadeloupe (intensities greater than or equal to VII): 1735, 1810, 1843, 1851, 1897, 2004 and 2007.

During the month of January 2019, the regional telluric activity is characterized by a number of earthquakes comparable to the number recorded in the last months.

Earthquakes are not predictable and can occur at any time in the Guadeloupe archipelago. Risk prevention actions are still required: compliance with the seismic regulations in force, correct layout of the interiors of living and working space, training on the safe conduct to follow before, during, and after an earthquake.

**Regional Seismicity**

The Observatory recorded during the month a total of 629 earthquakes of tectonic origin, of maximum magnitude 4.5. Figure 6 shows the map of epicentres in an area of about 550 km around Guadeloupe.

With regard to the Guadeloupe archipelago, the geographical distribution of the seismic activity is comparable to that of the previous months, with a shallow seismicity located mainly along the large fault systems distributed between Martinique and Barbuda.

On January 4th, a small earthquake (M = 4.5 ± 0.3) of tectonic origin was recorded at 22h52m UT (18h52m local time) and located 64 km north of La Désirade, at a depth of 15 km. This earthquake was weakly felt in Guadeloupe (macroseismic intensity II-III).

493 earthquakes were recorded between Les Saintes and Dominica (see Figure 7). 366 of these earthquakes are grouped into a swarm that occurred from 21 to 26 January.

On January 21st, a small earthquake (M = 4.1 ± 0.3) of tectonic origin was recorded at 14h42m UT (10h42m local time) and located 3 km east-southeast of Terre de Bas at a depth of from 7 km. This earthquake was strongly felt at the Saintes (macroseismic intensity V) and widely felt in Basse Terre (macroseismic intensity III-IV).

On January 21st, a small earthquake (M = 2.8 ± 0.3) of tectonic origin was recorded at 22h43m UT (18h43m local time) and located 8 km east of Terre de Bas, at a depth of 8 km. This earthquake was felt at the Saintes (macroseismic intensity II-III).

On January 22nd, a small earthquake (M = 2.3 ± 0.3) of tectonic origin was recorded at 01h34m UT (21 January 21h34m local time) and located 3 km east of Terre de Bas, at a depth of 7 km. This earthquake was weakly felt at the Saintes (macroseismic intensity I-II).

On January 22nd, a small earthquake (M = 2.8 ± 0.3) of tectonic origin was recorded at 11h14m UT (07h14m local time) and located 3 km east-southeast of Terre de Bas at a depth of from 8 km. This earthquake was felt at the Saintes (macroseismic intensity II-III).

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**Figure 6.** Map of the epicentres of January 2019 corresponding to earthquakes recorded and located by the OVSG-IPGP around Guadeloupe. Black features = known main faults (from Feuillet et al., 2000).

**Figure 7.** Map of the epicentres of January 2019 corresponding to earthquakes recorded and located by the OVSG-IPGP around the archipelago of Les Saintes. Black features = known main faults (from Feuillet et al., 2000).
Kick’em Jenny
The Kick’em Jenny is a submarine volcano that is located 9 km north of Granada. The summit is about 180 m below sea level. It is currently the most active volcano in the Lesser Antilles. Since its discovery in 1939 by the Seismic Research Center (SRC) of Trinidad, at least 13 underwater eruptions have been identified. The SRC records the evolution of the activity of the volcano via its seismic monitoring networks.

The level of alert reported in January by the National Disaster Management Agency (NaDMA) in Grenada is YELLOW. For more information, visit the websites of the Seismic Research Center (http://www.uwiseismic.com) and of the National Disaster Management Agency (www.nadma.gd).

Volcanic activity on Montserrat
The activity of the Soufrière Hills volcano was low during the month of January. From December 29th, 2018, to February 1st, 2019, the seismic network of the Montserrat Volcano Observatory (MVO) recorded 22 VT-type earthquakes and 1 rockfall. In the same period, the alert level was 1. This level of alert provides for the prohibition of access to Zone V, which includes the city of Plymouth. The Eastern and Western Maritime Zones can be crossed, but without stopping and only during the day, between dawn and sunset.

All information can be found on the MVO website (www.mvo.ms).

The Director of OVSG-IPGP, March 5th, 2018
(1): 1 megajoule = 1 MJ = 106 Joules; 1 gigajoule = 1 GJ = 109 Joules; 1 terajoule = 1 TJ = 1012 Joules. For example, an earthquake of magnitude 6 releases as much elastic energy as the energy released by the Hiroshima atomic bomb (63 TJ). An increase of 1 point on the scale of magnitudes equates to about 32 times more energy; for example, an earthquake of magnitude $M = 4$ releases about 900 times more energy than an earthquake of magnitude $M = 2$.

(2): GNSS (Global Navigation Satellite System) includes GPS (USA), Galileo (EU), GLONASS (Russia) and Compass (China).

(3): Here we summarise the most accepted interpretations of the indicators shown in Figure 4. The variation in the gas / water vapour ratio essentially measures the variation of the relative proportion of magmatic gas to the meteoric component (rainwater) in the hydrothermal system; this ratio may increase due to the arrival of magmatic gases and / or the condensation of steam. The C/S ratio can increase during the rise of deep magmatic gases or by loss of sulphur, especially $H_2S$ ("gas scrubbing") in the hydrothermal system, often associated with a decrease in temperature. An increase in the $CO_2/CH_4$ ratio is considered as a clear signal of the arrival of oxidized magmatic gases and of high temperature, thus enriched in $CO_2$ and whose arrival oxidises and potentially warms the base of the hydrothermal system, limiting the conversion of $CO_2$ in $CH_4$. Finally, the $CO/CO_2$ ratio, for an oxidation state set within the system, is normally associated with the heating of the hydrothermal system. It is also recalled that in hydrothermal systems characterised by the coexistence of water vapour and the liquid (pure water or brines), the heating and overpressure phenomena are associated, so that temperature and pressure increase together.

### Definition of volcanic activity levels for La Soufrière de Guadeloupe

<table>
<thead>
<tr>
<th>Overall observed activity</th>
<th>Low Activity</th>
<th>Increasing Activity</th>
<th>Strongly Increased Activity</th>
<th>Maximum Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Possible timescale</strong></td>
<td>Base level</td>
<td>Variations of some parameters</td>
<td>Variations of many parameters, seismicity frequently felt</td>
<td>Intense volcanic seismicity, major deformations, explosions</td>
</tr>
<tr>
<td><strong>Decision</strong></td>
<td>Century (s) / Years</td>
<td>Year (s) / Months</td>
<td>Months / Weeks</td>
<td>Imminent / In progress</td>
</tr>
<tr>
<td><strong>Alert level</strong></td>
<td>GREEN = No alert</td>
<td>YELLOW = Vigilance</td>
<td>ORANGE = Pre-alert</td>
<td>RED = Alert</td>
</tr>
</tbody>
</table>

### La Soufrière: further information

The Grande Découverte – Soufrière complex is made up of 3 stratovolcanoes, Grande Découverte, Carmichael and Soufrière which were built during the last 445 000 years. Soufrière is the most recent building and its eruptive history began about 9150 years ago. It is an active volcano, explosive type, that has experienced many magmatic and non-magmatic eruptions, the latter called "phreatic", in the past. The most recent major magmatic eruption dates from 1530 AD. This complex eruption began with a collapse of the old building causing a landslide that reached the sea at Basse-Terre. The explosive eruption that followed resulted in ash and pumice fallout on southern Basse-Terre, the outpouring of pyroclastic flows (incandescent avalanches of gas, ashes and rock blocks) that reached 5-7 km away volcano, and mudslides. It ended with the formation of the Soufrière dome (about 50 million m$^3$). The latest scientific data suggest that a smaller magmatic eruption took place in 1657. Although the volcano of La Soufrière is the only volcano that has shown a historical activity in Guadeloupe (since 1635), the current knowledge shows that the volcanic complex of Madeleine Trois-Rivières has been active in the last 5000 years. Therefore, there are two active volcanic complexes in Guadeloupe. The magmatic eruption of 1530 is representative of the hazards caused by an explosive eruption of medium magnitude, although more intense explosive eruptions have been identified in the last 10 000 years.

The historical activity of La Soufrière since 1635 is characterized by non-magmatic eruptions, which were minor in 1690, 1812, and 1956, and major in 1797-1798, 1836-1837, and 1976-1977. The phreatic eruption of 1956 lasted ten days with two explosions. That of 1976-77 was particularly violent with 26 major explosions between July 1976 and March 1977. It produced acid gas emissions, vertical outpouring of pyroclastic flows (incandescent avalanches of gas, ashes and rock blocks) that reached 5-7 km away volcano, and mudslides. It ended with the formation of the Soufrière dome (about 50 million m$^3$). The latest scientific data suggest that a smaller magmatic eruption took place in 1657. Although the volcano of La Soufrière is the only volcano that has shown a historical activity in Guadeloupe (since 1635), the current knowledge shows that the volcanic complex of Madeleine Trois-Rivières has been active in the last 5000 years. Therefore, there are two active volcanic complexes in Guadeloupe. The magmatic eruption of 1530 is representative of the hazards caused by an explosive eruption of medium magnitude, although more intense explosive eruptions have been identified in the last 10 000 years.

(1): Feuillard et al., 1983; Boudon et al., 1988; Komorowski et al., 2005; Boudon et al., 2008; Komorowski, 2008; Komorowski et al., 2008; Feuillard, 2011; Legendre, 2012; Hincks et al., 2014; Rosas-Carbajal et al., 2016.

The following map (Komorowski et al, 2013) represents the volcanic dome with the sites mentioned in this bulletin.
Map of location of the main structures, historical eruptive vents, observed fumarolic activity on La Soufrière lava dome
(Compiled by J-C Komorowski, 2016 with contributions from V. Robert, C. Desset, OVSG team, F. Beauducel, J-B de Chabailly, D. Gibert, G. Tamburello, S. Mouré, modified after Joket, 1958; Barabé et Joket, 1958; Le Guern et al., 1980; Feuillard et al., 1980; Beauducel et al., 1988; Komorowski et al., 2005; Komorowski, 2008; Nicolle et al. 2006; Feuillard, 2011; Lepenne et al., 2012; Brothelande et al., 2014; Villenave et al., 2014; Allard et al., 2014).

1976-1977
new fractures
reactivated fractures
active adventive fumaroles
hydrothermal fluid resurgence

1956
new fractures
active adventive fumaroles

1836-37
1809-12
1797-98
1690
water resurgence

(1) Route de la Citernelle,
(2) Morne Matan,
(3) Forage-Col de J Cheille,
(4) Col de J Cheille (Souфleur, Chaudières),
(5) Fumerolles du Carbet I,
(6) Fumerolles du Carbet II,
(7) Fumerolles Collardeau,
(8) Napoleon
(9) Cratère Sud and Lacroix-
Napoleon fumerolles supérieur,
(10) Fumerolles Lacroix inférieur,
(11) Fente du Nord,
(12) Faujas-Chemin des Dames,
(13) Bains chauds du Gallon,
(14) Fumerolles de la Matéjs. Primary lat long
graduations in 500 meters,
WGS84 geodetic system,
UTM 2009 projection.
Clarifications on earthquake magnitude

The concept of Magnitude was introduced in 1935 by Charles F. Richter to express the "force" of an earthquake in a quantitative and non-subjective way. Richter Magnitude, a logarithmic scale also known as Local Magnitude (ML), is expressed in terms of the amplitude recorded by a particular instrument, the Wood-Anderson torsion pendulum. The Richter Magnitude has been calibrated only for earthquakes occurring in California within 600 km of the station having recorded the event.

To compensate for the distance limitation given by the expression of the Richter Magnitude, other logarithmic scales of Magnitude have been introduced to express the energy radiated by an earthquake. Most quantities are based on the maximum amplitude of the seismic signal on the seismogram or on the relationship between the amplitude and the period of recorded seismic waves.

In order to calculate the local magnitude of small or medium intensity earthquakes at local or regional distances, the magnitude of duration (MD) was introduced. Its calculation is based on the measurement of the duration of the seismic signal on the seismogram, since the greater the magnitude of an event, the greater the duration of the recording.

Moment magnitude (MW) measures the size of events in terms of the amount of seismic energy released. Specifically, moment magnitude refers to the displacement along a fault or fracture and to the surface of the fault or fracture. Since the moment magnitude can describe something physical about the event, the calculated values can easily be compared to amplitude values for other events. The moment magnitude is also a more accurate scale to describe the size of events.

From the relationships between magnitude and seismic energy, it is possible to deduce that a variation of 1 point of Magnitude is equivalent to an energy increase of about 30 times. In other words, the energy generated by an earthquake of magnitude 6 is about 30 times greater than that produced by a Magnitude 5 earthquake and about 1000 times greater than that produced by a magnitude 4 earthquake.

Finally, like any physical parameter, an estimate of magnitude is associated with uncertainty. On the local Magnitude, it is generally of the order of 0.2 to 0.3, rarely less. Magnitude values provided by other international agencies (USGS, SRC for the Caribbean) generally fall into this variability.

The data and parameters used to locate an earthquake may differ from one agency to another, and contribute to the uncertainty of the estimate. The OVSG-IPGP and the OVSM-IPGP use calibrated procedures for the West Indies and a higher density of seismic stations than other international agencies that use global parameters.

Therefore, the different magnitude estimation methods provide estimates of the same magnitude, but may actually be slightly different while remaining within the uncertainties of each estimate.

Simplified definition of the European macroseismic scale (EMS98)

<table>
<thead>
<tr>
<th>Intensity</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>X-XI-XII</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Perceptions</td>
<td>Not felt</td>
<td>Very weak</td>
<td>Weak</td>
<td>Light</td>
<td>Moderate</td>
<td>Strong</td>
<td>Very Strong</td>
<td>Severe</td>
<td>Violent</td>
<td>Extreme</td>
</tr>
<tr>
<td>Probable damage</td>
<td>No damage</td>
<td>Very slight</td>
<td>Slight</td>
<td>Moderate</td>
<td>Important</td>
<td>Destructions</td>
<td>Generalized</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Report a felt earthquake

Actual intensities (the effects of an earthquake in a given place) can only be properly determined by collecting testimonies. If you have felt an earthquake, even weakly, you are invited to report it to the observatory and take a few minutes to complete the BCSF macroseismic survey form on the website http://www.franceseseisme.fr/.

Centre de Données Sismologiques des Antilles (CDSA)

The mission of the CDSA is to process and make available to the public technical and scientific information concerning the seismic activity in the Lesser Antilles archipelago (www.seismes-antilles.fr). It is a collaboration between the Institute of Physics of the Globe of Paris (IPGP), the BRGM and the University of the Antilles. The CDSA was set up gradually between 2002 and 2007 as part of a CPER-SPD project "KASIS" and financed by the ERDF, the Ministry of the Environment, the Guadeloupe Region, the IPGP and the BRGM. The second phase of the project started in October 2013 (under the CPER-OP 2007-2013). Located on the Houëlmont and hosted by the Volcanological and Seismological Observatory of Guadeloupe (OVSG-IPGP), the CDSA benefits from the reliability of the infrastructures and the continuous operational support of the IPGP equipment deployed for surveillance.

Thank you to organizations, elected assemblies, and associations to publically post this newsletter to maximize its dissemination. To receive it by e-mail, simply request it at <infos@ovsg.univ-ag.fr>.

Please find all the information on our website (http://www.ipgp.fr/ovsg), the Facebook page (https://www.facebook.com/ObsVolcanoSismoGuadeloupe/) and the Twitter account (https://twitter.com/ObsGuadeloupe?lang=en).

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