The Sound of Magma: Geographies of Infrasound, Vibrating Bodies, and Representing the Earth —

Adam Bobbette

Fig.1 (Overleaf) Perret's stationery for his proposed Volcano Museum in St-Pierre, Martinique, 20 June 1938. Document no. 7835–139. Courtesy Carnegie Institution for Science (Geophysical Laboratory Archives).

Volcanoes, we know, are loud. When Tambora erupted in 1815, people 2,000 km away thought they heard advancing gunfire. When Krakatoa erupted in 1883, the blast circled the earth four times. What are less well known are the sounds inside a volcano. Does magma sound like bubbling as it ascends through a mountain? When it moves through the earth, does it screech? The main difficulties that confronted efforts to answer these questions, especially the attempts of scientists in the early 20th century, were that humans could neither enter volcanoes nor hear under the ground from the surface.

The American volcanologist Frank Perret understood this and sought, probably for the first time, to hear the interior of volcanoes. His experiments on Vesuvius and then Kīlauea, Montserrat, Pelée and Sakurajima, with self-constructed listening devices, made the inaudible interior audible and recordable. He represented volcanoes in new ways through their sounds. He was convinced that one could learn to listen to volcanoes as one could listen to music, and he developed novel notation systems to transcribe what he heard. For Perret, listening to volcano sound was inseparable from drawing it. But drawing did not only mean the conventional mechanisms of scratching lines on paper – as seismographs did when they transcribed the shockwaves of volcanic tremors; instead, drawing for Perret belonged to a broader field of representation in which the invisible interior of the earth made itself present through a surprising range of improbable objects. Buildings, wine jugs, cans, even his own skeleton were enlisted in the endeavour of representing the sounds of a volcano. In Perret's world, placing lines on paper was only one strategy on an earth flourishing with devices and objects that amplified, resonated and mediated the hidden interior. Listening to volcanic sounds, then, meant experimenting with the limits and possibilities of how they could be represented, transcribed and codified.

Yet, rather than as a form of drawing, Perret's listening strategies were more often understood to intersect with those of physicians: in 1943, *The New York Times* reported that Perret applied a stethoscope to the earth. Perret himself even described his listening as auscultation, taking the pulse.[1] It is not surprising. The analogy between physiology and volcanology is ancient; modern volcanologists and physicians have long sought to understand the interior of the earth and humans 'non-invasively', and listening offered just such an opportunity. The analogy goes further, too; Perret's listening required his entire body. He viewed his frame as an amplifier for volcanic sounds; sound was not only of the ear, it resonated through the medium of earth into the medium of his body. Sound was wavy and the earth was watery, not solid, a planet-sized medium for the transmission of pulses. In Perret's vision of volcanology, his body was an extension of the earth, and sometimes this came to mean literally placing his body as close to a volcano as he could, inserting himself in its rumbling and shaking so that his corporeality could register its impressions. This, too, was even a kind of drawing for Perret.

This essay traces a line from Perret's auscultations to what would, towards the middle of the 20th century, come to be called planetary infrasound – sounds travelling around the earth that are below the threshold of human hearing. Perret is likely to have been one of the earliest volcanologists to become interested in what the buried sounds of the earth could tell us, and this promoted the later emergence of a scientific fascination with representing earth sounds at the scale of the planet. Where Perret was concerned with listening to volcanoes as a means to monitor them and predict their eruptions, or to hear eruptions when they were obscured in clouds or ash, the turn to planetary infrasound by mid-century geophysicists was born of a desire to monitor eruptions and even nuclear explosions around the earth. Perret's form of local monitoring was transformed into a network of infrasound stations distributed across the world that continuously transcribed infrasound waves into highly standardised lines on seismographs or digital data points.

What I am interested in by tracing this trajectory, from Perret's expansive approach to representing volcano sounds to the current techniques of planetary monitoring, is what happened to Perret's body. The shift to monitoring infrasound at the scale of the earth meant the displacement of the significance Perret gave to his feeling body. The body-as-amplifier, in itself a kind of inscription device because it registered and made underground sounds legible, was displaced by mechanical and electronic instruments of inscription. In place of Perret's body, seismographs and giant microphones became the recording devices and drawing machines of choice for planetary infrasound.

Yet machines replacing human bodies is a familiar enough story. This is not the most interesting dimension of the 20th-century history of infrasound. What is more compelling, in fact, is that the role of the body-as-amplifier persists in unexpected spaces. The final section of this essay proposes that we see the spectre of Perret's conception of his own body in contemporary concerns with infrasound illness. Indeed, there are two trajectories to this story about representing volcano sound: one is to do with the displacement of the body as infrasound became planetary, but the other is about where that displacement ended up, lingering, reminding us that some people still consider their bodies to register barely perceptible earth forces.

Volcanology: a new and greater science

In 1886, aged 22, Frank Perret was working for Thomas Edison in New York as an electrical engineer, designing portable batteries and electric motors. Soon afterwards he was to establish his own competing enterprise, the Elektron Manufacturing Company, in the new world of electronic engineering, where he designed some of the earliest electric elevators, streetcar lights, factory motors and fans. By the 1890s, Elektron motors were powering factories and office buildings, lifting people, and blowing air around New York and Massachusetts. In 1898, to compete with Henry Ford's combustion engines, Perret began designing electric cars.[2] At the age of 35, he suffered what one journalist described as 'a nervous prostration caused by overwork'; another journalist simply called it a 'nervous breakdown'.[3]

In 1903, he left his company and, following the advice of his doctor to recover abroad, moved to Naples, where he encountered Vesuvius for the first time.[4] Two years later, in 1905, he had joined the Vesuvius Royal Observatory as an unpaid Honorary Assistant to the director, Raffaele Vittorio Matteucci. He also monitored eruptions at Stromboli and Etna between 1907 and 1915, and in 1911–12 took up a post in Hawaii, where, with Thomas Jaggar from MIT, he helped to establish the first permanent volcano observatory on Kīlauea. In 1914, he was at Sakurajima in southern Japan to monitor seismicity. In 1929, he moved to Mount Pelée in French colonial Martinique and built an observatory hut, where he monitored activity for three years. While there, he also established Martinique's first Volcano Museum, which combined artefacts from the devastating 1902 eruption of Pelée with a scientific observatory. His stationery letterhead from that time described the institution as 'An outpost of Science – In touch with the Public – Combining History and Art – In a unique Institution' (Fig.1). Between 1934 and 1937, he visited nearby British colonial Montserrat 12 times to observe 'volcano-seismic disturbances'. In his early years on Vesuvius he was funded by the profits from his electric motors and, later, by a small and sometimes insecure stipend from the Carnegie Institution of Washington.

Building observatories on volcanoes was a relatively new ambition for scientists. It is often agreed that the first permanent observatory was on Vesuvius, built in 1841 by Ferdinand II, King of the Two Sicilies. The French colonial government of Martinique combined weather and volcano monitoring in the 1900s. After the eruption of Pelée in 1902, Thomas Jaggar was inspired to establish an observatory in Hawaii, and in 1911 Fusakichi Omori participated in establishing the first observatories in Japan.[5] The Netherlands East Indian *Volcano Watching Service* began to build observatories in Java in the 1920s.

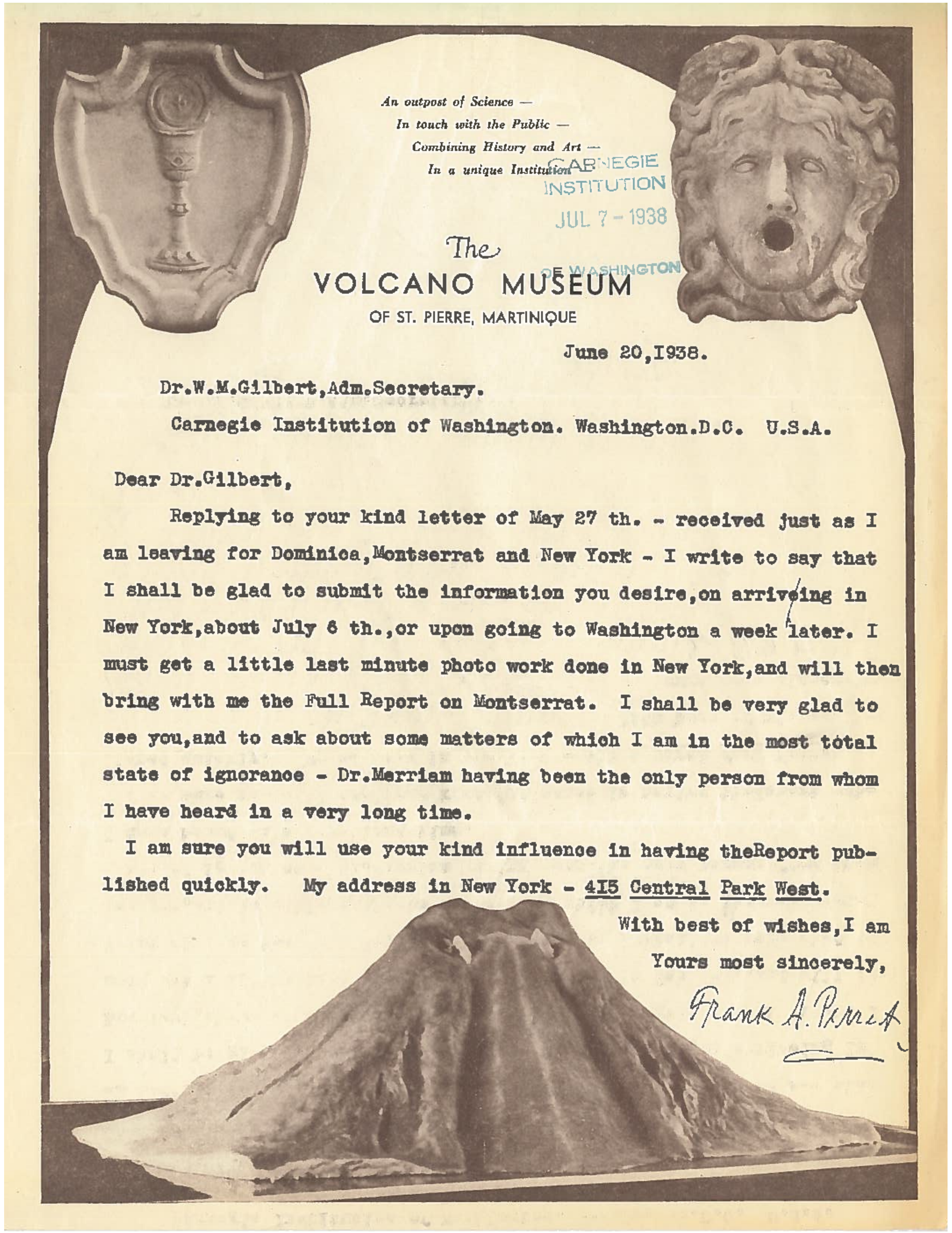
Unsurprisingly, the purpose for building many of these observatories was to advance their states' colonial ambitions. The Netherlands East Indies, for instance, home to Krakatoa and Tambora, built their first observatories, in part, to protect their plantation economy from frequent devastation in one of the most volcanically active regions on earth. When Krakatoa erupted in 1883, it put a sudden halt to the Netherlands East Indies' exports of tea, coffee, wood and spices that had for centuries made the Netherlands one of the wealthiest regions in the world; building permanent observatories and studying volcanism was one way to mitigate against future economic disruption.

The British and French developed observatories in their colonial possessions in the Caribbean – including Martinique and Guadeloupe – where eruptions threatened not only cities, but, as in the Netherlands East Indies, lucrative plantations. In the Pacific, the Hawaiian observatory was erected shortly after American possession of the island in 1900 and Native Hawaiians, Japanese, and Filipino labourers were evicted, a move justified by ideas of the American landscape sublime and volcanoes as 'nature's laboratories'.[6] Thomas Jaggar, a long-time collaborator with Perret, was encouraged to establish the first volcano observatory on Kīlauea by Lorrin A. Thurston, a media baron and activist for the colonisation of Hawaii. For Thurston, volcano science would help civilise the islands and thus add weight to the argument for joining the mainland. Perret was not exempt from the colonial geopolitics of volcanology; he was accused of espionage while working on Vesuvius.[7]

Permanently observing volcanoes was also, in part, the result of changing ideas about volcano science. Perret was one of the first scientists to argue for predicting eruptions by observing them at close range. Proximity would allow them to understand volcanoes according to their unique, local characteristics. Jaggar and Perret argued that it was important to know the conditions inside the caldera before, during, and after eruptions: the quality of clouds, the movement of lava, cataloguing the durations of eruptions, and identifying whether or not there were predictable cycles. Volcanic eruptions could last for months, even years, with peaks and troughs of intensity, and Perret thought that he had to experience the duration of these events to understand them. He wrote, 'Life on the volcano itself is a *sine qua non* for the investigation of major eruptions.'[8] Perret's approach was what might be considered a form of *volatile empiricism*: knowledge required witnessing, and this meant being present in extreme volcanic environments that could potentially harm him. According to Perret's theory of knowledge, the necessary condition for knowing volcanoes entailed approaching that which could kill the observer. As he stated it, on Pelée, he

> *lived* on the mountain itself, day and night in a hut amid penetrating ash, incessant noise and pungent smells, with the ruddy glare of the crater above shining through the open door…[9]

Such proximity scrambled his senses; he lost his bearings and injured himself. During an eruption of Vesuvius in 1906,



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OF ST. PIERRE, MARTINIQUE

June 20,1938.

Dr.W.M.Gilbert,Adm.Secretary.
Carnegie Institution of Washington. Washington.D.C. U.S.A.

Dear Dr.Gilbert,

Replying to your kind letter of May 27 th. - received just as I am leaving for Dominica,Montserrat and New York - I write to say that I shall be glad to submit the information you desire,on arriv~~e~~ing in New York,about July 6 th.,or upon going to Washington a week later. I must get a little last minute photo work done in New York,and will then bring with me the Full Report on Montserrat. I shall be very glad to see you,and to ask about some matters of which I am in the most total state of ignorance - Dr.Merriam having been the only person from whom I have heard in a very long time.

I am sure you will use your kind influence in having theReport published quickly. My address in New York - 415 Central Park West.

With best of wishes,I am
Yours most sincerely,

Frank A. Perret

> the gases made the air nearly unbreathable, and the ashes produced a darkness that was absolute. If the eyes were opened they filled at once with sand and ashes, which were driven by the blast with such force as to make the lips bleed.[10]

In the end, everything was covered in ash, a '*negativity* that is impossible to describe. As far as the eye could reach, there was not one note of colour; all was of one uniform tint'; the world was rendered featureless, a void. 'The sense walls of the universe', he reflected, 'are shattered.'[11] Volcanism, Perret seems to have suggested, can destroy the coordinates that make space, give depth, and situate objects – and human bodies – in time: 'the sense walls', as if he were referring to Kant's mental categories that were broken in his theory of the sublime. Volatile empiricism brought the body as close as possible to destroying the very conditions of possibility of knowledge – death.

Perret's cognitive disorientation coincided with monastic austerity. He was frequently described as thin, solitary, and obsessive about his work. Raffaele Matteucci, his research partner and mentor for over a decade at the Vesuvius observatory, described their approach to eating: 'How can I, when my beloved volcano is in eruption, and I should be counting the number of explosions per minute, occupy my mind with thoughts of mere food?'[12] Matteucci slept in a mouldy room in the observatory while Perret slept in lean-tos on the crater. Neither Matteucci nor Perret had families, and newspaper profiles at the time depicted them as austere bachelors with a single-minded focus on their extreme science. Matteucci explained in *Cosmopolitan* that 'I love my mountain. She and I dwell together in solitude mysterious and terrible.'[13] The scientists' austerities, single-minded focus, and eschewing of conventional social pursuits seemed to amplify their sensitivity to the sensual excesses of the volcanoes. The poverty of their science, as they depicted it, was necessary to tune their bodies to the signs of volcanism. Volcanology, Perret exclaimed in a manifesto pamphlet, was 'a new and greater science' of the 'living earth' because it combined existing sciences in novel ways (Figs 2, 3).[14] He used instruments such as seismographs and telescopes, developed his own diagram system for recording explosion clouds, and tinkered with tools to expand his capacity to see, feel, and record volcanism (Figs 4, 5).[15] His austerities were critical for the greater science he wanted to create because they tuned his feeling body to the 'living earth'. This was why sound mattered.

Teeth on the bedstead

In 1902, during the build-up of magma in Vesuvius, Perret noticed that the sounds of tremors were amplified by his pillow. He remembered an increasingly deaf Edison, when he used to work in the New York lab, searchingly biting on to objects to hear more clearly. Perret then bit his bedstead and amplified the tremors through his skull. Hearing became material, a corporeal connection of volcano to skull; sound was feeling, and Perret's body became a medium that collapsed the distance between his bed and the volcano. Scholars of sound studies have long argued that listening is no passive reception of sound but is instead the movement and arrangement of human bodies in space; in other words, sound creates geographies.[16] Perret's experience of his skull-as-amplifier opened a new geography of volcano sound that re-oriented his body in relation to volcanoes and from which a new choreography would emerge, in which he would tinker with ways of coaxing deep sounds to the surface, tuning his body to listen to the barely audible, and amplifying what had never been heard before. Bringing together his knowledge of electrical engineering with his handyman's attention to the available and *ad hoc*, he created a new sound-body-space.

Deborah Coen shows how important the body-as-medium was also for the related European science of seismology.[17] Before the widespread use of mechanical seismological instruments at the turn of the 20th century, people's bodies were often the first source for knowing seismic events. Naturalists encouraged people to record their experiences of earthquakes, including duration, time of day, intensity of vibrations as they felt them. Local newspapers in Switzerland, and even as far north as Scotland, included descriptions of tremors reported by local residents in a late-19th-century seismic fever. Some of the first seismological maps of the European Alps, where local tremors resulted from rifting glaciers, were derived from these reports by converting the newspaper accounts of tremors into spatialised diagrams of seismicity.

The enthusiasm for thinking of the body as a locus of sensitivity to vibrations was entwined with, as Shelly Trower explains in *Senses of Vibration*, new experiences of vibrations in an industrialising world. Physicists and psychologists, for instance, fretted over the effect of vibrations resulting from rapid urbanisation; trains, and electricity, it was thought, could negatively and invisibly affect bodies.[18] Some physicians worried about 'railway spine' caused by train carriage vibrations, or the vibrations created by the ubiquitous demolition and destruction of construction in major cities. The relatively recent application of physics to geology towards the end of the 19th century, followed by the emergence of geophysics at the turn of the 20th, brought together similar knowledges of vibrations derived from physics with re-thinking the solid earth. Ways of thinking about human bodies as media were applied to the earth as geophysicists began to reveal that the earth was in fact not solid but a giant medium for waves travelling through it, and human bodies were their amplifiers. John Milne, designer of seismographs and the first global seismograph network, put it, in his introduction to seismology in 1886, that rocks are 'elastic moduli' through which earthquakes 'propagate'.[19] By the turn of the 20th century, American and European scientists were transmitting electrical charges through the ground to prospect for profitable

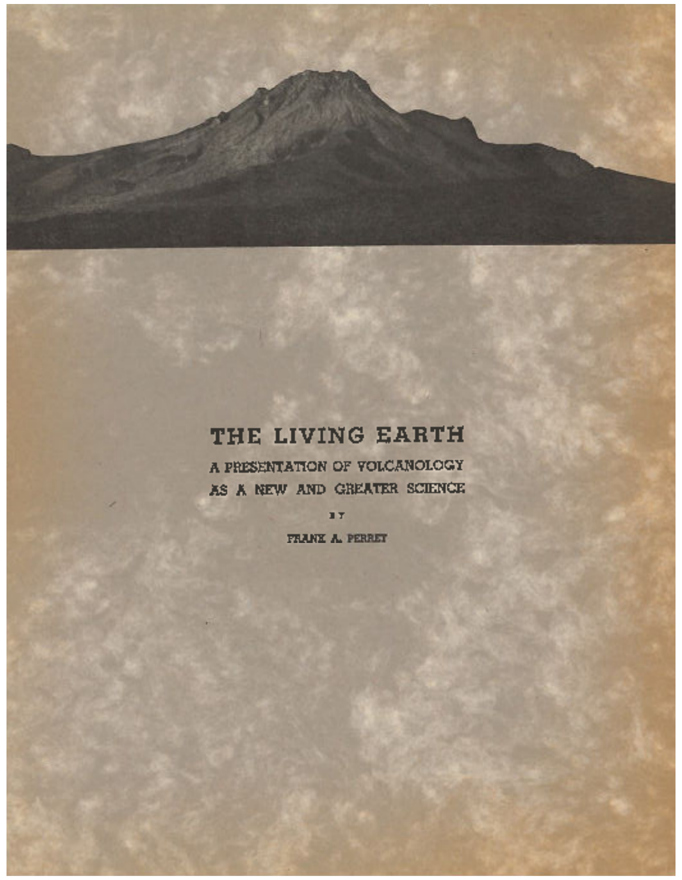


Fig.2 Frank Perret, *The Living Earth: A Presentation of Volcanology as a New and Greater Science*, n.d. Document no. 7835-32. Courtesy Carnegie Institution for Science (Geophysical Laboratory Archives).

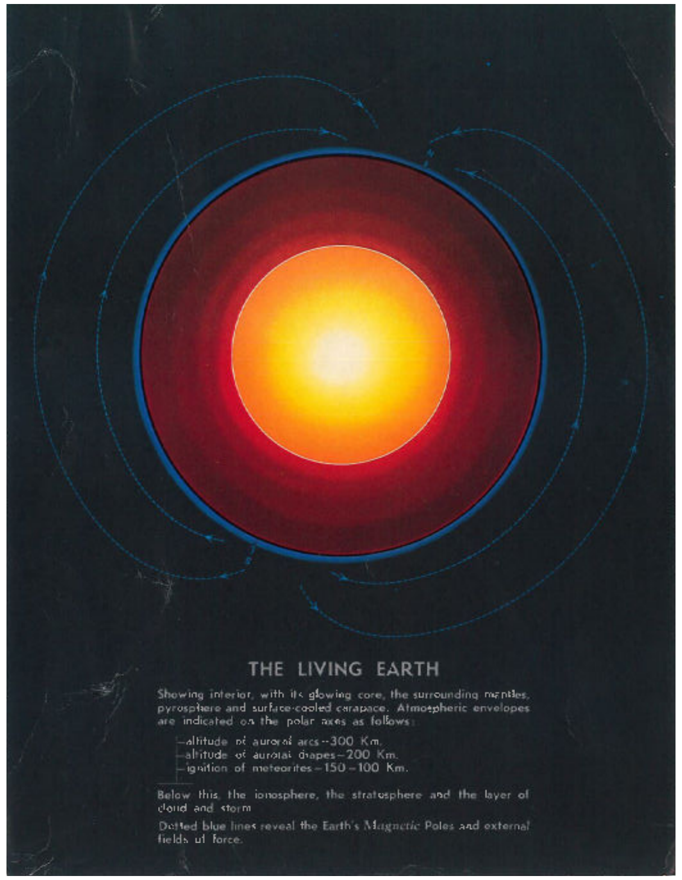


Fig.3 Frank Perret, *The Living Earth: A Presentation of Volcanology as a New and Greater Science*, n.d. Document no. 7835-128. Courtesy Carnegie Institution for Science (Geophysical Laboratory Archives).

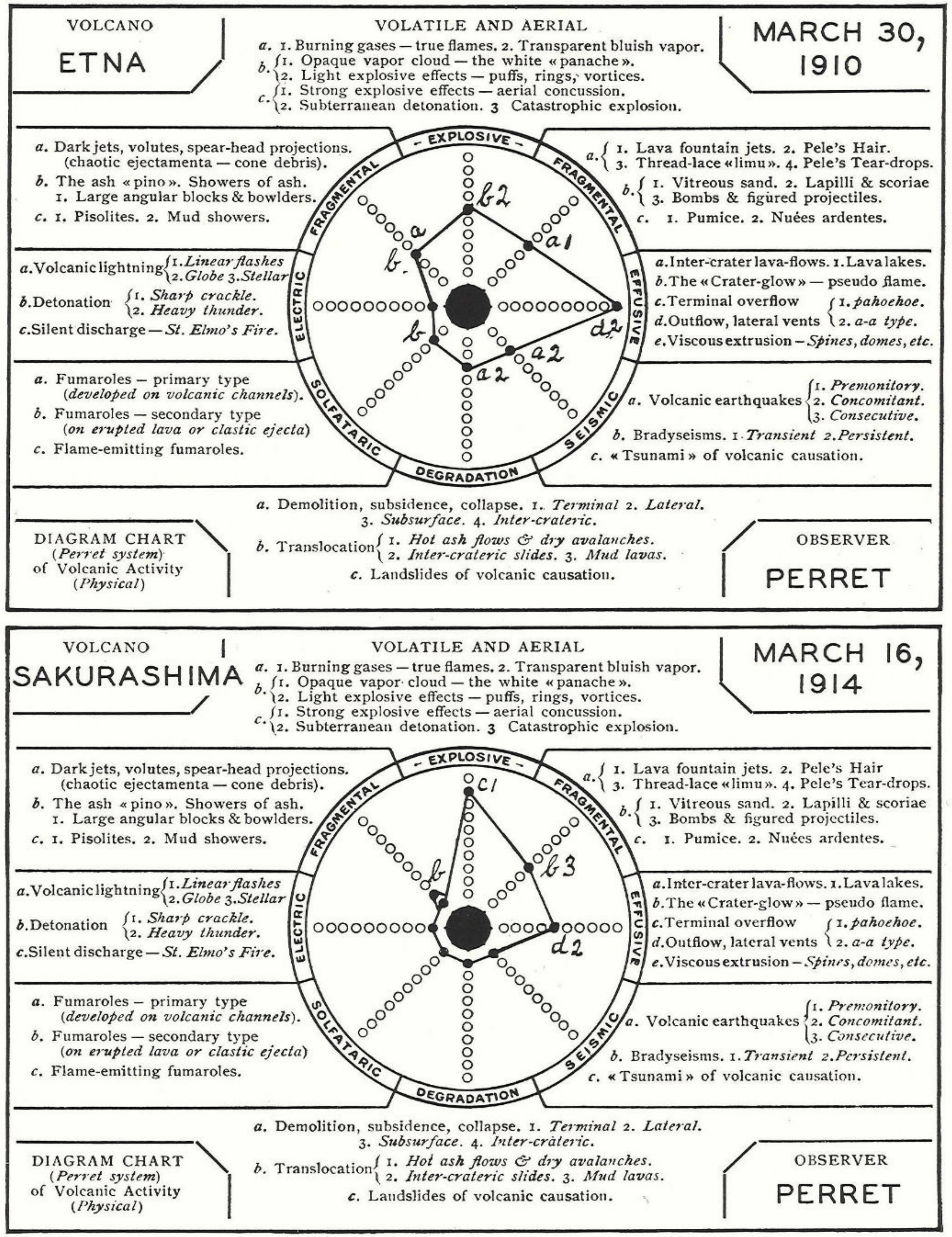


FIG. 116. Illustrating author's diagrammatic representation of conditions at Etna in March 1910 (cf. figures 46, 47, 50) and at Sakurashima in March 1914 (cf. figures 73, 74, 56) (page 151).

Fig.4 Frank Perret, 'The Perret System of volcanic activity', diagram and cards for cataloguing eruption clouds, in *Volcanological Observations* (Washington: Carnegie Institution of Washington, 1950), 151.

Fig.5 Frank Perret, *Volcanological Observations* (Washington: Carnegie Institution of Washington, 1950), 135.

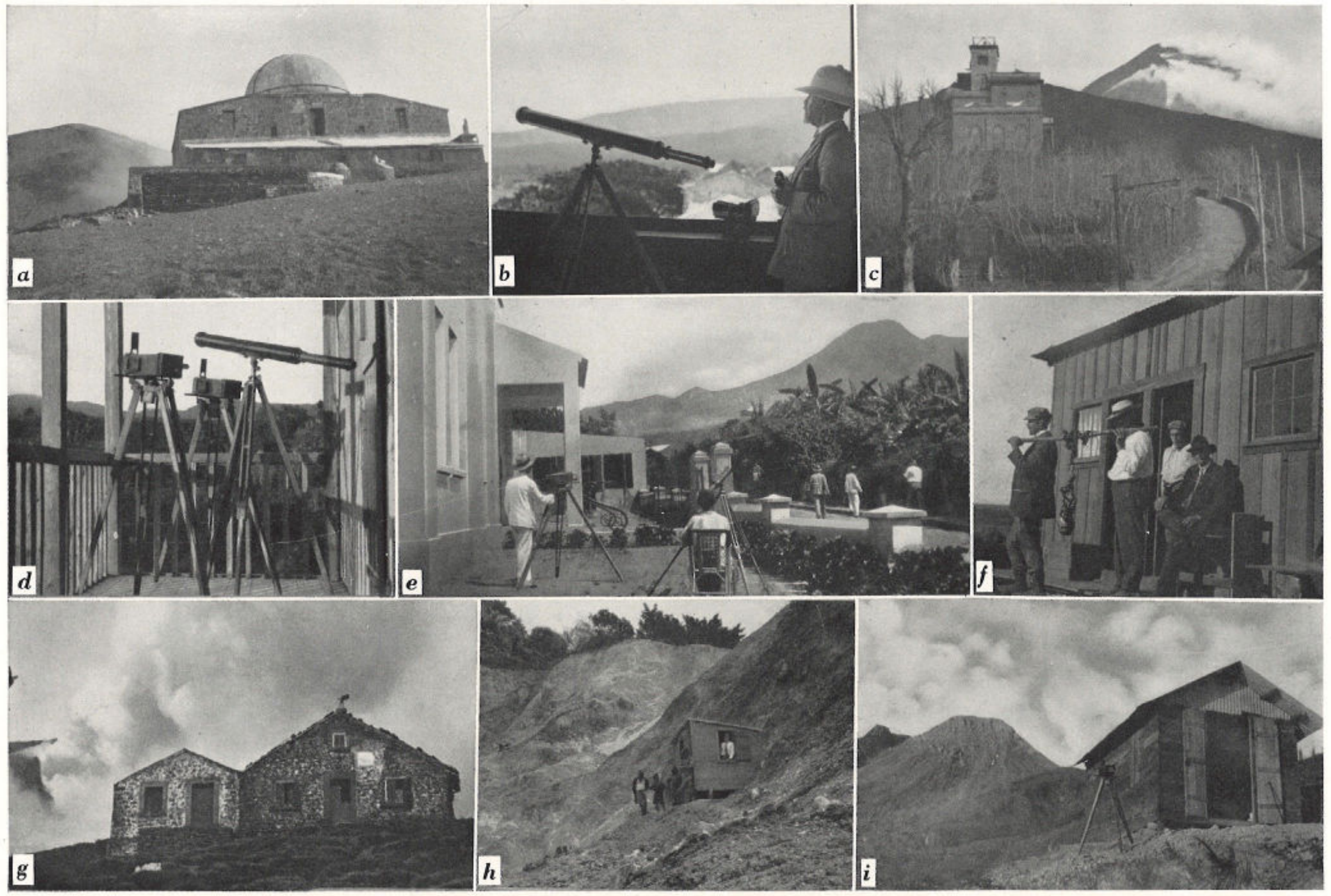


FIG. 105. Some field stations used in these investigations

(*a*) Royal Observatory, Etna. (*c*) Royal Observatory, Vesuvius. (*g*) Cantoniera, Etna.

Built by the author: (*b*) First station, St. Pierre. (*d*) Second station, St. Pierre. (*e*) Volcano Museum and Research Center, St. Pierre. (*f*) Field station, Kilauea. edge of Halemaumau crater. (*h*) Field station, Gage's Soufrière, Montserrat. (*i*) Field station, Pelée.

ores.[20] The electrified modernity that Perret helped engineer in Edison's lab in Manhattan was a force in this changing conception of geology and the earth as a medium for waves. Listening to Vesuvius with his teeth was perhaps the literal intersection of an electrical view of the earth with the vibrating human connecting to volcanism.

Sound, body, territory

When Vesuvius began to erupt in May 1905, Perret and Matteucci arranged with the Mayor of Naples that they would send telegrams if the city were in danger. Their work involved rising before or with the sun, counting explosions, taking close-range and distance photographs, collecting samples of rocks or volcanic bombs, temperature, and chemical analysis. Nearly one year later, in April 1906, the eruption had advanced and the observatory was covered in cinders and ash; 193,000 acres of villages and vineyards lay 'smoking in utter ruin…'[21] (Figs 6, 7). Perret and Matteucci were in the observatory while the tremors were so frequent they could barely walk. 'Electrical discharges' from the summit, Perret noted, sounded like lightning. He saw patterns: the eruptions were made by a 'rhythmic uplift of lava to higher levels, pulsing in surges of ever increasing amplitude…'; tearing and roaring, and 'each wave-crest on the sea of sound was louder than the one before; the jets of the great fiery geyser shot ever higher into the dark'.[22] On 8 April, as he and Matteucci retreated down the slope, debris fell on their heads and the observatory shook behind them. It was no longer safe to monitor, and he left his instruments behind.

Soon after the eruption began to subside, Perret tested his first mechanical hearing aid on the solfatara fields in Pozzuoli, west of Naples, where gases rise from the ground like boiling kettles. He overturned a phonograph-like cone with a microphone inside connected to a receiver and a sapphire needle that vibrated on to a phonograph wax cylinder (Fig.8). The contraption was a hybrid telephone-phonograph. It is not recorded how by Perret, but the wax inscriptions were used to confirm that he thought the 'underground rumblings' were the result of dry rocks moving and not, as had been proposed, subterranean liquid.[23] The inscriptions on the wax were correlated with geophysical processes in what was likely to have been the first recording of subterranean geological sounds on wax. Perret and Matteucci came to understand that geological sounds too faint to hear without amplification had signatures that, once inscribed and stabilised in wax, could be compared over time and across space. Suturing cutting-edge listening devices from radio and phonography with his electrical engineering training, Perret put earth sound into circulation with newly audible things such as the disembodied human voice in the telephone receiver or imprinted on the wax cylinder. As Douglas Kahn reminds us about the microphone, it was the audio equivalent of the microscope because it revealed a parallel but otherwise inaccessible universe of sound.[24] Perret's microphone revealed this parallel world of hidden geological sound. His skull had been the first medium to reveal this, but it was giving way to more stable forms of inscription in wax and more powerful means of amplification.

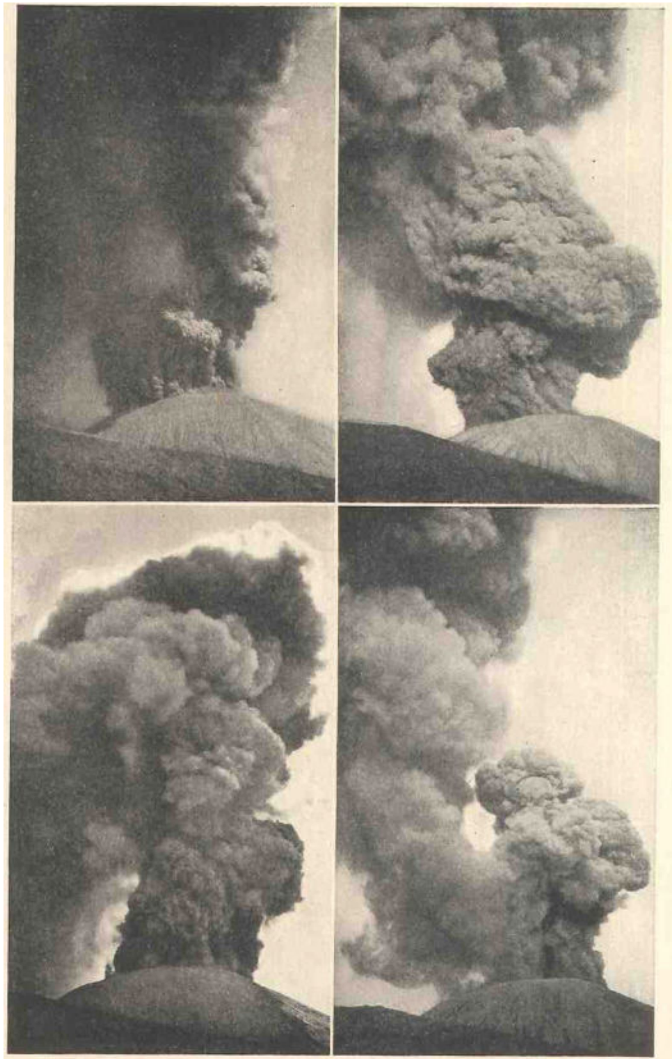
Perret extended the logic of listening to geology on Pozzuoli by turning a building into an amplifier. He inserted a microphone into a demi-john wine jug, then the jug into the tuff underneath the Naples observatory. The demi-john was connected by a pipe to an amplifier in the observatory and the microphone was an extension of the foundation of the building. To work, the microphone needed to be separated from the building's natural amplifications of waves. This was the careful work of 'dampening', removing local noise to increase the sensitivity to longer range sound-waves travelling from the volcano, as Perret put it, to register 'the molecular vibrations from the rock'.[25] Volcanoes made 'molecular sounds': the problem was magnifying them and identifying the underlying physical processes that created them.

His microphonic work expanded to Pelée between 1929 and 1932 when he consulted with the government over a potential eruption. The massive, devastating eruption of Pelée in 1902 seemed to be repeating itself and *The New York Times* reported that 'with headphones connected to a buried microphone, [Perret] listened to the churnings inside the volcano, literally taking the volcano's pulse'.[26] He modified his technique from Vesuvius by inserting a microphone inside a Sterno tin (a small portable stove), cemented it to the bottom of a gasoline can and buried it two metres into a valley wall. As he did at Vesuvius, he connected it with cables to a pair of headphones at the observatory. Observers heard the 'preliminary rumbles' of *nuées ardentes*, 'cauliflower clouds'; shortly after, they watched as the massive, superheated clouds of gases, ash and stones billowed out of the caldera and fell down the slopes.[27] Perret had achieved his goal of hearing the eruption before seeing it, of getting ahead of time, as sound collapsed distance.

He noticed also that the dome – the encrusted plug of cold solidified lava in the caldera – had a pitch. He proposed 'dome resonance' as a new diagnostic method:

> Whether it was the whistling of steam through a crack or its rushing through a larger vent, whether it was the clinkery rattle of a block slide or the roar of a great avalanche, a sensitive ear could always recognise the identity of the pitch even when the associated tones were octaves apart. Thus the dome as a whole acted as a resonant shell imposing its fundamental vibratory note upon all the minor vibrations….[28]

Changes in pitch resulted from changes in mass in the caldera. As lava was injected into the dome from the conduit below, or the dome was reduced by hydraulic forces of rain, earthquakes or erosion its pitch changed. Hisses shifted to wheezes to gurgles.



Figs 6, 7 Frank Perret, *Vesuvius Eruption of 1906: Study of a Volcanic Cycle* (Washington: Carnegie Institution of Washington, 1924), 54, frontispiece.

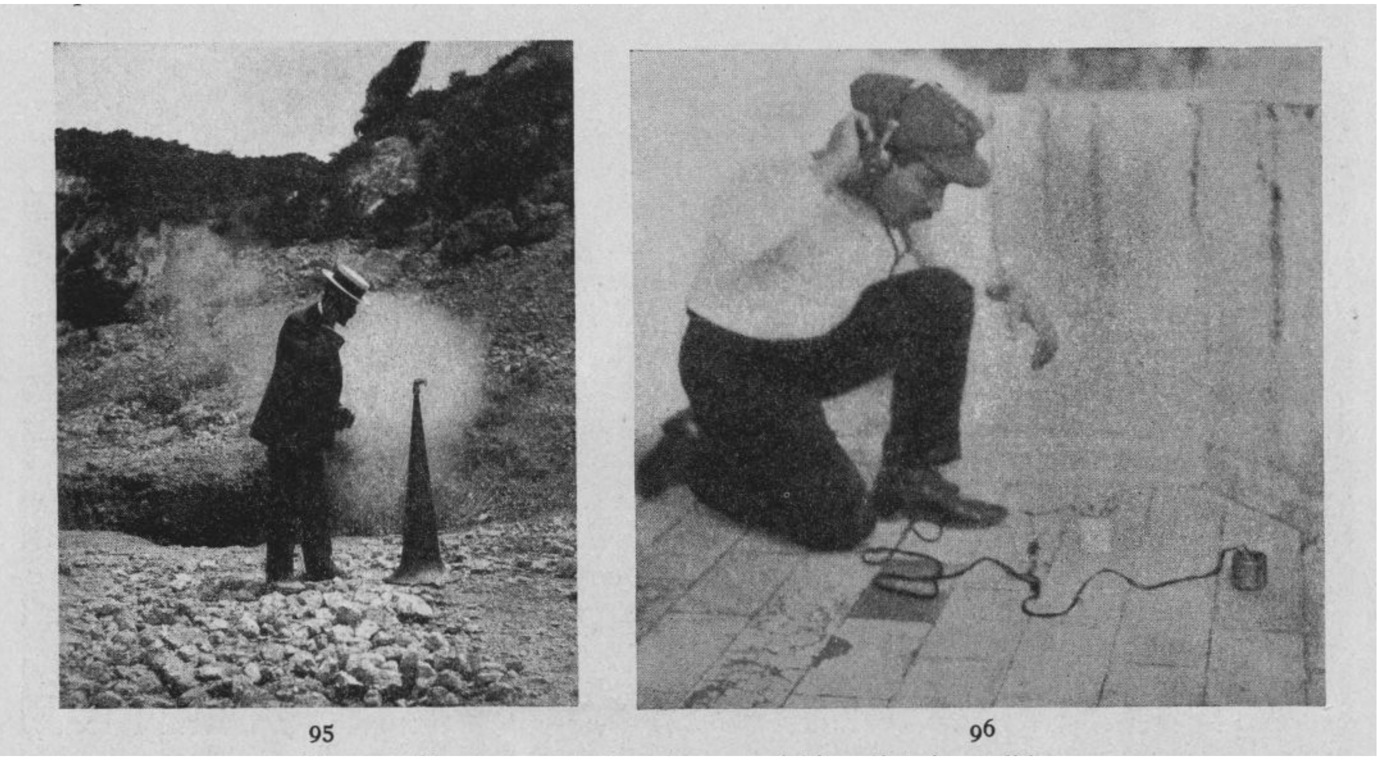


Fig.8 Frank Perret, *Vesuvius Eruption of 1906: Study of a Volcanic Cycle* (Washington: Carnegie Institution of Washington, 1924), 136.

The listening method, he argued, would be useful when vision of the crater was obstructed, though one had to learn to identify the tones.

In Montserrat in 1933, Perret investigated an increase in seismic activity. He puzzled: were earthquakes and eruptions the result of tectonic movements independent of volcanism or did they originate inside mountains? Were volcanoes connected or individual units? At the time, there was significant disagreement among scientists about these issues. Montserrat is roughly 100 sq. km, punctuated at two ends with volcanic hills. The active southern massif is called Soufriere.[29] Perret proposed that the chain of islands including Guadeloupe, Antigua, Nevis and St Kitts was a single system:

> These islands have arisen over a fissure system open at intervals to the solid surface … between them, though not visible to us, lie the remaining sections of a fissure system; and that these sections will constitute 'lines of approach' [for magma].[30]

He envisioned this subterranean system in three dimensions: the subterranean fissures extended horizontally and vertically under the ocean floor yet expanded vertically to create the profile of the islands above sea level. Montserrat was the materialisation of the fissures at the surface, and each island was a connected appendage of the other. Earthquakes, he suggested, resulted from the expansion and contractions within the conduit, the elastic waves of the movement transmitting through it, and concluded that 'the earthquake centra formed in the "lines of approach"' (Figs 9, 10).[31]

His ideas came, in part, from listening to geology. He drew on an account of a local, F.E. Peters, in the south of the island, who described 'rumblings', which 'by far', he continued,

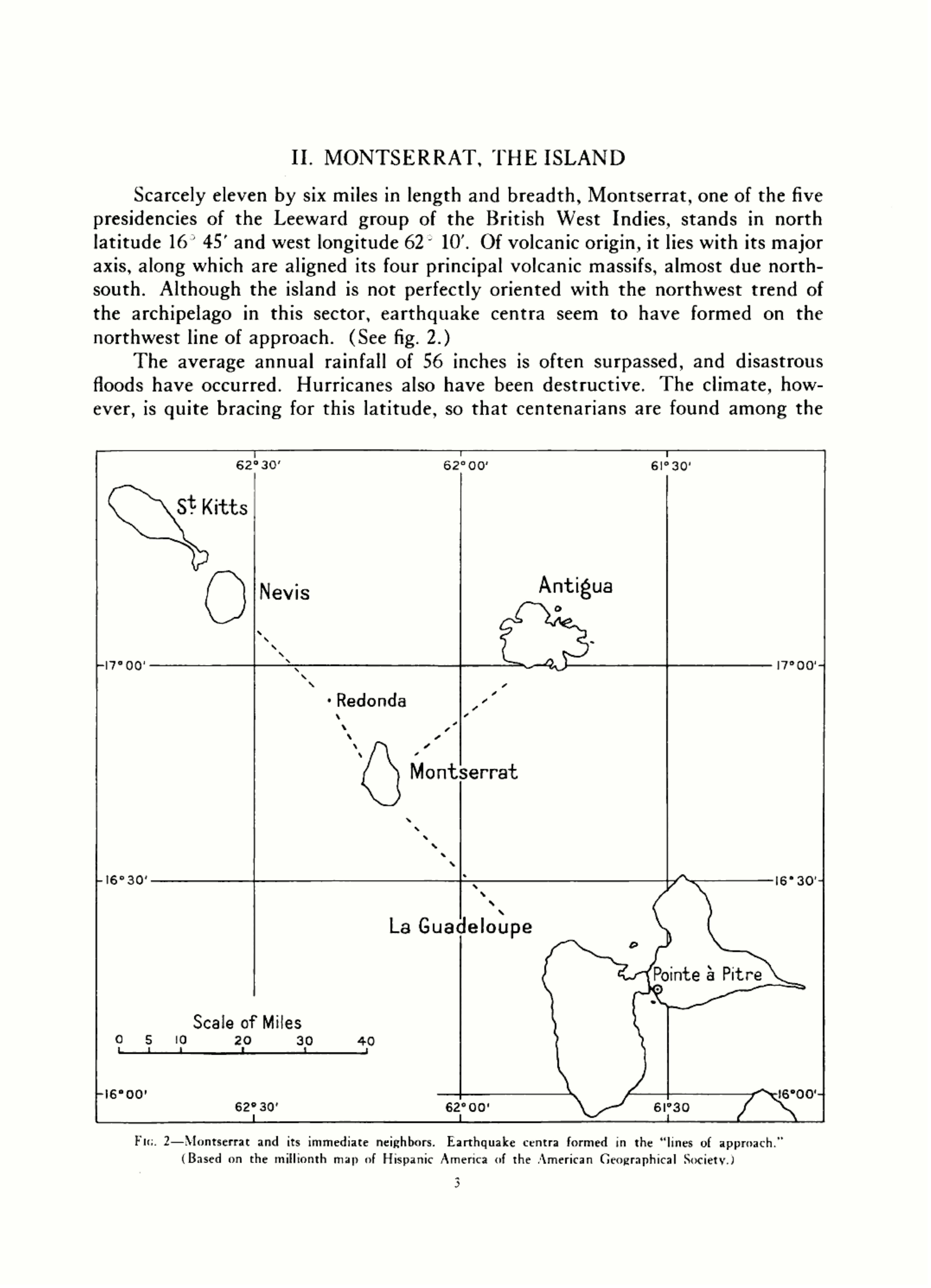
> the majority of them appear to proceed from the south-east; those farthest away are accompanied by no perceptible tremor, while others appear to move toward the land from the same direction, a slight tremor being felt as the sound dies away.

The south-east points to Guadeloupe. Sometimes, there were sounds but no earthquakes. Perret recorded 'long rollings, boomings, grindings, or sometimes detonations…'. There were sounds like trains in a tunnel, 'heavy rolling', he wrote. At other times, the direction of the sound was from the south-west or the south, and was followed, like a wake from a ship, by an earthquake coming from the same direction. He came to think of the hills as amplifiers, resonating with the deep pulsating vibrations and broadcasting them like phonograph cones.[32] He concluded that 'these subvolcanic Montserrat earthquakes result from expansive movement of subterranean magma which is seeking outlets along the old channels…'.[33] In Perret's media theory of geology, volcanoes were conduits for messages broadcast from underground where gases and liquid states differentiated within the subterranean network of fissures.[34] Where and when sounds and vibrations hit the body were signs of the subterranean movement of 'underground sheeting', the separation of gases and liquids in a vast hidden network of 'gas pockets like inverted lakes, some isolated, others with tunnel-like connections'.[35] These invisible movements, the ebbs and flows of magma, its chemical reactions, created earthquakes that pulsed through the conduits, out through mountains, shook houses and bodies. The superficial sounds, if traced, revealed a map of the invisible underground system.

The history of volcano sound upturns many of the conventional sensory hierarchies that are well known to have guided modern aesthetic thought. The whole body was a medium for terrestrial resonances and subterranean knowledge. 'Extracochlear modalities', as historian Sophia Roosth put it, were more significant to the geological sciences than conventionally assumed because they were attuned to 'entire percussing bodies as vibratory apparatuses'.[36] Contemporary maps of global volcanism and the tectonic plate boundaries that they identify contain as ghostly apparitions these resonant bodies, listening, feeling, and magnifying the ground. The contemporary tectonic map of Montserrat, for instance, when layered on top of Perret's map of 'lines of approach' that he heard in the landscape, shows how his listening was translated into a 'convergent boundary' between the Caribbean plate and the Atlantic plate. The Caribbean, as it is now argued by geologists, is being produced through the contact zone between oceanic and continental crusts which has resulted in the island arc with high levels of seismicity and volcanism. We know the existence of these plate boundaries, in part, because of the resonant bodies that heard or felt them, then mapped them.

Geophones at war

During World War I, Perret descended Vesuvius to work for the American–Italian Red Cross and repurpose his listening devices for combat tunnelling and detecting submarines. One of the tactics of trench war was for opposing sides to tunnel towards each other to lay charges and explode their trenches from below. Listening promised to identify sounds of advancing pickaxes, hammers, shuffling boots, banging, or hauling goods. The armistice was announced before Perret's listening technologies could be deployed, but his devices were contributions to a growing field of geological listening. The French physicist Jean Perrin, for instance, developed a microphone that combined a stethoscope – originally developed by doctors in the late 1850s – connected to two tins containing mercury and mica diaphragms. Perrin's devices did not amplify as Perret's did with electro-magnets, but through the displacement of air between the mica and the mercury which, as one writer put it, 'transforms the earth wave into an air wave, which is heard by the ear as a sound'.[37] In 1917, Perrin called his



II. MONTSERRAT, THE ISLAND

Scarcely eleven by six miles in length and breadth, Montserrat, one of the five presidencies of the Leeward group of the British West Indies, stands in north latitude 16° 45′ and west longitude 62° 10′. Of volcanic origin, it lies with its major axis, along which are aligned its four principal volcanic massifs, almost due north-south. Although the island is not perfectly oriented with the northwest trend of the archipelago in this sector, earthquake centra seem to have formed on the northwest line of approach. (See fig. 2.)

The average annual rainfall of 56 inches is often surpassed, and disastrous floods have occurred. Hurricanes also have been destructive. The climate, however, is quite bracing for this latitude, so that centenarians are found among the

Fig. 2—Montserrat and its immediate neighbors. Earthquake centra formed in the "lines of approach." (Based on the millionth map of Hispanic America of the American Geographical Society.)

3

Figs 9, 10 Frank Perret, *The Volcano-Seismic Crisis at Montserrat, 1933–1937* (Washington: Carnegie Institution for Science), 3, xii. 'Montserrat and its immediate neighbors. Earthquake centra formed in the "lines of approach".' 'Principal volcano-seismic events since 1657 along the arc of the Lesser Antilles.'

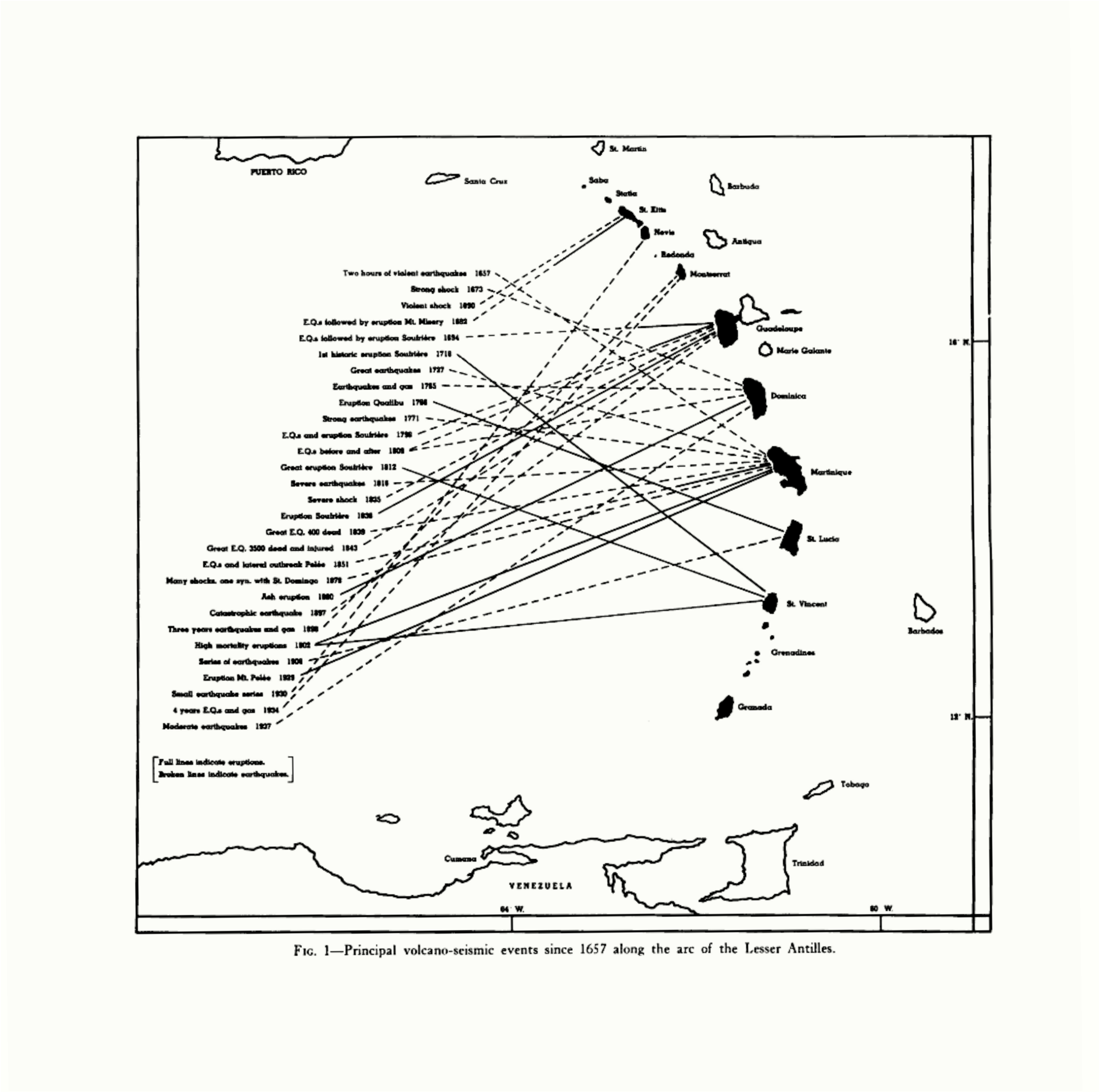


Fig. 1—Principal volcano-seismic events since 1657 along the arc of the Lesser Antilles.

Fig.11 'A Stethoscope for the Earth, The Geophone, Invented for War Service, but Which Gives Promise of Great Industrial Value', *Scientific American* (31 May 1919), 581.

invention a *géophone*; listeners submerged into dark tunnels heard a new and often overwhelming world of waves, bristling with confusion. The technologies that Perret had first applied to volcanoes were becoming useful for war and would soon be turned on the planet.

The European front in the global war in 1916 was generally clay and chalk and was highly conductive. With a geophone applied to each ear, soldiers could hear sounds transmitted through rock in stereo; they moved the discs along the ground in the tunnel until the sounds in each ear matched. Using a compass, they triangulated the horizontal direction of the sound but not its elevation. To resolve the inability to locate the vertical origin of the sound, soldiers undertook experiments, sliding the geophone along the mine wall, leaving one phone on a carved ledge while they sought the stereoscopic effect with the other; they could then indicate the horizontal and vertical position of enemy miners and the direction in which to drive their mine. Harry Davis Trounce observed in *The Military Engineer* that 'to become an expert listener required fairly long and well directed practice'.[38] One soldier, in the delirium of a gruelling shift, for instance, hallucinated, hearing the sound of a horse eating oats underground. Soldiers had to learn to recognise the difference between footsteps on boards, a sentry 'kicking his numbed feet against a firestep', the 'rattle' of guns, and rats scurrying; they had to find orientation in a dark world bursting with new sounds, huddled with a candle, concentrating because misidentifying a sound could mean death in a collapsed mine.[39] Other accounts described soldiers on their stomachs against the chalk floor with geophones at either side, at 90 degrees, slowly narrowing them towards each other in the direction of the sound, their entire bodies becoming compass needles.[40]

After the armistice of 1918, geophones were redeployed for retrieving miners in collapsed shafts. The United States Bureau of Mines conducted experiments determining the acoustic properties of the earth and they found that sledgehammer blows travelled 600 metres through coal;[41] speech and singing could be heard through 45 metres.[42] An article in *The Literary Digest* from 1924 titled 'An Ear That Listens Through a Half-Mile of Rock' states that 'With the geophone, sounds so faint that the listener has the sensation of feeling, rather than hearing them, can be detected and accurately identified'.[43] *A Scientific American* article of 1919 claimed that the geophone, though invented for war, 'gives promise of great industrial value' (Fig.11). The Inspector of Mines in Nottingham, Walter E.T. Hartley, found to his dismay that unpredictable intercalation of strata could interrupt the transmission of sounds. Uneven distributions of materials meant that sound travelled unreliably and a slight shift in the listener's position could change the effect.[44] Mining inspectors had hoped to identify mine fires by the sound of wood structures falling apart, 'the drawing of air' inside the mine and the crashing of broken slate

May 31, 1919 SCIENTIFIC AMERICAN 581

A Stethoscope for the Earth

The Geophone, Invented for War Service, but Which Gives Promise of Great Industrial Value

By Our Washington Correspondent

THE arts of peace are almost all convertible to the arts of war; much more seldom is it that a strictly war invention finds even greater uses in peace. But sometimes the invention brought into being by war's necessities has a wide application when war ceases and such seems to be the case with the geophone, a listening instrument invented by the French, for the purpose of the more readily detecting enemy sapping and underground mining operations and for locating enemy artillery.

The microphone we have always with us when it comes to devising any apparatus for the detecting of faint sounds. But the French engineers who designed the geophone began from another angle, for the very good reason that not all vibration translates itself as sound, and microphone tests show there is a distinct limit well within the danger zone when faint sounds of pick and shovel are not detected by the electrical apparatus.

The geophone has nothing electrical about it; it is mechanical entirely and operates upon the principle of the seismograph, the instrument used for detecting and recording earthquakes. As the reader undoubtedly knows, the seismographic principle is that of a so-called steady mass which remains practically motionless because of its inertia, when the earth moves beneath it in seismic disturbrances. Having thus a point in motion (the earth), and a point stationary (the steady mass) the seismologist is able by means of a chronograph drum and pen to record the amplitude and duration of earth vibrations.

The geophone consists of an iron ring about three and a half inches in diameter, within the center of which is suspended a lead disk, fastened by a single bolt through two mica disks, one of which covers the top and the other the bottom of the ring. Two brass cap pieces are fastened with bolts to the iron ring to hold the mica disks in place, the top one having an opening in its center to which is fastened a rubber tube, leading to a stethoscopic ear piece.

The apparatus, then, consists of a lead weight suspended between two mica disks cutting across a small air-tight box. If the instrument is placed on the ground and there is any pounding or digging in the vicinity, energy is transmitted as wave motion through the earth, and earth-waves shake the geophone case. The lead weight, on account of its mass and because it is suspended between the mica disks, remains comparatively motionless. There is then a relative motion between the instrument case and the lead weight and a compression and rarefaction of the air in the instrument takes place. Since the rubber tube leading to the stethoscopic ear piece is connected with this space in the geophone, this rarefaction and compression is carried to the ear when it makes itself manifest as sound. The diagram will make the construction clear and the photographs show the method of using the device.

It should be noted that it is not necessary for sound, meaning vibrations of such range as comes within the compass of the human ear, to reach the geophone in order that sound may be heard in the ear pieces. The wave motion communicated through the earth may be as absolutely soundless as is the electric current which serves to transmit a telephone conversation, and yet be transformed to sound in the air-chamber of the geophone, much as the electrical energy in the telephone circuit is made manifest in the receiver as sound, though no actual sound passes over the wires.

The geophone, which has been developed by army engineers and is now in use by the Bureau of Mines in connection with mine rescue work, has a number of peculiarities which particularly fit it for the work it has to do. One of these is the readiness with which the ear recognizes which of two sounds in two geophones reaches the auditory nerves first. Two geophones are used, one for each ear. The impression is that the sound in one ear is louder than the other; that it is not actual loudness, however, is proved by the readiness with which an operator slightly deaf in one ear is able to orient sounds. In using two geophones, it is merely necessary to move them about against the wall through which the vibrations are coming, until a point is found where the sounds have the same intensity to both ears. The direction in which the sound comes, then, will be perpendicular to a line connecting the two instruments. Whether the sound be in front of or behind the observer is a matter for further observation, but is readily determined.

Diagram of geophone showing the scheme of operation

What such an instrument may mean in mine rescue work can be best appreciated by those who have attempted to locate entombed miners by other means. Knowing where to dig and in what direction is often three-fourths of the rescue campaign.

The instrument is extremely sensitive, not only to vibration, but to variations in the vibrations, so that it is very easy to detect the source of the sound, whether it is pick, hammer, explosion, fire, running water or whatever the cause of the earth-waves may be. An experiment was made by a Bureau of Mines engineer who had never used the instrument before; after listening to sounds caused by 12 different mining and carpentering operations he was able, with ease, correctly to name nine of them and accurately to describe the other three sounds although they were too unfamiliar to him to allow him to name them.

While not unlimited the geophone is not narrow in its range; a pick striking into bituminous coal is easily heard through 900 feet of intervening coal and earth, and a sledge pounding can be heard 1150 feet with sufficient clearness to enable the direction to be accurately noted. The explosion of an ounce of dynamite transmitted wave energy, translated as sound in the geophone, for more than two thousand feet.

Another surprising feature of the geophone is that the presence of intervening rooms, galleries and entries seem to have little effect on the resulting sound. Apparently the earth waves are transmitted in all directions and are picked up by the geophone without much regard to the continuity of material between it and the source of the vibration. This is a very important factor in considering the instrument as an aid in mine rescue work.

While the geophone will locate the direction of a scource of wave motions with great accuracy, it cannot, of itself, determine distance. There are two ways of doing this, one by expertness of the operator, who is able after a little practice to determine with reasonable accuracy how far distant a recognizable sound may be produced, providing he knows the general character of the earth through which the vibration is coming; the other method, of course, is to use two sets of geophones and locate the sound source from two directions. Having two angles and a known base the distance is then a mere matter of arithmetic.

Another phenomenon of the geophone is the readiness with which it picks up sounds through the mine cover, although this readiness is largely influenced by the state of the air outside, any great amount of breeze seriously interfering with its action. A man pounding with a sledge can be located two or three hundred feet under the surface, from the surface, and at the experimental mine in Bruceton, Pa., a miner has repeatedly been located within 50 feet, through 150 feet of cover.

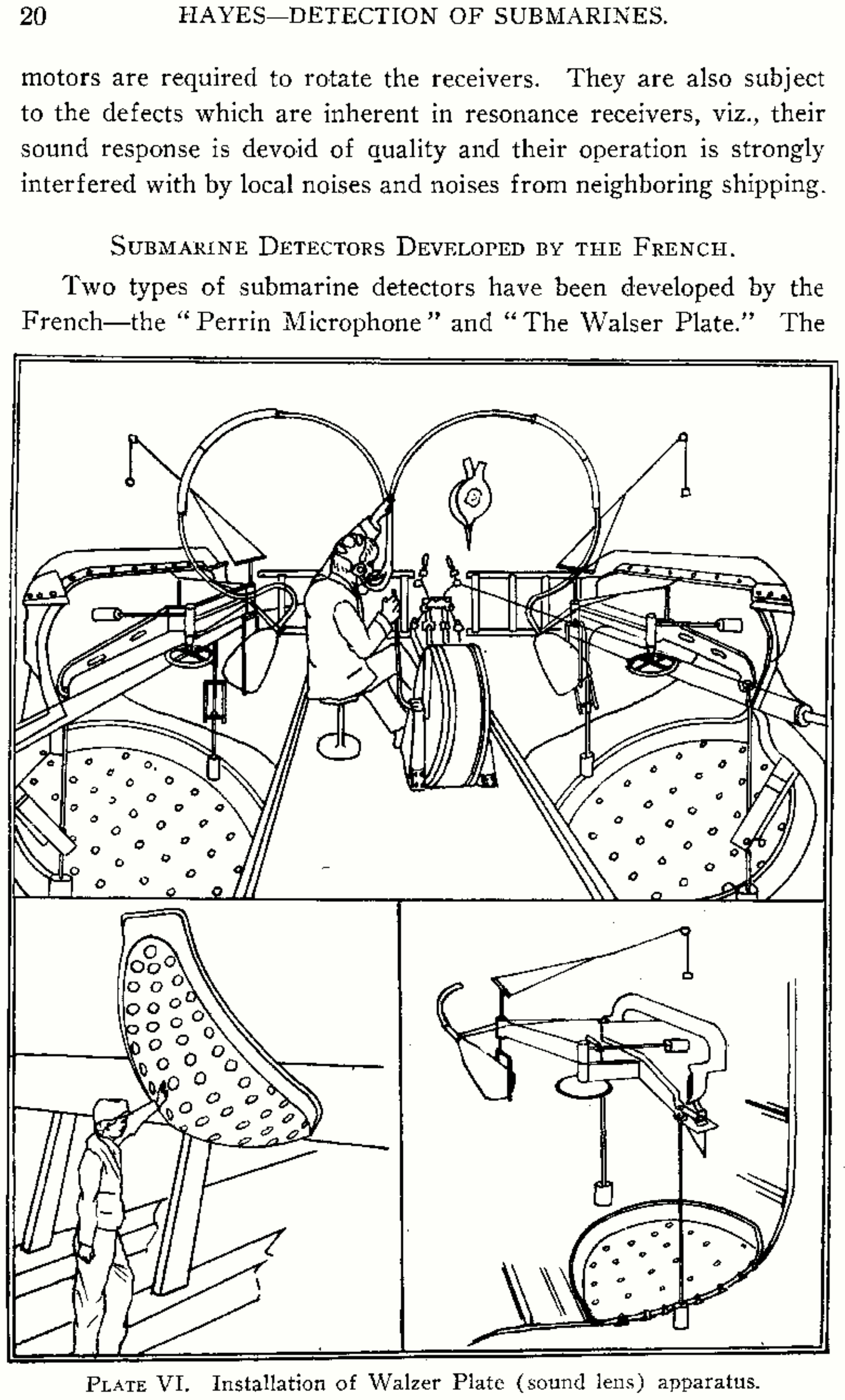
The geophone is by no means limited to rescue work in mining operations. In metal mining, experiments are proving that it can frequently take the place of difficult and expensive surveys designed to bring two borings to a meeting. This is not theory, but the result of an actual experience, in which Bureau of Mines engineers located the trouble in a metal mine where a drift and raise, supposed to meet, had missed. Observations were made in the drift, of pounding, in the raise, and then observations were made in the raise, of poundings in the drift. The engineers concluded that the two had missed by about six feet, and named the direction of each from the other. Not willing to trust the new instrument, the mine operators insisted on a survey, but when it was made the result was as already determined by the geophone. The instrument is particularly useful in direction determination in a metal mine, rather than a coal mine, because metal bearing rock transmits the vibrations in a more clear-cut manner than coal. This is probably because there is some reverberation to the sound from a blow on wood, while on the stone the sound is clean-cut.

Observations were made in another raise which was being driven up, about six or eight feet distant from a drift. Observations were made in the drift, of the sound from the drill in the raise, and a point located on the side of the drift behind which the drill in the raise was apparently operating. The survey mark was two and one-half feet to the right of this mark. A drill set up and operated at the survey mark did *not* break through into the raise, but a hole drilled at the point in the drift located by the geophones reached the raise and proved the geophone observation to have been correct within a few inches.

A geophone operator locating a miner working on a coal rib, through 600 feet of intervening rock

(*Continued on page 591*)

Fig.12 'Installation of Walzer Plate (sound lens) apparatus', Harvey C. Hays, 'Detection of submarines', *Proceedings of the American Philosophical Society* 59, 1 (1920), 20.



motors are required to rotate the receivers. They are also subject to the defects which are inherent in resonance receivers, viz., their sound response is devoid of quality and their operation is strongly interfered with by local noises and noises from neighboring shipping.

SUBMARINE DETECTORS DEVELOPED BY THE FRENCH.

Two types of submarine detectors have been developed by the French—the "Perrin Microphone" and "The Walser Plate." The

PLATE VI. Installation of Walzer Plate (sound lens) apparatus.

from the walls. The dimensions of the subterranean conflagrations, they hoped, could be mapped from the safety of the surface by listening to the fire.[45] But the geophone, ultimately, was subject to too much interference – signals could be thrown off by rescue operations in a mine. Further, the range of the geophone was too limited. The use of listening to underground sounds for saving miners' lives was found to be too flawed to be taken further.

Planetary infrasound

The next global war intensified the development of geophysical technologies as never before. Seismology was vital for locating weaponry, explosions and mapping. Submarine warfare advanced oceanography and the application of physics to understanding underwater processes and geographies. Geophysicists were mapping anomalies in the earth's gravity field and coming to understand that the ocean floors were crinkled with massive trenches. The 'lines of approach' that Perret speculated were hidden under the ocean in the Caribbean were beginning to be mapped as co-extensive with island arcs; scientists were finding the same patterns of depressions connected to volcanism and earthquakes in the Caribbean, East Indies, and Japan. By 1945, the geophone referred to a range of geophysical devices that measured and recorded signals passing through the earth or atmosphere. They recorded sound, infrasound and electrical currents; prospecting, underground engineering, and ocean and air defence were re-imagining the acoustic signals of the planet as states increasingly sought to monitor submarine movement (Fig.12) and nuclear testing in the ocean and atmosphere; acoustical monitoring of geological signals enlarged to the scale of the planet. Geophysicists found that the oceans and atmosphere operated together as vast acoustic mediums not only for the propagation of volcanic sounds (Fig.13) but also sounds of typhoons, calving glaciers, earthquakes, storms and waves. The earth was loud.

The significance of the body changed as listening to vibrations in the earth became linked to new forms of drawing. The resonating parts of the geophone that Perret had designed changed into ever larger apparatuses. Some infrasound experiments in the post-war period used microphones connected to 300-metre-long pipes in arrays of up to 14 km apart, nearly the scale of a small town. Microphones became the size of territories as geo-acousticians recorded infrasound disturbances at the scale of the planet. Resonating skulls and listening ears became redundant, as they were too insensitive and difficult to network into an array.

From the early 1950s, the Infrasonics Group in the United States National Bureau of Standards, then by the Geo-acoustics Group, studied the propagation of low-frequency acoustic signals through the earth and atmosphere.[46] They set up expansive monitoring arrays in Boulder (Colorado), Washington and Boston,

Fig.13 James M. Snodgrass and Adrian F. Richards, ‘Observations of underwater volcanic acoustics at Barcena Volcano, San Benedicto Island, Mexico, and in Shelikof Strait, Alaska’, *Transactions: American Geophysical Union* 37, 1 (1956), 100.

Fig.14 (Overleaf) V.H. Goerke, J.M. Young and R.K. Cook, ‘Infrasonic observations of the May 16, 1963, volcanic explosion on the island of Bali’, *Journal of Geophysical Research* 70, 24 (1965), 6020.

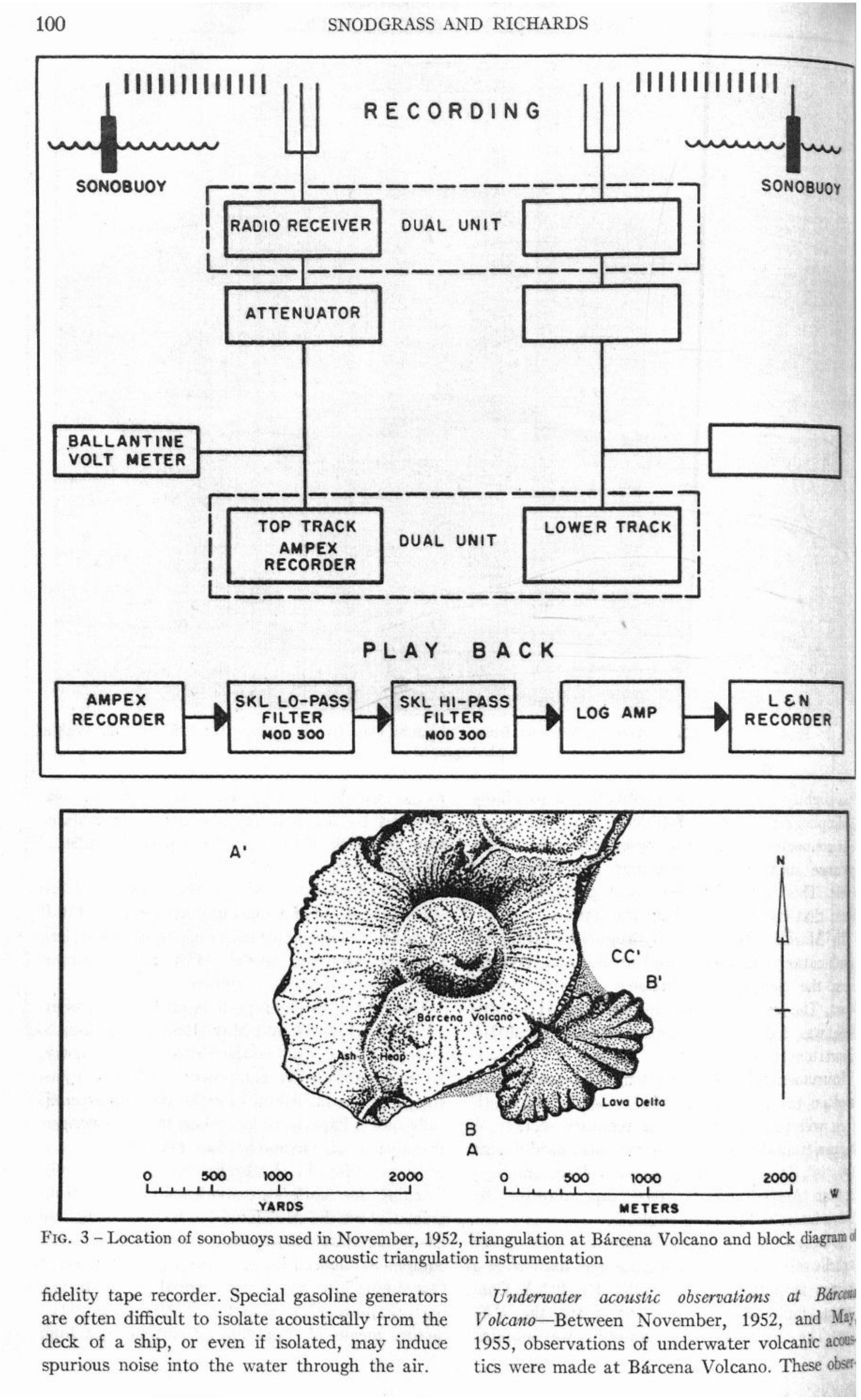
to correlate their readings. In May 1963, Mount Agung volcano in Bali exploded. More than 100,000 square km of forest were destroyed, and upwards of 1,000 people died.[47] The array in Colorado, 25,300 km away, registered Agung’s ‘perturbations’ travelling ‘at sonic velocities’, in the range of 345 metres per second, the average speed of sound (Fig.14).[48] Their recording devices, like Perret’s, were microphones connected to tubes but with filters to shave off interference and magnify inaudible frequencies. They recorded the sound waves not as scratches on a wax cylinder but as ink waves on paper and magnetic tape.

One of the problems for the Geo-acoustics Group was correlating the signal with the source, just as Perret had struggled to identify what caused particular underground sounds. The group needed accurate time stamps for the events of the eruption from the other side of the planet and contacted Djajadi Hadikusomo, the head of Indonesian volcanology. Hadikusomo volunteered his notes from three permanently staffed observatories arrayed around Agung. The observatories were the same as those created by the colonial Netherlands East Indies Volcanological Service in the 1920s as it attempted to protect the plantation economy from volcanic eruptions while Perret was on Vesuvius. Piggybacking on the original infrastructure made it possible for the Colorado group to identify the causes of their vibrations half a planet away:

> At 0855 BH reported ‘Nuee ardente d’explosion [*sic*] reaches a distance of about 5.5 km within five minutes.’
>
> RG 0904. ‘Beginning of eruption … continuous detonations and rumblings…’
>
> BG 0917. ‘Eruption cloud … 7 km above the crater rim.’[49]

The sound waves reached the giant microphones in Colorado at approximately 288 metres per second and bundled with all sorts of noises. Some 23 hours later – probably because they traversed the poles – stragglers arrived, travelling at 305 metres per second. The signatures were almost identical but delayed: the atmosphere, the scientists understood, was uneven and sound propagated at different rates; wind, they thought, created interference in the stratosphere; the White Sands in New Mexico perhaps shaped the waves as they moved across its surface. Infrasound was imprinted by the atmospheric geographies they traversed. ‘The propagation parameters of the atmosphere for acoustic waves’, they concluded, ‘are quite complicated.’[50]

On Kariya, Aichi, an observatory 700 km from Sakurajima volcano, southern Japan, an array of microphones was established in the 1980s to predict eruptions. Sakurajima’s waves lasted longer than a minute and Makoto Tahira speculated that they moved

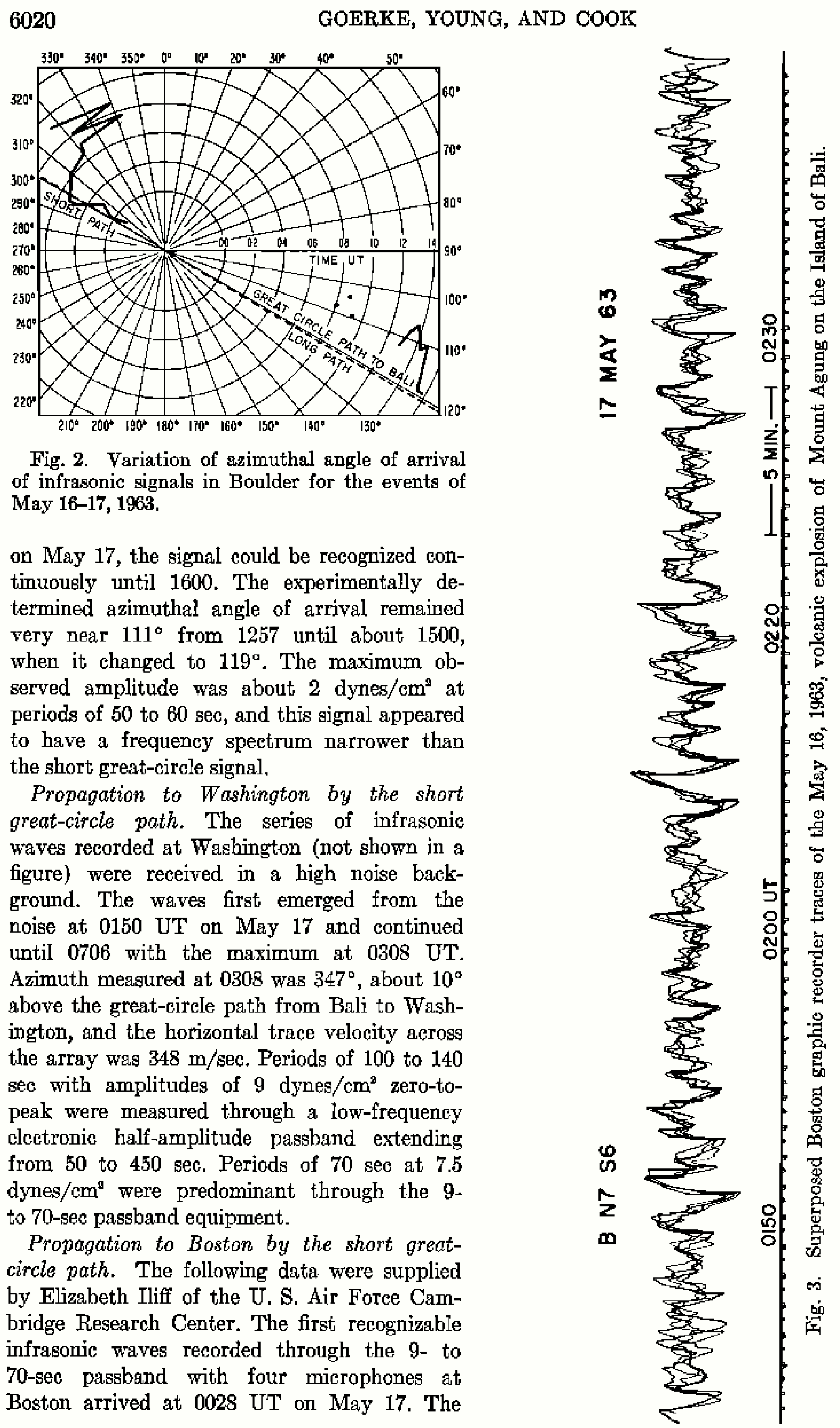


100 SNODGRASS AND RICHARDS

FIG. 3 – Location of sonobuoys used in November, 1952, triangulation at Bárcena Volcano and block diagram o
acoustic triangulation instrumentation

fidelity tape recorder. Special gasoline generators are often difficult to isolate acoustically from the deck of a ship, or even if isolated, may induce spurious noise into the water through the air.

Underwater acoustic observations at Bárcen Volcano—Between November, 1952, and May, 1955, observations of underwater volcanic acous- tics were made at Bárcena Volcano. These obser-



6020 GOERKE, YOUNG, AND COOK

Fig. 2. Variation of azimuthal angle of arrival of infrasonic signals in Boulder for the events of May 16–17, 1963.

on May 17, the signal could be recognized continuously until 1600. The experimentally determined azimuthal angle of arrival remained very near 111° from 1257 until about 1500, when it changed to 119°. The maximum observed amplitude was about 2 dynes/cm² at periods of 50 to 60 sec, and this signal appeared to have a frequency spectrum narrower than the short great-circle signal.

Propagation to Washington by the short great-circle path. The series of infrasonic waves recorded at Washington (not shown in a figure) were received in a high noise background. The waves first emerged from the noise at 0150 UT on May 17 and continued until 0706 with the maximum at 0308 UT. Azimuth measured at 0308 was 347°, about 10° above the great-circle path from Bali to Washington, and the horizontal trace velocity across the array was 348 m/sec. Periods of 100 to 140 sec with amplitudes of 9 dynes/cm² zero-to-peak were measured through a low-frequency electronic half-amplitude passband extending from 50 to 450 sec. Periods of 70 sec at 7.5 dynes/cm² were predominant through the 9- to 70-sec passband equipment.

Propagation to Boston by the short great-circle path. The following data were supplied by Elizabeth Iliff of the U. S. Air Force Cambridge Research Center. The first recognizable infrasonic waves recorded through the 9- to 70-sec passband with four microphones at Boston arrived at 0028 UT on May 17. The

Fig. 3. Superposed Boston graphic recorder traces of the May 16, 1963, volcanic explosion of Mount Agung on the Island of Bali.

through ‘atmospheric ducts’ in the thermosphere and upper stratosphere.[51] At Kariya, they were detecting eruptions as far as 1,200 km away, and some within 30 minutes of volcanic explosions 500 km away.[52] Kosuke Kamo and other scientists proposed networking all infrasound monitoring stations into a planetary International Monitoring System (IMS) that became the monitoring infrastructure for the 1996 Comprehensive Nuclear-Test-Ban Treaty. The treaty sought to put an end to nuclear weapons proliferation, in part by promising to monitor all nuclear testing on earth. If a state detonated a nuclear weapon its infrasonic signature would register in the network.

As of 2017, there were 49 stations in the IMS and its headquarters, the International Data Centre, was located in Vienna.[53] Each continent hosts a station and they are distributed, on average, 2,000 km apart; some were located in the oceans. The network operates locally and globally, monitoring volcanic eruptions for flight navigation and safety, but also hurricanes, tornadoes, and earthquakes. In 2013 and 2017, the Democratic People’s Republic of Korea tested nuclear weapons underground that registered on the local Korean Infrasound Network in South Korea and two International Monitoring System stations.[54] When, in 2017, another was detonated, it registered in Vienna 45 minutes later.[55]

Infrasound legacies

One trajectory of Perret’s experiments with listening to volcanoes was to contribute to the formation of a science of planetary infrasound. We have already begun to trace here some of the contours of that trajectory. A component of that transition from Perret’s ear nestled against a cone on Pozzuoli to registering a Balinese volcano on instruments in Colorado was a transformation in ideas about the significance of the body of the volcanologist. The monastic austerities that were fundamental to Perret’s conception of what it meant to know were absented from the operations of planetary infrasound monitoring. The body of Perret as he conceived it – sensitive, amplifying, vibrating – gave way to the geo-acoustician as technician who operated networked recording instruments so large that they were nearly the size of a small city. The transformation to remarkably different practices of volcanology was also characterised by different technologies of inscription. For Perret, his body was a medium and an amplifier – it was literally an extension of earth processes, and in some senses, it was also a representation of the earth; his body was a kind of drawing. In the world geo-acoustic network, inscription is primarily, if not absolutely, a mechanical or digital process shepherded by the technician-scientist.

This is not, though, only a familiar story that laments how the human body has been replaced by mechanical and digital technologies. Why Perret is interesting is not because his is a story of modern alienation – rather, it is because he is a figure that persists, perhaps in a spectral form. It seems to me that Perret can be used to name an experience of the earth that is persistent in the modern world and that holds together both the alienation of the scientific body and its enchantment. I think that we can see the ghost of Perret in contemporary anxieties about infrasound. Consider, for instance, the physician Nuno Castelo-Branco’s diagnosis in 1980 of what he called ‘vibro-acoustic disease’ in workers at an aircraft manufacturing plant in Portugal. Workers had been reported to be wandering around the plant in a dreamy, semi-conscious state – one of them nearly wandered into a propeller, only to be saved at the last minute by a colleague. Castelo-Branco argued that it was perhaps the result of industrial infrasound, which acted below the ability of our conscious mind to perceive it but nevertheless created micro-physical trauma. Scientists, according to Castelo-Branco, held an outdated view that sound only affected the ear, and they needed to incorporate the entire body as a receiver. ‘Acoustical phenomena’, he wrote, ‘whether perceived by the auditory system, or not, can indeed cause organic changes in biological tissue.’[56] His team found that infrasound thickened, stressed, and scarred tissues. The body was registering the sonic stresses of industrial modernity that could not be heard.

Castelo-Branco’s research was later used in a study of Puerto Ricans forced to live close to a controversial United States Navy base in Vieques. Environmental activists fighting to close the base argued that the sounds of planes and missile tests potentially resulted in higher-than-average cases of hypertension, heart disease, asthma and cancer.[57] Castelo-Branco’s research was even deployed in anti-wind farm protests in Australia, where right-wing activists, who renamed the syndrome ‘Wind-turbine syndrome’, claimed that:

> residents affected by infrasound and low-frequency noise from coal-fired power stations find they also react to wind turbines in the same way. The body and the brain do not care about the source of the sound and vibration. The reactions are involuntary and hardwired, and part of our physiological fight/flight response.[58]

The spectre of Perret is visible in vibro-acoustic disease. Anxieties about industrialisation as a source of sickness, often of subtle, barely legible forces of illness, persist in the contemporary diagnosis of Castelo-Branco. Yet, this diagnosis also shares a vision of the human body that Perret believed in, the body as a sensitive medium that amplifies the barely legible, whether that is vibrations from machines or sound from the inside of a volcano. Perret brought this vision of the sensitive body together with an understanding of volcano science, probably for the first time. That vision was fragmented as the study of volcano sounds scaled up to the planet, yet it persisted in the most unlikely places, of the body suffering from vibro-acoustic disease, a body sensitive to the silent and invisible.

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25 Perret, *Eruption of Pelée*, *op. cit.*, 12.

26 'F.A. Perret Dead', *op. cit.*, 23.

27 Perret, *Eruption of Pelée*, *op. cit.*, 32.

28 *Ibid.*, 61.

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31 *Ibid.*, 3.

32 *Ibid.*, 48–49.

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