The first seismo-volcanological observatory on Montserrat

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Abstract

The first seismo-volcanological observatory in the anglophone Caribbean was established on Montserrat in 1936, in response to a volcano-seismic crisis that began in in 1933. Staff at Montserrat's agricultural office began routinely observing earthquake shocks in 1934. In 1936, following a scientific expedition dispatched by the Royal Society, an observatory was established at the Grove Botanical Station, Plymouth. This was run by volcano-seismic observers who managed an instrumental network, and monitored gas and steam emissions and air quality. The observatory functioned until 1946. We reconstruct decision-making, and evolution of the instrument networks as the observatory was established, and highlight the personnel involved, including the first female seismo-volcanic observer on Montserrat, Greta Scotland.

Observations from the 1930s crisis emphasise the persistent seismicity and gas emissions associated with this extended episode of unrest, and suggest that there were minor phreatic explosions at the height of the crisis. We draw parallels with long-term observations of the activity of the Soufrière Hills Volcano since the 1990s.

Second-language abstract

Introduction

The island of Montserrat is one of eleven volcanically-active islands of the Eastern Caribbean Volcanic Arc, and one of the seven volcanic islands of the English-speaking Caribbean that currently fall under the purview of the UWI Seismic Research Centre (SRC) and its regional monitoring network (Latchman et al., 2012; Dondin et al., 2019). The origins of SRC, and the start of continuous, regional seismic monitoring in the Eastern Caribbean date back to 1952 and the colonial response to a short-lived seismic crisis on the islands of St Kitts and Nevis (Willmore 1952). This was yet another event where 'the observer had arrived .. late in the course of the crisis' (Willmore, 1952). Willmore proposed that there should be an instrumental network across the Eastern Caribbean, with sensitive seismographs on each island, a permanent scientifically-trained observer running the network from a centre, and a pool of shock recorders ready for rapid deployment if or when another earthquake sequence began to unfold (Willmore, 1952). With this proposal in mind, and financial support from British Colonial Development and Welfare funds, Geoff Robson was appointed as scientific officer for volcano-seismic observations in the West Indies by the Colonial Office in May 1952, and established the 'Volcanological Research Department' in Port of

Spain, Trinidad later that year. However, this was neither the first time that scientists had called for a regional monitoring effort, nor was it the first catalysing period of unrest in the Eastern Caribbean. Previous calls had been raised following the catastrophic eruptions on Martinique and St Vincent in 1902 and after subsequent seismic crises on Montserrat (1933-1937), Dominica (1937-38) and St Vincent (1946; Powell, 1938; Latchman et al., 2012; Barclay et al., 2022).

In this paper, we investigate the events on Montserrat from 1933-1937. This was a period marked by a significant episode of seismic unrest that included damaging earthquakes, repeated clusters of smaller shocks, and multiple manifestations of unrest at the island's sulphur and steam vents (soufrières). It also coincided with the effects of a significant regional (tectonic) earthquake (November 10th, 1935; Niemz and Amorese, 2015). We document evidence for the nature and organisation of the local, regional and colonial response to this episode, and explore how the local seismic and volcanic monitoring system was established across the island. We also look at the reasons why this event did not immediately lead to the establishment of a regional network; and why the systematic monitoring that was established on Montserrat was not sustained beyond 1946.

Prior to the start of the eruption of the Soufrière Hills Volcano in July 1995, there was no documented evidence for any eruptive activity on Montserrat during the previous 500 years. Over the previous 150 years, there had been several notable periods of seismic unrest on Montserrat, accompanied by changes in gas and fumarole emissions, including from 1897-1902, 1933-1937 and 1966-7. Here, we document the scientific response to the period of unrest during the 1930s. At that time, the island of Montserrat was one of five Presidencies within the British colony of the Leeward Islands, overseen by the Governor of the Leeward Islands. Montserrat was administered by a Commissioner, T.E.P. Baynes. The Government of Montserrat comprised a small Executive Council, and a larger Legislative Council which included both 'ex officio' members (from the Medical, Agricultural and other Departments), and unofficial and unelected councillors, including estate owners and managers (e.g. Harding and Gent 1935, p353), many descended from the planter oligarchy (Fergus 2004, p110). For our analysis, we draw on primary sources including correspondence, diaries, reports and datasets from scientists and observers who were involved in documenting and monitoring the events, and official correspondence from Montserrat, the Leeward islands and the colonial government. We explore how the response to the crisis evolved, and how it led to the creation of the first continuously instrumented 'seismo-volcanological' observatory in the English-speaking Caribbean that was charged with recording earthquakes, gas emissions, and air quality measurements on Montserrat.

Data sources

We base our analysis on archived materials accessed from the Montserrat Public Library, the Montserrat National Trust, the UK National Archives, the Royal Society, the British Geological Survey, the University of Oxford's Bodleian Libraries and Museum of Natural History, and the University of Bristol Special Collections. The materials we have consulted include field notebooks and diaries, official and personal correspondence, reports, photographs and sketches related to the seismic and volcanic crisis of 1933-1937, and the subsequent routine reporting of the seismo-volcanological observers on Montserrat. Additional sources of evidence and information come from the published papers and monographs from the time (notably, MacGregor, 1936, 1938; Powell, 1937, 1938; Perret 1939). A full list of sources is provided in Appendix 1, and particular sources are cited in endnotes to the paper.

Background

By the time of the first geological investigations of Montserrat in the early 1800's, the island was considered to be volcanic, based in part on the abundance of porphyritic rock (Nugent, 1811). At that time, and until 1995, the main manifestations of the volcanic nature of the island - and in particular of the region around the Soufrière Hills (**Figure 1; Figure 2**) - were the surface expressions of subterranean hydrothermal activity, including hot springs, fumaroles, and patches of sulphurous and steaming ground, which were together known as 'soufrières' (**Table 1**), in common with similar features on the other volcanic islands of the Caribbean. Nugent visited one such soufrière in 1810, 'The Sulphur', in a ravine beyond 'Galloways' (Galway's) estate. A sketch map of Montserrat from the early 1830s[1] contains two prominent ochre-coloured patches labelled 'volcano', joined by a 'line of communication between extinguished and unextinguished volcanos' (How, 2020). These locations were the two prominent soufrières on the island of the 19th century: Galway's (or Roches) and Tar River, or Cow Hill. Galway's soufrière lay within Henry Hamilton's 400 acre 'Mountain and Sulphur' estate, later known as 'Fergus Mountain Estate'. This was the location of short-lived attempts to mine sulphur commercially around 1836 - 1838, during the Sicilian sulphur crisis (Sturge and Harvey, 1838; Davy, 1854; Cunha, 2019).

Thomas Savage English gathered accounts of the histories of these various features on Montserrat, and recognised possible links between seismic activity and the activity of the soufrières. Several new soufrières appeared between 1830 and 1930: Upper Gage's soufrière formed after the great earthquake of February 8, 1843.[2] The 1843 earthquake was a destructive regional tectonic event with a source near Guadeloupe (Robson 1964) which damaged buildings across Montserrat, and left the 'Souffriere mountain rent in many places' by landslides.[3] Earthquakes and

soufrière activity both increased notably in 1897, shortly after the Lower Gages soufrière formed, with shocks large enough to damage buildings and cause landslides (Wadge and Isaacs, 1988). This elevated activity declined after the May 1902 eruptions on St Vincent and Martinique.[4]

The 1930's seismic-volcanic crisis on Montserrat: a chronology

1933-1934

The activity of the Lower Gages soufrière would have been readily visible from parts of Plymouth, the capital of Montserrat (Fig. 2), and changes in steam-plume activity or sulphurous smells would likely have attracted attention. Early in 1933, an increase in activity was noted at the Gages soufrière, and the pungent smell of H_2S was noticed intermittently in Plymouth. Shortly after, earthquakes were felt at Harris', where they were recorded by the school teacher, F. E. Peters. The Curator of the Grove Botanical Station and head of the Agricultural Department, C. A. Gomez, led an official visit to Gages soufrière, and reported that they had detected both the 'characteristic odour of H_2S at Gages, along with a certain pungency attributed to the presence of SO_2'.[5] They also used a 'lead sulphide' test to confirm the presence of hydrogen sulphide. The nature of this test isn't described, but likely involved exposing lead acetate solution, or impregnated filters, to the gas and observing the formation of a black precipitate in the presence of H_2S.

The first notable earthquake felt at Grove occurred in September 1933, and from January 1934 there was a marked increase in seismicity, sometimes with more than one felt event per day (Figure 3). In March 1934, Gomez led a second visit to Gages soufrière, taking with him a guide, the agricultural assistant H. L. Manning, and two officers from HMS Dragon, a Royal Naval light cruiser stationed with the America and West Indies squadron. Once again, observers reported the pungent smell of SO_2 near the soufrière vents, and of hydrogen sulphide, which was recognised as 'the offensive odour smelt in Plymouth'. Gomez collated records of felt earthquakes at Grove since the start of the crisis for the Commissioner, including the reports from Peters of seismicity at Harris', and Spring Gardens (Fig. 3). By early April 1934, Gomez and his team of forest officers, along with other local estate owners or observers, were keeping a daily eye on the state of the 'soufrières and their neighbourhood', and reporting weekly to the Commissioner.[6]

Following a meeting of the executive council, the Commissioner cabled representatives on nearby islands seeking information on whether there had been any increases in volcanic activity or earthquakes recently. At the Commissioner's request, the Governor also wrote to the Secretary of State for the Colonies asking that he might invite a scientist to 'report on the condition in Montserrat'[7]. The Governor made two suggestions: 'I have been informed somewhat vaguely that there is a volcanic scientist at present camping in a hut some 2000 feet up Mont Pelée .. [who] has microphones inserted in the mountain for test purposes'. Alternatively, 'you may consider it desirable to consult some expert in England in the first instance'.

The volcanic scientist in question was Frank Perret: a 67-year old American volcanologist with past experience on Vesuvius, Stromboli and Hawaii and connections to the Carnegie Institution in Washington (Perret 1924, 1950; Giblin, 1950; Belkin & Gidwitz, 2020). Perret had established an observing hut on the slopes of Mt Pelée on Martinique in 1929 (Perret, 1937a); the first volcano observatory in the Caribbean, and a volcano museum in St Pierre. Through the commissioner's contact with the British consul to Martinique and Guadeloupe, Henry Joseph Meagher, Perret was invited to visit Montserrat to assess the situation. Perret made a fleeting visit on the afternoon of May 13th, 1934. Perret was on the SS *Nerissa* from Martinique to New York, and disembarked at Plymouth, Montserrat, where he presented his credentials as 'Volcanologist, Founder and Director of the Volcanological Museum at St Pierre, Martinique' to the Commissioner. He then accompanied the Curator, Gomez, and the owner of the Gages estate, H.R. Howes, on a short visit to Gages soufrière. Perret had just long enough to collect a sample of hot, 'gas-charged water' for analysis, and to note that he was unable to smell any sulphur dioxide.

Immediately following his visit, and before leaving Montserrat, Perret wrote a brief report for the Commissioner assessing the state of the volcano, and offering to return for a fortnight later in the year, for a 'more thorough investigation'. While Perret was reassured that the gas levels might be declining, he anticipated that seismicity might increase over the next couple of weeks, following the 'luni-solar' cycle. This was based on an 'old and abandoned' hypothesis originally advanced by Palmieri (1873), which Perret revived during his close observations of activity at Vesuvius and Stromboli in 1906-7 (Perret, 1908; 1924), and later at Mont Pelée (Perret, 1937a). Perret's notion was that the variations in stress due to the gravitational pull of the sun and moon on Earth, would lead to times at which active volcanoes would be more likely to show increased activity – for example a change in eruptive nature - and that the timings of these peak would coincide with the syzygies, and peak ocean tides (Perret, 1924; see also Sottili et al., 2021). Perret's forecast gained particular traction with Commissioner Baynes, as the night of Perret's departure (13/14 May 1934) proved to be 'an ordeal of uncertainty' with a shock at 2 am on May

14th that was the 'worst so far experienced' during the recent episode, and which appeared to confirm Perret's insight into the volcano's behaviour.[8, 9]

Local monitoring of the status of the soufrière, and recording of earthquakes at Grove continued. During late May and early June 1934 Manning, the Agricultural Assistant, made daily visits to some of the soufrières; with monthly earthquake reports being sent to the Colonial Secretary in Antigua. In July 1934, the acting commissioner, Edward Bell, formally invited Perret to make an extended visit, at the request of the Executive Council. The Government of Montserrat offered to provide Perret with transport and accommodation, while Perret would offer his services 'gratis'. Perret initially planned to arrive on Montserrat in September, but delayed until he heard that he had a grant from the Carnegie Institution, which would allow him to purchase some instruments for his investigation. Perret's motivation was that this work supported his vision for a 'motor yacht equipped with proper apparatus' that might be used to respond to future seismic and volcanic crises in the region, and become a regional floating observatory.[10, 11] Perret eventually arrived in late November 1934 (Appendix 2).

In the interim, he continued correspondence with Gomez (and met him again, briefly, for one night offshore Montserrat, while heading back to Martinique), around his plan for measurements focussed on detecting earthquake shocks, tremor and the thermal state of the soufrières. In August 1934, Perret sent instructions for Gomez to build a simple pendulum array based on his experience at Vesuvius, as there was not yet any working shock recorder or seismometer on the island.[12] Gomez did install a pendulum apparatus, but didn't use it to record shocks, instead fleeing the house without checking which way the pendulum was swinging at the first sign of an earthquake.[13] Perret also ordered a set of 'maximum-registering thermometers', a microphone and a 'gas-filled Bristol Thermometer, with brass, lead-covered bulb and twenty foot .. cable .. attached to weather-proof recording apparatus'. Perret's plan was to bury the thermometer bulb in a steaming fissure, and record the temperatures continuously for a week at a time on a rotating circular chart.

Once Perret arrived on Montserrat, he set about establishing an experimental field station at Lower Gages soufrière; and visited several other soufrières to make observations and collect gas samples. Perret's plan was to live in the field station for a few days at a time, to record day and night-time observations. On 30 November 1934 he installed the Bristol Thermograph at Lower Gages. This continuous-recording bulb-thermometer had a wind-up mechanical clock, and a pen that recorded the ground temperature on a circular paper chart for a week at a time (Fig. 4). It worked well for a week, and then stopped, perhaps due to an earthquake shock, at which point Perret moved the

instrument closer to the steam vents. During this visit Perret also installed mercury baths - for the detection of tremor - at Meade's estate in Galway, at the Grove Botanical Station and at Howes' estate at Gages. Perret's prior experience on Vesuvius was that mercury baths could be very sensitive to tremor, in a way that contemporary shock recorders would not. Perret also finished installing a suite of pendulums at the Grove, and noted the presence of the 'sensitive plant' (*Mimosa pudica*; Brussell, 2004) along the trail up to Gages. He gathered some small plants to grow in pots at the Grove, to see whether they were sensitive to shocks or tremor (Perret, 1939). Perret also kept an eye out for examples of animal behaviour - watching a pair of parrots at the hotel, along with chickens and horses - but saw nothing he could link to the onsets of shocks (Perret, 1939, 61).

Perret completed his preliminary field study and a report for the Commissioner on 12 December 1934; establishing what would become his usual pattern, that he would leave a typescript report on Montserrat before departure. Perret's main conclusions on the state of the soufrières was that Gages was 'more like an active vent', with gases that were 'extremely irritating to the eyes and throat', but he was not able to detect any SO_2 (by smell), CO_2 (using lime water), or HCl (using ammonia). In contrast, Roches (or Galways) soufrière was in his view more like a 'solfatara' (such as that at Campi Flegrei, in the Bay of Naples), being cooler (<100 ^{o}C) and with more active precipitation of native sulphur. Perret concurred with previous observers, that the main gas of concern was H_2S as this had both a 'nauseous odor' and was an 'active poison', and so although the levels of dilution of the gas in populated areas around Plymouth meant that there was no health risk in his view, the strong smell - often most prominent at night and in the mornings – and the very visible impacts it had on fresh lead acetate paints, and polished metalwork, meant that it was liable to be a persistent source of distress (Table 2).

Perret suggested in his report that some relief from the hydrogen sulphide could be attained by using a wetted handkerchief to filter the gas out. He was able to confirm that H_2S was present, at varying concentrations, in Plymouth by exposing reactive papers - coated with lead acetate - for 12 hours each night in his room at the Cocoanut Hill hotel (Figure 4). These papers showed different amounts of darkening from one night to the next, due to the precipitation of lead sulphide as the acetate reacted with the H_2S; but Perret could not extract any quantitative information on exposure levels at this stage. He was convinced that most of the gas responsible for the fumigation was not from the wet soufrières, but from the nearby dry vents.

In Perret's absence, routine monitoring on the island was continued by the agricultural curator Gomez and his assistant Manning. They noted earthquake shocks detected at the Grove, and made routine visits to Gages soufrière to change over the paper discs on the thermograph and observe the behaviour of the soufrières. Perret returned in February 1935 to equip the field station which had by then been constructed, and was now set up with the Bristol thermograph, a mercury bath, a buried microphone connected to an ear-phone, and air-microphone and pitch pipes for measuring the 'pressure note' of the gas vents, a seismic pendulum with attached mirror and electric light, cameras, binoculars and sampling tubes. The field station was also supplied with water, and furnished with 'living appurtenances' by Howes, from the nearby Gages estate.

Collens, the government chemist who was based on Antigua, had dispatched a consignment of consumables for use in the field station, including filter papers, high-temperature thermometers and chemicals including lead acetate, sodium nitroprusside and magnesium ribbon. While stationed at Gages, Perret determined that the gases of the soufrière were alkaline and turned red litmus blue, while the waters of the gorge were acidic. Overnight at the field station, Perret heard the opening of a new but ephemeral dry vent in the gorge, which he described as a 'loud explosion .. followed by a whistling, wailing sound' (Perret, 1939 p 26), and was accompanied by a gust of the 'most concentrated hydrogen sulphide' he had ever smelt. He couldn't locate the vent in the fumes, but heard two more explosions. We interpret these events as small phreatic explosions (e.g. Barberi et al., 1992). Perret stayed, as planned, in the field hut but after 40 hours of continuous exposure he fell ill and ended up in hospital, needing attention for his throat and eyes. He resolved to find some more close-fitting goggles, and left the island in early March, having briefed the agricultural assistant over what was required for ongoing monitoring.

There was a period of anxiety in March and April 1935, as the thermograph began to show temperatures that were increasing over the stable baseline. Having started at 105 - 110 ^{o}C in late 1934 and shown no change for several months, in mid-March 1935 the readings rose quickly to over 130 ^{o}C. The rapid temperature increase caused some consternation, and the instrument was taken out of the ground, cleaned, and calibrated by Manning and Gomez before being redeployed; but still the recorded temperature rose.[14] Perret advised the Commissioner to consider evacuating Howes' estate buildings at Gages if the soufrière dried out, but after Perret made another flying visit in mid April, it became clear that the instrument was defective, perhaps due to corrosion - as there had been no change in any of the spot temperature measurements of either the ground or the steam vents. The thermograph was taken out of service, and returned to the Bristol company in New York for refurbishment.

In early May, Perret concluded his visit with an update, noting that while the Gages gorge was continuing to be enlarged by vapour and erosion, this had been happening over the past 35 years, since its formation. Chemical analysis of water samples by Shepherd at the Geophysical labs confirmed that the waters from Gages and Roches (Galways) were acidic, and rich in H_2S, silica and organic material and only traces of chlorine species. Overall, Perret was still satisfied that the activity was diminishing - the eye-stinging gas was less strong than in February, and the H_2S emissions and fumarole pressures were 'much less than a year ago'.

Shortly after Perret's departure, a very substantial earthquake struck on 6 May 1935. This caused widespread damage and disrupted the silver jubilee celebrations planned for that day to mark the 25th anniversary of the reign of the British monarch, George V. Perret returned quickly to the island, and soon convinced himself that this large earthquake was different from that of December 1934. The large earthquake of 12 December 1934 had been preceded by 'great vapor pressure' in Gages soufrière, and surface damage in the centre of the island close to Gages mountain, which Perret interpreted as reflecting a source near to the surface. In contrast, Perret didn't think that the 6 May 1935 earthquake was accompanied by any major changes in the soufrières, and the wider area affected by shaking suggested to him that the source was deeper; consistent with his hypothesis that the crisis was diminishing, and the chance of an eruption declining.[15]

In July 1935, Perret wrote to the Commissioner, postponing his next visit which was to have been in late July. Perret's exposure to volcanic fumes in February had triggered a cascade of symptoms, and he was still feeling quite unwell. 'The heart condition is now almost normal again, but the poison has seemed to infiltrate into the throat glands.' His doctors were clear that the cause was exposure to volcanic gases. Perret's planning for further investigations continued, and in preparation the government chemist Collens sent on another consignment of chemicals: 'benzole' or benzene for the detection of hydrogen persulphides (H_2S_2), and some notes on the detection of selenium hydrides, to test Perret's hypothesis on the trace constituents of the volcanic gases.[16]

While the weekly visits to Gages showed no change in the steam vent temperatures in August and September 1935, the strong earthquake shocks continued. Commissioner Baynes and Perret remained in contact, and on 18 September Baynes sent a telegram to Perret asking if he would object to another expert being called in, to collaborate and help out. 'Welcome other expert' Perret replied, by return.[17] After time recuperating in New York, Perret returned to Montserrat in October 1935 with a new thermograph and a prototype three-component seismometer, which he called a 'seismeter', which was designed to capture the integrated displacements in three directions (East-West, North-South, Up-Down) during large earthquakes (Perret, 1937b). He installed the seismeter

at Gages estate, and the thermograph at the soufrière, where he also carried out some more experiments on the hot fluids escaping from the vents.

Perret's observations suggested that while the gas remained 'strong and extremely nauseating at times', the flux was diminished and the gas mixture had not perceptibly changed since his earlier observations. Perret's field tests using benzole confirmed his 'diagnosis of these vapors as being composed of the higher and very unstable compound Sulphides of Hydrogen (sic), ranging from H_2S_2 to H_2S_5 .. [for which] .. field tests offer the only reliable proof of identity. The first field trials, by means of the dye-reaction tests ingeniously devised by Dr Shepherd .. were negative, but a recent repetition gave in one case a distinctly positive reaction. This together with the entire syndrome of concordantly favourable indications .. leaves no doubt … of the vapours being constituted of the per- and poly-sulphides of hydrogen.' Perret ruled out the presence of selenides, as these would have had a 'strong odor of garlic' and would probably be 'so extremely toxic as to be fatal to observers'.

Perret returned to Martinique on 4 November 1935; and then, in a pattern that Baynes had already noticed, managed not to be on Montserrat when it was struck by the largest earthquake during the crisis, on 10 November. This moment was decisive, as the damage was extensive across the island both to properties, and to the roads, embankments and bridges.[18] Unlike most of the local earthquakes, this event was felt more widely, causing damage on Antigua, landslides on Redonda, and notable shaking on St Kitts (Perret, 1939; Robson, 1964). It was the largest earthquake felt on Montserrat for the entire 1933-1937 sequence, and was sufficiently strong to leave a record on Perret's experimental seismeter,[19] with a trace that suggested a source north of Montserrat (Perret, 1937b). The event was detected world-wide, and the epicentre was later refined to a location close to Redonda (Powell, 1938; Perret 1939; Niemz and Amorèse, 2016). Following this earthquake, local seismicity continued. Perret returned in haste in early December, and sought to reassure the Commissioner that even when he was not on island, there was now a monitoring system in place: 'Besides mercury baths in strategic positions, which would indicate earth tremors between shocks (indicating any rise of magma), there is a working, recording Thermograph at Gages soufrière, a seismeter installed at Gages estate, and an ultra-sensitive Microphone at the soufrière connected by wire with the always inhabited estate.'[20]

On 6 December 1935 Perret noted that a small but prolonged earthquake shock was 'immediately followed by a sudden and great increase in the emission of gas from the vents'. Perret, who was taking a siesta at the hotel in Plymouth, felt a 'great wave of gas', that swept by three to four minutes after the earthquake shock. In contrast to his expectation - that gas pressure might increase prior to a shock - this example of gas emission following a shock

alarmed Perret sufficiently that he wrote in confidence to the Commissioner.[21] As it turned out, this was the only example of such a phenomenon that Perret noted during the crisis (Perret 1939, p 28). The description of the phenomenon suggests that this event might also have been a phreatic explosion, similar to the events experienced by Perret in February 1935.

By autumn 1935, Perret had installed a system for monitoring that could be maintained by the Curator and staff of the Grove Botanical Station; but his Carnegie funding was now exhausted.[22] Perret returned to Martinique, but remained 'on call' in case of emergency. Perret took very seriously his formal role as volcanological adviser during 1934-1935. He was motivated by a desire to diagnose what was happening, and to provide advice to the Commissioner on the implications for the island, and built a good rapport with Baynes - providing reports before he left at the end of each of his many visits; and responding quickly to urgent requests for information, reassurance and return visits. Perret's conceptual understanding of the nature of the crisis, and how he could track it, was driven very much by what he could see - and without any prospect of having a seismometer on island at an early stage, he looked for ways to automate measurements (thermograph); and to monitor subterranean activity remotely (microphones, connected into the telephone system). But while Perret had the confidence of the Commissioner, his short visits to the island, his ill health and advancing years provided little reassurance to the members of the executive and legislative council that the crisis was being appropriately managed. On Montserrat, the Curator and his agriculture department team were continuing to help install, maintain, repair and calibrate instruments, and make field measurements, but with no one on the island able to respond immediately to the question of whether or not the continuing tremors and gas emissions pointed to 'some pending major calamity' the anxiety of both the executive council, and the wider population continued to increase. Recognising the heavy reliance on Perret's expertise and presence to provide assurances about the likely trajectory of the seismic crisis, the Commissioner reinforced his requests to the colonial office for additional support throughout September,[23] and prominent business leaders and council members petitioned the Secretary of State for the Colonies, via the Commissioner, to seek expert assistance.[24] Meanwhile, expenditure on repairs to buildings, roads and bridges was mounting up, first due to the May 6th earthquake; and then again following the damaging earthquake of November 10th.[25,26]

With the continued earthquake activity of late 1935, the Curator and his team put in place a regular pattern of systematic reporting. Weekly 'brief seismo-volcanic reports' were completed by the Curator, with routine information on the general conditions, dates and times of tremors recorded at Grove, and reports on the smell of gas in Plymouth, and the temperature readings on the Bristol thermograph and hand thermometers.

The Royal Society Montserrat Committee and Expedition

In the early stages of the seismic crisis, in 1934, the Governor of the Leeward islands made contact with the Colonial Office in London, to seek advice on how to respond to the increasing numbers of earthquakes, and the detectable changes in gas emissions. The Colonial Office turned to Francis Whipple, a mathematician, meteorologist, seismologist and Superintendent of the Kew Observatory, to follow up. In his role as Superintendent, Whipple was well connected within the meteorological and seismological communities: the observatory was home to the meteorological office, which was in turn part of the Air Ministry; and it was also the hub for British seismic monitoring, after the closure of the Eskdalemuir seismograph station in 1925 (Rose, 2021). Whipple was also prominent within the British and international seismological communities, from his role as chair of the seismological committee of the British Association[27], and he had extensive practical knowledge of operating seismometers from his work at Kew.

By early May 1934, Whipple had written a short report[28] on the seismicity, and gas emissions, and outlined a plan by which two or three seismologists with suitable equipment might be able to determine the focal depths of the earthquakes, and thereby determine whether or not the volcanic system was reviving. He had also examined the statistical patterns of the earthquakes from January to April 1934, and concluded that there was no evidence for a link between the date of a full moon, and the seismic activity; a different interpretation from Perret's. From May to July 1934, Whipple reached out to colleagues in the Air Ministry, the Air Defence Experimental Establishment, the Chemical Defence research department of the UK War Office, and at various universities, seeking information ranging from rainfall at particular locations on Montserrat, to seismological data and practical defences against noxious gases, like H_2S.[29]

Whipple remained the main point of contact for the Colonial Office for the rest of 1934, and into 1935. Following the damaging 6 May 1935 earthquake, the Governor of the Leeeward islands once again telegraphed the Colonial Office about conditions on Montserrat. The Colonial Office instructed the national committee on geology and geophysics, chaired by applied mathematician Sydney Chapman, to assess the evidence and advise on the best course to follow. Fortunately, Whipple was the chair of the seismology and volcanology subcommittee, and he took the opportunity to convene a meeting to discuss events in Montserrat in July 1935. In advance of this meeting, he updated his memorandum on the earthquakes on Montserrat, acknowledging the observations that Perret was

already making, but identifying the need for seismological observations on Montserrat and neighbouring islands to better constrain the origins of the volcanic earthquakes.[30] The committee approved the proposal that two 'Wood-Anderson' seismographs (Anderson and Wood, 1925) should be set up on Montserrat, and operated by the Agricultural station. They also noted that Perret should continue to be supported in his work, but that the Caribbean lacked a network of seismic stations, and also lacked a government geologist. The proposal was endorsed by Arthur Day, president of the Geophysical Laboratories of the Carnegie Institution where Perret held an associate position, who was passing through the UK that week. Day also endorsed the suggestion that the Wood-Anderson seismographs would be fit for purpose; perhaps not a surprise, since he had supported the original development of these instruments, and Carnegie held the patent for the design.

Whipple explored avenues for funding the proposed work with Chapman, and with John Flett and Bernard Smith – the outgoing and incoming directors of the geological survey. Flett and Smith were clear that the geological survey would be willing to provide staff for an expedition, if the Colonial Office would pay for it. Flett was particularly supportive of the idea of an expedition, given his experience in 1902 when he had visited the Eastern Caribbean in the aftermath of the eruptions of Mont Pelée and the Soufrière, St Vincent (Anderson and Flett, 1902). Whipple continued to work on an equipment budget, and gathered quotes for the building of the instruments. He also followed up with seismological assistant Ethel Bellamy at the University of Oxford's Observatory, to see if they had any reports from the international network of seismological stations regarding the larger earthquakes felt on Montserrat on 14 May 1934 and 12 December 1934; they had not.[31]

By early December 1935, the national committee on geology and geophysics had a proposal for the Royal Society to consider: that there should be a scientific expedition to the West Indies, organised by the Royal Society, and that it should comprise a geologist and a seismologist, each of whom should spend three months making observations on Montserrat 'to investigate its geological structure, to determine whether the report of the existence of an old crater there is well-founded, to examine the source of the seismic disturbances … and to make other geophysical studies in the West Indies that may throw light upon the nature and development of the disquieting volcanic phenomena on the island.'

It was also suggested that the 'initial equipment of the seismologist should include four shock recorders, to be set up at different points on the island; a vibrograph; and a pair of suitable seismographs with the necessary auxiliary equipment including a good clock'. The equipment list had been put together by Whipple, based on his practical experience operating seismographs at Kew; but now with the inclusion of a Wiechert 2-component seismograph in

place of the Wood-Anderson instruments. Since the Wiechert instrument records the passage of seismic waves by the physical motion of a needle across a smoked disc, and could operate in daylight, it was recognised that this would be easier to operate than a seismograph that recorded an optical trace onto photographic paper, which would need a dark cellar or darkroom.[32]

The Royal Society duly convened a 'Montserrat Committee' to oversee the expedition, chaired by Chapman, with Flett and Smith (Directors of the Geological Survey); Harold Jeffreys, a mathematical geophysicist, and Whipple. News of the planned Royal Society expedition was reported to the Commissioner in early February 1936 'What a pity they did not begin this at the very commencement of these troubles!' Perret commented to Baynes, in which he explained that his funding and therefore plans were still uncertain.[33]

The two scientists who accepted the Royal Society's invitation to join the expedition were Archie MacGregor, a geologist employed by the Geological Survey; and Cecil Powell, a physicist from the University of Bristol. Powell was called up just two weeks before sailing, after the Committee's first nominee, A W Lee from Kew Observatory, withdrew for health reasons,[34] and their next, Edward Bullard, declined due to pressing commitments.[35] At the meeting of the Montserrat Committee on 21 February, 1936, it was also reported that Sir Gerald Lenox-Conyngham, geodesist and surveyor, had been asked by the council of the Royal Society to visit Montserrat towards the end of the expedition to supervise the seismological work; and that American volcanologist and director of the Hawaiian volcano observatory Thomas Jaggar had been invited by Lenox-Conyngham to visit Montserrat at the same time, to share his expertise (Jaggar 1956, p156). Jaggar had ample experience of working on degassing volcanoes in Japan and Hawaii, which was relevant to the episodes of hydrogen sulphide release from the soufrières, and the impacts of the gas 'sickening and alarming' the residents of Plymouth (Jaggar, 1956). Jaggar made arrangements to travel from Honolulu to Montserrat with his wife, Isabel (nee Maydwell) who had worked with him on Hawaii for many years, via the Panama canal, and the volcanic islands of Saba and St Kitts (Jagger 1956, p 157; Dvorak 2015).

MacGregor arrived on Montserrat on 9 March 1936 after crossing the Atlantic on the steamer '*Venezuela*', and was met at the port by Gomez, the curator of the Grove agricultural station. MacGregor's task was to evaluate the geology of the island, and the nature of any volcanic craters and the soufrières. Over the next three months he covered much of the island by foot, on horseback and by car. MacGregor published his preliminary report and geological map, including a map of the soufrières, and formally recognised the volcanic crater first described by T Savage English, in 1936. The full report of his work was published in 1938 (MacGregor, 1936; 1938).

Powell sailed on the *Ingoma*, and arrived on Montserrat on 21 March, where he too was met by Gomez. Powell's brief was to determine the locations of earthquakes, and to see whether the earthquakes and related phenomena were changing with time. To do this, Powell was going to construct a network of shock recorders, which he would then leave running until the crisis was over. By the time that Powell arrived on Montserrat, all of the equipment ordered on behalf of the Montserrat Committee had been delivered to the Grove, so Powell spent his first few days assembling the shock recorders and the Wiechert seismograph. He also met up with English, who was still collating the records of the ongoing shocks on Montserrat.

The Jaggar shock recorders – named for their inventor, Thomas Jaggar - were designed to work in a single orientation. Powell started with four that operated in a horizontal plane and one in a vertical plane (Jaggar 1929; Powell, 1938); these had been built on Whipple's instruction at the Kew Observatory. Each instrument took some time to set up, calibrate and refine, but Powell had all four instruments working in the Grove by March 25th. Initially, they all had a period of about 1 second. Powell's plan was to locate the shock recorders in different parts of the island, and to use the spatial variation of the maximum amplitude recorded for any particular shock to infer the approximate focus of the event. The Wiechert was a more complex two component seismograph, and was both more sensitive and much larger than the Jaggar instruments. To complicate matters, the instrument had arrived from Germany in nine boxes without an instruction manual. Powell's initial plan was to set up the Wiechert temporarily in a building in the Grove, while searching for a more suitable location and building to house it: locations including 'Wilson's hurricane shelter' and an 'old house in Richmond'. In the meantime, Powell found that the sensitivity of the Wiechert posed a challenge, as it was very sensitive to local shocks, and shocks arriving with a strong vertical component would throw the pens off the recording paper. The heavy weights used in the Wiechert mechanism also risked the safe running of the instrument. Powell dismounted the Wiechert after assembly once he realised that it was at risk of overbalancing during a strong shock, and waited until he could locate it in a building where it could be bolted to the floor. Mr La Barrie, who was in charge of the Public Works Department and superintendent of the telephone system, agreed to build a concrete shelter at the Grove to house the Wiechert.[36] This work was completed in July 1936, and in the interim Powell re-erected the Wiechert in a shed with a 2-inch thick concrete floor at the Grove, so that he could continue gathering measurements.

From April to June, Powell experimented to find the best locations for the long-term installation of the network of shock recorders, and also for the installation of some sound-ranging equipment (Fig. 5, Fig. 6). He first installed the horizontal Jaggar recorders in pairs at the Grove from 26 March - 20 April for tests, and then moved them to

different sites around the island to assess the sensitivity of the instruments to local shocks. The shock recorders had limited time-resolution, unlike the clock mechanism on the Wiechert seismograph, so Powell was restricted to measuring the maximum amplitude associated with any given shock at a particular location. Perret gave La Barrie permission to build a concrete pillar inside the Lower Gages hut, as a location for one shock recorder, and by mid-May Powell had a more-or-less complete instrument network, with each shock-recorder under the care of an individual house or estate owner: Olveston (Mr Shand); Gages (Mr Howes); Paradise (Miss Griffin); Bethel (Mr Penchoen, Jnr, later replaced by Mr Barzey) and St John's (Mr Daniel). A sixth instrument was placed at O'Garra's on 22nd July, under Mr Shand's care. Powell also set up sound ranging equipment, with a generator, batteries and an instrument installed at Cocoanut Hill Hotel, connected by telephone wire to microphones at the Hotel, Grove and Gages.

In early May, MacGregor took a short break from his geological investigations on Montserrat to visit Perret on Martinique, and the recently active volcano of Mont Pelee. He returned from Martinique to Antigua with Perret on a seaplane before catching a local boat back to Montserrat. Meanwhile Perret waited on Antigua for the arrival of the Jaggars: Perret and Jaggar had first met on Vesuvius in 1906, and had subsequently worked in the field together on Hawaii, and at Sakurajima, Japan. From 16 – 19 May, Thomas and Isabel Jaggar and Frank Perret joined the Royal Society expeditionary team of Powell and MacGregor, and toured the island and the seismic instrument network. Perret then headed back to the US; while the Jaggars departed on a short visit to St Vincent, an island that Jaggar had first visited in the immediate aftermath of the May 1902 eruption.

On Montserrat, the curator and his team continued to take responsibility for writing the formal weekly brief seismo-volcanological reports on the seismicity and the state of the soufrières. The new Bristol thermograph continued working at the Lower Gages, but the corrosive environment took its toll: it needed a repair to the winding key in May, and started to show other signs of wear. In June 1936, the acting curator Schouten reported that the disk had stopped rotating, and the ink in the marker clogged and needed cleaning. No further thermograph temperatures were reported after June 1936.

With the shock recorders in place, Powell now turned his attention to measurements of the gas emissions. Jaggar had brought with him some gas sampling apparatus, including some evacuated gas collection tubes and some glassware. Whipple, on the Royal Society's Montserrat Committee, had also recommended that Powell take some equipment for SO_2 detection, as described in a Department of Scientific and Industrial Research report (Ellis,

1931);[37] and an atmospheric sulphur recorder, designed by air pollution specialist John Switzer Owens, who was known to Whipple through their air ministry and meteorological office work. The Owens recorder was a hand-pumped suction apparatus, which could be modified to draw a known volume of air through lead acetate-impregnated filter paper (Bilham, 1932).[38] If hydrogen sulphide was present in the air, the filter paper would darken with the formation of lead sulphide, and the concentration of H_2S in air could be determined by comparison of the intensity of the spot to some calibrated spots. Truesdell (1930) had verified the efficacy of this technique as a spot test for low concentrations of H_2S in gas.

Powell's first attempts at making measurements in Plymouth were disappointing '150 pumps doesn't give visible trace. Felt pretty bad.' But his field tests with Schouten, Maloney and Kelsick at Lower Gages soufrière on 30 June were much more successful - recording an H_2S concentration of '1 in 10,000' (100 ppm) by the thermograph station. From this point on, the suction test became a part of the routine observation of the soufrières, with measurements taken across a range of locations both close to and distant from the gas and steam vents. The weekly report of 2 August 1936 was the first to report the use of lead acetate / suction pump measurements of H_2S in the gorge around the Gages soufrière.[39]

In early July, Sir Gerald Lenox-Conyngham arrived to mark the conclusion of the Royal Society expedition. He met the Commissioner on arrival, and then spent a week touring the island with Powell, developing plans for the hand-over of the responsibilities for ongoing monitoring from the Royal Society to the Government of Montserrat, and gathering materials for his summary report to the Commissioner. On 18 July, the Wiechert seismograph was moved and re-assembled in the new purpose-built building at the Grove, which was designated to be the centre for seismic observations. Haddon Shand, of the Montserrat Company, and E P Maloney, the Cotton Officer at the agricultural station, were both trained by Powell in the maintenance of this instrument, and a 'youth' (Ian Kelsick) was formally employed as Clerk in charge of the Volcanological Instruments. Kelsick was tasked with routine maintenance of the instruments, the smoking and fixing of the disks for the Jaggar shock recorders, and the paper for the Wiechert instrument. Arrangements were also put in place to pay for the annual costs of methylated spirits and other consumables used for fixing disks, and for the regular shipping of disks and paper records to the Royal Society in London (Appendix 4). The weekly report of Tuesday 25th August 1936 was the first signed off by Kelsick.

Powell and Lenox-Conyngham left the island on 24 July. Before departure, Powell ran a briefing session for the observers who would be involved in the collection and distribution of shock recorder charts, and for the care of the

instruments. Shand committed the Montserrat Company to purchase two further Jaggar shock recorders, to augment the seismic network. To all intents and purposes, by July 1936 Montserrat had a functioning and fully-staffed seismo-volcanological observatory; and an instrumental network that was the first of its kind in the English-speaking Eastern Caribbean. It wasn't until 1995 that a similarly extensive network was once again installed across the island of Montserrat (Shepherd et al., 2002; Kilburn 2024).

In his parting report[40] Lenox-Conyngham provided the commissioner with a synopsis of the main outcomes of the Royal Society Expedition, and some recommendations for the continuous monitoring of volcanoes in the Caribbean. His report was clearly influenced by reports from Jaggar and Perret, and discussions with Powell in the field.[41] Lenox-Conyngham's view was that continuous observation would allow rapid detection of renewed activity in the volcano. 'If there is a renewal what is then to be done? So far as earthquakes are concerned, nothing can be done beyond a gradual replacement of all buildings that have suffered injury .. by others more adapted to tolerate such shocks'. He also reflected on the hazard posed in the case of a future eruption, commenting that 'In the event of an eruption being threatened the only secure course is flight. Judging from the sketch map, based on the hydrographic surveys of 1867, the whole of the island to the north of the Central Hills appears to be quite out of reach of any danger from an eruption in the Soufrière Hills. .. The first essential .. is a good contoured map on a scale of about 3 inches to 1 mile. A request for assistance to the Colonial Office would be sure to receive sympathetic consideration.' His conclusion was explicit: 'it is of the utmost importance that the behaviour of this volcano should be watched continuously for many years, if not for ever, and it seems to me that the governments of volcanic islands should put the organisation of this sort of continuous observation among its foremost duties to the population'.[42] Jaggar (1937) echoed the same points in his report, adding that the need for 'collection and analysis of the gases which are emitted at the soufrières - can only be done by visiting the place of emission, involving considerable labour and expense'.

Cecil Powell and earthquake locations

Powell's main objective in creating a network of shock recorders was to use the data from detected earthquakes to locate the earthquake focus. With the instruments that were available at the time, Powell recognised that he would not be able to distinguish the records of P and S wave arrivals from local events, since they would be too closely spaced in time to resolve. On the boat returning from Montserrat to the UK, Powell approximated the foci of the fifty events that he had recorded on the network between April and June 1936[43]. To do this, he used the simplifying

assumptions that the earthquake foci were point sources, and that the amplitude of the seismic waves diminished inversely with distance from the focus. He neglected topography, assumed that crust through which the waves passed was uniform and, finally, assumed that the instruments all had an equivalent response. Powell then used the relative amplitudes recorded across the network for each event to determine the focus, and epicentre. His provisional distribution of epicentres (Powell, 1937) showed a broad distribution of events across the centre of the island. Once back in Bristol, Powell updated his analysis of earthquake foci by using data from newly detected events which were reported by Kelsick (about 200, by July 1937). He also used the known orientations of both the shock recorders, which were mainly fixed to the inside walls of hurricane shelters, and the observations from the more sensitive and 2-component Wiechert seismograph, to refine his assessments of where the earthquake shocks had originated. Powell deduced that there were several regions beneath central Montserrat where the earthquakes were being generated (Fig. 7); and that these locations were at shallow depths, and that events produced in each focal region were 'strikingly similar' (Powell 1938).

1937-1938

Seismicity and activity at the soufrières continued to diminish through 1936 and 1937, but the routine work of the seismo-volcanological observer was now embedded in the activities of the Agricultural department. Kelsick, the clerk of the volcanological instruments, continued to make weekly visits to Gages and monthly visits to other soufrières, as well as recording earthquakes, maintaining the seismic network and preparing and fixing the recording charts for the various instruments.

Routine gas monitoring now included quantitative colourimetric analysis of H_2S at various points within the gorge, using the suction pump and lead acetate-impregnated filter papers, and collection of gas in vacuum tubes once a month at two soufrières for analysis back in England. The inspector of roads and telephones, La Barrie, was still installing new telephone lines for dedicated data collection late in 1936, connecting microphones at Gages and Rose Hill back to the Cocoanut Hotel; and from Richmond to Dagenham.[44]

Perret's re-purposed thermograph was now also providing routine air quality measurements from the grounds of the Cocoanut Hill Hotel or later, the Grove 'volcanological station', which were also reported in the weekly bulletins. In December 1936, Perret had converted the refurbished thermograph, which had once again failed due to corrosion, so that it would instead record 3-hourly exposure to ambient hydrogen sulphide, on lead acetate-treated paper charts for a week at a time (Fig. 8). Perret had tested the modified instrument at Gages, and then

located it within a wooden box, in the grounds of the Cocoanut Hill Hotel for continuous measurement. The measurements were qualitative, as the technique was not calibrated, but the intensity of the discolouration of the disks was clearly associated with episodes of elevated H_2S in Plymouth, based on the noxious and unpleasant smells noticed by observers. The observations from the weekly and monthly reports show that fumigation events often coincided with periods of low wind, and often lasted for a few days with peak concentrations overnight (Fig. 9).

At the end of 1937, the Royal Society Montserrat committee disbanded, and requested that the monthly reports should now go directly to Powell, who had returned to his post of Lecturer in Physics at the University of Bristol. By 1938, the seismic crisis was essentially over, but the seismo-volcanological observatory and the monitoring network continued to function - it now comprised 7 horizontal Jaggar shock recorders and the Wiechert seismograph (Fig. 6). The impact of hydrogen sulphide on air quality in Plymouth remained a persistent problem, with occasional 'intense' fumigation events every month. In response to an emerging seismic crisis on Dominica in late 1937[45], Perret took his seismeter from Gages estate, but arrived too late to record any strong shocks. The Royal Society also requested permission to redeploy four of the Jaggar instruments to Dominica, to monitor the crisis; and the Governor of the Leeward islands wrote to the Presidencies of the islands asking if they might each wish to subscribe to the costs of maintaining a regional seismic network, so that they might be better prepared to respond to future crises. Antigua, St Kitts and Nevis were all opposed to incurring any additional expenditure, and the proposal stalled.

Frank Perret and gas monitoring

By the time that he first visited Montserrat in 1934, Perret was proficient at sampling high temperature volcanic gases and fluids, and was familiar with wet chemical techniques for the detection and quantitative analysis of specific gaseous chemical species, and of techniques that could be used to measure exposure to ambient gases, for example based on surface reactions of indicator chemicals on photographic papers. Perret had developed his expertise in this area during his many visits to Vesuvius, between 1904 and the 1920s; and during fieldwork in Hawaii (1911), at Sakurajima (1914) and on Martinique (1929-1932).

On Vesuvius, Perret distinguished 'primary' fumaroles - fed by hot gases or fluids from within the volcano, and 'secondary' fumaroles developed on cooling lava flows. He had collected gases and condensates using an aspirating pump and glassware, and fumarole salts, each of which were analysed later by laboratory chemists. Perret was

adamant that the 'sensitiveness of the nose, if trained to distinguish slight differences' could be used effectively to detect gas species including HCl, SO_2 and H_2S in the field (Perret, 1924, p 135). Perret claimed that he detected SO_3 at Kilauea using his nose. To confirm these observations at Vesuvius, Etna and Stromboli, Perret used wet chemical tests with reagents including silver nitrate solution (for HCl); lead acetate solution (for hydrogen sulphide); lime water (for CO_2), and 'Casoria's reagent' for SO_2.

After working on Martinique and Montserrat, Perret also distinguished between 'crateral' soufrières or solfataras - driven by exhalations from a magmatic conduit system, and those formed in volcanic regions 'which are inactive at the surface, but where meteoric water has infiltrated to still-heated subterranean strata'. Perret recognised that this second type of soufrière was particularly common in the Caribbean volcanic islands, and that those on Montserrat were 'inconveniently activated' during the 1933-1937 volcano-seismic crisis (Perret, 1950; p 97). On Martinique in the 1930s, Perret was not able to do much gas and fluid analysis around Pelée: the old (accessible) soufrières were cool, while the new ones were not accessible (Perret, 1938). He attempted to detect the presence of gases in passing *nuee ardentes* on a couple of occasions, but in the absence of any equipment he simply used his sense of smell to infer that there were minimal levels of HCl and SO_2.

On Montserrat, Perret used a suite of instruments for monitoring the soufrières, including a manometer for gas pressure and a microphone and tuning fork for the 'pitch' of the steam vents. He also collected gas and water samples for analysis by his colleague E. S. Shepherd at the Carnegie Institution, and used a variety of diagnostic field tests for particular gas species. Perret and Shepherd had first worked together on Hawaii in 1911, along with Jaggar (Shepherd, 1927).

Jaggar was impressed by Perret's pioneering work on Montserrat, not least because at that time there were still 'no good techniques for the continuous study of gases, sublimates and temperature' in volcanic systems. It is clear that both had discussions on how to take the sampling further, and to automate the processes of continuous sampling for both temperature and trace gases, while they were both on Montserrat and Martinique.[46] Following Jaggar's departure, Perret modified his corroded 'Bristol thermograph' to create the first continuous air quality recorder for ambient exposure to H_2S in Plymouth.

1939 - 1946

Following the start of the war in 1939, monitoring efforts were gradually scaled down. From February 1940, visits to Gages soufrière became monthly, and those to Galways and Roches quarterly. The last three Jaggar shock recorders were mothballed, but the Wiechert seismograph continued to operate, and the seismic charts were still bundled up and sent quarterly to the Colonial Office in England; several missing batches in 1942 and 1944 were chased up, but 'presumed lost in transit due to enemy action'.

The technical and administrative duties of the seismo-volcanological observers didn't diminish as the network contracted, since the Wiechert seismograph and its clock system needed careful attention, maintenance, and routine sensitivity tests and calibration. The 'war-time dry batteries' proved to be an unreliable source of electrical power for the instruments, and the wear of some instrument parts was problematic since the seismograph had been manufactured in Germany, and spare parts were not available. In time, Kelsick was replaced by other seismo-volcanological observers: his brother Cecil Kelsick stood in first, while Kelsick returned to his cotton duties; and later by Wilfred Barzey, from 1942-1943 (perhaps the same Barzey, who looked after the shock recorder at Bethel), and JPE Teisheira from February 1944 (Table 3). In March 1944, Greta Scotland began as an assistant seismo-volcanological observer, and by December both Teisheira and Scotland were named as seismo-volcanological observers, and both signed off on the monthly reports. Greta Scotland's role covered 'most of the seismological work at the Grove', while 'Mr Teisheira visits the soufrières'. To our knowledge, Greta Scotland was the first woman employed as a seismo-volcanological observer on Montserrat.

In late December 1945 and early January 1946 seismicity was felt across St Vincent, following a large earthquake on December 23rd. In response to urgent requests from the Administrator, two of the mothballed Jaggar seismometers were shipped to St Vincent for deployment in mid-January. 'It is assumed that Mr Nanton or Mr Schouten will know how to assemble and operate these instruments' wrote Bassett, the Agricultural Officer.[47] These instruments would complement the single Jaggar instrument that was then running in Kingstown.

In April 1946, the authorities on St Vincent asked if they could also use the more sensitive Wiechert seismograph from Montserrat as a part of their monitoring efforts. With the agreement of the Commissioner, Mr Shand oversaw the taking down of the seismograph in May 1946, and its transfer to St Vincent. This was a challenging task - the instrument was both very sensitive, and once packed up in nine boxes weighed over one tonne. The Agricultural Officer on Montserrat was adamant that the shipment would need very careful handling, and by the time it was finally shipped to St Vincent in late June 1946, it was carried on a direct boat, the SS Cartier Park, with strict instructions that a 'responsible officer' should board the steamer in St Vincent to supervise the unloading.[48] There

is no record in the Montserrat papers as to what happened to the instrument after shipping; but it presumably arrived safely as the Administrator for St Vincent authorised payment of the shipping costs (timber, rope, porterage, freight and tax) to the Government of Montserrat in August 1946. There are no records of what happened to the Wiechert after arrival in St Vincent; but there is certainly a suggestion that the instrument did not arrive at its intended destination - whether due to damage in transit, or the complexity of the reassembly, is not known (Latchman et al., 2012). The Colonial Office were informed that there would be no more shipments of charts, now that the network had been disbanded, and there was once again no working seismograph or shock recorder on Montserrat. We have no records of when the air quality measurements in Plymouth ceased.

Aftermath

In September 1946, the Executive Council on Montserrat received a copy of a report written by Dr Alfred Senn, geologist with the British Union Oil Company in Barbados, of a field visit to St Vincent during the phase of unrest in April 1946.[49] Senn had been sent by British Union Oil, in response to a request for assistance from the Colonial Office's Comptroller for Development and Welfare. Senn's report documented the phenomena associated with volcanic unrest on St Vincent, and made recommendations as to the phenomena that should be routinely measured, observed and documented at restless volcanoes. Senn also recommended that a 'volcanologist-geologist could be considered for the entire volcanic arc'.

Members of the Montserrat executive committee took Dr Senn's report to heart realising, too late, that they had overseen the dismantling of the Caribbean's first seismo-volcanic observatory. They resolved that arrangements for the Jaggar shock recorders 'be put into use again at the Experimental Station'; and several commented further on the report.[50]

[Hon J R Wilson] 'it is a pity that the detailed and continuous recording by Jaggar shock recorders has been given up in Montserrat. MacGregor and Powell both stressed the importance of observations being continuous in ALL the islands'

[Howes] 'Read with interest, and I fully support the opinion that a big mistake has been made in failing to carry out the professional and scientific advice of the Royal Society's mission'

[Hon W E Bassett] 'It looks as if we need the Volcanologist .. to come and give us a fresh start with the keeping of useful records'. The minutes noted that 'HH' (the Commissioner) would follow up, but it is not clear what further actions if any did follow beyond this.[51]

Legacy: unrest and monitoring on Montserrat, 1946-1995

After the short-lived unrest on St Vincent in 1946, the next volcano-seismic swarm struck the islands of St Kitts and Nevis in 1950-1. British geophysicist Patrick Willmore was sent out on the instruction of the Colonial Office, and arrived in time to catch the tail-end of the activity (Willmore, 1952), to deploy some of his newly-designed short-period seismometers (Willmore, 1950). This time, his call to put in place capacity for monitoring seismic and volcanic activity across the islands of the Eastern Caribbean was successful. Within a year the Volcanological Research Department had been established in Trinidad, staffed by Geoff Robson; and Robson and Willmore began a programme of systematic investigations of the volcanic systems of the English-speaking islands of the Eastern Caribbean. One early project was a survey of the heat outputs from the soufrières of the region in 1952 - 1953, using an inverted steel drum and manometer to estimate heat fluxes from the steam vents (Willmore 1952; Robson and Willmore 1955). By 1953, soufrière activity on Montserrat was greatly diminished, and Lower Gages soufrière was almost inactive. (Willmore 1952; Robson and Willmore 1955).

The next sequence of felt earthquakes on Montserrat began in early 1966. The Seismic Research Unit responded by installing a network of four short-period seismographs ('Willmore type'): one at Grove Agricultural Station in March 1966; the others at Salem, Farrell's and St Patricks in April 1966. There were no other seismographs on island. The network was augmented with a set of wet tilt meters. From May 1966 to the end of 1967, the short period seismograph network detected 723 local earthquakes, of which 32 were reported as felt on the island. Hypocentres were determined for 189 of these earthquakes, and most of these lay in a WNW to ESE belt beneath the Soufrière Hills, at depths of less than 15 km (Fig. 7).

Similar to the patterns observed by Perret in the 1930's, maxima in rates of seismic energy release were seen in May and November 1966 and 1967 (Shepherd et al., 1969; Shepherd et al., 1971; Kilburn, 2024). During this phase of unrest, Galways soufrière showed an increase in activity, and there was no change detected at Gages Upper or Lower soufrières. During 1966/7, the unrest in Montserrat was closely monitored, with SRU staff serving several tours of duty until activity subsided (Latchman et al., 2012).

After the seismic swarm had ended, the portable seismographs were removed, and from 1968 - 1980, seismicity was monitored with a single, short-period vertical station which was located at the Grove. In 1980, this was upgraded to an instrument located at St George's Hill, which connected by telemetry to Trinidad, via Antigua (Shepherd et al., 2002; Smith 2013). This was augmented with a network of dry-tilt stations which were remeasured annually. There was no regular monitoring of the soufrières (Wadge and Isaacs, 1988). Following a large tectonic earthquake near Redonda in 1985, lots of aftershocks were detected on Montserrat in 1985-6, and SRU installed two new stations on Montserrat in 1989 to help distinguish the aftershocks from any local earthquakes. This network was damaged by Hurricane Hugo in September 1989, and the network was eventually re-instated in 1992 (Smith, 2013).

From 1992 to 1994, there were occasional swarms of local volcano-tectonic earthquakes at depths of 6-15 km (Aspinall et al., 1998; Robertson et al., 2000; Shepherd et al., 2002; Kilburn 2024). Persistent unrest began in January 1995, with seismicity at depths of less than 6 km, recorded by a network of between five and eight short-period seismometers (Aspinall et al., 1998). Earthquakes occurred in similar regions to those observed in the 1930's and 1966-7 (Fig. 7), focussed in two regions, one extending beneath the Soufriere Hills; the other beneath St George's Hill, about 4 km to the NW (Aspinall et al., 1998). In the lead up to the 1995 eruptions, there were no significant changes noted in the temperature or compositions of the four main soufrières at Galways, Tar River or Upper and Lower Gages (Chiodini et al., 1996; Boudon et al., 1998; Hammouya et al., 1997), and no sulphur dioxide was detected at any stage before the magmatic eruption began. Early phases of activity in July 1995 were phreatic in nature, and ejecta included prominently samples of hydrothermally-altered materials (Boudon et al., 1998).

Discussion and Conclusions

As we have shown in this paper, the 1930s saw the establishment of the first volcano-seismic observatory in the English-speaking Caribbean. The success of the Montserrat observatory required four ingredients:

(1) An engaged and aware agricultural department, which was able to take responsibility for observing and reporting on the state of the soufrières and for the recording of earthquake shocks.
(2) Frank Perret's response to the call for assistance; his proximity to Montserrat, and his ability to make return visits and report effectively on his observations was an important element in supporting the capacity of the staff of the agricultural department to make a suite of regular, routine measurements;

while his experience and his notable successes in explaining and anticipating events was an important reassurance to the Commissioner in terms of the management of the crisis. Perret's expertise as a field volcanologist and his experience in setting up field stations for continuous observation of active volcanoes was a key element of his response to the extended events of 1934-7.

(3) An experienced and well-connected scientist in charge of the day-to-day operations of the meteorological and geophysical observatory at Kew, Francis Whipple, who recognised what would be required locally and long-term to assess the state of the volcanic system on Montserrat, and to characterise the nature of the unrest.

(4) The final element was Cecil Powell, of the Royal Society expeditionary team, who took on the practical challenges to establish an instrumental network that could run under local supervision, and form the backbone of a long-term monitoring system. By ensuring that he had buy-in from key individuals on the island – notably Haddon Shand of the Montserrat Company, and Mr Howes of Gages' estate – who were competent to oversee the maintenance of the instruments, and in positions of authority (both were on the legislative or executive councils), Powell ensured that the observatory elements would become, at least for a time, part of the institutional fabric of the island. Powell's close engagement in May 1936 with the two field volcanologists who both had practical experience of monitoring active volcanoes, and of setting up and running observatories, Frank Perret and Thomas Jaggar, certainly helped with the establishment of an integrated gas and air quality monitoring system on the island. Importantly, Powell, Perret and Jaggar all shared a commitment to training local observers to run the seismic and gas monitoring instruments, thus ensuring continuity after the departure of visiting scientists.

The relatively short-lived nature of the seismo-volcanological observatory in part reflects the institutional fragility of British colonial volcanology in this period which, at that time, had no professional or academic practitioners, and no experience of managing volcanic crises, other than in the aftermath of disasters – such as that on St Vincent in 1902-3 (Pyle et al., 1998; Barclay et al., 2022). In the absence of any volcanological leadership, either on Montserrat or back in the UK, once the Montserrat Committee had disbanded, decisions about whether to keep an instrumental network running devolved down to the balance between there being little activity to detect on Montserrat, compared to the need for re-deployment of instruments elsewhere (e.g. Dominica in 1937/1938, and St Vincent in 1946), so that it seemed something of a surprise to the Montserrat legislators only to discover too late, in late 1946, that they had dismantled the observatory almost by accident. The other reason for the short-lived nature of the observatory was the reluctance of colonial governments in particular to commit funding to long-term

observational systems and networks. Funding long-term disaster preparedness often could not compete with more immediate demands on government finances. The status of instrumental networks in the region therefore waxed and waned along with the occurrence of periods of volcanic unrest and quiet, with the effect that a stable system of monitoring seismicity and volcanicity across the region, and in Montserrat in particular, took many years to re-
795 emerge, despite the urgings of many of the scientists involved in the 1930s crisis.

Author contributions

This paper is a collaborative output from the 'Curating Crises' project. Conceptualisation: DMP, JB, MM, KP, EPJ, JS; data gathering (archives) all authors; manuscript outline DMP, JB, MM; manuscript preparation and review all authors.

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Data availability

Datasets derived from archival materials which we use in this paper are available on figshare: https://figshare.com/projects/The_first_seismo-volcanological_observatory_on_Montserrat/214351

Table 1 – Soufrières and Hot Springs on Montserrat, adapted from MacGregor (1938).

Name	Synonyms	History
Gages, Lower		First noted in 1897, after floods of November 1896. Sapper visited in 1903. Perret installed his field station here in 1934.
Gages, Upper		English reports that it appeared in 1843, perhaps after the great earthquake. Lively in 1897-1902 and 1933-1936.
Spring Ghaut		First noted 1933-36.
Galway's	The Sulphur, Galloway's, Roches and South	Nugent visited in 1810. Commercial sulphur extraction was attempted during 1836-1840.
Cow Hill	Tar River	Featured on 1830's sketch map; mentioned by Nugent 'on the side of a mountain 1 mile distant' from Galway's. English thought it was 'extinct' in 1930. Some activity in 1933-36.
New Cow Hill		First noted 1933-34.
Spring Ghaut		First noted 1933-36.
Mulcair		Active 1896-99, and 1933-6.

Table 2 – Reports of impacts of H_2S emissions outside the soufrières

Date	Location	Event
9 October 1934	Plymouth	Rapid tarnishing of clean brass and silverware before seismicity on October 5-8, 1934.[i]
2 - 3 November 1934	Plymouth harbour	Hull of a newly painted ship discolours overnight, with brasswork tarnished and the white hull turned dark brown.[ii]
18 Sep 1935	Gages Estate	'Mrs Howes has so far gauged very correctly the coming of strong conditions by the household silver turning an olive color.'[iii]
18 October 1935	Plymouth	'The smell of sulphur from the Gages soufrière has been very bad lately; early yesterday morning it had a suffocating effect for a short while.'[iv]
1935 (all year)	Plymouth	'The odour of the abnormally increased gaseous emissions from Gages' soufrière was at times nauseating and irritant, but generally speaking there has been little noticeable effect upon the inhabitants.'[v]
March, 1936	Plymouth	Discomfort to people in Plymouth. Canadian ship N S *Colborne* in port on 2nd. White hull badly discoloured by sulphide gases.[vi]
August, 1936	Gages	Silver at Gages house badly tarnished on Saturday night. Suction pump / lead acetate tests indicate increased concentration of H_2S at various stations in the gorge.[vii]

[i] MPL 82-158 360/34 117 Report by H L Manning 'Observations of the main soufrieres of Montserrat'

[ii] Perret, 1939 p 19. Perret may have mistaken the timing of this event (see March 1936). The white paint was a 2:1 mix of lead and zinc.

[iii] MPL 82-158 -- 175 f117 Perret to Baynes

[iv] MPL 82-158 -- 175 Baynes to Perret

[v] MPL 82-1801 Annual medical and sanitary report for the year 1935

[vi] Monthly reports of the Seismo-Volcanological Observatory, March 1936

[vii] Monthly reports of the Seismo-Volcanological Observatory, August 1936

Table 3 - Staffing of the Agriculture Department, Grove, Montserrat.

Curators and Assistants, 1934 - 1945	
ESA Chin, Assistant Curator	1934
C A Gomez, Curator	1934-1936
H L Manning. Assistant Curator	1934-1936
S A Schouten (Assistant, then Acting, then Curator)	1936-1941
W E Bassett (Curator)	1942-1945
Seismo- Volcanological Observers	
1936 – 1937, 1939 – 1942	Ian O Kelsick 'clerk in charge of volcanological instruments'
1937 – 1938	Joseph Jeffers, assistant
1938	Cecil A Kelsick (January – June)
1938	T H Kelsick, Jr (July)
1938	J A Hughes (August – December)
1941	S St A Meade
1942 – 1943	Wilfrid Osmond Barzey
1944 – 1945	JPE Teisheira
1944 – 1946	Greta B Scotland
April 1946	E Leverock

Source: MPL 82-158 – 175 Monthly reports of the Seismo-Volcanological Station

845

Figure 1 – Map of 1930's Montserrat, showing the locations of soufrières (labelled in italics, after MacGregor, 1938), selected estates and other locations mentioned in the text. Base map adapted from Rothenberg (2021).

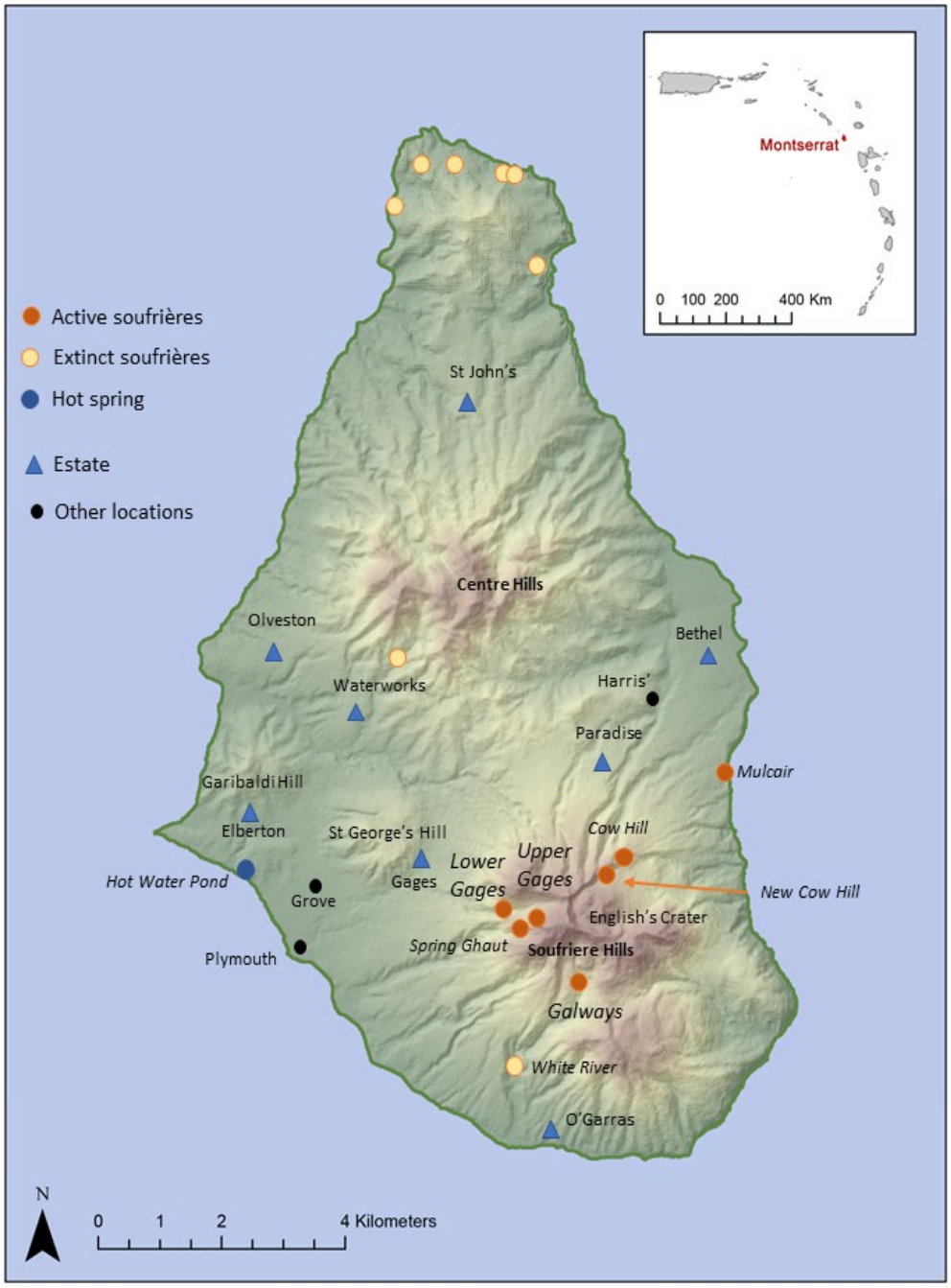
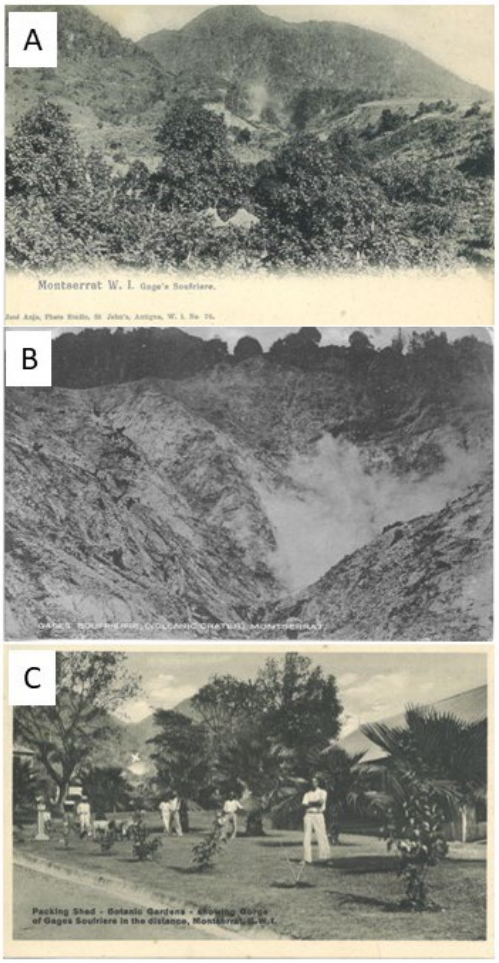


Figure 2. Three views of Lower Gage's soufrière, Montserrat between 1900 and 1940. (A) Gage's soufrière, ca. 1902. Postcard no. 70, by José Anjo, photographer from Antigua. (B) Gage's Soufrière (volcanic crater), ca. 1908, by W.H. Irish. (D) Botanic gardens showing the gorge of Gages soufrière in the background, marked by an X, ca. 1930s. Photograph by C.E.E Browne who worked in the Commissioner's office, and claimed to be the only recognised photographer on the island in the 1930s.[viii]



[viii] MPL 82-1801 – 1850. Letter from CEE Browne to Commissioner's Office, 3 December 1936

Figure 3. Earthquake counts, 1933-1936, based on reports collated by schoolteacher F. Peters (Harris) and curator of the Grove agricultural station, Gomez. Some events were simply recorded as shocks, others were assigned an intensity on the Rossi-Forel scale. The most damaging episodes on December 12, 1934, May 6, 1935 and November 10-11, 1935 were Rossi-Forel intensity 8. The annual pattern of clusters of events in May and November was noted by Perret, among others (Perret, 1939).

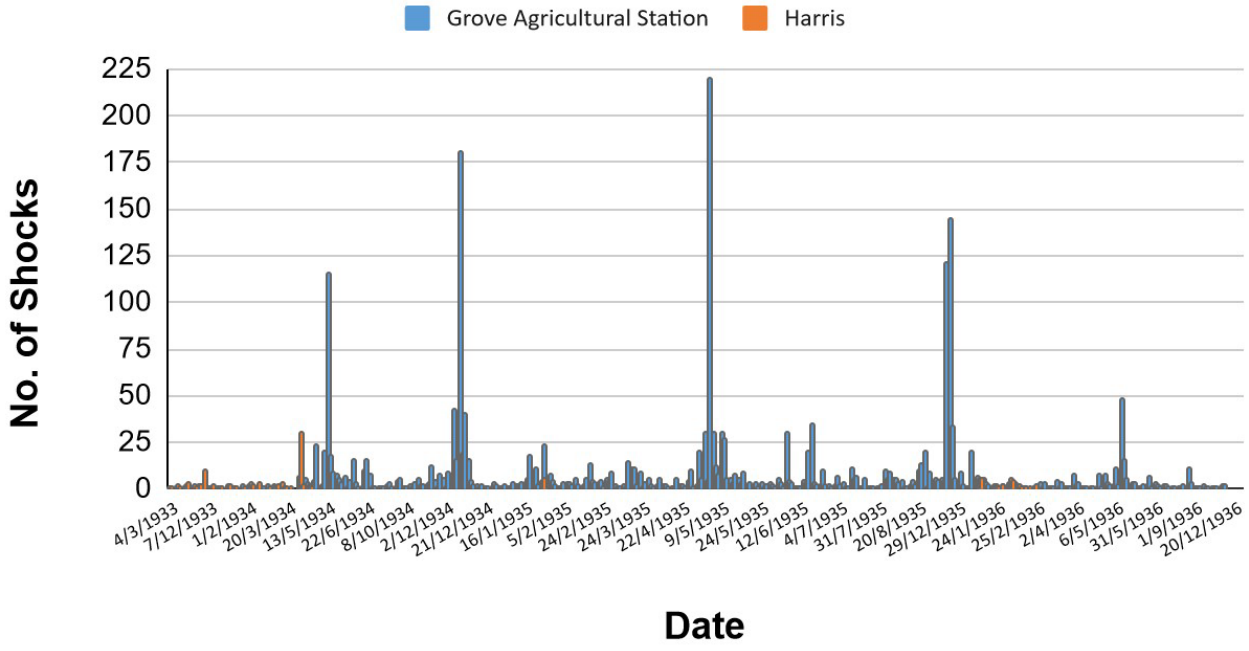


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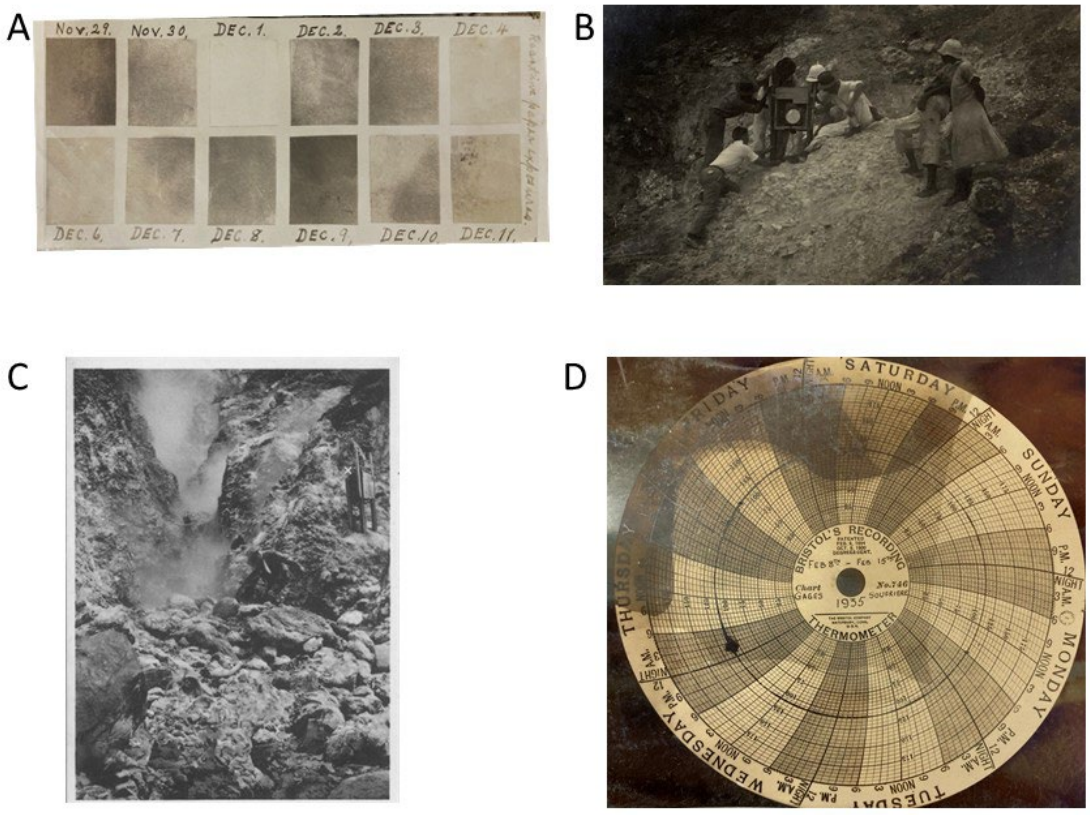
Figure 4. Frank Perret's experiments in soufrière and gas monitoring, 1934-5. (A) 'Reactive paper' experiment at Cocoanut Hill Hotel, November 29 - December 11, 1934. Perret exposed pieces of lead acetate coated paper overnight, and inferred that the darkening of the strip was an indication of the levels of ambient H_2S in the air.[ix] (B) Installation of the recording thermometer at Lower Gages soufrière. The identities of the people in the
880 photograph are not known. Photograph by Perret. (C) Photograph of Perret collecting a water sample in the gorge at Lower Gages with the thermograph visible (top right, marked with an x). Photograph by CEE Browne taken 4 March 1935, and later sold commercially as a postcard. (D) Temperature chart from Lower Gages for February 8 – 15, 1935. The thermometer, which was buried in the ground, recorded a stable temperature of 110ºC all week.



[ix] Montserrat Public Library. Montserrat Commissioner's Office, Report on investigations into seismo-volcanic conditions prevailing in Montserrat. 675 (1934), 22.

885

Figure 5. Map showing locations of instruments deployed by Perret in 1934-5 (pendulum, seismeter, thermograph) and 1937 (air quality recorder) and Powell or the staff of the seismo-volcanic observatory in 1936 (horizontal shock recorders, H; vertical shock recorder, V and Wiechert 2-component seismograph).

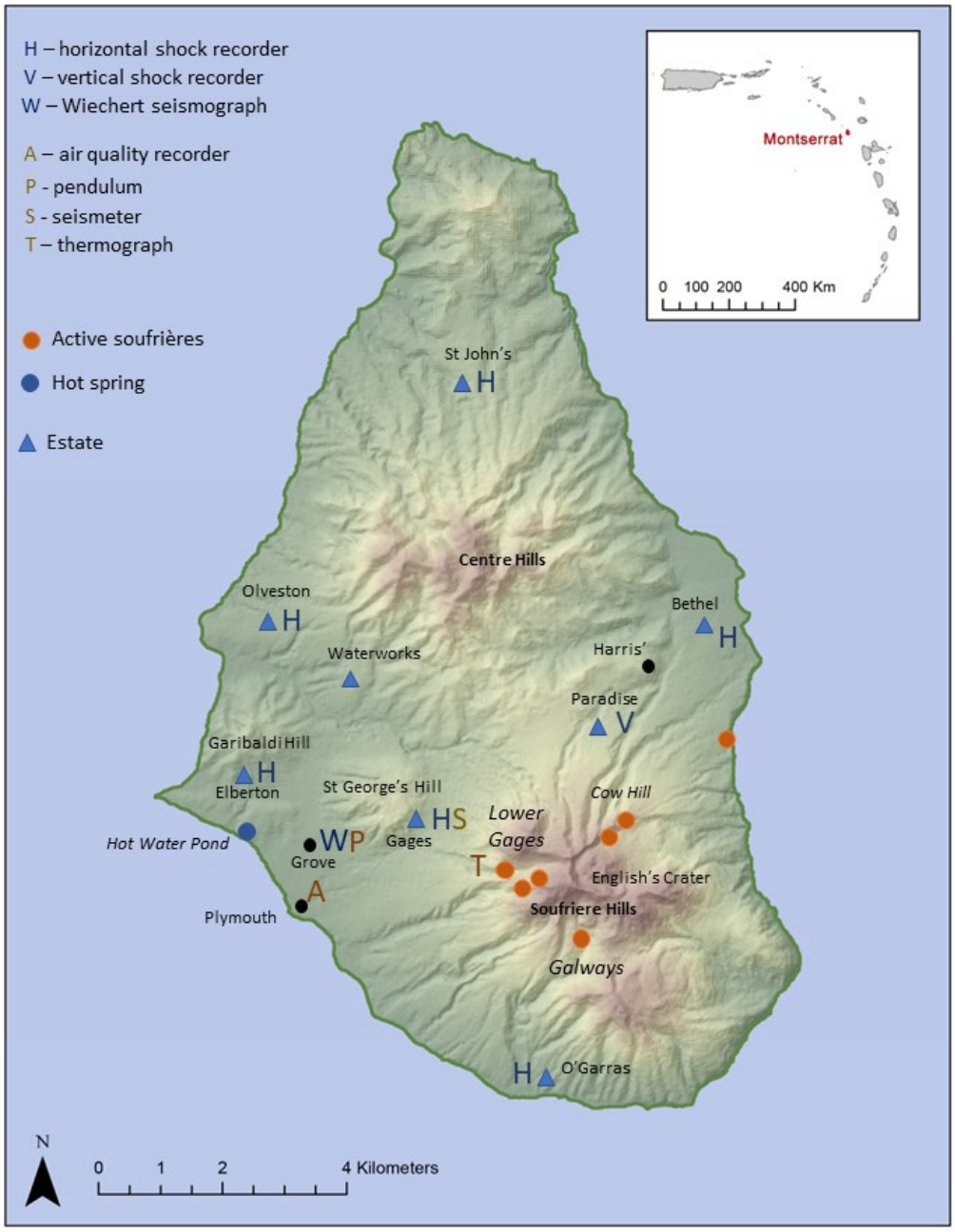


Figure 6. Summary chronology of instrument deployment on Montserrat from 1934 to 1943 by Frank Perret (pendulums, continuous thermograph, 3-component seismeter and air-quality recorder); by Cecil Powell (shock recorders at various locations; H – horizontal, V - vertical, and the 2-component Wiechert seismograph). The seismo-volcanological observatory began operations formally in July 1936, and continued operations until 1946.

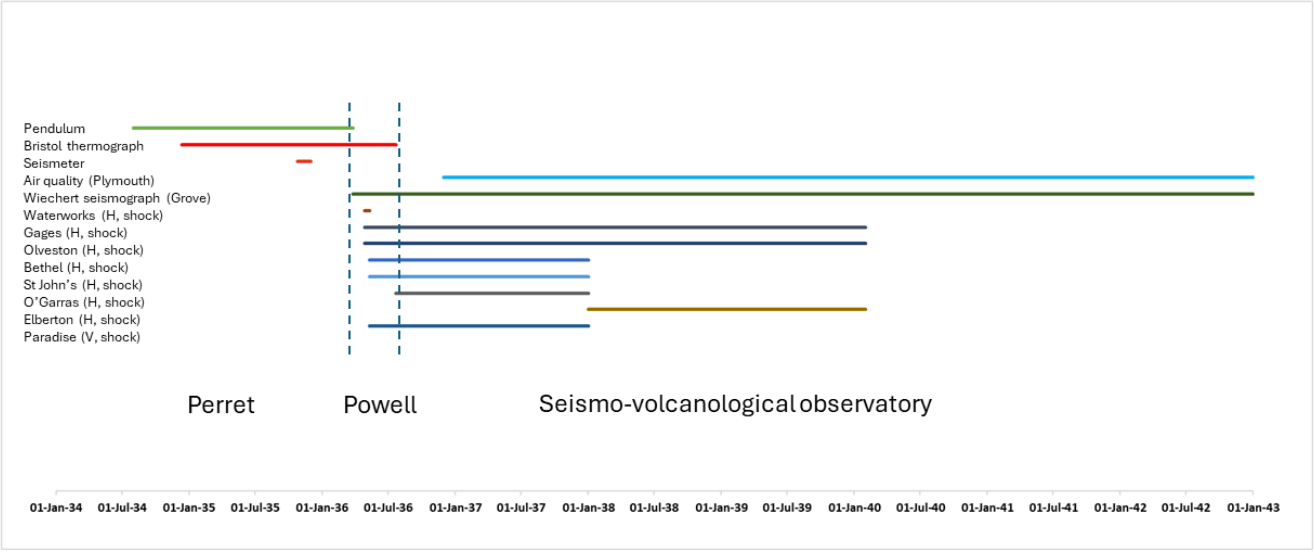


Figure 7. Map showing approximate epicentres of earthquake shocks in 1936-7 (Powell, 1938; dark grey), 1966-7 (Shepherd et al., 1971; white) and 1995-6 (Aspinall et al., 1997). Powell identified five regions that appeared to generate earthquakes, notably under St George's Hill (his focal region I) and under the Soufriere Hills and English's crater (focal region II). This pattern is remarkably similar to that determined for the early stages of the 1995-6 eruption of Soufriere Hills volcano, which were constrained from a network of between 5 and 8 instruments (pale grey).

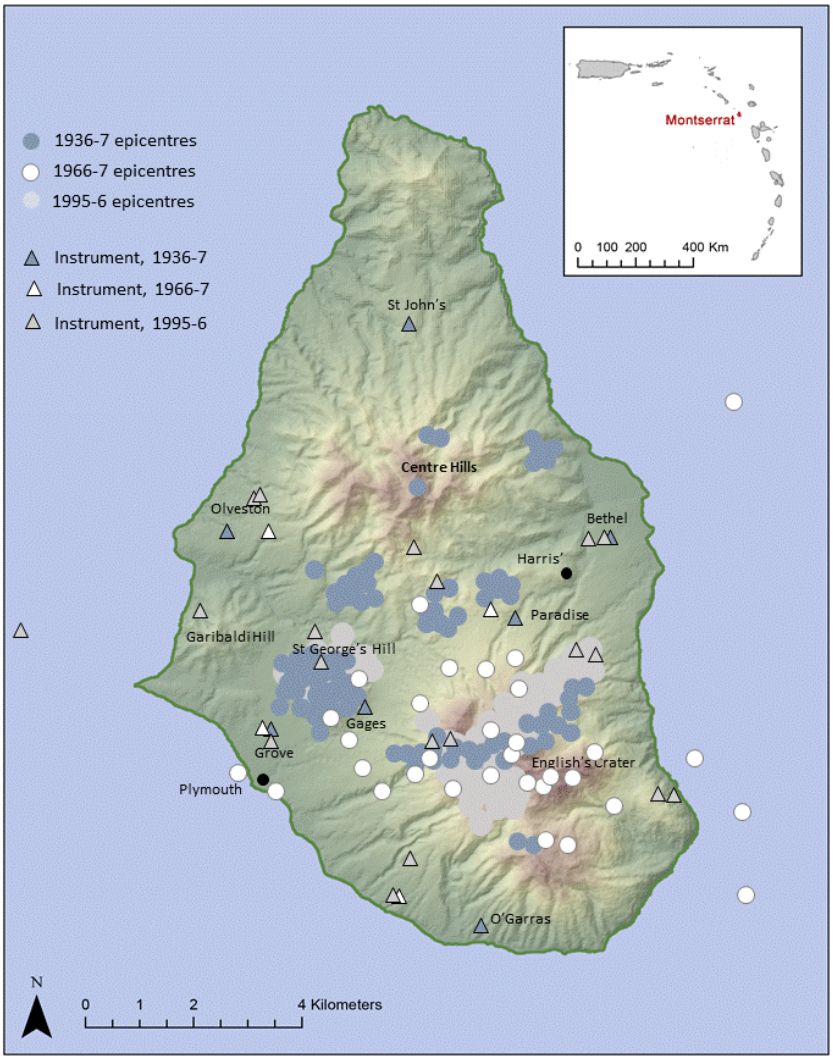


Figure 8. Air quality chart from Montserrat, for the week commencing 18 October 1937. The 'Perret Gas Recorder' was based on a repurposed rotating thermograph, with a lead acetate-coated disk designed so that an open window would expose the surface of the rotating chart to ambient air for about three hours. The chart would record continuously for up to 1 week. Observers would record the intensity of discolouration, using a qualitative scale. The instrument was installed in Plymouth, either at the volcanological observatory, at the Grove agricultural station, or the Cocoanut Hotel (Perret, 1939).

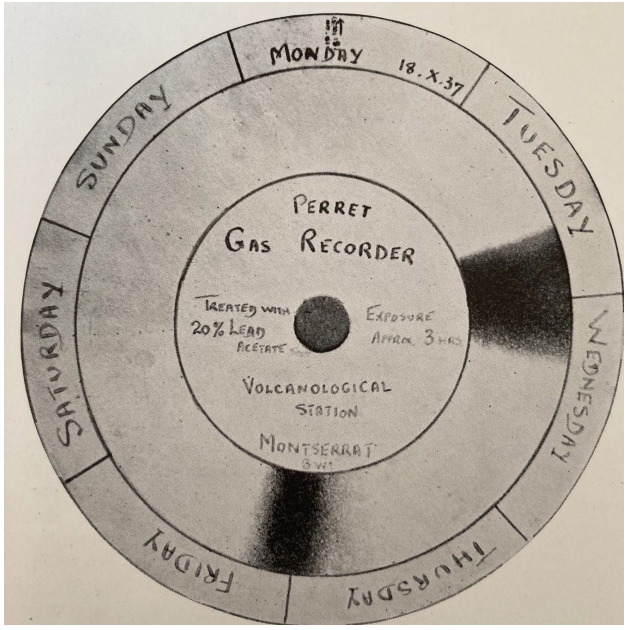
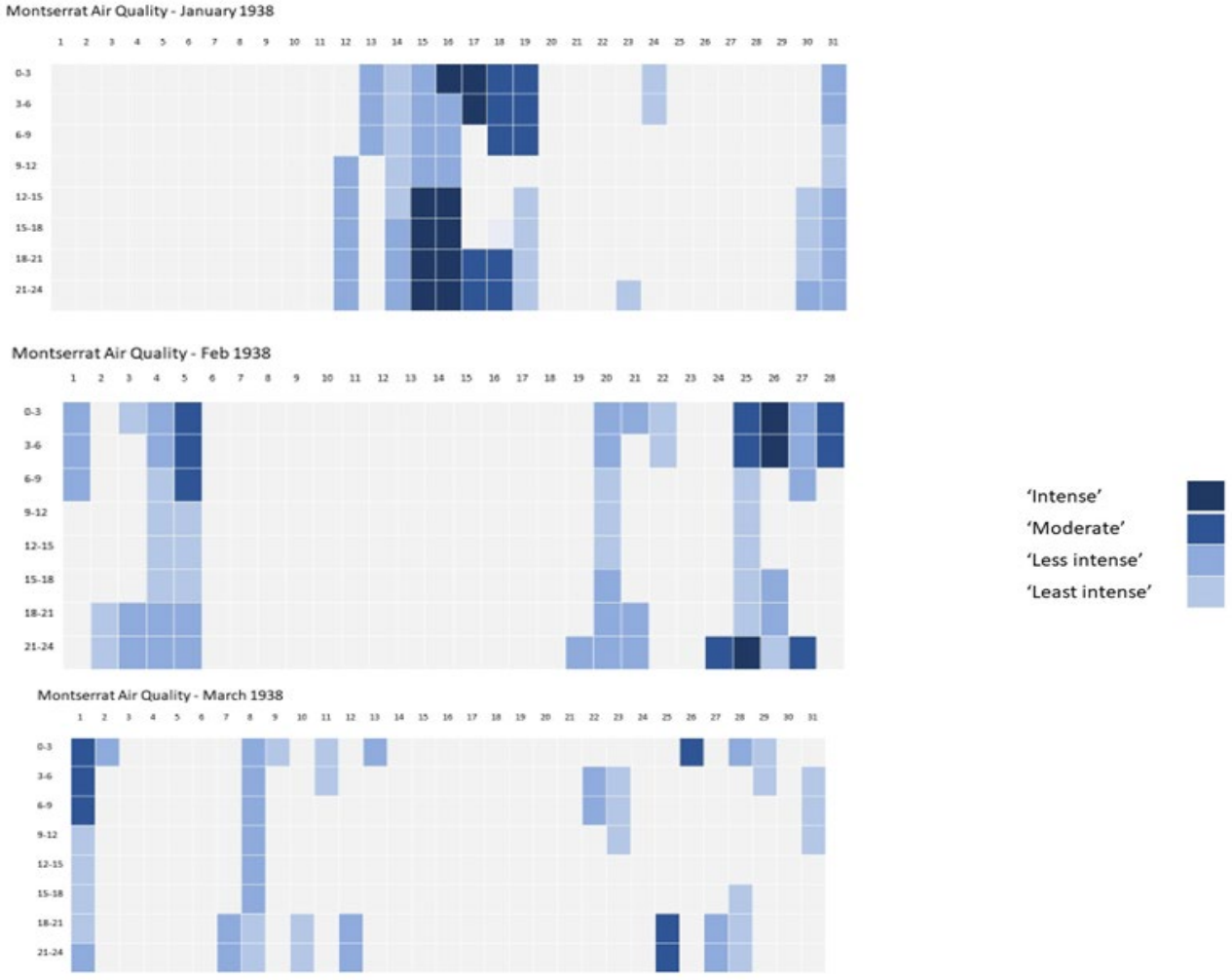


Figure 9 - Summary of qualitative air quality measurements in Plymouth, January - March 1938 recorded in the monthly reports of the seismo-volcanological observatory. Boxes are coloured according the reported intensity, the x-axis represents the day of the month, the y-axis the time. The intensity of discolouration of the disk was assessed by the observer using a simple relative intensity scale. Moderate to intense discolouration corresponded to times when the smell of H_2S in Plymouth was 'strong' or 'unpleasant'; and many of the most noticeable episodes were late evening or early morning. Less intense discolouration corresponded to episodes when the smell of H_2S was weak to barely noticeable. During windy weather, there was often no discolouration of the disks.



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Appendix 1 - List of archive sources consulted

Abbreviation (adopted here), name and location	File number(s)	Brief summary
BGS - British Geological Survey Archives	SA 368.01	MacGregor's diaries and field notes, February - June 1936; correspondence and photographs relating to Montserrat.
CI - Carnegie Institution	GL and HQ	Frank Perret correspondence
MNT - Montserrat National Trust, Woodlands, Montserrat		T.M. Savage English, Records of Montserrat (ms).
MPL - Montserrat Public Library, Brades, Montserrat	82-17, 82-158 to 82-175, 82-851 to 82-900, 82-1801 to 82-1850; 82-2001 to 82-2100	Commissioners Office correspondence 1920's, 1930's and 1940's; Government House Guest book.
OUM - Oxford University Museum of Natural History Archives, Oxford, UK.	Folders L61-L63, archives of Lawrence R Wager.	Wager's correspondence with Geoffrey R Robson, 1950 - 1965.
TNA - The National Archives, Kew, UK.	BJ 1/270; CO 152 (various), CO 321, 1934 - 1943.	'Earthquakes on Montserrat' correspondence, monthly reports, damage reports, and Royal Society expedition, 1934-1943
UoB - University of Bristol Special Collections, Tyndall Ave, Bristol, UK.	DM 517/F, 191 - 193. Cecil Powell notebooks, Montserrat, 1936.	191, 192 – scientific notes, data and sketches relating to Montserrat, 21 Mar – 19 July 1936. 193 – July 1936. Hand written report on the Montserrat work.

Appendix 2. Frank Perret's visits to Montserrat, 1934-1938

Perret (1939), p vii 'based on observations I made during a series of twelve visits to the island from 1934 to 1937 inclusive. .. At the close of each of these visits, a brief report was left for transmission to His Excellency, the Governor of the Leeward Islands.'

Visit	Dates	Notes
1	13 May 1934	Disembarked the *Nerissa*, en route to NY. First short sampling trip to Gages.
	October 1934	Met the Curator, his assistant and two others on ship, while in port at Montserrat, en route to Martinique.[x]
2	27 Nov – 12 December 1934	Installs thermograph; samples gases. 7 December, has tea with the Commissioner.[xi] Preliminary report, 12 December. 18 December addendum.[xii]
3	18 Feb – 7 March 1935	Gages field hut completed. Second report, 7 March.[xiii]
4	16 April – 2 May 1935	Flew from Martinique to check the thermograph. Completed a special report (27 April), and a third report (2 May).[xiv]
5	9 - 27 May 1935	Returned quickly from Martinique (plane and sloop) after the May 6 earthquake. 27 May report.[xv]
6	23 October – 4 November 1935	New thermograph installed at Gages hut, and seismeter installed at Gages estate house on 25 Oct. Set up a line from a buried microphone at the hut to Gages estate house. Further brief report, November 2, 1935.[xvi]
7	2 - 10 Dec 1935	Installed ultra-sensitive microphone at Gages; observed unusual pulse of gas after an earthquake on 6 December. 10 December report and confidential addendum.[xvii]

[x] Carnegie Archives Letter from Perret (Martinique) to Arthur Day, Director Geophysical Laboratory, 26 October 1934

[xi] MPL 82-17 Government House, Montserrat Visitors' Book, 1925-1937

[xii] TNA CO 152/455/14 3 Earthquakes on Montserrat /Preliminary report, Perret (Plymouth) to HE The Governor (Antigua) in care of His Honour the Commissioner (Montserrat)

[xiii] TNA CO 152/455/14 13 Earthquakes on Montserrat / Second visit, Perret (Gages Field Station) to Governor and Commissioner; not dated.

[xiv] TNA CO 152/455/14 29 Earthquakes on Montserrat / Report following third field visit, Perret (Gages Field Station) to Governor and Commissioner

[xv] TNA CO 152/455/14 45 Earthquakes on Montserrat / Report on local conditions, Perret (Montserrat) to Governor and Commissioner

[xvi] TNA CO 152/455/14 83 Earthquakes on Montserrat / Further brief report, Perret (Plymouth) to Governor and Commissioner

[xvii] MPL 82-672 23

	8 - 13 May 1936	*Meets MacGregor on Martinique*
8	13 – 19 May 1936	Flew to Antigua with MacGregor, thence to Montserrat to meet Jaggar and Powell
9	Late 1936	next return to the island
10	May/June 1937	May 16, 1937, Perret has tea with the Commissioner (MPL).[xviii] Letter dated 15 June 'just returned from a month at Montserrat .. and must go there again'.[xix]
11	Sep 4 1937	'I plan to go from Antigua to Montserrat .. then direct to NY by Nerissa, arriving about 15 September'[xx]
12	Dec 1937 - Jan 1938	Last investigation in 1937. (Perret, 1939).
13	June 1938	'it is my hope to come [to NY] .. first to Dominica, thence to Montserrat, and then by Nerissa to NY'[xxi] Final visit of the 1933-37 investigations (Perret, 1939).

[xviii] MPL 82-17 Government House, Montserrat Visitors' Book, 1925-1937

[xix] Bodleian CMD 15206/2 Letter from Frank Perret to Mrs Emil (Nicoline) Mix, 15 June 1937

[xx] Bodleian CMD 15206/2 Letter from Frank Perret to Mrs Mix, 9 August 1937

[xxi] Bodleian CMD 15206/2 Letter from Frank Perret to Mrs Mix, 4 June 1938

Appendix 3. Royal Society Montserrat Expedition timings, February – July 1936

Date	Person/People	Notes	Source
22 Feb 1936	MacGregor	Departs Dover, UK, on the *Venezuela*	MGD
6 March 1936	MacGregor	Disembarked at Barbados. Transferred to *Lady Drake* for Montserrat, via St Lucia and Dominica	MGD
9 March 1936	MacGregor	Arrived Montserrat, staying at Cocoanut Hotel	MGD
21 March 1936	Powell	Arrives Montserrat, with instruments. Instruments delivered to the Grove. MacGregor attends cocktail party at Govt House	MGD
26 March		All Jaggar shock recorders working; Wiechert not yet working	MGD
27 March		Wiechert now working at the Grove	MGD
23 April	Powell	Begins installing sound-ranging equipment in hotel	MGD
6 May	MacGregor	Departs Montserrat on *Nerissa*, for Martinique	MGD
8 May 1936	MacGregor	Arrives Martinique, meets Perret	MGD
13 May 1936	MacGregor	Flies to Antigua with Perret, then by boat to Montserrat	MGD
	Jaggars	Travel from Honolulu, via Los Angeles, Panama Canal, Jamaica, Virgin Islands, St Martin, Saba, St Kitts to Montserrat.	Jaggar 1956
16 May 1936	Jaggars and Perret	Arrive Montserrat on *Lady Drake* from Martinique and Antigua	MGD
17 May 1936	MacGregor, Perret, Jaggar, Powell	Lower Gages 'found Perret's microphone had been removed by La Barrie; the old man (Perret) was very disappointed'	MGD
19 May 1936	Perret	Departs from Montserrat to New York on the *Nerissa*	MGD
22 May 1936	MacGregor and Jaggars	Called on Commissioner Moir for tea	MGD and MPL
22 May 1936		Horizontal Jaggars are now at St. Johns, Olverton, Gages and Bethel. Vertical Jaggars at Paradise. Wiechert at the Grove.	MGD

25 May 1936	MacGregor, Jaggar	'Jaggar advocated .. scheme for preparedness on all islands .. he said he would suggest it to Lenox-Conyngham'	MGD
30 May 1936	Thomas and Isabel Jaggar	Depart Montserrat to St Vincent, on the *Lady Nelson*	JIR; MGD
3 June 1936	MacGregor	Departed from Montserrat on *Nerissa*	MGD
14 June 1936	Jaggars	Return from St Vincent	CFP
14 June 1936	Powell	Powell tries out the suction pump method for gas in Plymouth	CFP
15 June 1936	Powell and Jaggars	Call on Commissioner	MPL
16 June 1936	Powell	Departs for 3-day trip to St Kitts. Returns on a sloop, and is becalmed off Nevis	CFP
22 June 1936	Powell	Returns from St Kitts	CFP
29 June 1936	Jaggars	Depart Montserrat for Boston on the *Lady Hawkins*	JIR
30 June	Powell, Kelsick, Schouten, Maloney	Gages, first measurements of H_2S with the suction pump and lead acetate	CFP
11 July 1936	Powell and Lenox Conyngham	Sir Gerald Lenox Conyngham arrives	CFP
24 July 1936	Powell	Departs Montserrat on the *Ingoma*	Powell, 1937

1070

Sources: MGD – A G MacGregor's Diary (BGS); MPL – Montserrat, Government House visitors book. JIR - Jaggar interim report; CFP - Powell notebooks, Bristol University Special Collections. Boat names are italicised.

Appendix 4. Operations manual for the seismo-volcanogical observer, ca. 1936.

DESCRIPTION

Of the ARRANGEMENTS made and the COST of CONDUCTING

SEISMO-VOLCANOLOGICAL OBSERVATIONS

In MONTSERRAT, B.W.I.[xxii]

By

I.O. Kelsick

Clerk-in-charge

of Volcanological Instruments

CONTENTS

On arrangements and cost of conducting Seismo-Volcanological Observations in Montserrat. By I.O. Kelsick, Clerk in charge of Volcanological Instruments.

Following the visit of an expedition from the Royal Society in March 1936 arrangements were made for conducting observations in connection with Seismo-Volcanological conditions in the island of Montserrat, which had been troubled by earthquakes and the emission of sulphurous gases from the beginning of 1934.

[xxii] Undated. Copy sent to St Kitts-Nevis and Dominica in July 1937 by Commissioner Baynes. MPL 82-158 – 175 Montserrat. Commissioner's Office. Number 97, 1936 Vol. I. 145 'Despatch of scientific expedition to Montserrat to investigate occurrence of earth tremors'.

The present note, undertaken upon the instructions of His Honour the Commissioner contained in Minute Paper No 97 of 1936 is intended as a description of the arrangements being carried out in Montserrat, and is meant for the transmittal to and the guidance of the neighbouring Presidencies.

LIST OF INSTRUMENTS

Type	Approximate cost	Maker
1. 1. Wiechert Seismograph with smoking and fixing apparatus	£180	Messrs Spindler & Heyer, Gottingen, Germany
2. 2. Electric clock attached to Wiechert Seismograph	£30	The Synchronome Co, Ltd, 32 & 34 Clerkenwell Rd, London E.C.
3. 3. 6 Jaggar Shock Meters & 1 set of apparatus for smoking and fixing charts	Total £120	Particulars not available, obtainable from Royal Society
4. Barograph	Not available	Particulars not available, obtainable from Royal Society
5. For Volcanological Purposes (a) Earth Thermometers (b) Maximum hand thermometers (c) Suction pump & pump for determining concentration of H2S	 Ditto Ditto Ditto	 Ditto Ditto Ditto
6 1 stop watch	Ditto	Ditto

DETAILS OF OBSERVATIONS

(a) Seismological

1. Wiechert Seismograph. This unit is the most sensitive of the system of instruments established in the island for the recording of earthquakes. It is so sensitive that its main purpose is the recording of very slight shocks, and those tremors which are not heavy enough to be felt, as well as earthquakes occurring in distant parts of the world. Any local shock of great intensity, however, displaces the pens on the instrument, and its great degree of sensitivity therefore limits its usefulness in providing a continuous record during a period of great seismic activity such as that experienced in Montserrat during the last three years.

The routine work in connection with this instrument entails replacing the chart daily by a freshly smoked chart, recording the time of removing and attaching of charts, winding up the clock mechanism that drives the drum to which chart is attached, and fixing the removed chart with a mixture of methylated spirits and shellac. Once a week the instrument is overhauled to ascertain whether all its component parts are functioning satisfactorily; its sensitivity is checked by observing the period taken by each of its pens to make a complete swing, while undamped, and by observing the deflections made by the pens damped and undamped, these records being indicated on the respective charts.

II. Jaggar Shock Meters. These instruments have been established at six stations in the island. The instruments are primarily designed to record those shocks, which are of such intensity as to dislodge the pens on the Wiechert Seismograph. The distribution of these shock meters at six points throughout the island also serves to locate the epicentre or variation in intensity of any seismic agitation.

The service of volunteers in each district has been enlisted to carry on the routine work in connection with these instruments: this involves the changing of charts daily. The preparation, i.e. the careful smoking of charts, is however performed by the clerk at headquarters; his duties also entail the fixing of charts after removal from the instruments, in order to prevent their being smudged: this process of fixing is done by sraying the smoked chart with shellac – methylated spirits mixture, after which the clerk proceeds to time any shocks that may be recorded. In addition to the regular routine work performed by the Clerk at headquarters and the volunteers at the respective stations these instruments claim little other attention. A regular monthly visit is however paid to each station by the clerk for the purpose of inspecting the various units and testing their sensitivity. Such sensitivity tests are indicated on the particular chart, and these tests, as well as the record of any earthquakes, complete the data despatched for the attention of the Royal Society in England.

Transport facilities for visiting these stations have been provided free of cost through the generosity of the Montserrat Co, Ltd.

(b) Volcanological. Without attempting to explain the correlation between soufrieres and seismic activity, it must be stated that considerable attention is devoted to observational work connected with the two main Soufrieres[xxiii] in the island and to one in particular. This is probably due to the association of sulphurous gases, originating at the Soufrieres, with the periods of greatest seismic activity, and the suspicion that in the event of an eruption indications might be most marked at the soufrieres although it is known that lava outbursts may occur at any point on land or sea and not necessarily in the region of a preserved crater or hilltop.

Accordingly regular weekly visits are made to the more important of these two soufrieres *a monthly visit to the other*[xxiv] and the following observations are recorded.

(1) Gas.

(a) Concentration of Sulphuretted Hydrogen. At various points within the Soufriere gorge and in the immediate vicinity of the vents. The method adopted is the passing of the gas by means of a suction pump through filter paper treated with 10% lead acetate solution. The concentration is determined by comparing the discolouration made on the paper with standard charts.

(b) (determination of sulphur dioxide gas, only in the event of greatly increased activity).

(c) Gas samples. In addition to local deteminations of suphuretted hydrogen concentration and occasionally of sulphur dioxide, collections of gas in vacuum tubes are made the two soufrieres once a month. These samples are forwarded to the Royal Society for analysis.

(2) Temperatures. Temperatures are also recorded in pools of warm water in the soufriere gorge and more especially in the main vents. Although there has been no appreciable change in these temperatures throughout this period, it is felt that here would lie the surest indication of any approaching climax. The temperature at this particular Soufriere has been 95 to 100 degrees centigrade throughout this period. It might be mentioned that a temperature of 400 degrees centigrade is usually to be recorded before an eruption occurs, and the temperature of the gas emitted in the great eruption of Mount Pelee in Martinique is believed to have been 800 degrees centigrade.

[xxiii] Gages and Galways

[xxiv] inserted in pen

(b) Soil temperatures. A pair of earth thermometers have been installed at each of two stations, one at a point about 200 yds from the Soufriere and the other set in the garden of an estate about 1 mile further away. At each of these stations the thermometers are placed so as to record temperatures at a soil depth of 1 foot and 4 feet respectively.

(c) Meteorological. Meteorological records are kept of barometric pressure and rainfall at the Botanic Station. In the first instance a self recording barograph, functioning for weekly periods is used. The chart is changed at weekly intervals and this record checked against the mercurial barometric reading at the Botanic Station is also forwarded to the Royal Society, with the despatch of other data once a month.

(d) Clerical. A certain amount of time is also expended upon necessary clerical routine connected with this observational work. Apart from frequent communication with the local Head of administration and with the observers at the respective stations the attendant is also occupied with the preparation of a weekly report covering the observations at the Soufrieres and a summary of the seismic record, which report is submitted to His Honour the Commissioner, The Hon'ble the Federal Secretary and Mr Frank A. Perret, Volcanologist. In addition a full monthly report on the entire observational work is prepared for transmittal to the Royal Society.

The packing and despatch of charts, samples, and data to the Royal Society is also a claim upon the attendant's time.

REQUIREMENTS, COST OF OPERATION and STAFF

The following is a list of the estimated annual requirements and cost of operating the units in Montserrat.

(a) Paid staff.	Amount	Total
1. Clerk for general routine observations and the care and attention of instruments	£60	£60
2. Labour general assistance fixing charts etc, etc	£7	£7
		£67
(b) Materials & Supplies		
1. 18 gallons Methylated Spirits	£10	
2. 1 gallon Shellac	£1	
3. Contingencies	£3	
4. Batteries	£1	
5. Freight & other charges on charts to England etc.	£4	£19

In addition to this expenditure the cost of charts for the various instruments, gas tubes for obtaining gas samples and other requirements such as filter paper and chemicals for preparation of lead acetate papers, also any unforeseen replacements must be included. This expenditure is ascertainable from the Royal Society.

(d) In addition to the paid staff, voluntary mechanical assistance is provided by Messrs H.F. Shand and E.P. Maloney in connection with the Wiechert Seismograph. The Jaggar shock meters are also operated by volunteers, in Montserrat.

(e) Transport of attendant and charts from the country Stations are provided free in Montserrat.

RESULTS.

The Royal Society has emphasised the importance of maintaining the programme of observational work.

An example of the practical usefulness of the records obtained from the Seismograph was recently reported from the island of Hawaii. It is said that a severe subterranean earthquake occurred off the coast of Japan. The shock was recorded by Seismographs located at Hawaii and Japan, and utilising modern means of communication warning was issued to villagers along the Hawaiian coast that the island might be threatened by a tidal wave within a certain calculated time. Precautions were taken for securing shipping, and inhabitants retired from the threatened area. It is a tribute to scientific prediction that the anticipated tidal wave arrived within 12 minutes of the calculated time.[xxv]

The less sensitive Jaggar Shock Meters are equally important. As has been previously stated, they provide records of earthquakes during a period of activity so intense as to render the more sensitive instrument useless. Recently there was an example of the importance of having these instruments scattered over the island of Montserrat. It has been observed that some shocks seem to be strictly local; on July 14th a local tremor was recorded at 9:36 am by the Wiechert Seismograph. The tremor was not heavy enough to be felt in Plymouth, and its intensity was just heavy enough to be recorded by the sensitive Wiechert Seismograph, at the Botanic Station. The shock was reported to have been heavy enough to be felt in the Salem – Olveston district, where the intensity of the shock was heavy enough to be recorded by the Jaggar shock meter at Olveston. The shock was not recorded anywhere else.

The shock on July 14th occurred after a period of slight seismic activity. During these periods there might often be a tendency on the part of operators to be disappointed and to wish to depend on the Seismograph for the necessary records, neglecting the Jaggar Shock Meters. The observation noted above therefore stresses the need for coordination and sustained effort in this observational work if results are to be useful.

I.O. Kelsick

Clerk in charge of

Volcanological Instruments

MONTSERRAT.

[xxv] This refers to the Showa-Sanriku earthquake and tsunami of March 2, 1933. (Okal et al., 2016). Geophysical Journal International, 206, 1492–1514. Doi: 10.1093/gji/ggw206

Appendix 5. Brief biographical summaries, and roles from 1934-1938.

Name	*Role on Montserrat*
Barzey, Wilfrid O.	Seismo-volcanic observer
Bassett, W	Curator of the Agricultural Station, Grove
Baynes, TEP	Commissioner
Bell, Edward	Acting Commissioner (1934)
Browne, CEE	Assistant clerk to the Commissioner; photographer
Chapman, Sydney	Mathematician, Royal Society Montserrat Committee (UK)
Collens, AE	Government Chemist, Antigua
English, Thomas Savage	Worked in Government House
Gomez, CA	Curator, Grove Agricultural Station. Legislative council, 1934-7.
Grell, GH	Serviced the Wiechert seismograph for some years. Acting Head, Montserrat Secondary School
Griffin, Miss	Paradise estate
Griffin, WR	Owner, Paradise estate. Legislative council, 1934-7.
Howes, HR (Harry)	Owner, Gages Estate. Executive and Legislative councils.
Jaggar, Thomas	Volcanologist from Hawaii Volcano Observatory, invited to join the Royal Society expedition
Jaggar, Isabel (née Maydwell)	American volcano-observer.
Jeffreys, Harold	Royal Society Montserrat Committee; geophysicist.
Kelsick, CA	Seismo-volcanic observer during Ian Kelsick's (his brother) absence
Kelsick, Ian Oswald	Clerk of the instruments. First seismo-volcanic observer.
Kelsick, TH	Seismo-volcanic observer during Ian Kelsick's absence
La Barrie, GV	Inspector of works and roads, and superintendent of telephones.
Lenox-Conyngham, Sir Gerald	Representative of the Royal Society; geodesist.
Leverock, E	Seismo-Volcanological observer
MacGregor, Archie	Geologist, Royal Society Expedition
Manning, HL	Assistant Agricultural Officer

Margetson, NJL	Medical officer. Executive and Legislative councils.
Maloney, EP	Cotton Officer. Provided servicing and technical assistance for the Wiechert seismograph.
Maloney, JD	Clerk to Executive and Legislative councils, 1934-1936.
Meade, CR	Galways Estate. Legislative council, 1936-8.
Moir, S	Acting Commissioner, 1936
Perret, Frank	American volcanologist, based in Martinique and New York.
Peters, FE	Schoolteacher, Harris'
Powell, Cecil F	Physicist, Royal Society Expedition
Schouten, S A	Assistant Curator then Curator, Grove Botanic Station
Scotland, Greta B	Seismo-volcanic observer, 1944-1946
Shand, Haddon S	Representative of the Montserrat Company
Shepherd, E S	Carnegie Inst Chemist
Whipple, Francis JW	Director, Kew Observatory. Member, Montserrat Committee.

Sources: Executive and legislative council data from Harding, AJ and Gent, GEJ (eds., 1934, 1935, 1936, 1937, 1938), 'The Dominions Office and Colonial Office List, Waterlow and Sons, London.
MPL 82-17 Government House, Montserrat Visitors' Book, 1925-1937

Endnotes

[1] Anon. (ca. 1832). This Plan of the Island of Montserrat, John Carter Brown Map Collection, C-8102, Brown University, Providence R.I.

[2] Montserrat National Trust (MNT) T Savage English, 'Records of Montserrat' 7 vols, ms, History Ref 788

[3] Bodleian Libraries 'A narrative of the late awful and calamitous earthquake in the West India islands of Antigua, Montserrat, Nevis, St Christopher, Guadeloupe etc. etc. on February 8th, 1843. Written by an eye-witness.' Thomas Tegg, London. 32 pp. RHO 500.24 r.6 (1)

[4] Watkins, F.H. (1902). Commissioner's submission to the Royal Society Commission on the Eruptions in the West Indies GSM DR FT S 1

[5] MPL 82-1277; f31-38 'Seismic activity during 1934'

[6] MPL 82-158 f 28

[7] Johnston to Philip Cunliffe-Lister; 14 April 1934 MPL 82-158 f30

[8] MPL 82-158 f48

[9] Carnegie Institution GL 22 May 1934 Letter from Perret to Day (Geophysical Laboratory)

[10] MPL 82-158 f111

[11] Carnegie GL 24 April 1934 Letter from Perret (Martinique) to Day (Geophysical Lab)

[12] In April 1936, Cecil Powell heard that 'young Howes had a primitive Milne seismograph' at Gages estate.

[13] Carnegie GL 26 October 1934 Letter from Perret (Martinique) to Day (Geophysical Lab)

[14] MPL 82-672

[15] Carnegie GL 27.05.1935 Perret 'Report on local conditions' for the Governor and Commissioner.

[16] MPL 20 Jul 1935, Collens to Baynes.

[17] TNA - Public alarm, petition, and arguments from UK over the existence of a crater Sep/Oct 1935.

[18] MPL 82-1253

[19] Carnegie GL 21/11/1935 Letter from Perret (Martinique) to Day (Geophysical Lab).

[20] MPL 82-672 f23

[21] Carnegie GL 10.12.1935 Perret (Gages) to Commissioner, Confidential addendum to report.

[22] TNA Dec 7 1935 telegram, Governor to Colonial Sec

[23] MPL 82-158 Letter from Commissioner to the Colonial Secretary, Antigua, 7 September 1935; telegram no 60 from Commissioner to Colonial Secretary, 16 September 1935; letter from Commissioner to Colonial Secretary, 21 September 1935; f112.

[24] MPL 82-158 f132 Cover letter from FE Peters to the Commissioner dated 12 October 1935 and petition to HM Secretary of State for the Colonies dated 18 September 1935, signed by FE Peters, Charles Mercer and many others.

[25] MPL 82-851 f15 28 September 1935 GV la Barrie to Commissioner Baynes, Schedule of repairs to earthquake damage

[26] MPL 82-1253 f1 28 November 1935 GV la Barrie, Inspector of Roads, to Commissioner Baynes. Further repairs to roads and bridges.

[27] Forty-first report of the committee on seismological investigations, British Association for the Advancement of Science, Report of the Annual Meeting, 1936, pp 249-251.
[28] The National Archives - Papers: BJ 1/270 1934 Earthquake disturbances in Montserrat. 'Earthquakes in Montserrat', report by F J W Whipple, dated 17 May 1934. 4 pp.

[29] The National Archives - Papers: BJ 1/270 1934 Earthquake disturbances in Montserrat. Various letters from Whipple, May – July 1934.
[30] TNA BJ 1/270 1934 'Earthquakes in Montserrat' 4 pp. Undated, but circulated by Whipple in June 1935.
[31] TNA BJ 1/270 1934 Whipple correspondence with J S Hughes and EF Bellamy, October and December 1935.
[32] TNA BJ 1/270 1934 Whipple letter to Sir Gerald Lenox-Conyngham, 11 December 1935
[33] MPL 82-1277 f13; letter Perret to Baynes, from Martinique, Feb 12, 1936
[34] RS minutes, 21 Feb 1936
[35] Churchill Archives Centre, Churchill College, Cambridge. Letters from Bullard to the Secretary of the Montserrat Committee and Dr Whipple, 1936 GBR/0014/BLRD F.83
[36] MPL 82-671 f1
[37] Royal Society CMB134/1/2/2 Montserrat Committee, 6 February 1936
[38] BGS MacGregor archive 05.05.1936 SA 368.01 f7 – Report from Dr Jaggar to Sir Gerald Lenox-Conyngham, dated 5 May 1936 (this is clearly incorrect – date is most likely 5 June 1936).
[39] MPL 82-1277 f61
[40] MPL 82/761 1 'Confidential Report' Lenox-Conyngham 18 July 1936
[41] BGS MacGregor archive SA 368.01 f5 – Report from Dr Jaggar to Sir Gerald Lenox-Conyngham, June 1936
[42] MPL 82/761 4 Letter from Lenox-Conyngham to Acting Commissioner Moir, 21 July 1936
[43] Powell notebook 193 DM 517F, University of Bristol Special Collections.
[44] MPL Commissioners office, November 1936
[45] Forty-third report of the committee for seismological investigations, British Association for the Advancement of Science Report for 1938, pp 263-267.
[46] BGS MacGregor archive SA 368.01 f7 – Report from Dr Jaggar to Sir Gerald Lenox-Conyngham.
[47] MPL 82 158-175, minute paper 5018 14 Jan 1946
[48] MPL 82 159-175 f120
[49] MPL 5300 (MPL 158--175) Senn, A. (1946) A geological investigation at the Soufriere Volcano of St Vincent, B.W.I., in April 1946. Unpublished report, 25 pp.
[50] MPL 5300 f34-35
[51] MPL 5300 – note records 'Further Action taken in MP 5316, by H.H's instruction.