RESEARCH ARTICLE

VOLCANICA

The first seismo-volcanological observatory on Montserrat

David M. Pyle [*α], Martin Mahony[β], Jenni Barclay[β, γ], Bridie V. Davies[β, δ], Karen Pascal[ε], Thiffanie Williams[ε], Erouscilla P. Joseph[ζ], and Jazmin P. Scarlett[β, η]

[α] Department of Earth Sciences, University of Oxford, Oxford OX1 3AN, UK.
[β] School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK.
[γ] School of Earth Sciences, University of Bristol, Bristol BS8 1RJ, UK.
[δ] Department of Earth and Environmental Sciences, The University of Manchester, Manchester M13 9PL, UK.
[ε] Montserrat Volcano Observatory, P.O. Box 318, Flemmings, Montserrat.
[ζ] Seismic Research Centre, The University of the West Indies, St. Augustine, Trinidad and Tobago.
[η] Environment Agency, Bristol BS1 5AH, UK.

Submitted: 2024-07-25 | Accepted: 2025-12-02 | Published: 2026-02-16

Editor: J. Morin | Typesetter: J. Farquharson

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 with repeated felt events in 1933. Staff at Montserrat's agricultural office began routinely recording 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 the 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.

Résumé

Le premier observatoire sismo-volcanologique de la Caraïbe anglophone a été établi à Montserrat en 1936, en réponse à une crise sismo-volcanique qui avait débuté par des secousses répétées ressenties par la population en 1933. Le personnel du service agricole de Montserrat a commencé à enregistrer régulièrement les secousses sismiques dès 1934. En 1936, à la suite d'une expédition scientifique dépêchée par la Royal Society, un observatoire fut installé à la station botanique de Grove, à Plymouth. Celui-ci était géré par du personnel qui administraient un réseau instrumental et surveillaient les émissions de gaz et de vapeur ainsi que la qualité de l'air. L'observatoire a fonctionné jusqu'en 1946. Ici, nous reconstituons le processus décisionnel et l'évolution des réseaux instrumentaux lors de la mise en place de l'observatoire, et mettons en lumière les personnes impliquées, notamment la première femme qui a travaillé à l'observatoire de Montserrat, Greta Scotland. Les observations issues de la crise des années 1930 soulignent la persistance de la sismicité et des émissions gazeuses associées à cet épisode prolongé d'agitation, et suggèrent qu'il y eut de petites explosions phréatiques au plus fort de la crise. Nous établissons des parallèles avec les observations à long terme de l'activité du Soufrière Hills Volcano depuis les années 1990.

Keywords: Volcanic unrest; Volcano monitoring; Frank Perret; Eastern Caribbean Volcanic Arc; Historical volcanology.

1 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 University of the West Indies 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, which was yet another event where 'the observer had arrived … late in the course of the crisis' [Willmore 1952]. Patrick Willmore proposed that an instrumental network should be installed across the Eastern Caribbean, with sensitive seismographs on each island; a permanent scientifically trained observer running the network; 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, Geoffrey 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 (1937–1938) and St Vincent (1946) [Powell 1938; Latchman et al. 2012; Barclay et al. 2022]. In October 1902, following the catastrophic eruption of Mont Pelée, Martinique, Alfred Lacroix installed two heavy-pendulum seismographs and other instruments at

*✉ David.Pyle@earth.ox.ac.uk

a new observing station on Morne des Cadets [Hovey 1903; Lacroix 1904; Dondin et al. 2019]. This, the first volcano observatory in the Caribbean, was operated by military personnel for several years. By 1910, the main function of the observatory was meteorological, and it was decommissioned and relocated to the geophysical observatory at Fort Desaix, Fort de France, after being damaged by a hurricane in 1928. A new volcanic observatory was built at Morne des Cadets in 1933–1934, following renewed activity at Pelée from 1929 to 1932 [Romer 1931; Tanguy 1994; Boudon et al. 2005; Verlin 2022; Dumoulin Kervran et al. 2024].

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). The unrest also coincided with the effects of a significant regional (tectonic) earthquake, on November 10, 1935 [Powell 1938; Niemz and Amorèse 2016]. We document evidence for the nature and organisation of the local, regional, and colonial responses to this period of unrest, and explore how the local seismological and volcanic monitoring system was established across Montserrat. We also look at the reasons why this episode 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. In a related paper, we explore how such moments of volcanic and seismic crisis provide windows into the spatial politics of knowledge and expertise [Mahony et al. 2025].

Prior to the start of the eruption of the Soufrière Hills Volcano in July 1995, there had been no documented evidence for any eruptive activity on Montserrat since the island was colonised in 1632 [Rea 1974; Wadge and Isaacs 1988]. Over the previous 150 years there had, however, been several notable periods of seismic unrest accompanied by changes in gas and fumarole emissions, including 1897–1902, 1933–1937 and 1966–1967 [Shepherd et al. 1971].

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, p. 353], many descended from the planter oligarchy [Fergus 2004, p. 110]. 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 British 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 qualitative assessments of air quality on Montserrat.

1.1 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, the University of Bristol Special Collections, and personal archives held in Carnegie Science, Washington (Frank Perret), the University of Hawai'i (Thomas Jaggar) and the University of Cambridge (Gerald Lenox-Conyngham). The materials we have consulted include field notebooks and diaries, official and personal correspondence, reports, photographs and sketches related to the seismo-volcanological crisis of 1933–1937, and the subsequent routine reporting of the 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 [1935, 1939]). A full list of sources is provided in Appendix A, and particular sources are cited in footnotes to the paper.

2 Background

By the time of the first geological investigations of Montserrat in the early 1800s, 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, 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* 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, a colonial administrator, 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.† This earthquake was a destructive regional tectonic event with a source near

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

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

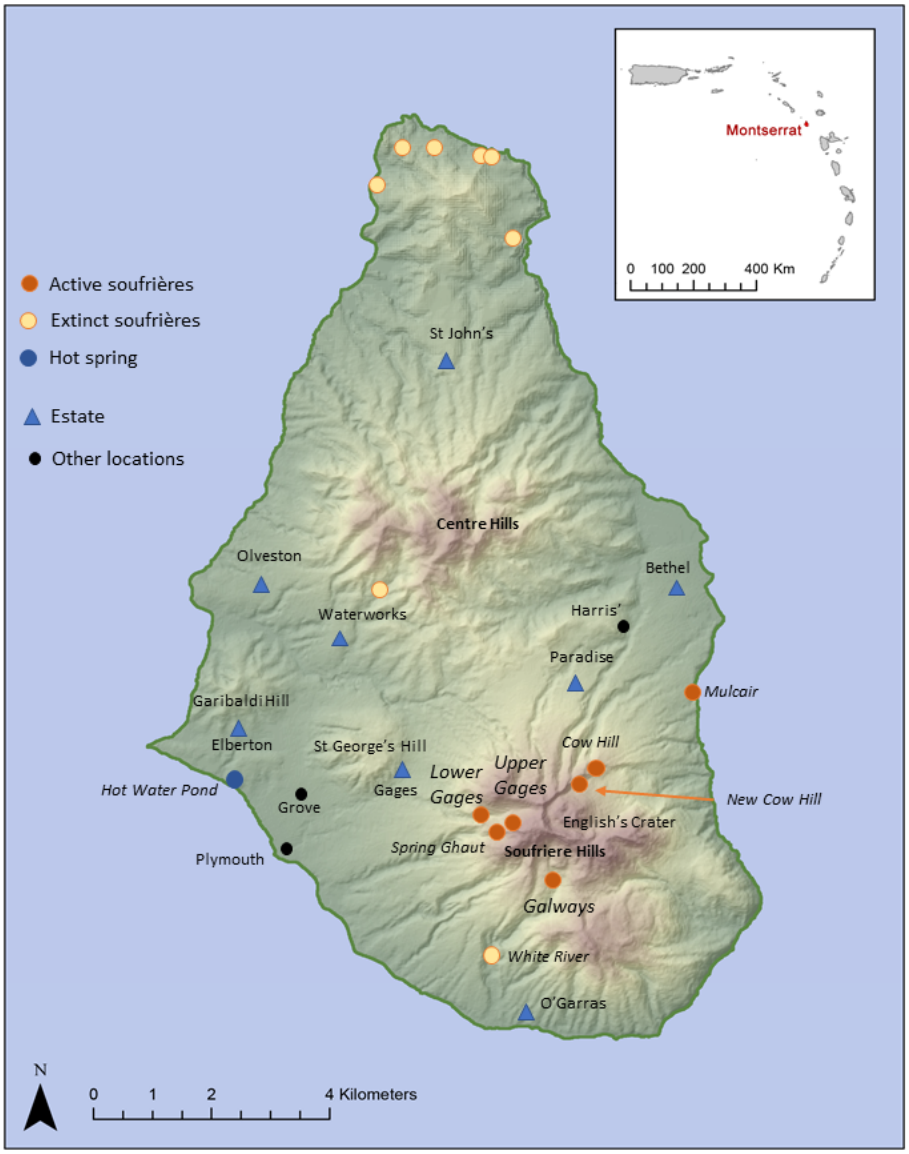

Figure 1: Map of 1930s Montserrat, showing the locations of soufrières (labelled in italics, after MacGregor [1938]), selected estates and other locations mentioned in the text. Base map adapted from Rothenberg [2021].

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 1933–1936.
New Cow Hill		First noted 1933–1934.
Spring Ghaut		First noted 1933–1936.
Mulcair		Active 1896–1899, and 1933–1936.

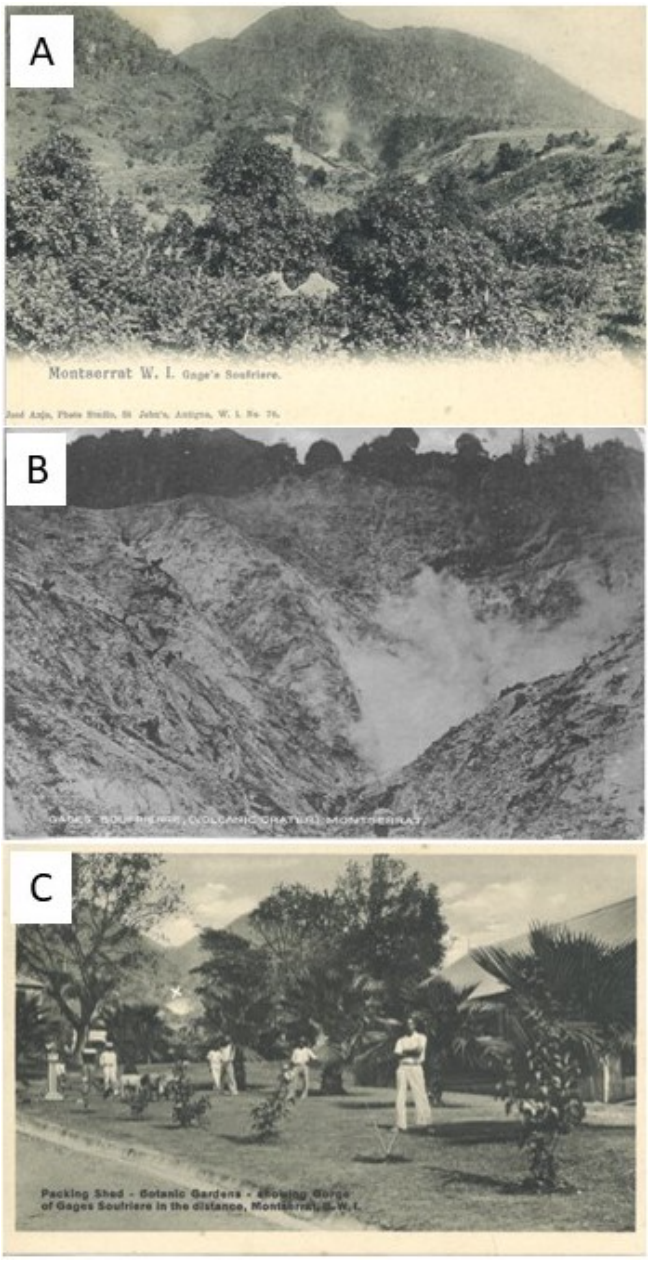

Figure 2: Three views of Lower Gage's soufrière, Montserrat between 1900 and 1940. [A] Gage's soufrière, ca. 1902. Postcard no. 70, by José Anjo, photographer from Antigua. [B] Gage's Soufrière (volcanic crater), ca. 1908, by W. H. Irish. [D] Botanic gardens showing the gorge of Gages soufrière in the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

Guadeloupe [Robson 1964] which damaged buildings across Montserrat, and left the 'Souffriere mountain rent in many places' by landslides.* 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 1987]. The seismic activity declined after the May 1902 eruptions on St Vincent and Martinique.†

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

3.1 1933–1934

The activity of the Lower Gages soufrière was readily visible from parts of Plymouth, the capital of Montserrat (Figure 2), and changes in the vigour of the steam vents and sulphurous smells would have attracted attention. Early in 1933, there was an increase in visible activity at the Gages soufrière, and the pungent smell of H_2S was noticed intermittently in Plymouth. Shortly after, F. E. Peters, the school teacher at Harris', began to keep a record of the small earthquakes that he felt. In response to these reports, Clement Gomez, the Curator of the Grove Botanical Station and head of the Agricultural Department, led an official visit to Gages soufrière, where they detected both the 'characteristic odour of H_2S,' and a pungent smell which they attributed to the presence of SO_2.‡ Gomez used a 'lead sulphide' test to confirm the presence of hydrogen sulphide, which 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 was felt at the Grove in September 1933, and after 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 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, they reported the pungent smell of SO_2 near the soufrière vents, and of hydrogen sulphide, which they recognised as 'the offensive odour smelt in Plymouth'. Gomez collated the accounts of felt earthquakes at Grove for the Commissioner, including the reports of seismicity from Peters at both Harris', and Spring Gardens (Figure 3). By early April 1934, Gomez and his team of forest officers, and 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.§

With anxiety growing, and at the request of the executive council, the Commissioner cabled representatives on nearby islands to find out whether they had seen any recent increases in volcanic activity or earthquakes. At the Commissioner's request, the Governor also wrote to the Secretary of State for the Colonies, seeking to invite a scientist to 'report on the condition in Montserrat'¶. 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

*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)

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

‡MPL 82-1277; f31-38 'Seismic activity during 1934'

§MPL 82-158 f 28

¶Johnston to Philip Cunliffe-Lister; 14 April 1934 MPL 82-158 f30

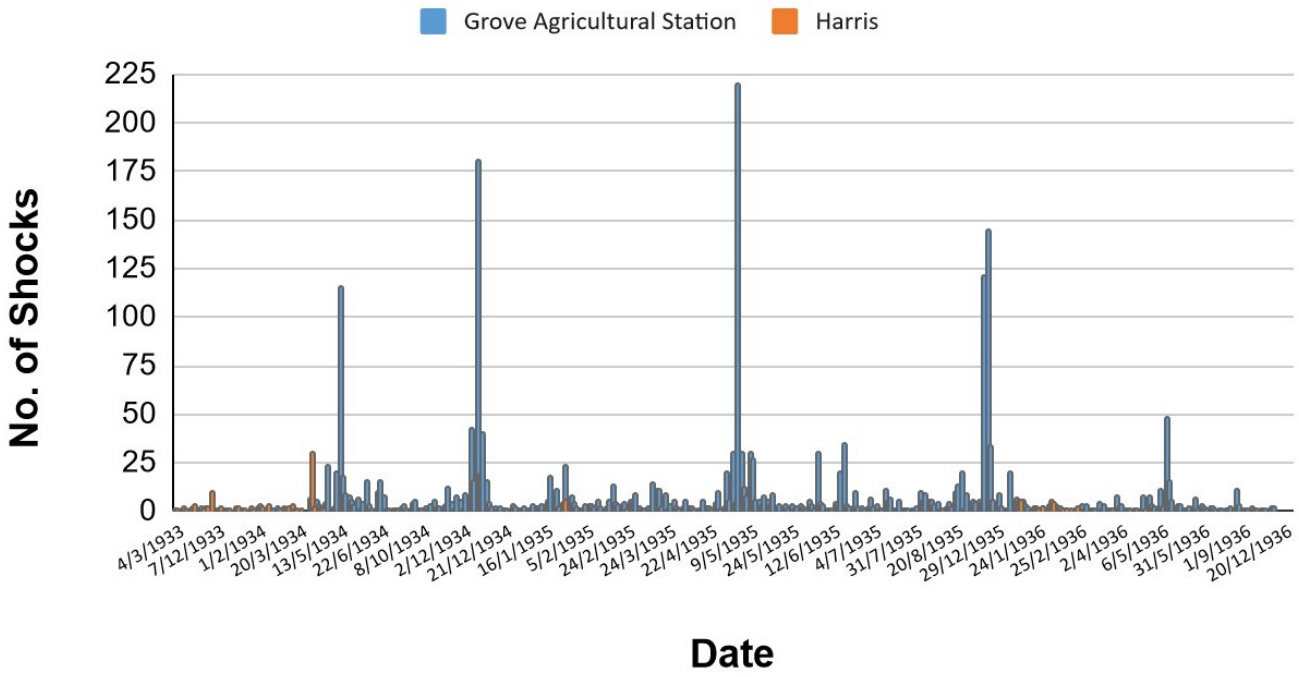

Figure 3: Earthquake counts, 1933–1936, based on reports collated by schoolteacher F. Peters (Harris') and Curator of the Grove agricultural station, C. A. Gomez. Some events were simply recorded as shocks, others were assigned an intensity on the Rossi-Forel scale. The most damaging episodes on December 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].

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 Hawai'i, and connections to the Carnegie Institution in Washington [Perret 1924; Giblin 1950; Perret 1950; Belkin and Gidwitz 2020]. In September 1929, there had been an unexpected rejuvenation of eruptive activity at Mont Pelée, Martinique: there was no functioning volcano observatory at that time, and the nearest seismographs were in Fort de France, 30 km distant [Verlin 2022]. In Puerto Rico, Perret heard news of the activity, and travelled to Martinique in late December to investigate. In early January, Perret began observations from a hotel roof in St Pierre, and by November 1930, had built a field station on Morne Saint-Martin on the slopes of Mt Pelée [Perret 1935]. He later built a volcano museum, memorialising the events of 1902, and a research laboratory 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 13, 1934, disembarking from the *SS Nerissa* en route from Martinique to New York. In Plymouth, Perret presented his credentials as 'Volcanologist, Founder and Director of the Volcanological Museum at St Pierre, Martinique' to the Commissioner and then accompanied the Curator, Gomez, and the owner of Gages estate, Henry Howes, on a short visit to Gages soufrière. There, Perret had just long enough to collect a sample of hot, 'gas-charged water' for analysis; but 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 1906–1907 [Perret 1908; 1924], and later at Mont Pelée [Perret 1935]. 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 after Perret departed there was with a shock at 2 am on May 14 that was the 'worst so far experienced,' and which appeared to confirm Perret's insight into the volcano's behaviour.*†

Local monitoring of the status of the soufrière, and documenting of earthquakes felt at Grove continued. During late May and early June 1934, Manning, the Agricultural Assistant,

*MPL 82-158 f48

†Carnegie Institution GL 22 May 1934 Letter from Perret to Day (Geophysical Laboratory).

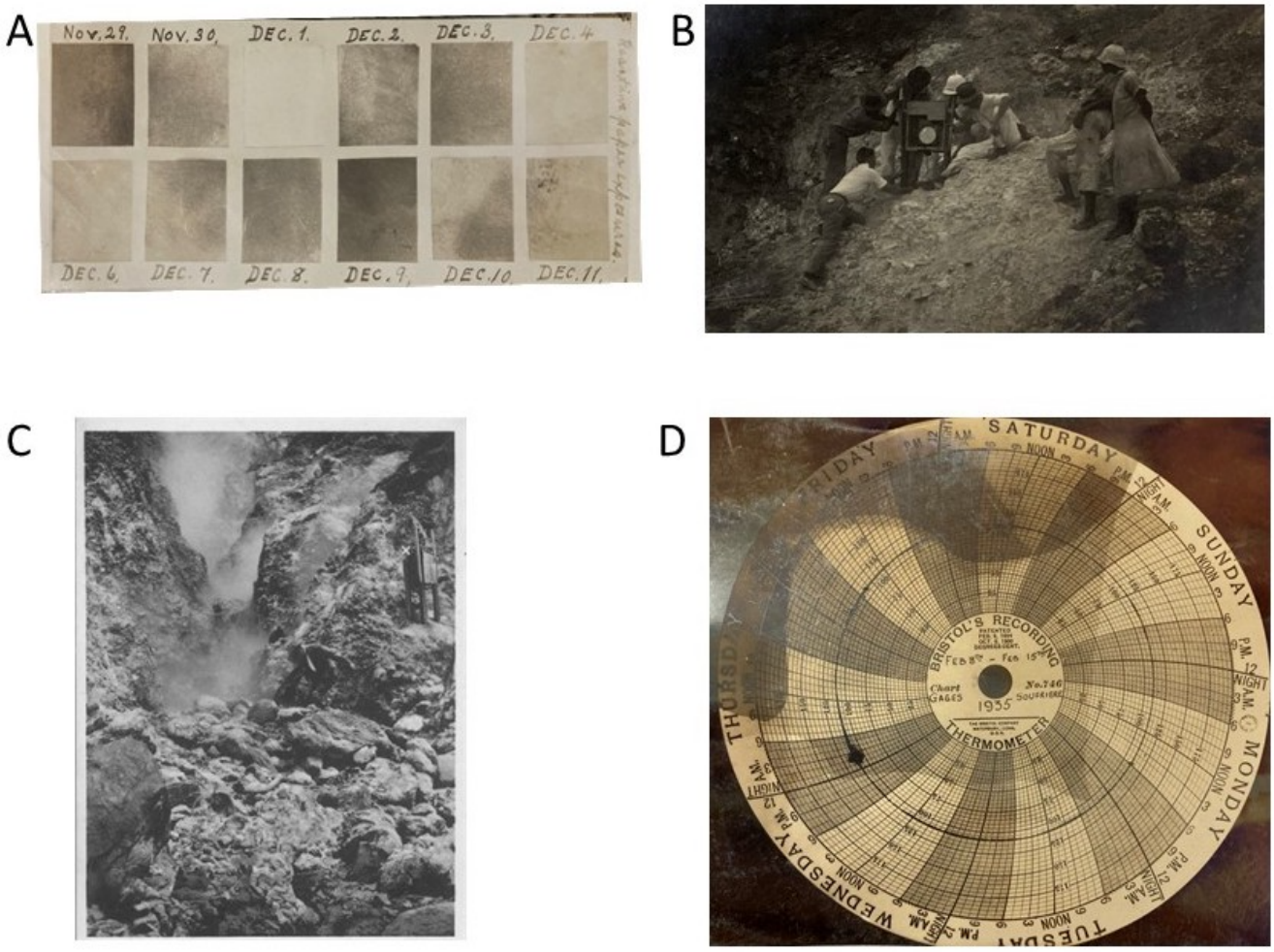

Figure 4: Frank Perret's experiments in soufrière and gas monitoring, 1934–35. [A] 'Reactive paper' experiment at Cocoanut Hill Hotel, November 29–December 11, 1934. Perret exposed pieces of lead acetate coated paper overnight, and inferred that the darkening of the strip was an indication of the levels of ambient H_2S in the air.* [B] Installation of the recording thermometer at Lower Gages soufrière. The identities of the people in the 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 ×). Photograph by C. E. E. 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 110 °C all week.

made daily visits to some of the soufrières, and sent monthly reports of felt earthquakes 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 1934, but held off until he heard that he had a grant from the Carnegie Institution, which allowed him to purchase some instruments for his investigation. Perret's motivation was that this work supported his wider vision for a regional floating observatory, that would include a 'motor yacht equipped with proper apparatus' to respond to future seismic and volcanic crises in the region.*† Perret eventually arrived in late November 1934 (Appendix B).

During his absences from Montserrat, Perret had continued correspondence with Gomez. In August, Perret sent instructions for Gomez to build a simple pendulum array based on his experiences at Vesuvius [Perret 1924], as there was not yet any working shock recorder or seismograph on the island.‡ They met, briefly, one evening in the port at Plymouth, while Perret was en route from New York to Martinique, to discuss Perret's plan for monitoring the earthquake shocks, and the thermal state of the soufrières. Perret's pendulum apparatus

*MPL 82-158 f111

†Carnegie GL 24 April 1934 Letter from Perret (Martinique) to Day (Geophysical Lab)

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

was not designed to record shocks, but would allow an observer to identify the direction of motion and characteristic frequency of a shock from the responses of the pendulums of different lengths. Gomez did install a set of pendulums at the Grove, but did not manage to make any observations, as he fled the building after the first jolt of an earthquake.*† Other equipment ordered by Perret included a set of 'maximum-registering thermometers,' a microphone and a 'gas-filled Bristol Thermometer,' with a 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 on a rotating circular chart.

Once Perret arrived on Montserrat in November, he set about establishing an experimental field station at Lower Gages soufrière, and visited other soufrières to make observations and collect gas samples. Perret intended to live in the field station for a few days at a time, to make observations day and night. On 30 November he installed the Bristol Thermograph at Lower Gages. This thermometer had a wind-up mechanical clock, and a pen to trace the ground temperature on a circular paper chart for a week at a time (Figure 4). It worked well for the first week, and then stopped, perhaps due to an earthquake shock, so Perret moved the instrument closer to the steam vents. He also installed mercury baths to detect tremor at Meade's estate in Galway, at the Grove Botanical Station and at Howes' estate at Gages. Perret's experience on Vesuvius was that mercury baths could be very sensitive to low intensity tremor, in a way that contemporary shock recorders were not. Perret installed a suite of pendulums at the Grove, and gathered some examples of a 'sensitive plant' [*Mimosa pudica*; Brussell 2004] from the trail up to Gages, which he placed in pots at the Grove, to see whether they were sensitive to shocks or tremor; they were not. [Perret 1939]. Perret also kept an eye out for examples of animal behaviour linked to shocks—watching a pair of parrots at the hotel, along with chickens and horses—but saw nothing he could link to felt events [Perret 1939, p. 61].

Perret's report for the Commissioner of 12 December 1934 established what would become his usual pattern—that he would leave a typescript report on Montserrat before departure. Perret's main conclusions on 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), or CO_2 (using lime water), or HCl (using ammonia). In contrast, in his view Galways soufrière was more like a 'solfatara' (like that at Campi Flegrei, in the Bay of Naples), being cooler (<100 °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'. Although the dilution of the gas in populated areas around Plymouth meant that there was no health risk, 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 a persistent source of distress (Table 2).

Perret suggested that people could get some relief from the hydrogen sulphide by using a wetted handkerchief to filter out the gas. He confirmed 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). The 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.

3.2 1935

In Perret's absence, routine monitoring on the island was continued by Gomez, and his assistant Manning. They continued to record earthquake shocks detected at the Grove, and made routine visits to Gages soufrière to change the paper discs on the thermograph and observe the steam vents. Perret returned in February 1935 to equip the newly-constructed field station, which he set up with a mercury bath, microphones, pitch pipes for measuring the 'pressure note' of the gas vents, a 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.

Perret was supplied with field station consumables, including filter papers, high-temperature thermometers and chemicals including lead acetate, sodium nitroprussideand magnesium ribbon, by Collens, the Government Chemist on Antigua. At Gages, Perret determined that the gases of the soufrière were alkaline and turned litmus paper blue; while the stream waters of the Gages gorge, below the soufrière, 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], accompanied by a gust of the 'most concentrated hydrogen sulphide' he had ever smelt. He could not 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 the need for ongoing monitoring.

There was a period of anxiety in March and April 1935, as the thermograph temperatures began to increase. Having started at 105–110 °C in late 1934 and remaining steady for several months, in mid-March 1935 the readings quickly rose to over 130 °C. The rapid temperature change caused 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.‡ Perret

*Carnegie GL 26 October 1934 Letter from Perret (Martinique) to Day (Geophysical Lab)

†Perret, 1924 p 136

‡MPL 82-672 f9 to f17 Exchange of telegrams and letters between the Commissioner, and Perret, April 8–15, 1935

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.
2–3 November 1934	Plymouth harbour	Hull of a newly painted ship discolours overnight, with brasswork tarnished and the white hull turned dark brown.
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.'
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.'
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.'
March, 1936	Plymouth	Discomfort to people in Plymouth. Canadian ship *N S Colborne* in port on 2nd. White hull badly discoloured by sulphide gases.
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.

advised the Commissioner to consider evacuating Howes' estate buildings at Gages if the soufrière dried out.* But after another brief visit in mid-April, Perret realised that the instrument was defective, 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.

By early May 1935, following another visit, Perret was of the opinion that activity was in decline. Gages gorge was continuing to enlarge due to the acidic emissions and erosion, but this had been continuing for many years. The gas emissions were less strong than in February, and the fumarole pressures were 'much less than a year ago'. Chemical analysis of water samples by Ernest Shepherd at the Geophysical Laboratory confirmed that the waters from Gages and Galways were acidic, rich in H_2S and with only traces of chlorine species.†

Shortly after Perret's departure, a large 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 convinced himself that this earthquake was different from that of December 1934. The 12 December earthquake had been preceded by 'great vapor pressure' in Gages soufrière, and had caused surface damage in the centre of the island close to Gages mountain, which Perret thought implied a source near to the surface. In contrast, the 6 May 1935 earthquake was not accompanied by any major changes in the soufrières, and the wider area affected by shaking suggested that the source was deeper; consistent with Perret's hypothesis that the crisis was diminishing, and the chance of eruption declining.‡

In July 1935, Perret wrote to the Commissioner to postpone his next visit. Perret's exposure to 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. Nonetheless, Perret's planning for further investigations continued, and the Government Chemist, Collens, sent another consignment of chemicals for the field station: '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.§

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 help out. 'Welcome other expert' Perret replied, by return.¶ 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,' designed to capture the integrated displacements in three directions (East-West, North-South, Up-Down) during large earthquakes [Perret 1937]. He installed the seismeter at Gages estate, and the thermograph at the Lower Gages soufrière.

While the gas remained 'strong and extremely nauseating at times,' the flux was diminished and the composition had not perceptibly changed since Perret's earlier observations. Per-

*MPL 82-672 f14 11 April 1935, Telegram from Perret (Martinique) to the Commissioner, 'If Soufriere water dries up advise evacuate Howes estate'

†MPL 82-158 f35 2 May 1935 Letter from Perret (Montserrat) to the Governor and Comissioner, 'report concerning a third visit of investigation'

‡Carnegie GL 27.05.1935 Perret 'Report on local conditions' for the Governor and Commissioner.

§MPL 20 Jul 1935, Collens to Baynes.

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

ret's field tests for gaseous sulphur compounds using benzole confirmed his hunch that the gases were 'composed of the higher and very unstable compound Sulphides of Hydrogen [sic], ranging from H_2S_2 to H_2S_5.' Perret's first field trials, using a dye-reaction test devised by Ernest Shepherd, had been negative, but a later test gave 'a distinctly positive reaction'. Perret concluded that the '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 be 'so extremely toxic as to be fatal to observers'.

Perret returned to Martinique on 4 November. Then, in a pattern that Baynes had already noticed, managed not to be on Montserrat when it was struck by the largest earthquake of the whole crisis, on 10 November 1935. This moment was decisive, as the damage was extensive across the island both to properties, and to the roads, embankments, and bridges.* Unlike the local earthquakes, this event was widely felt off island, 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,† with a trace that suggested a source north of Montserrat [Perret 1937]. The event was detected by seismographs 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 reassured 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.'‡

On 6 December, Perret noted a small but prolonged earthquake shock that was 'immediately followed by a sudden ... 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.§ 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 monitoring system that could be maintained by the Curator and staff of the Grove Botanical Station; but his Carnegie funding was now exhausted.¶ Perret returned to Martinique, but remained 'on call' in case of emergency. Perret had taken 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; without any prospect of having a seismometer on island at an early stage, he looked for ways to automate and make continuous measurements (thermograph); and to monitor subterranean activity remotely (microphones that 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 Councils that the crisis was being appropriately managed. On Montserrat, the Curator and his 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,‖ and prominent business leaders and Council members petitioned the Secretary of State for the Colonies, via the Commissioner, to seek expert assistance.** Meanwhile, expenditure on repairs to buildings, roads, and bridges was mounting up, first due to the May 6 earthquake; and then again following the damaging earthquake of November 10.††‡‡

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, reports on the smell of gas in Plymouth, and the temperature readings on the Bristol thermograph and hand thermometers.

*MPL 82-1253

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

‡MPL 82-672 f23

§Carnegie GL 10.12.1935 Perret (Gages) to Commissioner, Confidential addendum to report.

¶TNA Dec 7 1935 telegram, Governor to Colonial Sec

‖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.

**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.

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

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

4 The Royal Society Montserrat Committee and Expedition

In the early stages of the seismic crisis, in 1934, the Governor of the Leeward islands had 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 in England, to follow up. In his role as Superintendent, Whipple was well connected within the meteorological and seismological communities: Kew observatory was home to the UK 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 2022]. Whipple was also prominent within the British and international seismological communities, from his role as chair of the seismological committee of the British Association, and vice president of the International Association of Seismology*, and he had extensive practical knowledge of operating seismometers from his work at Kew [Simpson 1944].

By early May 1934, Whipple had written a short report† 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 assess the state of the volcanic system. 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 dates of the full moon, and seismic activity; an interpretation at odds with Perret's. Over the next few months, Whipple corresponded with 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 measures for protection against noxious gases, like H_2S.‡

Whipple remained the main point of contact for expert advice to the Colonial Office for the rest of 1934, and into 1935. Following the damaging 6 May 1935 earthquake, the Governor of the Leeward 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. Whipple, who was chair of the seismology and volcanology subcommittee, 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 a network of seismological observations on Montserrat and neighbouring islands to better constrain the origins of the earthquakes.§ 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 agreed 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 of Great Britain. 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.¶

In early December 1935, the National Committee on Geodesy and Geophysics formally proposed to the Royal Society that there should be a scientific expedition to the West Indies. The proposed expedition would be organised by the Royal Society, and comprise a geologist and a seismologist, each of whom would spend three months on Montserrat 'to investigate its geological structure,' to verify the nature of the suspected volcanic crater, to 'examine the source of the seismic disturbances' and to make other geophysical studies to throw light on the 'nature and development of the disquieting volcanic phenomena on the island.' The committee suggested that the seismological equipment 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 two-component seismograph in place of the Wood-Anderson instruments. Since the Wiechert instrument records seismic waves mechanically by the physical motion of a needle across

*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.

†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.

‡The National Archives - Papers: BJ 1/270 1934 Earthquake disturbances in Montserrat. Various letters from Whipple, May–July 1934.

§TNA BJ 1/270 1934 'Earthquakes in Montserrat' 4 pp. Undated, but circulated by Whipple in June 1935.

¶TNA BJ 1/270 1934 Whipple correspondence with J S Hughes and E F Bellamy, October and December 1935.

‖Royal Society CMB 134 (L) 8, Montserrat Committee minutes 12 December 1935

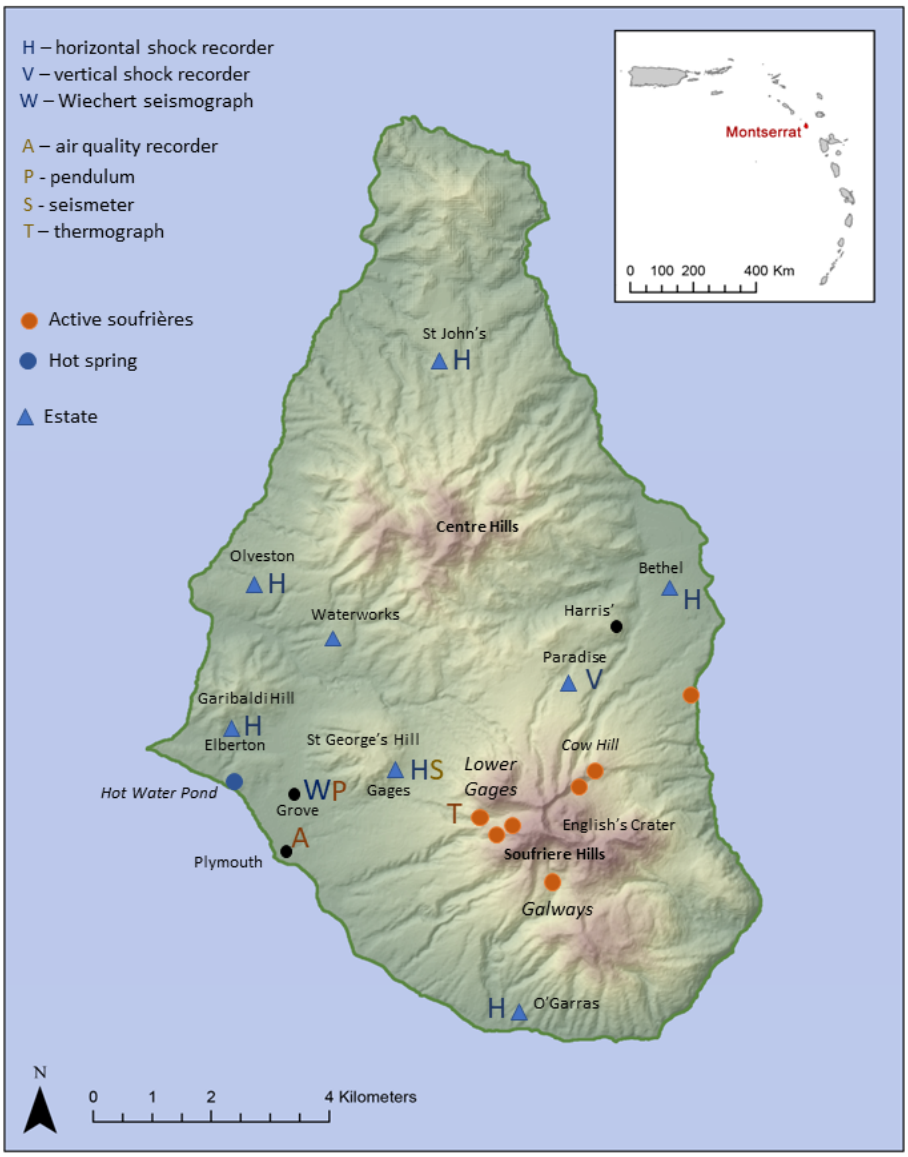

Figure 5: Map showing locations of instruments deployed by Perret in 1934–45 (pendulum, seismeter, thermograph) and 1937 (air quality recorder) and Powell or the staff of the seismo-volcanic observatory in 1936 (horizontal shock recorders, H; vertical shock recorder, V and Wiechert 2-component seismograph).

a smoked disc and could operate in daylight, this would be easier to operate than the Wood-Anderson seismograph, which recorded an optical trace onto photographic paper and would need a dark cellar or darkroom.*

One of the scientists on the National Committee was the geodesist and surveyor Sir Gerald Lenox-Conyngham. He had previously run the Great Trigonometrical Survey in India, from 1912 to 1921, before taking up the position of Reader in Geodesy in Cambridge in 1922 [Bullard 1957]. Lenox-Conyngham had expertise in building and operating geophysical field equipment, and a wide network of colonial and scientific connections: in 1935–1936, he was on the council of the Royal Society [Hughes 2010]; while in Cambridge he was on the council of the schools for physical sciences, and the board of geography and geology. He had hired Edward Bullard as a research assistant in 1931, and knew Francis Whipple's older brother, Robert Whipple, who was managing director of the Cambridge Scientific Instrument Company, and had built some new instruments for him [Lenox-Conyngham 1929; Thomas 1954].

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 pioneering probabilistic mathematician at Cambridge University [Robert et al. 2009], and Francis Whipple. Funding for an expedition to Montserrat was approved by the Colonial Office on 14 January 1936, and the Montserrat Committee met to approve the details on January 30. There was little time to recruit the two expeditionary scientists: Flett had a survey geologist in mind, and

*TNA BJ 1/270 1934 Whipple letter to Sir Gerald Lenox-Conyngham, 11 December 1935

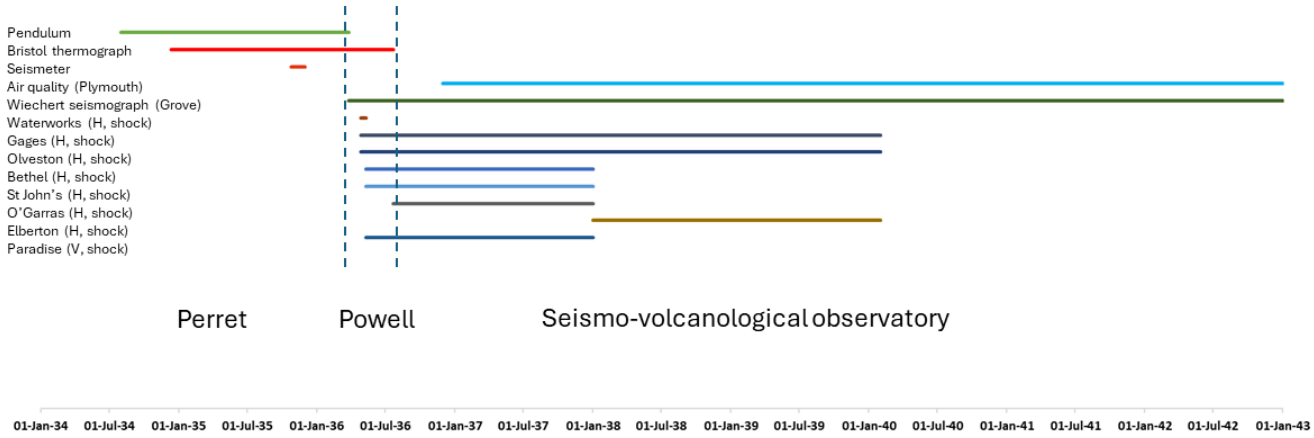

Figure 6: Summary chronology of instrument deployment on Montserrat from 1934 to 1943 by Frank Perret (pendulums, continuous thermograph, 3-component seismeter and air-quality recorder); by Cecil Powell (shock recorders at various locations; H – horizontal, V - vertical, and the two-component Wiechert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

Archie MacGregor accepted the invitation. The Committee's first pick for the expedition physicist, A. W. Lee from Kew Observatory, withdrew for health reasons,* and their next choice, Edward Bullard, declined due to pressing commitments, after discussions with Lenox-Conyngham.†‡ After considering another Cambridge physicist, Ben Browne, who had just been appointed as demonstrator in geodesy [Bullard 1969], the committee secured the services of Cecil Powell, a physicist from the University of Bristol, just two weeks before sailing.

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, noting that his own funding and plans were still uncertain.§

Lenox-Conyngham discussed the plans for the expedition with the secretary of the Council of the Royal Society, Frank Smith, who was concerned that the expedition scientists' planned work and reports might not 'carry enough weight'¶. To address this, Lenox-Conyngham resolved to visit Montserrat once the expeditions were underway, to inspect and report. He also offered to invite an international expert on volcanoes, Thomas Jaggar, to assist. Lenox-Conyngham had met Jaggar and his wife in Japan at the third pan-Pacific science congress in 1926 [Anonymous 1926], and by 1936 Jaggar had nearly 25 years of experience as director of the Hawaiian Volcano Observatory. Jaggar was a field scientist, had invented a number of instruments including a shock recorder and earthquake annunciator [Jaggar 1929], and had experience of managing volcanic crises in the public gaze—most notably in December 1935, when he directed a bombing raid by the Unites States airforce to divert an active lava flow that was threatening Hilo, Hawai'i [Jaggar 1936]. Jaggar had ample experience of working on degassing volcanoes in Japan and Hawai'i, which was relevant to the hydrogen sulphide release from the soufrières, and the impacts of the gas that was 'sickening and alarming' the residents of Plymouth [Jaggar 1956]. Jaggar arranged to travel from Honolulu to Montserrat with his wife, Isabel, who had worked with him on Hawai'i for many years, via the Panama Canal, and the volcanic islands of Saba and St Kitts [Jaggar 1956 p. 157; Dvorak 2015].

Lenox-Conyngham joined the Montserrat Committee, and at the next meeting on 21 February, 1936, it was confirmed that the Council of the Royal Society had approved his proposal to visit Montserrat to oversee the seismological work; and had also approved the plan to invite Thomas Jaggar to visit the team on Montserrat, and to report on the crisis.

MacGregor arrived on Montserrat on 9 March 1936 after crossing the Atlantic on the steamer *Venezuela* (Appendix C), and was met at the port by Gomez, Curator of the Grove Agricultural Station. MacGregor's task was to study and map the geology of the island, including any volcanic craters and 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 in 1936, and formally recognised the volcanic crater first described by T. Savage English. 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. Powell planned 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 Agricultural Station, so Powell spent his first few days assembling the shock recorders

*Royal Society Montserrat Committee minutes, 21 Feb 1936

†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

‡Cambridge University Library, Gerald Lenox Conyngham diary for the year 1936, GB 12 MS Add. 9249/I/19. GLC met Bullard to discuss Montserrat on February 5 and 7, 1936.

§MPL 82-1277 f13; letter Perret to Baynes, from Martinique, Feb 12, 1936

¶CUL GB 12 MS Add. 9249/I/19 Diary for 1936, 20 February

and the Wiechert seismograph. He also met up with English, who was still collating the records of the ongoing shocks on Montserrat. Powell was aware of the peaks in seismic events in May 1934 and May 1935, and his goal was to have a functioning instrumental network in place before May 1936 [Powell 1938].

The Jaggar shock recorders—named for their inventor, Thomas Jaggar—were one-component mechanical seismographs 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 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 25. Initially, they all had a natural 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 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 place to house it: suggested locations included '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 responsive 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 once he realised that it was at risk of overbalancing during a strong shock, and waited until he could place 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.* This work was finally completed in July 1936, but in the interim Powell used a shed with a two-inch-thick concrete floor at the Grove, so that he could start gathering measurements.

From April to June, Powell experimented to find the best locations for the long-term deployment of the network of shock recorders and sound-ranging equipment (Figure 5, Figure 6). He first installed the horizontal Jaggar recorders in pairs at the Grove for testing from 26 March–20 April, 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 could only measure 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 the Cocoanut Hill Hotel in Plymouth, 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 and the recently active volcano of Mont Pelée on Martinique. MacGregor returned from Martinique to Antigua on a seaplane with Perret, 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 Hawai'i in 1911, and at Sakurajima, Japan, in 1914. From 16–19 May, Thomas and Isabel Jaggar and Frank Perret joined the Royal Society team of Powell and MacGregor on Montserrat, and toured the island and the seismic instrument network. Perret then headed back to the US; while the Jaggars left for a short visit to St Vincent, an island that Jaggar had first visited immediately after the catastrophic May 1902 eruption [Jaggar 1902].

On Montserrat, the Curator and his team continued to take responsibility for writing the weekly 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 disc had stopped rotating, and the ink in pen was clogged and needed cleaning. No further thermograph temperatures were reported after June 1936.

With the shock recorders in place, Powell turned his attention to measurements of the gas emissions. Jaggar had brought with him some sampling apparatus, including some evacuated gas collection tubes and thermometers.† Whipple, on the Royal Society's Montserrat Committee, had recommended that Powell take some equipment for SO_2 detection, as described in a Department of Scientific and Industrial Research report [Ellis 1931];‡ 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].§ If hydrogen sulphide was present in the air, the filter paper would darken as the lead sulphide formed, and the concentration of H_2S in air could be determined by comparing the darkness of the spot to a calibration chart. Truesdale [1930] had verified the efficacy of

*MPL 82-671 f1

†Jaggar Day book, diary entry for 12 April 1936.

‡Royal Society CMB134/1/2/2 Montserrat Committee, 6 February 1936

§BGS MacGregor archive 05.05.1936 SA 368.01 f7 – Interim report from Dr Jaggar to Sir Gerald Lenox-Conyngham, dated 5 May 1936. This date is clearly incorrect. From Jaggar's 1936 diary, this 'interim report' was written between 7 and 9 June, 1936 and mailed to Lenox-Conyngham and Flett on 10 June 1936.

this technique as a spot test for low concentrations of gaseous H_2S.

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 at 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.*

In early July, Gerald Lenox-Conyngham arrived to mark the conclusion of the Royal Society Expedition. He met the Commissioner on arrival, and 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 local '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 discs 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, shellac and other consumables used for fixing discs, and for the regular shipping of used discs and paper records to the Royal Society in London (Section 11). The weekly report of Tuesday 25 August 1936 was the first signed off by Kelsick.

Powell and Lenox-Conyngham left the island on 24 July 1936. Before departure, Powell briefed the observers responsible for the collection and distribution of shock recorder charts and for the care of the instruments, and 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 was not until 1995 that a similarly extensive network was once again installed across the island of Montserrat [Shepherd et al. 2002; Kilburn 2025].

In his parting report† 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 the interim reports from Jaggar and Perret, and discussions with Powell in the field.‡ 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 … 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.' His recommendations were that a new topographic map was needed for the island, to improve on the 1867 hydrographic chart, and, above all, 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'.§

5 Cecil Powell and earthquake locations

The expedition physicist, Cecil Powell, had no practical experience in seismology [Frank and Perkins 1971], so shortly before leaving England he met up with geophysicists Edward Bullard and Gerald Lenox-Conyngham in Cambridge to discuss the fieldwork. Powell's main objective in creating a network of shock recorders was to use the records from detected earthquakes to locate the earthquake foci. With the instruments that were available at the time, Powell recognised that he would not be able to distinguish the onsets 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¶, using 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 the crust through which the waves passed was uniform and, finally, assumed that the instruments all had an equivalent response. From this, Powell used the relative amplitudes recorded across the network to locate the foci and epicentres of events. His provisional distribution of epicentres [Powell 1937] showed a broad distribution of events across the centre of the island.

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 both of the shock recorders, which were mainly fixed to the inside walls of hurricane shelters, and observations from the more sensitive two-component Wiechert seismograph to refine his assessments of where the earthquake

*MPL 82-1277 f61

†MPL 82/761 1 'Confidential Report' Lenox-Conyngham 18 July 1936

‡BGS MacGregor archive SA 368.01 f5 – Report from Dr Jaggar to Sir Gerald Lenox-Conyngham, June 1936

§MPL 82/761 4 Letter from Lenox-Conyngham to Acting Commissioner Moir, 21 July 1936

¶Powell notebook 193 DM 517F, University of Bristol Special Collections.

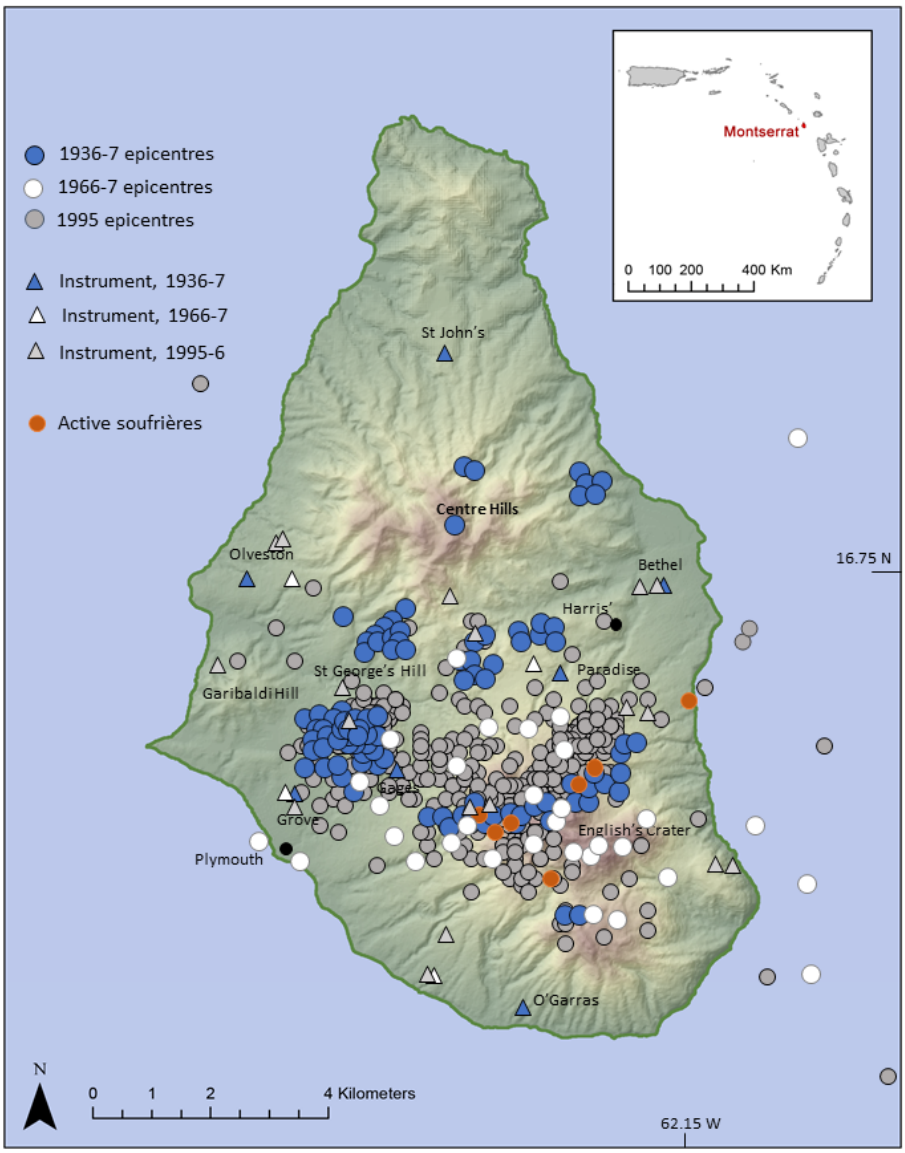

Figure 7: Map showing estimated epicentres of earthquake shocks in 1936–1967 (Powell [1938]; blue), 1966–1967 (Shepherd et al. [1971]; white) and 1995–1996 (Aspinall et al. [1998]; grey). Powell identified five regions that appeared to generate earthquakes, notably under St George's Hill (his focal region 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 eruption of Soufriere Hills volcano, which were constrained from a network of between five and eight instruments ([Aspinall et al. 1998]; pale grey). Uncertainties on Powell's epicentre locations are not known.

shocks had originated. Finally, he was also able to use his observations of regional earthquakes to constrain the ratio of the P- and S-wave velocities. Harold Jeffrey's review of Powell's draft report also gave some additional insights into the contemporary models for seismic waves in layered media.* From his new analysis, Powell revised his preliminary assessment that the earthquakes were located in a broad belt running across the middle of the island between the Centre Hills and the Soufriere Hills, and instead deduced that there were several regions beneath central Montserrat where the earthquakes were being generated (Figure 7; Section 11). He also concluded that these locations were at shallow depths, and that the events produced in each focal region were 'strikingly similar' [Powell 1938].

6 1937–1938

Seismicity and activity at the soufrières diminished 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 record-

*Royal Society RR/63/50 Referee's report by Harold Jeffreys, on a paper 'The Royal Society expedition to Montserrat, B.W.I. Final report' by Cecil Frank Powell, March 1937

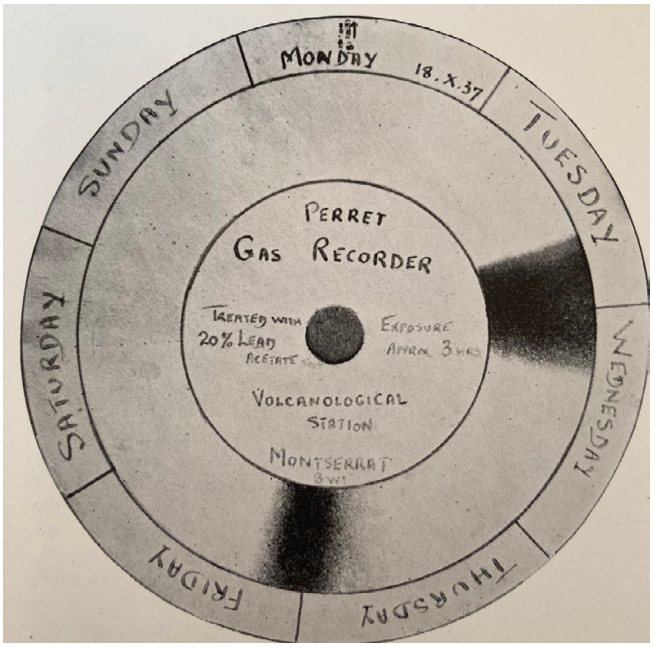

Figure 8: Gas recorder chart from Montserrat, designed to detect ambient atmospheric H_2S, for the week commencing 18 October 1937. The 'Perret Gas Recorder' was based on a repurposed rotating thermograph, with a lead acetate-coated disc designed so that an open window would expose the surface of the rotating chart to ambient air for about three hours. The chart would record continuously for up to one 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].

ing earthquakes, maintaining the seismic network and preparing and fixing the recording charts for the various instruments.

Routine gas monitoring included the 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 in Plymouth; and from Richmond to Dagenham.*

Perret's re-purposed thermograph was now providing routine air quality measurements from the grounds of the Cocoanut Hill Hotel or later, the Grove 'volcanological station'. In December 1936, Perret converted the refurbished thermograph, which had once again failed due to corrosion, so that it would record three-hourly exposure to ambient hydrogen sulphide on lead acetate-treated paper charts for a week at a time (Figure 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 discs was clearly associated with episodes of elevated H_2S in Plymouth, based on the noxious smells noticed by observers. 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 (Figure 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 seven horizontal Jaggar shock recorders and the Wiechert seismograph (Figure 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†, Perret moved his seismeter from Gages estate, but arrived too late to record any strong shocks. The Royal Society also requested the redeployment of four of the Jaggar instruments to Dominica, for monitoring. The Governor of the Leeward Islands wrote to the Presidencies of the islands inviting them to subscribe to the costs of maintaining a regional seismic network, so that they might be better prepared to respond to future crises, but Antigua, St Kitts and Nevis were all opposed to incurring any additional expenditure, and the proposal stalled.

7 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 Hawai'i (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 was skilled at collecting gas and condensate samples using an aspirating pump and glassware, and believed 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]. He claimed that he detected SO_3 at Kīlauea using his nose. To augment his olfactory 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.

*MPL Commissioners office, November 1936

†Forty-third report of the committee for seismological investigations, British Association for the Advancement of Science Report for 1938, pp 263–267.

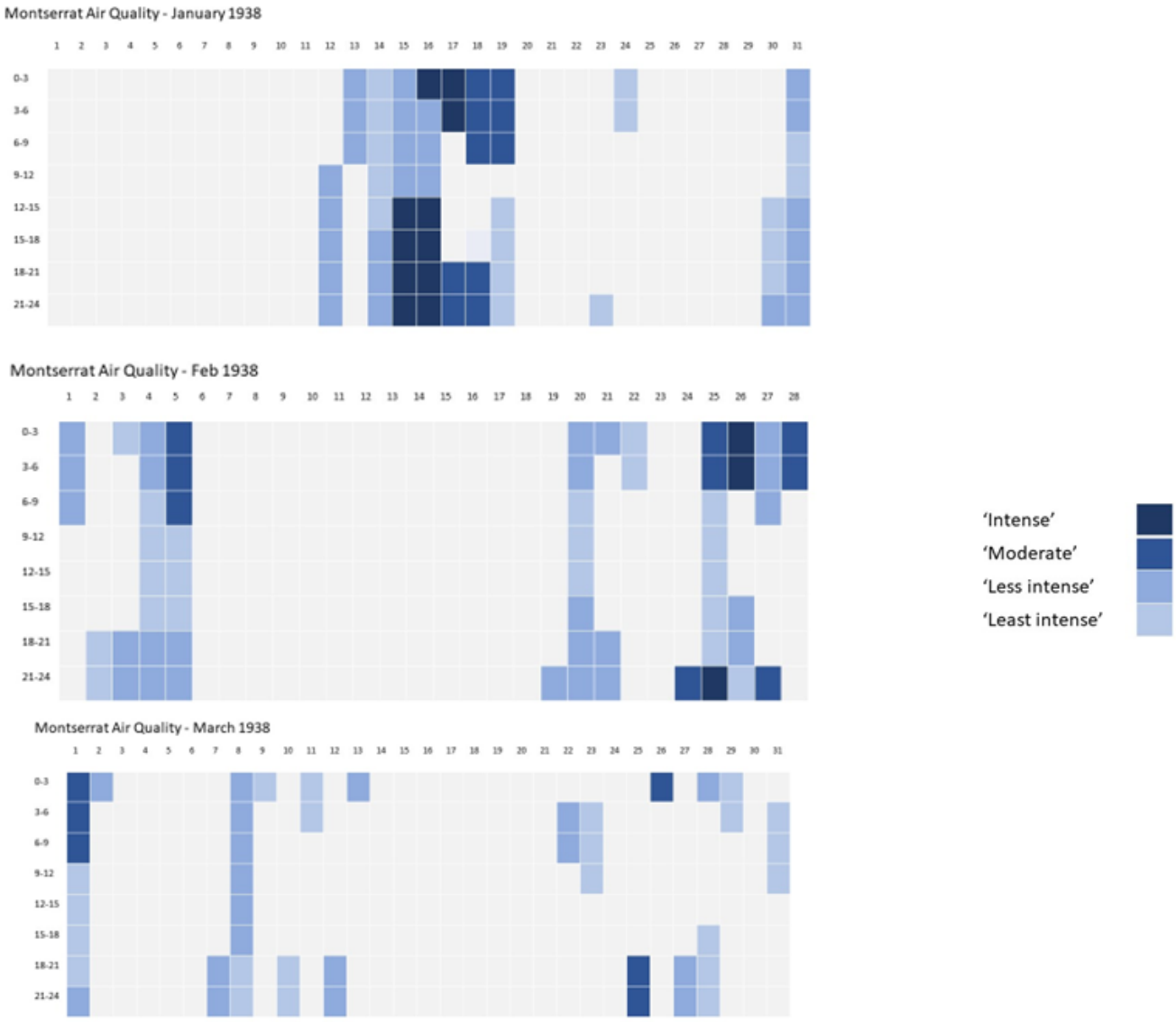

Figure 9: Summary of qualitative air quality measurements in Plymouth, January–March 1938 recorded in the monthly reports of the seismo-volcanological observatory. Boxes are coloured according the reported intensity, the x-axis represents the day of the month, the y-axis the time. The intensity of discolouration of the disc 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 discs.

After working on Martinique and Montserrat, Perret also distinguished between 'crateral' 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 [p. 97 Perret 1950]. On Pelée, Martinique, in the 1930s, Perret was not able to carry out much gas and fluid analysis: the older, accessible soufrières were too cool, while the new ones were not accessible [Perret 1935]. He attempted to detect the presence of gases in passing *nuée 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 collected gas and water samples for analysis by Ernest 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 Hawai'i in 1911, along with Jaggar [Shepherd 1927]. Perret also employed a suite of instruments for monitoring the soufrières, including a manometer for gas pressure, and a microphone and tuning fork to detect the dominant pitch of the steam vents. Perret first used this technique on the solfatara at Campi Fle-

grei in Italy, and later on the lava domes of Mont Pelee [Perret 1924; 1937]. Perret supposed that the pitch of the sound in a solfatara system would offer an indication of the internal pressurisation and gas content of the system [Perret 1924]; while a shell-like lava dome would have a characteristic resonant frequency, and 'the musical tone ... mi, fa, sol, la ...' would change with dome mass, or internal pressure [Jaggar 1932]. More recent work has verified that fumarole-dominated systems do indeed resonate [e.g. Chiodini et al. 2017; Falanga et al. 2021], and that the characteristic frequency varies with the level of activity, and can be modelled as an acoustic response of the system [Montegrossi et al. 2019].

Jaggar was impressed by Perret's pioneering work on Montserrat, not least because at that time there were 'no good techniques for the continuous study of gases, sublimates and temperature' in volcanic systems. Their discussions on Montserrat and Martinique* on the need for continuous sampling for both temperature and trace gases likely inspired Perret's modification of the Bristol thermograph to create the first continuous air quality recorder for ambient exposure to H_2S.

8 1939–1946

Following the start of WWII in 1939, monitoring efforts on Montserrat were gradually scaled down. From February 1940, an observer visited Gages soufrière monthly, and Galways every three months. The last three Jaggar shock recorders were mothballed, but the Wiechert seismograph continued to operate, and used 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 did not diminish as the network contracted, since the Wiechert seismograph and its clock system needed careful attention, maintenance, and routine sensitivity testing and calibration. The 'war-time dry batteries' proved to be an unreliable source of electrical power for the instrument, and the wear of some parts was problematic since the seismograph had been manufactured in Germany, and spare parts were no longer available. In time, Ian Kelsick was replaced by other seismo-volcanological observers: his brother Cecil Kelsick stood in first, while Ian returned to his cotton duties; then Wilfred Barzey, from 1942–1943 (perhaps the same Barzey, who looked after the shock recorder at Bethel), and J. P. E. 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 for St Vincent, 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.† These instruments would complement the single Jaggar instrument that was then running in Kingstown, St Vincent.

In April 1946, the authorities on St Vincent asked if they could also use the more sensitive Wiechert seismograph 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 delicate, and once packed up in nine boxes weighed over one tonne. The Agricultural Officer on Montserrat was adamant that the shipment would need 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.‡ 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 reimbursement of the shipping costs (timber, rope, porterage, freight and tax) to the Government of Montserrat in August 1946. There are also no records of what happened to the Wiechert after arrival in St Vincent; but it seems likely that the instrument was never used, potentially due to damage in transit, or the complexity of the reassembly [Latchman et al. 2012]. The Colonial Office were informed that there would be no more shipments of charts from Montserrat, now that the network had been disbanded, and there was once again no working seismograph or shock recorder on the island. There is no record of when the air quality measurements in Plymouth ceased.

9 Aftermath

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

The Executive Council took Dr Senn's report to heart realising, too late, that they had overseen the dismantling of the Caribbean's first seismo-volcanic observatory and network. They resolved that arrangements should be made for the Jag-

*BGS MacGregor archive SA 368.01 f7 – Report from Dr Jaggar to Sir Gerald Lenox-Conyngham.

†MPL 82 158-175, minute paper 5018 14 Jan 1946

‡MPL 82 159-175 f120

§MP 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.

Table 3: Staffing of the Agriculture Department, Grove, Montserrat. Source: MPL 82-158 – 175 Monthly reports of the Seismo-Volcanological Station.

Curators and Assistants, 1934–1945	
E. S. A. 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	J. P. E. Teisheira
1944–1946	Greta B. Scotland
April 1946	E. Leverock

gar shock recorders to be 'put into use again at the Experimental Station'; and several commented further on the report.* For instance:

> *'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'*
> –Hon J. R. Wilson

> *'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"*
> –Howes

> *'It looks as if we need the Volcanologist ... to come and give us a fresh start with the keeping of useful records'*
> –Hon W. E. Bassett

The minutes noted that the Commissioner would follow up, but it is not clear what further actions, if any, followed.†

*MP 5300 f34-35

†MP 5300 – note records 'Further Action taken in MP 5316, by H.H's instruction.

10 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 1950–1951. 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, the 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 Dr Geoffrey 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 UWI Seismic Research Unit (SRU) responded by installing a network of four short-period 'Willmore type' seismographs: 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 (Figure 7).

Similar to the patterns observed by Perret in the 1930s, maxima in rates of seismic energy release were seen in May and November 1966 and 1967 [Shepherd et al. 1971; Kilburn 2025]. During this phase of unrest, Galways soufrière showed increased in activity, but no change was detected at Gages Upper or Lower soufrières. During 1966–1967, 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 to 1980, seismicity was monitored with a single, short-period vertical station which was located at the Grove. In January and February 1980, a network of ten radio-telemetered vertical seismographs with magnetic tape recording was set up on Montserrat, in support of the "Lesser Antilles Deep Lithosphere Experiment"; a seismic refraction profile experiment in the western North Atlantic [The LADLE Study Group et al. 1983]. After the experiment, one instrument remained at St George's Hill, and the telemetry was redirected to the Seismic Research Unit headquarters in Trinidad, via Antigua [Shepherd et al. 2002; Smith 2013]. This was augmented with a network of dry-tilt stations which were re-measured annually, but there was no regular monitoring of the soufrières [Wadge and Isaacs 1987]. Following a large tectonic earthquake near Redonda in 1985, multiple aftershocks were detected on Montserrat in 1985–1986, and two new stations were installed on Montserrat in 1989 to help distinguish aftershocks from any local earthquakes. This network was damaged by Hurricane Hugo in September 1989, and 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 beneath Montserrat [Aspinall et al. 1998; Robertson et al. 2000; Shepherd et al. 2002; Kilburn 2025]. 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 1930s and 1966–67 (Figure 7), mainly 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. 1998], and no sulphur dioxide was detected at any stage before the magmatic eruption began. The earliest phases of eruptive activity in July 1995 were phreatic in nature, and ejecta included abundant samples of hydrothermally altered materials [Boudon et al. 1998]. Following the start of the eruption, a temporary observatory was set up in Plymouth, and by October 1995, the Montserrat Volcano Observatory had been established in a house in Old Towne [Aspinall et al. 2002; Donovan et al. 2012].

11 Discussion and Conclusions

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

1. Engaged and aware officers and staff in the Agricultural Department, who took responsibility for observing and reporting on the state of the soufrières and for documenting felt earthquake shocks, before instruments were deployed, later in the episode.

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 regular, routine measurements of seismic and other phenomena, 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 familiarity with setting up field stations for continuous observation of active volcanoes was a key element of his response to the extended events of 1934–1937.

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 Montserrat 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, Frank Perret and Thomas Jaggar, who both had practical experience of monitoring active volcanoes and of setting up and running observatories, 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 the visiting colonial 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 1902–1903 [Pyle et al. 2018; Barclay et al. 2022; Mahony et al. 2025]. 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 successive colonial governments in Britain, 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-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 (https://curatingcrises.omeka.net/). Conceptualisation: DMP, JB, MM, KP, EPJ, JS; data gathering (archives) all authors; manuscript outline DMP, JB, MM; manuscript preparation and review all authors.

Acknowledgements

This work was funded primarily through the Arts and Humanities Research Council (AHRC) and Natural Environment Research Council (NERC). 'Hidden Histories' programme, the Curating Crises Project, grant reference AH/W00898X/1. Additional support was provided from NERC COMET (to DMP), GNCA (Oxford and UEA) and the Oxford Martin Programme on Rethinking Natural Resources (to DMP). We gratefully acknowledge the assistance of the many professional staff who facilitated our visits and access to archive materials, and provided assistance and support in kind through digitisation, including Sonja Smith (Montserrat Public Library), Sarita Francis, Jean Handscombe, Fay Needham and Samantha Lauren (Montserrat National Trust), Louisiana Ferlier and Keith Moore (Royal Society), Pad Kumlertsakul, Elizabeth Haines and Kaja Marczewska (The National Archives, Kew), Lucy McCann and Matthew Neely (Bodleian Libraries, Oxford University), Andrew Morrison (British Geological Survey), Shaun Hardy (Carnegie Science), Karen Anderson (Bristol University Special Collections), Danielle Czerkaszyn and Matthew Barton (Oxford University Museum of Natural History) and Helen Wong Smith (University of Hawai'i). Some of these digitised materials are freely available through the Curating Crises website (https://curatingcrises.omeka.net/).

We thank many others both in the UK and the Caribbean for feedback, discussion and assistance including Petros Bogiatzis, Gracelyn Cassell, James Christie, Thomas Christopher, Richie Robertson, Miriam Rothenberg, Rod Stewart, Julio Rodriguez Stimson, and Graham Ryan; and we also thank Willy Aspinall and Amy Donovan for helpful reviews.

Abstract translation provided by M. Oryaëlle Chevrel.

Data Availability

Datasets derived from archival materials which we use in this paper are available on figshare: data from Montserrat seismo-volcanological observatory reports, 1935–1938; locations of 1936–1938 earthquakes; and transcribed list of Montserrat's Government House visitors, 1934–1937. https://figshare.com/projects/The_first_seismo-volcanological_observatory_on_Montserrat/214351.

Copyright Notice

References

Anderson, J. A. and H. O. Wood (1925). "Description and theory of the torsion seismometer". *Bulletin of the Seismological Society of America* 15(1), pages 1–72. DOI: 10.1785/BSSA0150010001.

Anderson, T. and J. S. Flett (1902). "Preliminary report on the recent eruption of the Soufrière in St. Vincent, and of a visit to Mont Pelée, in Martinique". *Proceedings of the Royal Society of London* 70(459–466), pages 423–445. DOI: 10.1098/rspl.1902.0042.

Anonymous (1926). "The Third Pan-Pacific Science Congress". *Science* 64, pages 269–272.

– (1936). "Societies and Academies. Royal Society, December 10". *Nature* 138, page 1069.

– (1937). *Nature* 139(3516), pages 499–499. DOI: 10.1038/139499a0.

Aspinall, W. P., S. C. Loughlin, F. V. Michael, A. D. Miller, G. E. Norton, K. C. Rowley, R. S. J. Sparks, and S. R. Young (2002). "The Montserrat Volcano Observatory: its evolution, organization, role and activities". *Geological Society, London, Memoirs* 21(1), pages 71–91. DOI: 10.1144/gsl.mem.2002.021.01.04.

Aspinall, W. P., A. D. Miller, L. L. Lynch, J. L. Latchman, R. C. Stewart, R. A. White, and J. A. Power (1998). "Soufrière Hills Eruption, Montserrat, 1995–1997: Volcanic earthquake locations and fault plane solutions". *Geophysical Research Letters* 25(18), pages 3397–3400. DOI: 10.1029/98gl00858.

Barberi, F., A. Bertagnini, P. Landi, and C. Principe (1992). "A review on phreatic eruptions and their precursors". *Journal of Volcanology and Geothermal Research* 52(4), pages 231–246. DOI: 10.1016/0377-0273(92)90046-g.

Barclay, J., R. Robertson, J. P. Scarlett, D. M. Pyle, and M. T. Armijos (2022). "Disaster aid? Mapping historical responses to volcanic eruptions from 1800–2000 in the English-speaking Eastern Caribbean: their role in creating vulnerabilities". *Disasters* 46(S1). DOI: 10.1111/disa.12537.

Belkin, H. E. and T. Gidwitz (2020). "The contributions and influence of two Americans, Henry S. Washington and Frank A. Perret, to the study of Italian volcanism with emphasis on volcanoes in the Naples area". *Vesuvius, Campi Flegrei, and Campanian Volcanism*. Elsevier, pages 9–32. ISBN: 9780128164549. DOI: 10.1016/b978-0-12-816454-9.00002-x.

Bilham, E. G. (1932). "Measuring Atmospheric Pollution". *Nature* 129(3246), pages 103–104. DOI: 10.1038/129103a0.

Boudon, G., A. Le Friant, B. Villemant, and J.-P. Viodé (2005). "Martinique". *Volcanic Atlas of the Lesser Antilles*. Edited by J. M. Lindsay, R. E. A. Robertson, J. B. Shepherd, and S. Ali. Trinidad and Tobago: Seismic Research Unit, The University of the West Indies, pages 65–102.

Boudon, G., B. Villemant, J.-C. Komorowski, P. Ildefonse, and M. P. Semet (1998). "The hydrothermal system at Soufriere Hills Volcano, Montserrat (West Indies): Characterization and role in the on-going eruption". *Geophysical Research Letters* 25(19), pages 3693–3696. DOI: 10.1029/98gl00985.

Brussell, D. E. (2004). "A Medicinal Plant Collection from Montserrat, West Indies". *Economic Botany* 58(sp1), S203–S220. DOI: 10.1663/0013-0001(2004)58[s203:ampcfm]2.0.co;2. [Supplement].

Bullard, E. C. (1969). "Obituary notice. Benjamin Chapman Browne". *Quarterly Journal of the Royal Astronomical Society* 10, pages 336–341.

Bullard, E. C. (1957). "Gerald Ponsonby Lenox-Conyngham, 1866-1956". *Biographical Memoirs of Fellows of the Royal Society* (3), pages 129–140. DOI: 10.1098/rsbm.1957.0009.

Chiodini, G., R. Cioni, A. Frullani, M. Guidi, L. Marini, F. Prati, and B. Raco (1996). "Fluid geochemistry of Montserrat Island, West Indies". *Bulletin of Volcanology* 58(5), pages 380–392. DOI: 10.1007/s004450050146.

Chiodini, G., F. Giudicepietro, J. Vandemeulebrouck, A. Aiuppa, S. Caliro, W. De Cesare, G. Tamburello, R. Avino, M. Orazi, and L. D'Auria (2017). "Fumarolic tremor and geochemical signals during a volcanic unrest". *Geology* 45(12), pages 1131–1134. DOI: 10.1130/g39447.1.

Cunha, D. (2019). "The Frontier of Hell: Sicily, Sulfur, and the Rise of the British Chemical Industry, 1750–1840". *Critical Historical Studies* 6(2), pages 279–302. DOI: 10.1086/705370.

Davy, J. (1854). *The West Indies Before and Since Slave Emancipation*. London: W. and F.G. Cass. 551 pages.

Dondin, F. J.-Y., L. Lynch, C. Ramsingh, G. A. Ryan, I. Papadopoulous, D. Rueppel, E. P. Joseph, J. L. Latchman, R. E. A. Robertson, N. Nath, R. Mathura, A. Balchan, S. George, I. Juman, F. Madoo, G. Manette, and H. Ramsingh (2019). "The University of the West Indies-Seismic Research Centre Volcano Monitoring Network: Evolution since 1953 and Challenges in Maintaining a State-of-the-Art Network in a Small Island Economy". *Geosciences* 9(2), page 71. DOI: 10.3390/geosciences9020071.

Donovan, A. R., M. Bravo, and C. Oppenheimer (2012). "Co-production of an institution: Montserrat Volcano Observatory and social dependence on science". *Science and Public Policy* 40(2), pages 171–186. DOI: 10.1093/scipol/scs078.

Dumoulin Kervran, D., J. Lamy, and J. Verlin (2024). "Outposts of science: placing scientific infrastructures at the margins of French (post)colonial territories". *Science as Culture* 34(2), pages 137–167. DOI: 10.1080/09505431.2024.2381002.

Dvorak, J. (2015). *The Last Volcano*. New York: Pegasus Books. 309 pages.

Ellis, B. A. (1931). "Appendix I: Report on the Determination of Sulphur Gases in Air". *The Investigation of Air Pollution*. HMSO, pages 38–49.

Falanga, M., P. Cusano, E. De Lauro, and S. Petrosino (2021). "Picking up the hydrothermal whisper at Ischia Island in the Covid-19 lockdown quiet". *Scientific Reports* 11(1). DOI: 10.1038/s41598-021-88266-9.

Fergus, H. A. (2004). *Montserrat: History of a Caribbean Colony*. 2nd edition. Oxford: Macmillan Caribbean. 280 pages.

Frank, F. C. and D. H. Perkins (1971). "Cecil Frank Powell, 1903-1969". *Biographical Memoirs of Fellows of the Royal Society* (17), pages 541–563. DOI: 10.1098/rsbm.1971.0021.

Giblin, M. (1950). "Frank Alvord Perret (1867 – 1943 †)". *Bulletin Volcanologique* 10(1), pages 191–196. DOI: 10.1007/bf02596088.

Hammouya, G., P. Allard, P. Jean-Baptiste, F. Parello, M. P. Semet, and S. R. Young (1998). "Pre- and syn-eruptive geochemistry of volcanic gases from Soufriere Hills of Montserrat, West Indies". *Geophysical Research Letters* 25(19), pages 3685–3688. DOI: 10.1029/98gl02321.

Harding, A. J. and G. E. J. Gent (1934). *The Dominions Office and Colonial Office List for 1934*. Volume 73. London: Waterlow and Sons.

– (1935). *The Dominions Office and Colonial Office List for 1935*. Volume 74. London: Waterlow and Sons.

– (1936). *The Dominions Office and Colonial Office List for 1936*. Volume 75. London: Waterlow and Sons.

– (1937). *The Dominions Office and Colonial Office List for 1937*. Volume 76. London: Waterlow and Sons.

– (1938). *The Dominions Office and Colonial Office List for 1938*. Volume 77. London: Waterlow and Sons.

Hovey, E. O. (1903). "The new cone of Mont Pele and the gorge of the Riviere Blanche, Martinique". *American Journal of Science* s4-16(94), pages 269–281. DOI: 10.2475/ajs.s4-16.94.269.

How, N. (2020). *This Plan of the Island of Montserrat*. Manuscript, 12 pp.

Hughes, J. (2010). "'Divine right' or democracy? The Royal Society 'revolt' of 1935". *Notes and Records of the Royal Society* 64(suppl$_1$). DOI: 10.1098/rsnr.2010.0048.

Jaggar, T. A. (1902). "Notes of a Geologist in Martinique and St Vincent". *Popular Science Monthly* 61, pages 352–368.

– (1929). "A Needed Shock Recorder". *The Volcano Letter* (226). Edited by R. S. Fiske, T. Simkin, and E. Neilsen.

– (1932). "The New Dome of Pelée". *The Volcano Letter* (380).

– (1936). "The Bombing of Mauna Loa, 1935". *The Military Engineer* 28, pages 241–245.
– (1956). *My Experiments with Volcanoes*. Honolulu: Hawaiian Volcano Research Association. 198 pages.
Kilburn, C. R. J. (2025). "Prospects for Forecasting Volcanic Eruptions After Long Repose". *Modern Volcano Monitoring*. Springer Nature Switzerland, pages 399–419. ISBN: 9783031868412. DOI: 10.1007/978-3-031-86841-2_13.
Lacroix, A. (1904). *La Montagne Pelée et ses éruptions*. Paris: Masson. 662 pages.
Latchman, J., L. Lynch, and S. Edwards (2012). "60 Years of Monitoring Volcanic and Earthquake Activity in the English-Speaking Eastern Caribbean". *Caribbean Geography* 17, pages 3–17.
Lenox-Conyngham, G. (1929). "The Cambridge Pendulum Apparatus". *The Geographical Journal* 73(4), page 326. DOI: 10.2307/1783784.
MacGregor, A. G. (1936). "Royal society expedition to Montserrat, B. W. I.: Preliminary report on the geology of Montserrat". *Proceedings of the Royal Society of London. Series B - Biological Sciences* 121(822), pages 232–252. DOI: 10.1098/rspb.1936.0061.
– (1938). "The Royal Society expedition to Montserrat, B. W. I. - The volcanic history and petrology of Montserrat, with observation on Mt Pelé, in Martinique". *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 229(557), pages 1–90. DOI: 10.1098/rstb.1938.0002.
Mahony, M., J. Barclay, K. Pascal, D. M. Pyle, and J. Scarlett (2025). "Science in a crisis: Assembling volcanic knowledge in twentieth century Montserrat". *Journal of Historical Geography* 90, pages 1–12. DOI: 10.1016/j.jhg.2025.08.002.
Montegrossi, G., A. Farina, L. Fusi, and A. De Biase (2019). "Mathematical model for volcanic harmonic tremors". *Scientific Reports* 9(1). DOI: 10.1038/s41598-019-50675-2.
Niemz, P. and D. Amorèse (2016). "Relocalizing a historical earthquake using recent methods: The 10 November 1935 Earthquake near Montserrat, Lesser Antilles". *Journal of South American Earth Sciences* 66, pages 166–179. DOI: 10.1016/j.jsames.2015.12.010.
Nugent, N. (1811). "VII. An Account of "The Sulphur, " or "Souffrière" of the Island of Montserrat." *Transactions of the Geological Society of London* 1(1), pages 185–190. DOI: 10.1144/transgsla.1.185.
Okal, E. A., S. H. Kirby, and N. Kalligeris (2016). "The Showa Sanriku earthquake of 1933 March 2: a global seismological reassessment". *Geophysical Journal International* 206(3), pages 1492–1514. DOI: 10.1093/gji/ggw206.
Palmieri, L. (1873). *The Eruption of Vesuvius in 1872*. Edited by R. Mallet. London: Asher and Co.
Perret, F. A. (1908). "Some Conditions Affecting Volcanic Eruptions". *Science* 28(713), pages 277–287. DOI: 10.1126/science.28.713.277.b.
– (1924). *The Vesuvius Eruption of 1906*. Carnegie Institution of Washington. 151 pages.
– (1935). *The Eruption of Mt. Pelée 1929–1932*. Carnegie Institution of Washington. 126 pages.
– (1937). "An experimental "seismeter"". *American Journal of Science* s5-34(204), pages 469–474. DOI: 10.2475/ajs.s5-34.204.469.
– (1939). *The Volcano-Seismic Crisis at Montserrat, 1933–1937*. Carnegie Institution of Washington. 76 pages.
– (1950). *Volcanological Observations*. Carnegie Institution of Washington. 162 pages.
Powell, C. F. (1937). "Royal society expedition to Montserrat, B.W.I. Preliminary report on seismic observations". *Proceedings of the Royal Society of London. Series A-Mathematical and Physical Sciences* 158(894), pages 479–494. DOI: 10.1098/rspa.1937.0034.
– (1938). "The Royal Society expedition to Montserrat, B.W.I. Final report". *Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences* 237(771), pages 1–34. DOI: 10.1098/rsta.1938.0002.
Pyle, D. M., J. Barclay, and M. T. Armijos (2018). "The 1902–3 eruptions of the Soufrière, St Vincent: Impacts, relief and response". *Journal of Volcanology and Geothermal Research* 356, pages 183–199. DOI: 10.1016/j.jvolgeores.2018.03.005.
Rea, W. J. (1974). "The volcanic geology and petrology of Montserrat, West Indies". *Journal of the Geological Society* 130(4), pages 341–366. DOI: 10.1144/gsjgs.130.4.0341.
Robert, C. P., N. Chopin, and J. Rousseau (2009). "Harold Jeffreys's Theory of Probability Revisited". *Statistical Science* 24(2). DOI: 10.1214/09-sts284.
Robertson, R. E. A., W. P. Aspinall, R. A. Herd, G. E. Norton, R. S. J. Sparks, and S. R. Young (2000). "The 1995–1998 eruption of the Soufriére Hills volcano, Montserrat, WI". *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences* 358(1770). Edited by P. Francis, J. Neuberg, and R. S. J. Sparks, pages 1619–1637. DOI: 10.1098/rsta.2000.0607.
Robson, G. R. (1964). "An earthquake catalogue for the Eastern Caribbean 1530-1960". *Bulletin of the Seismological Society of America* 54(2), pages 785–832. DOI: 10.1785/bssa0540020785.
Robson, G. R. and P. L. Willmore (1955). "Some heat measurements in West Indian soufrières". *Bulletin Volcanologique* 17(1), pages 13–39. DOI: 10.1007/bf02596041.
Romer, M. (1931). "La dernière Éruption de la montagne Pelée". *Bulletin Volcanologique* 8(1), pages 89–116. DOI: 10.1007/bf02720214.
Rose, A. (2022). "Seismographs at Eskdalemuir Observatory, 1908–1925: tools for rethinking the origins of international cooperation in seismology". *Science Museum Group Journal* 16(16). DOI: 10.15180/211607.
Rothenberg, M. A. W. (2021). "Wind-Powered Sugar Mills as Constructions of Control in Colonial Montserrat". *International Journal of Historical Archaeology* 25(1), pages 144–169. DOI: 10.1007/s10761-020-00553-9.
Shepherd, E. S. (1927). *Eos, Transactions American Geophysical Union* 8(1), pages 259–263. DOI: 10.1029/tr008i001p00259.

Shepherd, J. B., R. Robertson, J. Latchman, and L. Lynch (2002). *Precursory Activity to the 1995 Eruption of the Soufrière Hills Volcano, Montserrat*. Technical report. Seismic Research Unit, page 17.

Shepherd, J. B., J. F. Tomblin, and D. A. Woo (1971). "Volcano-seismic crisis in Montserrat, West Indies, 1966–67". *Bulletin Volcanologique* 35(1), pages 143–162. DOI: 10.1007/bf02596813.

Simpson, G. C. (1944). "Francis John Welsh Whipple, 1876–1943". *Terrestrial Magnetism and Atmospheric Electricity* 49(2), pages 125–126. DOI: 10.1029/te049i002p00125.

Smith, P. (2013). "Volcano-Tectonic Seismicity of Soufriere Hills Volcano, Montserrat". *Encyclopedia of Earthquake Engineering*. Springer Berlin Heidelberg, pages 1–14. ISBN: 9783642361975. DOI: 10.1007/978-3-642-36197-5_93-1.

Sottili, G., S. Lambert, and D. M. Palladino (2021). "Tides and Volcanoes: A Historical Perspective". *Frontiers in Earth Science* 9. DOI: 10.3389/feart.2021.777548.

Sturge, J. and T. Harvey (1838). *The West Indies in 1837: Being the Journal of a Visit to Antigua, Monsterrat, Dominica, St. Lucia, Barbadoes, and Jamaica: Undertaken for the Purpose of Ascertaining the Actual Condition of the Negro Population of Those Islands*. London: Hamilton, Adams, and Company, Paternoster-Row. 380 pages.

Tanguy, J.-C. (1994). "The 1902–1905 eruptions of Montagne Pelée, Martinique: anatomy and retrospection". *Journal of Volcanology and Geothermal Research* 60(2), pages 87–107. DOI: 10.1016/0377-0273(94)90064-7.

The LADLE Study Group, R. B. Whitmarsh, C. E. Keen, L. Steinmetz, J. Tomblin, R. B. Whitmarsh, M. Donegan, R. C. Lilwall, B. D. Loncarevic, B. Nichols, and J. B. Shepherd (1983). "A lithospheric seismic refraction profile in the western North Atlantic Ocean". *Geophysical Journal International* 75(1), pages 23–69. DOI: 10.1111/j.1365-246x.1983.tb01912.x.

Thomas, H. H. (1954). "Obituary: Robert Stewart Whipple". *Bulletin of the British Society for the History of Science* 1, pages 249–250.

Truesdale, E. C. (1930). "Sensitivity of Various Tests for Traces of Hydrogen Sulfide". *Industrial & Engineering Chemistry Analytical Edition* 2(3), pages 299–302. DOI: 10.1021/ac50071a038.

Verlin, J. (2022). "Comment surveiller le volcan outre-mer ?: Observation scientifique ou gestion de crises volcaniques en Martinique". *Revue d'anthropologie des connaissances* 16(3). DOI: 10.4000/rac.27608.

Wadge, G. and M. C. Isaacs (1988). "Mapping the volcanic hazards from Soufriere Hills Volcano, Montserrat, West Indies using an image processor". *Journal of the Geological Society* 145(4), pages 541–551. DOI: 10.1144/gsjgs.145.4.0541.

Wadge, G. and M. C. Isaacs (1987). "Volcanic Hazards from Soufrière Hills Volcano, Montserrat, West Indies". Unpublished report to the Government of Montserrat and the Pan Caribbean Disaster Preparedness and Prevention Project.

Willmore, P. L. (1950). "The theory and design of two types of portable seismograph". *Geophysical Journal International* 6, pages 129–137. DOI: 10.1111/j.1365-246x.1950.tb02987.x.

– (1952). "The Earthquake Series in St. Kitts – Nevis, 1950–51: With Notes on Soufrière Activity in the Lesser Antilles". *Nature* 169(4306), pages 770–772. DOI: 10.1038/169770a0.

Appendix A

Table A1: List of archive sources consulted.

Abbreviation (adopted here), name and location	File number(s)	Brief summary
BGS - British Geological Survey Archives, Keyworth, UK.	SA 368.01	MacGregor's diaries and field notes, February - June 1936; correspondence and photographs relating to Montserrat.
CI - Carnegie Science Archives, Washington DC.	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 Avenue, 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 B

Table B1: 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]
	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 1933–1937 investigations [Perret 1939].

[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.
[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 C

Table C1: Royal Society Montserrat Expedition timings, February 1936 to March 1937. Sources: CFP–Powell notebooks, Bristol University Special Collections; GLC–Gerald Lenox-Conyngham diary for 1936, or 1937 Cambridge University Library Special Collections; JIR–Jaggar interim report; MGD–A G MacGregor's Diary (BGS); MPL–Montserrat, Government House visitors book. RS-MC Royal Society Montserrat Committee minute, CMB 134 (L) 21 February 1936; TAJ–Jaggar's Day Book for 1936 (University of Hawai'i). Boat names are italicised.

Date	Person/People	Notes	Source
22 Feb 1936	MacGregor	Departs Dover, UK, on the Venezuela	MGD
4 March 1936	Powell	Powell meets Bullard and Lenox-Conyngham in Cambridge	GLC
6 March 1936	MacGregor	Disembarked at Barbados. Transferred to *Lady Drake* for Montserrat, via St Lucia and Dominica	MGD
6 March 1936	Powell	Departs London on the *SS Ingoma*	RS-MC
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 1936	Powell	All Jaggar shock recorders working; Wiechert not yet working	MGD
26 March	Lenox-Conyngham	Visits Thomas Cook travel agents to 'see about joining for Honolulu to Montserrat'	GLC
27 March		Wiechert now working at the Grove	MGD
8 April	Lenox-Conyngham	Invites Jaggar (Hawaii Volcano Observatory) to visit Montserrat in May	TAJ
9 April	Lenox-Conyngham	Jaggar accepts invite 'sail 18th'	TAJ, GLC
18 April	Jaggar	Thomas and Isabel Jaggar depart Honolulu on *SS Lurline*, for Los Angeles	TAJ
23 April	Powell	Begins installing sound-ranging equipment in hotel	MGD
27 April	Jaggar	Jaggars depart Los Angeles on *SS Canada* for St Thomas, via Panama Canal and Jamaica.	TAJ
30 April	Lenox-Conyngham	Decides to go to Montserrat	GLC
6 May	MacGregor	Departs Montserrat on *Nerissa*, for Martinique	MGD
8 May 1936	MacGregor	Arrives Martinique, meets Perret	MGD
12 May 1936	Jaggar	Depart St Thomas on *SS Baralt* (KNSM) for St Kitts	TAJ
13 May 1936	MacGregor	Flies to Antigua with Perret, then by boat to Montserrat	MGD
15 May 1936	Jaggar	Depart St Kitts for Antigua on *Lady Drake*	Jaggar [1956]
16 May 1936	Jaggars and Perret	Arrive Montserrat on *Lady Drake* from 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, 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
7–10 June 1936	Jaggar	Completes an interim report on West Indies volcanoes for Lenox-Conyngham; mails a copy to Flett	TAJ
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

Continued on next page.

Table C1: (Continued) Royal Society Montserrat Expedition timings, February 1936 to March 1937. Sources: CFP–Powell notebooks, Bristol University Special Collections; GLC–Gerald Lenox-Conyngham diary for 1936, or 1937 Cambridge University Library Special Collections; JIR–Jaggar interim report; MGD–A G MacGregor's Diary (BGS); MPL–Montserrat, Government House visitors book. RS-MC Royal Society Montserrat Committee minute, CMB 134 (L) 21 February 1936; TAJ–Jaggar's Day Book for 1936 (University of Hawai'i). Boat names are italicised.

Date	Person/People	Notes	Source
26 June	Lenox-Conyngham	Departs London on the *SS Ingoma*	GLC
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
9 July 1936	Lenox-Conyngham	Lands in Antigua. Meets Sir Gordon Lethem, Governor of the Leeward Islands	GLC
11 July 1936	Powell and Lenox-Conyngham	Lenox-Conyngham meets Mr Gomez on Antigua. Then to Montserrat on the *Lady Nelson*. Meets Powell at the dock, and Commissioner Moir	CFP; GLC
15 July 1936	Powell and Lenox-Conyngham	Meet with seismo-volcanological observers. Powell explains operation of the Jagger shock recorders. Dismantle the Wiechert with Powell, Shand, Maloney and Kelsick, in order to move it	GLC
21 July	Powell and Lenox-Conyngham	Rebuild the Wiechert in the new seismograph house	GLC
24 July 1936	Powell	Departs Montserrat on the *Ingoma*	CFP; GLC
28 September 1936	Powell	Submits preliminary report to the Royal Society	Powell [1937]
4 November 1936	Jaggar	Completes and mails his final report	TAJ
10 December 1936	MacGregor and Powell	Present their preliminary reports to the Royal Society	Anonymous [1936]
16 February 1937	Powell	Submits final report to the Royal Society	Powell [1938]
12 March 1937	Lenox-Conyngham	Presents a Friday evening Discourse on West Indian Volcanoes at the Royal Institution	GLC; Anonymous [1937]

Appendix D

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.*
By
I.O. Kelsick
Clerk-in-charge
of Volcanological Instruments

CONTENTS

LIST of INSTRUMENTS

DETAILS of OBSERVATIONS

(a) Seismological
(b) Volcanological
(c) Meteorological
(d) Clerical

REQUIREMENTS, COST of OPERATION, and STAFF RESULTS.

REPORT

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.

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. Wiechert Seismograph with smoking and fixing apparatus	£180	Messrs Spindler & Heyer, Gottingen, Germany
2. Electric clock attached to Wiechert Seismograph	£30	The Synchronome Co, Ltd, 32 & 34 Clerkenwell Rd, London E.C.
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	Ditto	Ditto
(b) Maximum hand thermometers	Ditto	Ditto
(c) Suction pump & pump for determining concentration of H2S	Ditto	Ditto
6 1 stop watch	Ditto	Ditto

*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'.

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* 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*† 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.

*Gages and Galways

†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 Hawai'i. It is said that a severe subterranean earthquake occurred off the coast of Japan. The shock was recorded by Seismographs located at Hawai'i 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.*

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 14 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.

*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

The shock on July 14 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.

Appendix E

Montserrat 1936 to 1937 earthquake locations, extracted from Fig 11 in Powell [1938].

Table E1: Group: I to V are Powell's groupings. Some locations fell outside these areas, and their location is indicated with a nearby place name (CH–Centre Hills, S–Streatham, SJ–St John's ; SSH–South Soufriere Hills). #: labelled event number from Powell [1938]. Several numbers are duplicated on Powell's map.

Group	#	Longitude (°W)	Latitude (°N)	Date	Time
I	1	−62.203	16.716	28-Apr-36	20:21:00
I	3	−62.199	16.72	29-Apr-36	21:49:00
I	4	−62.202	16.721	29-Apr-36	22:24:00
I	4	−62.204	16.727		
II	19	−62.189	16.712	3-May-36	02:45:00
II	24	−62.191	16.712	3-May-36	03:48:00
II	27	−62.184	16.711	3-May-36	11:51:00
II	27	−62.177	16.711		
II	28	−62.184	16.713	4-May-36	06:40:00
II	28	−62.176	16.713		
II	34	−62.184	16.715	4-May-36	15:23:00
II	39	−62.181	16.713	6-May-36	15:00:00
V	48	−62.176	16.739	7-May-36	19:51:00
V	49	−62.171	16.739	7-May-36	19:58:00
S	52	−62.182	16.733	7-May-36	21:31:00
I	61	−62.205	16.726	9-May-36	23:59:00
I	62	−62.198	16.721	10-May-36	00:02:00
I	63	−62.205	16.724	10-May-36	00:13:00
I	64	−62.202	16.725	10-May-36	00:17:00
I	65	−62.202	16.726	10-May-36	00:23:00
I	66	−62.204	16.726	10-May-36	02:07:00
IV	67	−62.194	16.738	10-May-36	02:15:00
I	80	−62.202	16.727	12-May-26	12:14:00
II	81	−62.16	16.723	12-May-36	17:36:00
I	82	−62.207	16.725	13-May-36	00:56:00
I	83	−62.209	16.724	13-May-36	01:15:00
I	84	−62.208	16.726	13-May-36	01:16:00
S	85	−62.186	16.736	13-May-36	06:54:00
II	86	−62.16	16.722	13-May-36	07:49:00
II	88	−62.186	16.713	13-May-36	09:20:00
II	91	−62.158	16.724	13-May-36	19:12:00
S	94	−62.185	16.733	15-May-36	08:13:00
II	96	−62.178	16.713	17-May-36	03:42:00
II	97	−62.168	16.715	17-May-36	03:48:00
II	102	−62.166	16.715	17-May-36	09:35:00
II	102	−62.161	16.716		
I	104	−62.201	16.727	21-May-36	15:06:00
I	107	−62.201	16.723	22-May-36	10:37:00
I	108	−62.208	16.728	25-May-36	18:10:00
SJ	111	−62.185	16.765	28-May-36	02:04:00
II	112	−62.16	16.719	28-May-36	12:00:00
II	116	−62.188	16.711	31-May-36	22:41:00
III	119	−62.167	16.761	4-Jun-36	04:30:00
SSH	120	−62.169	16.697	5-Jun-36	05:42:00
II	120	−62.182	16.711		
I	121	−62.205	16.718	6-Jun-36	07:26:00
SSH	122	−62.167	16.697	6-Jun-36	09:42:00
S	123	−62.181	16.736	7-Jun-36	17:23:00
II	124	−62.174	16.714	8-Jun-36	10:34:00
II	125	−62.172	16.715	8-Jun-36	10:36:00
II	126	−62.172	16.712	8-Jun-36	13:21:00
IV	127	−62.198	16.741	9-Jun-36	13:22:00
IV	128	−62.197	16.742	17-Jun-36	17:40:00
IV	129	−62.195	16.741	17-Jun-36	22:37:00
V	131	−62.177	16.741	22-Jun-36	21:44:00
II	134	−62.168	16.717	30-Jun-36	08:45:00
III	135	−62.166	16.763	30-Jun-36	23:30:00
III	136	−62.163	16.763	1-Jul-36	05:46:00
III	137	−62.164	16.761	1-Jul-36	05:49:00
III	140	−62.167	16.765	31-Jul-36	09:14:00
S	142	−62.182	16.74	3-Aug-36	07:50:00
I	146	−62.21	16.72	12-Aug-36	10:13:00
I	151	−62.204	16.723	27-Aug-36	08:05:00
I	152	−62.202	16.723	27-Aug-36	08:06:00
I	153	−62.201	16.725	27-Aug-36	08:08:00
IV	154	−62.196	16.739	27-Aug-36	08:21:00
I	156	−62.2	16.722	27-Aug-36	09:01:00
I	157	−62.204	16.725	27-Aug-36	09:13:00
I	158	−62.207	16.72	27-Aug-36	09:16:00
I	161	−62.201	16.722	27-Aug-36	09:40:00
S	163	−62.184	16.739	3-Sep-36	20:28:00
I	165	−62.205	16.72	21-Sep-36	11:43:00
S	166	−62.184	16.736	30-Sep-36	08:19:00
S	167	−62.184	16.734	30-Sep-36	17:00:00
II	169	−62.166	16.717	25-Oct-36	17:11:00
IV	173	−62.201	16.739	20-Nov-36	23:55:00
I	174	−62.208	16.723	22-Nov-36	10:16:00
SJ	175	−62.184	16.765	27-Nov-36	20:01:00
I	177	−62.209	16.722	4-Dec-36	14:30:00
V	178	−62.173	16.742	20-Dec-36	22:35:00
V	179	−62.171	16.741	29-Dec-36	08:48:00
IV	180	−62.204	16.743	30-Dec-36	02:03:00
V	182	−62.173	16.74	11-Jan-37	15:35:00
I	182	−62.199	16.728		
I	183	−62.21	16.727	20-Jan-37	03:21:00
I	184	−62.209	16.726	20-Jan-37	03:23:00
I	185	−62.205	16.728	23-Feb-37	04:30:00
I	186	−62.206	16.727	23-Feb-37	05:43:00
I	187	−62.199	16.725	24-Feb-37	00:17:00
IV	189	−62.201	16.737	27-Mar-37	13:30:00
II	190	−62.163	16.717	31-Mar-37	19:30:00
II	191	−62.165	16.719	1-Apr-37	16:45:00
IV	192	−62.194	16.744	5-Apr-37	04:05:00
IV	193	−62.199	16.74	6-Apr-37	12:07:00
IV	195	−62.197	16.739	21-Apr-37	23:24:00
IV	197	−62.199	16.739	5-May-37	18:16:00
CH	199	−62.187	16.757	19-May-37	12:39:00
IV	200	−62.197	16.738	26-May-37	06:49:00

Appendix F

Table F1: Brief biographical summaries, and roles from 1934–1938. Sources: Executive and Legislative Council data from Harding and Gent [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

Name	Role on Montserrat, or in the UK
Barzey, Wilfrid O.	Seismo-volcanic observer.
Bassett, W.	Curator of the Agricultural Station, Grove.
Baynes, T. E. P.	Commissioner.
Bell, Edward	Acting Commissioner (1934).
Browne, C. E. E.	Assistant clerk to the Commissioner. Photographer.
Chapman, Sydney	Royal Society Montserrat Committee. Mathematician.
Collens, A. E.	Government Chemist, Antigua.
English, Thomas Savage	Worked in Government House.
Gomez, Clement A.	Curator, Grove Agricultural Station. Legislative Council, 1934–1937.
Grell, G. H.	Serviced the Wiechert seismograph. Acting Head, Montserrat Secondary School.
Griffin, Albert W.	Owner, Paradise estate. Legislative Council, 1934–1937.
Howes, Henry R.	Owner, Gages Estate. Executive and Legislative Councils.
Jaggar, Thomas	Volcanologist from the Hawaiian Volcano Observatory, invited to join the Royal Society Expedition.
Jaggar, Isabel (née Peyran)	American volcano-observer.
Jeffreys, Harold	Royal Society Montserrat Committee. Geophysicist.
Kelsick, C. A.	Seismo-volcanic observer during Ian Kelsick's absence.
Kelsick, Ian Oswald	Clerk of the instruments. First seismo-volcanic observer.
Kelsick, T. H.	Seismo-volcanic observer during Ian Kelsick's absence.
La Barrie, George V.	Inspector of works and roads, and superintendent of telephones.
Lenox-Conyngham, Sir Gerald	Representative of the Royal Society. Royal Society Montserrat Committee. Geodesist.
Leverock, E.	Seismo-Volcanological observer.
MacGregor, Archie	Geologist, Royal Society Expedition.
Manning, H. L.	Assistant Agricultural Officer.
Margetson, N. J. L.	Medical officer. Executive and Legislative Councils.
Maloney, E. P.	Cotton Officer. Provided servicing and technical assistance for the Wiechert seismograph.
Maloney, J. D.	Clerk to Executive and Legislative Councils, 1934–1936.
Meade, Charles R.	Galways Estate. Legislative Council, 1936–1938.
Moir, Stedman E.	Acting Commissioner, 1936.
Perret, Frank	American volcanologist, based in Martinique and New York.
Peters, F. E.	Schoolteacher, Harris'.
Powell, Cecil F.	Physicist, Royal Society Expedition.
Schouten, Swithin 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, Ernest S.	Chemist at the Geophysical Laboratory, Carnegie Institution.
Whipple, Francis J. W.	Director, Kew Observatory. Royal Society Montserrat Committee.