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The insurance of volcanic risks

> The last September 19th 2021, Nature reminded us that we are on a living planet, in which no element, as permanent as it might seem, is static. And it also reminded us that the Canary Islands owe their very existence to a very long succession of events just like the one that started that very day along the Cumbre Vieja Ridge in the island of La Palma, along not too many millions of years, compared to other geological processes.

Summary

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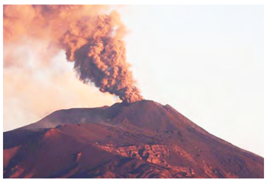

Editors Board

The Consorcio de Compensación de Seguros digital magazine “Consorseguros” (CCS) is published every six months, its content particularly addressing matters related to the Consorcio’s activities in various fields of insurance, reflecting on and analysing them.

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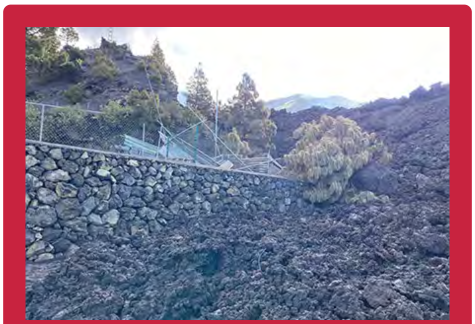
Summary

Editorial

The last September 19th 2021, Nature reminded us that we are on a living planet, in which no element, as permanent as it might seem, is static. And it also reminded us that the Canary Islands owe their very existence to a very long succession of events just like the one that started that very day along the Cumbre Vieja Ridge in the Island of La Palma, along not too many millions of years, compared to other geological processes.

In fact, many La Palma islanders have been able to experience three volcanic eruption events: the San Juan in 1949, the Teneguía in 1971 and this of 2021, the three of them very much alike and obeying to the same cause, a mantle rift under the somewhat misnamed Cumbre Vieja (Old Peak, in Spanish), that in fact is one of the most active volcanic areas in the Canary Islands, where 8 of the 17 historic (since the 15th Century) eruptions of the archipelago have taken place. For Consorcio de Compensación de Seguros (CCS) it has been, nevertheless, its first experience with volcanic losses: the 1971 event took place in an uninhabited area and caused no losses on insured individuals or properties. The 2011 submarine eruption in El Hierro caused no damage either.



We are lucky to edit the probably most international issue in the history of Consorseguros. In it we have contributions from different corners of the World representing risks from all Continents, in which volcano science and insurance experts enlighten us about volcanic risk, its management and its insurance cover. Contributions come from Colombia, France, Iceland, Italy, Japan, New Zealand and Portugal.

This is the reason why we devote this issue of Consorseguros Digital Magazine to the insurance of volcanic risk. We are lucky to edit the probably most international issue in the history of Consorseguros. In it we have contributions from different corners of the World representing risks from all Continents, in which volcano science and insurance experts enlighten us about volcanic risk, its management and its insurance cover. Contributions come from Colombia, France, Iceland, Italy, Japan, New Zealand and Portugal. We hope the readers can broaden their knowledge about the question as much as we have done during the preparation of this issue.

We would like to thank all and every one of our international contributors for the effort they have made by writing this series of outstanding contributions that raise significantly the level of our digital magazine. We would also like to publicly thank the help received from Mr. Leigh Wolfrom, from OECD, and Ms. Carolina Cárdenas, from Mapfre RE, in identifying part of our magnificent contributors.

We round up this issue with the summary of a very recent event, the Symposium of the AON Foundation Observatory of Catastrophes, that took place in the National School for Civil Protection, in which the volcanic eruption in La Palma was one of the most prominent items tackled.

Management of volcanic hazard in Colombia: eruption history and lessons learned

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Volcanic hazard in Colombia

Colombia's terrain is extremely varied, ranging from low valleys to high snow-capped peaks. This is due primarily to the fact that the country is located right in the middle of the Pacific Ring of Fire, known to be one of the subduction zones that harbours some of the world's most important zones of seismic and volcanic activity as a result of the interaction between the Nazca and the South American tectonic plates. Its privileged location in the tropical region at the north-western tip of South America makes it the only country in this part of the continent with coasts washed by both the Pacific and Atlantic oceans.

In terms of area, Colombia spans nearly 1,143 million km² (twice the size of Spain), crossed by the Andes mountain range, which covers a large part of the territory, and the Amazon basin. The Andes mountain system divides into three ranges separated by the valleys of the Magdalena and Cauca rivers, the Western [Occidental], Central, and Eastern [Oriental] ranges, crossing more than 69% of the total territory (22 of Colombia's 32 departments).

All this makes our country one of the regions with the highest diversity of flora and fauna in the world, and its territory is host to the planet's largest extent of paramo, more than 3,000 species of butterflies, and 20% of existent bird species. This, its volcanic relief, and the large variety of high mountain climates impart great environmental value, evinced by a wealth of water resources and a high degree of biodiversity that lend beauty to its imposing landscapes.

Turning our attention now to the matter of volcanoes, this coffee-producing country is situated in the Andean Volcanic Belt, which as its name implies spans the Andes mountain range in Argentina, Chile, Bolivia, Peru, Ecuador, and Colombia. Most of the 23 active volcanoes in Colombia are located in branches of the Central range, with some in the Eastern range, displaying activity in the southern, middle, and northern regions of the country.

Many of the features associated with the volcanism inherent to the geological attributes of the country referred to above make the country an ideal location for ecotourism in the form of sporting activities like mountaineering and hiking, offering such attractions as hot springs and hiking trails, adding to the country's cultural richness.

The products and services supplied by the insurance and re-insurance industry are, now more than ever, one of the alternatives for responding to natural events that are relied on by the productive fabric of regions that are subject to high threat levels. A detailed understanding of this type of hazards is still critical for the insurance industry, since, lest we forget, these events have the potential to wipe out entire population centres.

A new type of earthquake insurance has been in operation in Colombia for a little over two years. Now earthquake losses are to be estimated using any of the probabilistic models authorised by Colombian regulatory authorities. Under this new scheme, computational software uses the physical information concerning both personal property and real estate making up the earthquake portfolio, much obtained through field work. One of the main tasks of insurers selling this type of property insurance is to be able to access new data on the zones under the influence of the hazards in question.

Nevertheless, based on the latest population census statistics from 2018 released by the National Administrative Statistics Office [*Departamento Administrativo Nacional de Estadística (DANE)*] and on a set of over 165 hazard maps for Colombia, some 5.5 million people live at risk from volcanic activity in the country.

This figure has placed the important task of advancing our detailed understanding of volcanic perils on the radar of the government agencies charged with managing disaster risk with a view to being able suitably to define the vulnerabilities arising from the above-mentioned attributes and thus continuously to improve all those actions and measures aimed at managing volcanic hazard in Colombia.

Colombia's eruption history

Each volcano has its own individual characteristics that raise different challenges for managing disaster risks. Exposure and threat conditions and social and physical vulnerability of the areas within the regions of influence of volcanoes produce different risk scenarios that make it necessary to take measures designed to protect the lives of the country's inhabitants and to reduce the economic damage and losses that could ensue.

Two tremendous events stand out in the history of eruptions in Colombia. They have played a key role in recent years and involve two of the most dangerous volcanoes on the continent of South America, the Nevado del Ruiz Volcano and the Galeras Volcano.

The Armero tragedy: the Nevado del Ruiz Volcano

This natural catastrophe caused by the eruption of the Nevado del Ruiz Volcano on Wednesday, 13 November 1985, is one of the most important events in Colombia's history and the second-most deadly eruption of the twentieth century after the volcanic cataclysm of Mount Pelée on the French island of Martinique in May 1902.

The eruption affected Colombia's Departments of Tolima and Caldas, where the Nevado del Ruiz is found, and took the inhabitants of the areas surrounding the 5,321 m-tall giant by surprise. It melted around 10% of the glaciers, causing a lahar that rushed down the Lagunilla River, as it went burying and obliterating the entire town of Armero, a prosperous agricultural community located in the northern part of Tolima whose main crop was cotton.

This natural tragedy took the lives of more than 25,000 people and according to a study released by the World Bank with the Colombian Agency for International Cooperation and Colombia's National Planning Department [*Agencia Colombiana de Cooperación Internacional y el Departamento Nacional de Planeación (DNP)*] cost the country 2.05% of its gross domestic product (GDP) at the time, the equivalent of 712.8 million US dollars at the average exchange rate of 142 Colombian pesos, that is, some 25.50% less than today[1].

Total estimated damage came to USD 246 million, representing 0.70% of the GDP. Rescue and relief efforts cost USD 14.7 million (0.04% of the GDP); rebuilding nearly USD 360 million (1.02% of the GDP), and operating expenses have been put at USD 95.1 million (0.27% of the GDP). The study calculated that the cost of the impact on manufacturing totalled USD 84 million and damage to agriculture and livestock got close to USD 5 million.

In the wake of the eruption, the RESURGIR (Rebuild) Reconstruction Fund [*Fondo de Reconstrucción*] was established on 24 November 1985 and put in charge of reconstruction measures. Its recovery plan came to nearly USD 316 million.

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(1) The current representative exchange rate in Colombia is 1 USD = 4,010 Colombian pesos.

These figures, though by no means negligible, are far from the much greater cost of the loss of human lives taken by the tragedy. One of the most memorable, which has become a symbol of the victims of this natural catastrophe, was the death of Omaira Sánchez, a young girl just 13 years old whose legs were trapped under a wall. She struggled in the mud to hold onto life for three days but ultimately succumbed and was one of the victims whose bodies had to be recovered by rescue teams amid all the destruction.

This volcano has been active for about two million years and has gone through two major periods of eruptions to the present day.

The volcano is composed of layers of lava alternating with hardened volcanic ash and is located in the Los Nevados National Nature Park [*Parque Nacional Natural Los Nevados*], which, together with the Nevado de Santa Isabel and Nevado del Tolima volcanoes and a series of craters, paramos, wetlands, and rainforests, is one of the country's largest volcanic complexes thanks to the geological features of the region and makes up one of Colombia's main tourism areas.

The volcano has been showing signs of activity for 11 years and is currently under a yellow alert, namely, there is no imminent threat of eruption. Still, at that alert level earth tremors, the ejection of ash, lahars, morphological changes, and venting of gases are common and certainly affect the quality of life of the populace living within its area of influence. Three events stand out in its history of eruptions: one in 1595 (160 victims), a second in 1845 (more than 1,000 victims), and the event recounted above in 1985 (25,000 victims).

Figure 1. Geological Survey [*Servicio Geológico*]. [@sgcol (26 November 2021)]. Nevado del Ruiz Volcano weekly activity bulletin for 16 to 22 November 2021 [Tweet].
Source: Twitter. https://twitter.com/sgcol/status/1463269108481466371

The Galeras Volcano

The Galeras Volcano is found in Colombia's Department of Nariño, located at the southwestern tip of the country, just 9 km distant from the capital city (San Juan de Pasto). This volcano is considered to be the most active in the country and has a record of numerous eruptions over various centuries. It has been classified as one of the 16 most important volcanoes in recent times by the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI)'s *"Decade Volcano"* Project (Spain's Teide Volcano on the island of Tenerife in the Canary Islands is another on the list). This project was designed to promote the assessment and dissemination of studies on the activity of volcanoes with the potential to cause high losses because of their proximity to populated areas.

This relatively cone-shaped giant is not covered with snow or ice. It is a stratovolcano, which means that its structure is formed by a series of layers of material expelled by previous eruptions. Its age is put at around 4,500 million years and has been active for about 1 million years. It is the volcano with the most active recorded history in Colombia and is continuously expelling smoke and ash, and the population living in its vicinity has had to be evacuated on several occasions.

Since the 1990s the volcano has been exhibiting various minor eruption events, mostly volcanic in nature, culminating in the release of small flows of thick lava, gases, and ash. Precisely during one of these active periods, on 14 January 1993, a sudden eruption in the middle of an expedition into the crater cost the lives of six volcanologists and three tourists who were collecting gas samples directly in that spot, an event that is sadly memorable among experts, since in its aftermath eruption events were able to be relate to previous *tornillo* seismic movements[2].

Figure 2. Geological Survey. [@sgcol. (13 June 2018)]. Current state of activity at the Galeras Volcano. [Tweet]. Source: Twitter. https://mobile.twitter.com/sgcol/status/1007053957280272385

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(2) Called a tornillo event, these special seismic events are recorded in andesitic volcanoes and precede most eruptions in massive volcanoes of this type.

Lessons learned, measures taken

The main eruption of the Nevado del Ruiz Volcano was preceded on 22 December 1984 (11 months earlier) by a reawakening in the form of a swarm of 30 tremors, 4 of which were felt according to reports by the region's inhabitants. This series of events gave rise to the establishment of a Nevado del Ruiz technical monitoring committee made up of various national public and private entities and even some international bodies under the direction of the National Institute of Mining and Geological Research [*Instituto Nacional de Investigaciones Geológico-Mineras (INGEOMINAS)*] (now the Colombian Geological Survey [*Servicio Geológico Colombiano (SGC)*]), which on its creation in 1968 had initially been assigned the task of systematically exploring and mapping Colombian territory.

A network of four portable analogue microseismographs had been installed in July 1985 (four months before the above-mentioned eruption). These recorded data on paper and had to be collected on site, and then an attempt to interpret the data had to be made. The state of technological progress and the relatively negligible experience with volcanic seismology at the time meant that the measurement and geochemical sampling results obtained before the volcano erupted proved to be insufficient for taking decisions and preventive action and measures. Nonetheless, the first version of what was then called the first specific volcanic hazard map to assess the state of activity of the Nevado del Ruiz Volcano was presented on 7 October of that same year. The map depicted high threat areas which included most of the towns that would subsequently be affected by the lahar.

The dearth of information leading up to the catastrophe led to the design and creation of a national disaster risk management policy and issue of a set of guidelines that together gave rise to the initial version of the National Disaster Risk Management System [*Sistema Nacional de Gestión del Riesgo de Desastres*], which 33 years later has enabled the country to have in place a regulatory framework and a national disaster risk management policy. A series of national public, private, and community bodies have been set up and all work together under this policy. They have been provided with means, guidelines, and policies aimed at performing societal risk management designed to protect the population of Colombia as a whole. Chief among these is the Colombian Geological Survey (formerly *INGEOMINAS*), the body charged with monitoring the country's active volcanoes at three volcanology and seismology observatories located in the cities of Manizales, Popayán, and Pasto.

One of the actions worthy of note undertaken subsequent to the Armero tragedy was the eruption of the Nevado del Huila Volcano on 20 November 2008, which caused a lahar that was up to twice as strong as the Nevado del Ruiz lahar. This time, although the flows of mud and debris swept down the Páez River and affected the town of Belalcázar in the Department of Cauca (in the southwestern part of the country), thanks to the institutions that had been put in place and the advances in technology that had been made, the volcanology observatory in the city of Popayán (Department of Pasto) had been able to record data ahead of the changes in the volcano. As a result, the community was able to put a series of measures into effect in cooperation with the bodies in charge of disaster risk monitoring in record time, allowing the populace to be evacuated quickly. The death toll unfortunately totalled 10 people, but given the size of the affected area, it could easily have been much higher.

Another significant milestone that can be mentioned was the establishment of the Latin American Volcanology Association [*Asociación Latinoamericana de Vulcanología (ALVO)*] in Manizales on the 25th anniversary of the eruption of the Nevado del Ruiz on 7 November 2010, with participants from Mexico, Guatemala, El Salvador, Nicaragua, Costa Rica, Panama, Ecuador, Peru, Argentina, Chile, and of course Colombia. The Association's main purpose continues to be to strengthen and promote ties between Latin American volcanologists through international cooperation among Latin American countries and even with other countries from around the world.

Volcanic hazard assessment

Monitoring volcanic hazard in Colombia is a fundamental part of its National Disaster Risk Management System. The Colombian Geological Survey tracks material ejected by the region's active volcanoes, studies changes and magma warning signs, interactions with the environment, fluid flows, craters (signs associated with magma movement), and the rocks and deposits, preserved over time, that make up the topography of the territory. To that end, Colombia monitors its 23 currently active volcanoes through some 670 telemetry and non-telemetry stations, acoustic systems, real-time monitoring equipment, webcams, seismographs, magnetometers, weather stations, inclinometers, and other devices used by its volcanology observatories. The Colombian Air Force and the National Disaster Risk Management Unit [*Unidad Nacional de Gestión de Riesgo de Desastres (UNGRD)*] have helped install domes on the main volcanoes, and reconnaissance flights are increasingly being used to monitor volcanoes.

Turning to academic advances, as one of the two countries in the region that monitors 100% of its active volcanoes, Colombia is a constant source of learning for the Latin American region in a scenario in which Latin America accounts for 25% of the world's volcanology observatories. In addition, Colombia is at the forefront of developing hazard maps, employing new technologies, formulating regional risk management scenarios, conducting drills, issuing bulletins, etc.

Generally speaking, the bodies involved in disaster risk management perform tasks related to learning about, handling, and responding to disasters of this kind, addressing five broad categories:

1. Knowledge of eruption history (volcano DNA).
2. Assessing volcanoes' genetics and potential threats.
3. Diagnosing the state of activity (uncertainty).
4. Continuous monitoring.
5. The important task of communicating and awareness raising.

In approaching some of the main challenges in assessing this hazard in Colombia, monitoring geological development in the region continues to be one of the main aspects that are taken into consideration, at the same time supported by the ongoing task of keeping the population living near the threat informed and actively involved. Another job faced by the experts tasked with assessing the volcanic hazard is to purchase state of the art equipment and implement innovative monitoring and risk assessment methods and measures, naturally in combination with the new digital environments arising from current technological advances.

Insurance coverage of volcanic hazards

The products and services supplied by the insurance and re-insurance industry are, now more than ever, one of the alternatives for responding to natural events that are relied on by the productive fabric of regions that are subject to high threat levels. A detailed understanding of this type of hazards is still critical for the insurance industry, since, lest we forget, these events have the potential to wipe out entire population centres.

A new type of earthquake insurance has been in operation in Colombia for a little over two years. Now earthquake losses are to be estimated using any of the probabilistic models authorised by Colombian regulatory authorities. Under this new scheme, computational software uses the physical information concerning both personal property and real estate making up the earthquake portfolio, much obtained through field work. One of the main tasks of insurers selling this type of property insurance is to be able to access new data on the zones under the influence of the hazards in question.

In this new situation there are insurers in Colombia that have been taking steps to obtain information that will allow them to better assess the risks. For instance, a joint project in the city of Pasto involving the fire protection service, academics, and an insurance company has developed a tool that is capable of better assessing potential damage to buildings located in the region affected by the Galeras Volcano. One of this tool's deliverables is a seismic microzoning study that was developed taking into account the differing impacts of volcanic activity in the region.

At all events, volcanic eruption cover for both individuals and companies is one of the covers conventionally included, mainly in property insurance sold in Colombia. This hazard is therefore one of a range of covers commonly available in, for instance, home, condominium, car, government property[3], and business property insurance policies. It should be noted, however, that in keeping with traditional insurance practice, the value of the premium for property insurance is generally calculated based on the individual attributes of the property being insured, chief among these being the geographical location of the property[3], a factor unquestionably taken into account for properties located in areas in the vicinity of active volcanoes in Colombia.

In recent years the Colombian insurance industry has had to face a series of natural disaster events, and consequently claims adjustment has come to the fore as part of the process of paying out compensation for losses. Even so, advancing the work done by claims adjusters as a whole in proper combination with emergency rescue services is still one of the main challenges facing the insurance sector.

Accordingly, insurance and even re-insurance sales in Colombia need to continue working to place on the table innovative alternatives that will help enhance people's resilience. One of the main alternatives is parametric (agricultural or property) insurance, while another entails including various special considerations for covering occupational risks and life insurance, to mention just some, in order to engage the populace and promote penetration by insurance in an increasingly changing environment.

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(3) Colombian law requires public officials to insure government-owned properties against damage.

Volcanic hazard in France: the insurance response

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CCR Re

The extensive eruption of the Cumbre Vieja Volcano in the Canary Islands, at the time of this writing still in progress after many weeks, has raised our awareness that a hazard that may seem tenuous and infrequent can have a huge impact on the insurance industry, destroy hundreds or thousands of properties, disrupt communications and distribution networks, and bring local economic activity to a halt for many months. An event of this type could take place in the territory of France, which harbours some of the most active volcanoes on the planet that have caused tremendous catastrophes in the past. Like Spain, France has established an insurance instrument capable of responding effectively to the need for compensation specific to natural disasters.

Despite the fact that French territory, its overseas territories in particular, are exposed to this peril, there has been only a single event that was declared to be a natural disaster since the Nat Cat scheme began in 1982, namely, the April 2007 eruption on Réunion. That eruption had only marginal cost for the insurance industry, because the lava flows affected very little insured property. There was no official assessment of the total economic cost, but it was at all events minimal, even though a main highway was cut off for two months and entry into tourism and fisheries areas was prohibited while the lava flowed into the ocean.

The plethora of natural hazards connected to volcanic eruptions means that there is a not inconsiderable likelihood that French territory will be affected by an event similar to or even more destructive than the eruption of the Cumbre Vieja Volcano in the Canary Islands.

The natural catastrophe compensation scheme and the role of the CCR

France is one of a small group of countries with a mechanism that ensures suitable compensation, at affordable rates, for property damage sustained by private individuals, companies, and local government produced by natural disasters. This mechanism is a compensation scheme for natural catastrophes (Nat Cat) that was brought into being by the Act of 13 July 1982. This insurance scheme has proved successful in alleviating a gap in coverage for natural hazards, which had been underinsured until that time.

In practice the insurance scheme takes the form of a public-private partnership. In that legal form the *Caisse Centrale de Réassurance* [Central Reinsurance Fund], or CCR, is enabled to provide insured parties who are interested in unlimited reinsurance coverage backed by the French government for natural disaster hazards in France. The CCR was established in 1946 and is wholly owned by the Government of France. As a public reinsurer, it supplies the public component in this partnership.

The CCR's area of activity extends beyond the bounds of insurance coverage, by also: (i) bringing financial balance to the natural disaster compensation scheme; (ii) participating in evaluating the financial consequences of natural catastrophes, collecting data on insured property damage, and devising its own modelling tools; and (iii) boosting the prevention of natural perils by providing a knowledge base and key indicators for industry stakeholders.

Operation of the Nat Cat scheme

General principles

In practice, natural disaster insurance is a compulsory extension of coverage for all property insurance policies (multirisk home, all-risk car, commercial premises insurance, etc.) except for marine insurance. Accordingly, insuring property against physical damage (fire, theft, water damage, etc.) is the prerequisite for gaining entitled to compensation.

The insured will be compensated for damage caused by a natural catastrophe when the municipal authorities have asked the French government to declare a natural disaster. The government then evaluates those requests based on detailed scientific reports that will show whether the natural event was unusual in its intensity or not (Figure 1). Under this procedure, frequent low-intensity events are excluded, and only events that have the highest impact are covered. The government will then issue an interministerial decree and declare a natural disaster depending on the characteristics of the event, its geographic extent, and the length of time it has lasted.

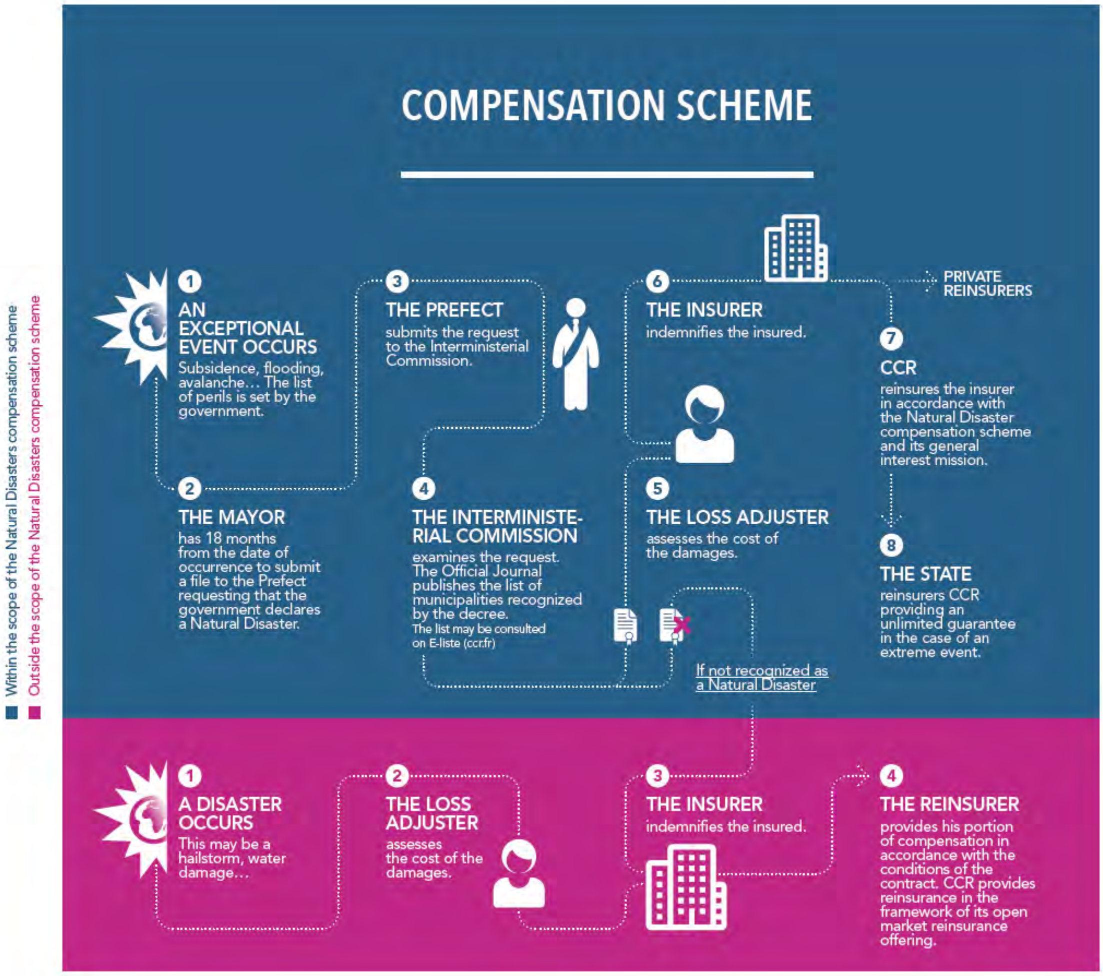

Figure 1. How the natural catastrophe indemnity scheme operates in France.
Source: CCR, 2021.

Funding for the scheme

The Nat Cat coverage extension requires paying a surcharge on the premium. The surcharge is based on the principle of national solidarity, the cornerstone of the French Constitution, and hence it is the same throughout France, irrespective of the insured property's exposure to natural hazards. The surcharge is set by the French government, and the rate is currently 12% of the premium for the property damage cover under the basic policy for property other than motor vehicles and 6% of the premium for fire and theft coverage for land motor vehicles (or, where there is no such cover, 0.50% of the property damage premium).

In 2020, the cumulative premiums collected under the Nat Cat scheme came to 1,720 million euros for the automobile and property damage lines. Business risks (commerce, industry, agriculture) accounted for some 690 million euros, private property risks (homes) some 910 million euros, and motor vehicles some 110 million euros.

Thus, it is estimated that a business is covered under the Nat Cat scheme for a premium surcharge of around 100 euros a year, a private individual for between 25 and 30 euros a year, and a vehicle for less than 10 euros a year.

Limits of indemnity

By law Nat Cat protection covers "non-insurable direct property damage caused by the unusual intensity of a natural agent where the usual measures taken to prevent such damage could not be taken or would not have prevented the damage from occurring". This applies to an extensive series of natural phenomena including floods, drought, ground movement, storm surges, hurricanes, earthquakes, tsunamis, avalanches, and volcanic eruptions, as well as all of their associated repercussions.

The law stipulates that direct property damage will be covered only if there is coverage under an insurance policy that serves as the basis for the Nat Cat coverage extension. The risks covered are:

- direct property damage to buildings, structure and contents, including the replacement value if the policy includes that coverage,
- demolition and debris removal expenses for the insured property that has suffered the loss,
- damage caused by moisture or condensation from standing water on the property,
- the cost of pumping, cleaning, and disinfecting damaged property and salvage measures in general,
- the cost of geotechnical studies needed to recover the property that is covered,
- vehicles that have own damage insurance (compulsory third-party liability does not cover losses of this kind).

Also covered is business interruption from direct damage where the underlying policy includes this cover.

The law provides for the following deductibles:

- €380 for residential properties and motor vehicles,
- 10% of the loss, with a €1,140 minimum, for business properties,
- 3 business days, with a €1,140 minimum, for business interruption.

These deductibles may be raised by a factor of from 2 to 4 in case of repeated losses in municipalities that do not have a natural risk prevention plan or based on the number of declarations of natural disasters issued for the same type of natural catastrophe in the five years preceding the date of the latest declaration.

Lastly, it should be pointed out that damage is covered whether it occurs in the territory of metropolitan France or in the overseas territories of Guadeloupe, Martinique, French Guiana, Réunion, Saint Pierre and Miquelon, Mayotte, Saint Barthélemy, Saint Martin, and Wallis and Futuna. Insured property damage in each of these territories will be covered even if the event that causes the damage is located outside France. For instance, an earthquake in Italy that causes damage in Nice, a tidal wave that crosses the Indian Ocean and causes damage in Réunion, or volcanic ashfalls that affect Guadeloupe even if they come from the Soufrière Hills Volcano on the island of Montserrat 80 km distant are indemnifiable if the natural events can be demonstrated to be unusually intense.

Several French overseas territories are active volcanic islands in the Caribbean or in the Indian Ocean and hence are directly exposed to multiple impacts caused by volcanic activity.

Nat Cat losses and extreme events

Nat Cat premiums brought in 1,720 million euros in 2020, but losses from natural catastrophes are themselves quite substantial, though subject to interannual variations (Figure 2). Around 41,000 million euros in losses were paid out in the period from 1982 to 2020, that is, mean annual compensation of 1,086 million euros. Some 42 million euros of that was in the motor vehicle line. France is mainly exposed to two recurring natural perils, floods, which account for around 53% of cumulative losses, and drought (clay soil contraction and expansion), which account for 37% of losses. The other perils account for the remaining 10%.

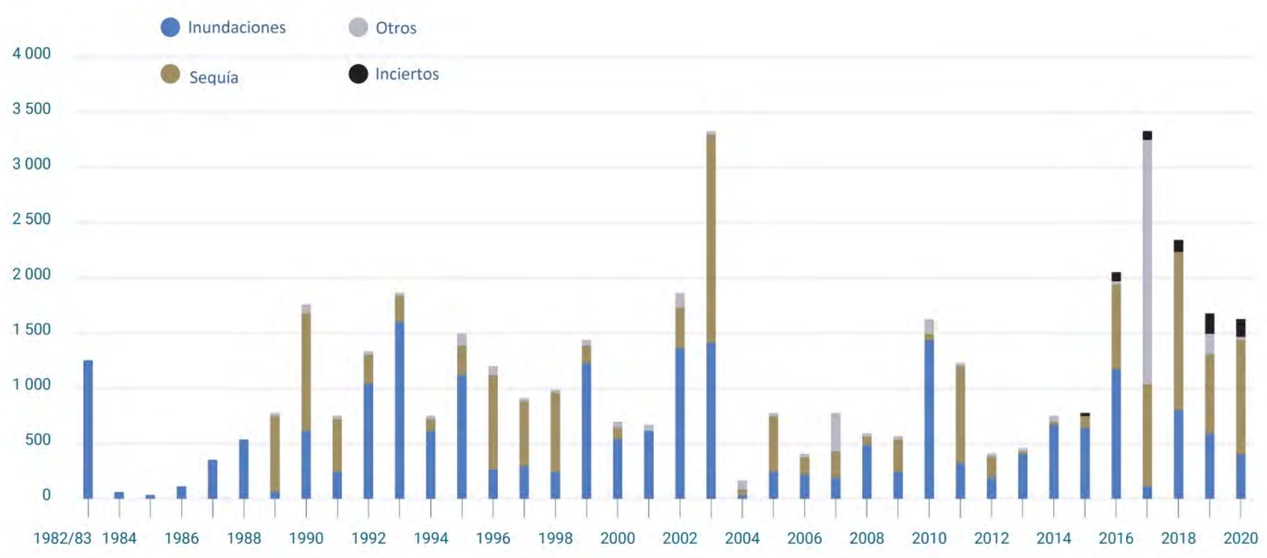

Figure 2. Nat Cat loss rate, property damage from 1982 to 2020.
Source: CCR, 2021.

The most recent of the chief significant events over the history of the scheme is unquestionably Hurricane Irma, which occurred in 2017 and swept across the islands in the French Antilles, producing insured damage totalling on the order of 2,000 million euros, substantially higher than that year's Nat Cat premiums. Other events also took place in that same year, particularly an intense drought that caused some 800 million euros in losses. Another year, 2003, was also a year of record losses amounting to 3,300 million euros, including over 1,500 million euros from drought and close to 1,000 million euros from a major flooding event.

Apart from the observed losses, in the CCR's estimation there are other probable extreme events, such as flooding in Paris and the surrounding region, that could produce losses ranging between 16,000 and 28,000 million euros, or an earthquake near Nice in southern France, whose cost could come to between 9,000 and 13,000 million euros.

Volcanic eruptions and France's Nat Cat scheme

Despite the fact that French territory, its overseas territories in particular, are exposed to this peril, there has been only a single event that was declared to be a natural disaster since the Nat Cat scheme began in 1982, namely, the April 2007 eruption on Réunion. That eruption had only marginal cost for the insurance industry, because the lava flows affected very little insured property. There was no official assessment of the total economic cost, but it was at all events minimal, even though a main highway was cut off for two months and entry into tourism and fisheries areas was prohibited while the lava flowed into the ocean.

The plethora of natural hazards connected to volcanic eruptions means that there is a not inconsiderable likelihood that French territory will be affected by an event similar to or even more destructive than the eruption of the Cumbre Vieja Volcano in the Canary Islands.

Exposure in the territory of France

Most volcanic activity is related to plate tectonics. As a general rule active volcanoes are concentrated along the edges of those plates, especially in subduction zones like Guadeloupe and Martinique. Volcanism in those places is ordinarily explosive, with pyroclastic flows and ash plumes. Volcanic activity is episodic, with dormant periods that can last for centuries. This makes it difficult for the insurance industry to estimate this risk.

Other types of volcanic activity are caused by "hot spots" located far from the edges of the plates, locations that are permanently fed by a magma source, such as Réunion in France or the Canary Islands in Spain. Volcanism in these locations is effusive, with lava fountains and flows. Eruptions may occur often (on Réunion, 173 eruptions in 350 years), but their impact tends to be limited.

Metropolitan France is close to a hundred extinct volcanoes, particularly in the region from the Massif Central to Catalonia in Spain. Though now extinct, the volcanoes in the chain of Puys in Auvergne were active until just 7,000 years ago.

The hazards of volcanic eruptions

Volcanic eruptions have a range of repercussions, and having in mind the different volcanic contexts in metropolitan and overseas France, could give rise to declarations of a series of natural disasters.

Lava flows

Lava flows (Figure 3) run down the flanks of volcanoes from craters or fissure vents, as is the current case on the island of La Palma. On the scale of volcanic risks, the danger to the population is low, because there is usually time to escape, although the potential for destruction is high due to buried infrastructure and the devastation caused by the advancing lava, not to mention the fires that are produced.

Figure 3. Lava fountain (roughly 200 m high) and lava flow from the Pu'u 'O'o Volcano in Hawaii in 1984. Source: USGS.

Collapses and landslides

Collapses (Figure 4) are associated with the formation of a caldera from the collapse of a volcano's magma chamber. Collapses of the flanks are generally related to magma pushing into the volcano's structure, with progressive transformation of the rock, or to a landslide caused by a large earthquake. The impact of this phenomenon depends on its speed and on the volume of material displaced. The main dangers to infrastructure are destruction caused by burial and impact, changes to terrain, the formation of barriers in watercourses which can give rise to major flooding when they give way, and the generation of tsunamis.

Figure 4. Collapse of part of Mount St. Helens (USA) after the 1980 eruption.
Source: USGS.

Pyroclastic flows

Pyroclastic flows (Figure 5) are pieces of lava and rocks moving at very high speed (up to 700 km/h) in a cloud of extremely hot gas (from 200 °C to 1,000 °C). They are often formed when an overly dense ash plume collapses in on itself or when a lava dome collapses. Without a doubt it is the most destructive volcanic hazard: entire cities can be razed in minutes, as happened to Pompeii in the year 79 CE.

Volcanic gases

Water vapour is the main volcanic gas, along with numerous acidic and sometimes lethal gases that increase the production of acid rain, which damages buildings, crops, pasture, and drinking water supplies. In 1986 a pocket of some 1 km3 of CO_2 that had collected at the bottom of Lake Nyos (Cameroon) suddenly erupted and in a very short time killed more than 2,000 people.

Figure 5. Ash column destabilisation and start of pyroclastic flow at Mount St. Helens (USA) in 1980.
Source: USGS.

Lahars

Lahars are flows consisting of mud, ash, rocky debris, and other materials mixed with water from a lake in the crater, rivers, sudden snow or ice melts, or simply rainwater. Slides of unconsolidated volcanic deposits can occur a number of years after the deposits were laid down. These slides can be devastating, for example the case of Armero (Colombia) located 45 km from the Nevado del Ruiz Volcano, where some 23,000 people lost their lives in 1985.

Ash plumes

Explosive eruptions can eject ash plumes up to more than 40 km into the air (Figure 6). Ashes are small bits of lava and/or rocks, variable in size and shape, that tend to be extremely abrasive. Breathing in the ash can cause respiratory difficulties. Major infrastructure risks include roof cave-ins from the build-up of sometimes wet ash. Mechanical systems that suck the ashes in can also be affected, for instance, land vehicles and aircraft. A good

Figure 6. Ash plume from the Mount Pinatubo (Philippines) eruption in June 1991.
Source: USGS.

example of this was the 2010 Eyjafjallajökull volcanic eruption in Iceland, which forced 28 European countries to close all or part of their airspace and caused economic losses that the European Commission estimated at between 1,500 and 2,500 million euros.

Other hazards: earthquakes, tsunamis, and explosions

Earthquakes caused by volcanic activity are usually limited to active zones and tend to be low in magnitude (M<4). A recent case that affected France is recounted below and changed our perception of this hazard associated with volcanic activity.

Volcanic tsunamis are generally caused by large lahars, pyroclastic flows, or flank collapses that slide into the ocean. Local tsunamis of this kind are harder to monitor and control than tsunamis triggered by strong earthquakes.

Lastly, we should also mention the explosive propagation of shock waves following a volcanic eruption. They pose a major hazard to infrastructures, buildings, and people. These blasts are similar to those caused by industrial accidents or terrorist attacks, but because of the size of volcanoes, they can cause damage over hundreds of kilometres. For example, after the Mount Tambora eruption in Indonesia in 1815 damage was reported up to 400 kilometres away.

One event that France remembers is the eruption of Mount Pelée in Martinique in 1902

On the morning of 8 May 1902, 29,000 people lost their lives in just a few minutes when a pyroclastic flow from Mount Pelée completely destroyed the city of Saint-Pierre, then the capital of the Department of Martinique (Figure 7).

The cloud of burning material engulfed Saint-Pierre at an estimated speed of 180 km/h and a temperature of around 300 °C. It was preceded by a shock wave travelling at nearly 450 km/h.

In addition to the thousands of victims, the socioeconomic repercussions of this eruption were extremely important: thousands of people lost their homes and were forced to leave their lands, which were made unreachable and uncultivable for decades. Saint-Pierre, the capital of the Department of Martinique and the economic centre of the French Antilles, had to be abandoned, and the capital was moved to Fort-de-France, located outside the volcano's direct hazardous area.

Figure 7. Mount Pelée (Martinique) after the 1902 eruption. Pyroclastic flows reached the sea and the city of Saint-Pierre in a matter of minutes.

What impact would an event like the 1902 eruption in the Antilles have today?

Precise economic estimates for an event of this kind are hard to make, because the physical scars of the eruption and its socioeconomic effects would be felt at a regional scale for many years. The total economic cost might be put at more than 10,000 million euros.

Fortunately, the return period for events like these involving volcanoes of this kind tend to be several centuries. At any rate, Mount Pelée has since 2020 shown signs of new volcanic activity unlike those observed in previous decades. A major eruption could today be predicted weeks or months in advance based on the record of eruptions by this volcano, quite unlike that of Cumbre Vieja in the Canary Islands.

The question could be addressed before the eruption, and the costs relating, for instance, to evacuation of the population could be defrayed by a body to be decided, inasmuch as the natural catastrophe compensation scheme in France is designed only to cover material losses that have already occurred.

This situation may seem implausible, but it already occurred in Guadeloupe in 1976, when there was a recurrence of some activity that ultimately caused very little damage despite a score of blasts and numerous landslides. At the height of the eruption, an evacuation of the surrounding population in July 1976, at first spontaneously by around 25,000 people, subsequently followed by another of around 75,000 people over nearly half the island ordered by the authorities lasted for around five months.

Mayotte: the birth of a new submarine volcano

The island of Mayotte, French territory in the Indian Ocean, is a part of the active volcanic archipelago of the Comoros. The last volcanic activity on Mayotte proper is estimated to have occurred around 500,000 years ago.

Mayotte has been undergoing intense seismic activity since May 2018, with more than 1,500 tremors with a magnitude greater than 3.5 felt by the population. A distinctly stronger earthquake, magnitude 5.8, took place on 15 May 2018 and caused considerable damage on the island. The combined seismic activity that has occurred since 2018 was declared a natural disaster, which brought entitlement to compensation as stipulated under the insurance scheme.

In parallel to this unusual seismic activity, high-precision GPS devices located on the island have recorded displacement of the island about 25 cm to the east together with drop in elevation of 10 to 20 cm.

All this seismic activity and movement of the island as a whole is related to the emergence of a volcano on the ocean floor some 50 km east of Mayotte. Scientifically speaking, this is an extremely rare and exceptional event that has been able to be documented for the first time thanks to modern methods of observation. At this time the submarine volcano has grown to a height of over 800 m above the sea bed, and continued growth over the coming years, decades, or centuries will give rise to sporadic incidents and occasional damage on Mayotte.

Conclusion

While infrequent, volcanic eruptions and their repercussions on the population, buildings, infrastructure, and socioeconomic fabric of the affected territories can represent major events for different insurance industry lines all at once, e.g., personal injury, property damage, motor vehicle, marine, and aviation insurance, etc., like few other natural catastrophes can produce.

Up to now there have been few large-scale eruptions in territories with mature insurance markets accustomed to handling losses of several thousand million euros a year caused by hurricanes or earthquakes around the world. The Cumbre Vieja eruption in the Canary Islands is a recent example, and historical eruptions in the territories of France should remind us that this peril exists and that it needs to be quantified and included in assessments of our exposure, so that we can ensure continued operation of special compensation schemes for natural catastrophes like the CCR, which plays a central role in France, or the Consorcio de Compensación de Seguros in Spain.

Volcanic hazard in Italy: a variegated landscape

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Cover photograph. Etna eruption in February 2021.
Source: Photograph by Boris Behncke.

Southern Italy is one of the most active tectonic and volcanic settings in the Mediterranean area, comprising persistently active and dormant volcanoes. As we write, two volcanoes feature a persistent eruptive activity: Stromboli, belonging to the Aeolian Archipelago, in the Tyrrhenian Sea, and Etna, along the Eastern coast of Sicily. Both volcanoes are usually characterized by mild explosivity featuring the launch of pyroclasts near the vent, occasional lava flows and lava fountains up to several hundreds of meters. This kind of activity may culminate in the development of eruptive columns, which may reach up to 10-15 thousand meters, in the case of Etna.

The assessment of volcanic hazard is a formidable challenge, given the wide variety of phenomena potentially involved, which operate on different spatial and temporal scales. Italian volcanoes well represent the wide spectrum of possible states of activities and eruptive styles: from dormant volcanoes to persistent activity, from the largest volcano in Europe to small volcanic islands, Italy faces all sorts of actual and potential threats from volcanic sources. The *Istituto Nazionale di Geofisica e Vulcanologia* (INGV) is the main institution in charge of the monitoring and surveillance of active Italian volcanoes. To fulfil its mission INGV installs and maintains observational networks with technologically advanced instruments concentrated around active volcanoes. Collected signals are conveyed by redundant transmission systems to the 24-h operating rooms in Naples (Figure 1) and Catania, which grant continuous surveillance.

Figure 1. The monitoring room operating 24h/7d in Naples at INGV Osservatorio Vesuviano.
Source: www.ov.ingv.it

Southern Italy is one of the most active tectonic and volcanic settings in the Mediterranean area, comprising persistently active and dormant volcanoes. As we write, two volcanoes feature a **persistent eruptive activity:** Stromboli, belonging to the Aeolian Archipelago, in the Tyrrhenian Sea, and Etna, along the Eastern coast of Sicily. Both volcanoes are usually characterized by mild explosivity featuring the launch of pyroclasts near the vent, occasional lava flows and lava fountains up to several hundreds of meters. This kind of activity may culminate in the development of eruptive columns, which may reach up to 10-15 thousand meters, in the case of Etna. At these altitudes erupted pyroclasts can be dispersed by tropospheric winds for hundreds of kilometres around the volcano. The impacts of these phenomena are broadly different for the two volcanoes, both due to their intrinsic differences and because of their geographic position. Stromboli is a small island and a popular tourist attraction especially during the summer, while Etna is a 3,357 m high volcano surrounded by a productive countryside which overlooks Catania and foothill villages, where about a million people live.

A different kind of threat is posed by **dormant volcanoes.** These volcanoes have been inactive long enough to lose a direct connection with the magmatic system at depth and thus their capacity to erupt frequently. Nevertheless, these volcanoes maintain their full potential to erupt again in the future. With respect to frequently erupting volcanoes that have an open volcanic conduit, a renewal of eruptive activity at dormant volcanoes requires greater energy, and this may lead to explosive eruptions with a larger impact. Prolonged repose time may also contribute to reduce the **risk perception** among the local residents. People may peacefully live on the volcano slopes for decades and acquire a false sense of security that may hinder the implementation of long term mitigation actions.

The re-awakening of a dormant volcano does not pass unnoticed. The development of a new pathway for magma ascent toward the surface is generally accompanied by a number of geophysical and geochemical phenomena, such as shallow seismicity, ground deformation, and by changes in the composition and discharge rate of volcanic gases. These precursory signs may warn against the impending danger, and may directly threaten the local communities even before the eruption begins. Multidisciplinary monitoring networks enable to capture even small changes in observed parameters and the number and magnitude of observed anomalies help to constrain the current state of a volcano. Unfortunately, these precursors do not always provide actual clues on the duration and outcome of the ongoing unrest period. Volcanic unrest may terminate before magma reaches the surface, or may escalate into eruptive activity, and the entire process may take from a few days to several years. This large uncertainty about the final outcome and the time frame involved makes it really difficult to manage volcanic unrest. At this time (late November 2021), two Italian volcanoes are going through volcanic unrest: the Phlegraean Fields caldera, in the densely populated Neapolitan area, and the island of Vulcano, belonging to the Aeolian Archipelago. The volcanic unrest at these two volcanoes poses very different challenges to the community involved and emergency managers.

Other active but dormant Italian volcanoes are completely quiet, but their possible re-awakening must be accounted for in risk assessment. The most famous of these volcanoes is certainly Somma-Vesuvius, also located in the metropolitan area of Naples. Other quiescent volcanoes are the Island of Ischia, in the Gulf of Naples, two Aeolian islands (Panarea and Lipari), and Pantelleria, an island in the Sicilian channel. The list is completed by the submarine volcanoes in the Tyrrhenian Sea and the Sicilian Channel.

In the following, we describe significant features for the main volcanic areas in Italy and highlight the different problems posed by persistently active, unresting and dormant volcanoes. We believe they represent well many of the typical challenges related to volcanic risk assessment and mitigation.

Active volcanoes in Sicily

Stromboli

Stromboli is a volcanic island entirely formed by a stratovolcano that rises from the bottom of the sea (at a depth of 2,000 m) and reaches a maximum height of 930 m above the sea level (Figure 2). At least for the last 1,000 years, Stromboli has been characterized by a persistent, mildly explosive activity, sometimes accompanied by the effusion of lava flows that usually propagate along a horseshoe-shaped escarpment known as Sciara del Fuoco (literally, the Fire slope). This persistent activity features an average of 10 to 15 explosions in an hour, from three active craters situated on a terrace facing the Sciara del Fuoco, at an elevation of 750 m. These explosions have usually a minor impact, with fallout of lapilli and ash that is limited to the summit area. However, bigger events may take place with greater consequences.

Figure 2. Stromboli Island, seen from the west. In the foreground, the erosive depression known as "Sciara del Fuoco". At the top, the summit craters which degases continuously. Bottom left, the town of Stromboli; bottom right, the houses of Ginostra.
Source: Photograph by Marco Neri.

Paroxysmal eruptions usually form eruptive columns that may reach up to a maximum of 7-8 km and may eventually collapse feeding pyroclastic flows, hot mixtures of gas and ashes that rush down the volcano's slope. Given the specific morphology of the island, these flows are commonly directed along the steep and desert western slope of the island. Once they reach the coast, they may threaten shipping as they propagate along the sea surface or cause anomalous waves. These events also launch volcanic bombs and blocks that occasionally reach the two villages located to the NE and SW corners of the island (Figure 2). Even when they are not hit by bombs, the villages are easily engulfed in lapilli and ashes fallout, which may affect roads, crops and air quality, and ignite fires. A recently redacted catalogue of eruptive events at Stromboli shows that 36 paroxysmal eruptions occurred over the last 140 years. The analysis of available data suggests an increased frequency of extreme events during the last 10 years, and shows that paroxysms are more likely to happen shortly after one another. Examples of this behaviour are the two paroxysmal events that took place in 2019, on the 3rd of July and then again on the 28th of August. The first of these two events was marred by one casualty, due to the inhalation of a mixture of smoke, ash and gases. The current alert level for Stromboli is yellow, characterized by a high level of Strombolian activity (Figure 3).

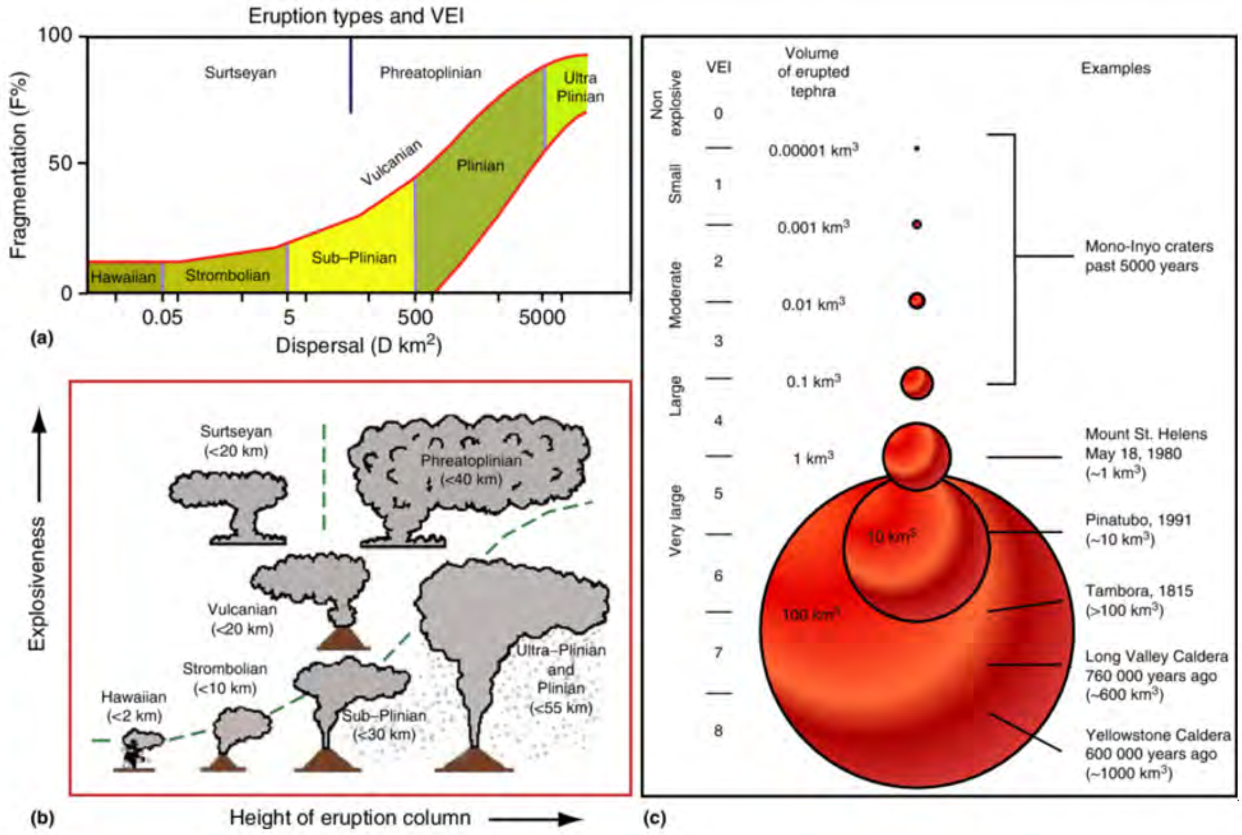

Figure 3. These diagrams show three different ways to classify explosive volcanic eruptions, according to a) the area of ash dispersion and the percentage of fragmentation of pyroclastic fall deposits; b) the height reached by the eruptive column and explosiveness degree; c) Volcanic Explosivity index (VEI).
Source: Hickson, Catherine & Spurgeon, T. & Tilling, Robert. (2013). Eruption Types (Volcanic Eruptions). 10.1007/978-1-4020-4399-4_122.

Etna

Etna is the tallest volcano in Europe and one of the most active volcanoes on Earth. Volcanic activity is mainly focused at the summit, generating gas emissions, strombolian to paroxysmal activity (Hawaiian, violent Strombolian to sub-Plinian, Figure 3) and lava overflows from one of the four summit craters. These nearly continuous summit eruptions do not pose only a seemingly minor threat to human life and property. The development of tall volcanic columns during major eruptive events may inject significant quantities of ashes in the atmosphere (Figure 4) and affect air traffic: sometimes this requires rerouting flights and occasionally it may prevent landing and take-off in local airports. Ash fallout can also affect road conditions and crops. The greater frequency of paroxysmal summit eruptions in recent decades (since 1977 there have been hundreds of paroxysmal explosive episodes!) has undoubtedly increased the hardships for the Etnean populations, who are continually forced to face the problem of ashes and lapilli accumulation on the roofs of houses and on streets and cultivated land.

At times, the Etnean volcanic activity occurs along radial fissures, producing **flank eruptions** (Figure 5) mostly from three main “rift zones”, that is, areas of structural weakness of the volcanic apparatus. In these cases, magma moves vertically towards the topographic surface through the central conduit and, at shallow levels (few hundreds of meters up to 1-3 km), propagates laterally penetrating, in most cases, into the rift zones.

Figure 4. March 4, 2021: Explosive eruption from the Southeast Crater of Etna, seen from the Gulf of Ognina, in Catania. The eruptive column rises vertically for about 8-10 kilometres in height before being pushed by the wind towards the north-east.
Source: Photograph by Marco Neri.

Flank eruptions represent the most dangerous type of eruptive activity, since they occur at lower altitude (between 2000 and 500 meters above the sea level) and thus closer to vulnerable areas such as towns, villages, lifelines, and cultivated land. Potentially hazardous flank eruptions have a frequency ranging from a few months to a few decades, although the time intervals between such eruptions have shrunk to an average of 1.5-3.0 years since 1971.

All known Etnean flank eruptions have produced lava flows, many of which invaded areas of cultivated land, destroyed human property and infrastructures, and sometimes buried entire villages. In 1928, for example, the village of Mascali was almost totally buried and destroyed by the lava and rebuilt elsewhere, further downslope. On the other hand, during the past 70 years the urbanized areas around the volcano have rapidly developed, with an extensive system of lifelines and rapid growth of population centres, often in areas that have been covered by lava flows in the historical period. Tourist facilities have been established high on the volcano (up to 2,600-2,800 m high) and were repeatedly damaged by lava flows, most recently in 2001 and 2002-2003. For these reasons, the Etnean region is more vulnerable now than at any time before.

In order to mitigate the impact of lava flows by preparing appropriate intervention and civil protection plans, numerous scientific studies, many of which made by INGV researchers, have recently been carried out, focused on mapping the areas of most probable lava invasion and therefore most exposed to destruction. These studies show that the risk from lava invasion is highest

Figure 5. July 28, 2001: flank eruption of Etna. Lava flows invaded and destroyed part of the Etna-Sud tourist centre.
Source: Photograph by Marco Neri.

around the summit area, due to the frequent activity and the limited range of vent locations. The level of hazard decreases away from the summit, but at the same time, the vulnerability increases exponentially, especially in the areas located downstream of the volcanic rift zones.

The vulnerability of the Etna area is well known by the populations who have lived on its slopes for thousands of years. However, people consider Etna to be a "good volcano", as it hardly ever claims victims, with its lava flows that move slowly enough to allow people to escape. The alert level for Etna is currently yellow.

Vulcano

The island of Vulcano, in the Aeolian archipelago, is made up of several different-sized volcanic centres. The eruptive activity of the island was characterized by a wide range of explosive eruptions, and lava flow effusions, which over time built two important volcanic edifices and several minor centres. These volcanic structures were partially or even largely destroyed by multiple volcano-tectonic collapses, forming two calderas. Inside the most recent caldera, starting from about 5,500 years ago, the tuff cone of La Fossa grew and was mainly characterized by phreatomagmatic (Vulcanian) eruptions (Figure 3). Some effusive eruptions along La Fossa volcanic history are present, too. Afterwards, in the northernmost part of the island the cone of Vulcanello was formed, initially through an underwater lava eruption that began in 126 BC (according to the Roman chronicles) and then from both subaerial explosive and effusive eruptions. It’s noteworthy that in the last 1,500 years, the activities of these two young eruptive centres occurred repeatedly, both alternating and simultaneous. The remnants of another small tuff cone - Il Faraglione -, strongly fumarolized and located just in front of the Vulcano harbour, reveal that a third volcanic centre aroused from the caldera floor in recent but indefinite times. The last La Fossa eruption occurred between 3 August 1888 and 22 March 1890, following several centuries of short-lived, discontinuous but recurring eruptive activities. This eruption, well documented and described by Giuseppe Mercalli, led to the introduction of the term "Vulcanian" activity in the volcanological nomenclature.

Since the last eruption, Vulcano has gone through periods of unrest characterized by an increase of fumarolic activity and gas discharge, both at the fumarolic field on the crater rim and at the base of the cone. Between 1988 and 1993, in particular, a notable increase in the temperatures of fumarolic gases was observed; up to 690° C. Heating was associated with changes in gas composition, suggesting an increased magmatic contribution. With time, all the anomalous signals returned to their background values and the unrest ended without a renewal of eruptive activity. More recently, since September 2021, the INGV monitoring systems have highlighted changes of geophysical and geochemical signals, including shallow seismicity, ground deformation of the crater area, changes in gas composition, temperature and discharge rate (Figure 6). Some inhabited areas have been affected by anomalous gas discharge through the soil, and the evidence of dangerous concentration of volcanic gases in air prompted a temporary ban to overnight in those areas. Based on the changes described above, the Department of Civil Protection has ordered the transition of the alert level from Green to Yellow for the island. Very recently, the framework related to the alert levels that describe the volcanic state of activity by a combination of monitoring parameters and data collected to any ongoing events, has been re-defined through a close collaboration among INGV, Civil Protection and some Universities. In the new scheme, the yellow level corresponds to unrest of the hydrothermal system that feeds the fumaroles.

Different hazard scenarios are possible on Vulcano, which is characterized by a long-standing history of eruptive activities and a geothermal system that has been active since historical times. Some hazardous phenomena from La Fossa cone are also possible due to the slopes instability, strongly influenced by either the volcanic dynamics or hydrothermal activity, as seen in many other tuff cones. The potential renewal of volcanic activity from La Fossa (or caldera rims) carries a high risk especially for the more inhabited northern sectors of the island, which are crowded by thousands of tourists during the summer and located just at the foot of La Fossa cone.

Figure 6. La Fossa crater on the Vulcano island and, in the background, the islands of Lipari, Panarea and Stromboli in November 2021.
Source: Photograph by Gianfilippo De Astis.

The active volcanoes in the Neapolitan area: Somma-Vesuvius, Phlegraean Fields and Ischia island

The densely populated metropolitan area of Naples is located between two highly explosive active volcanoes, the Phlegraean Fields volcanic district (including the Phlegraean Fields caldera and the volcanic islands of Ischia and Procida-Vivara) to the west and the iconic Somma-Vesuvius stratovolcano to the east. The area is inhabited by more than 3 million people and is one of the places at highest risk of volcanic disaster in Europe (Figure 7).

Figure 7. The Somma Vesuvius volcano in the background and the tuff cone of Capo Miseno, in the Phlegraean Fields caldera, in the foreground.
Source: Photograph by Fabio Sansivero.

The two volcanic complexes show remarkable differences in their morphologies as well as eruptive dynamics.

Figure 8. Inside the Vesuvius crater.
Source: Photograph by Giuliana Alessio.

The Somma-Vesuvius volcano is worldwide well known for the catastrophic eruption of 79 AD that destroyed the Roman cities of Pompeii, Herculaneum and Stabiae (Figure 8). Its eruptive history is characterized by the shift from a quiescent (closed-conduit) state, generally interrupted by large-explosive eruptions of either Plinian or Sub-Plinian type, to open-conduit periods producing mixed effusive/low-explosivity events. According to a classification based on the volcanic explosivity index (VEI, Figure 3), these eruptions range from a VEI of 4-5 for large explosive events, to a VEI of 0-3 for open conduit periods. The latest of these periods lasted around 300 years and ended with the last eruption of the volcano, in March 1944 (Figure 9). Since that time, the volcano has entered a new state of closed-conduit repose, with very modest fumarolic activity, low magnitude seismicity, and rare earthquakes swarms. The volcano is at its base level of alert ("green") due to the absence of significant variations in monitored parameters. Today the area immediately surrounding the volcano hosts about 500,000 residents.

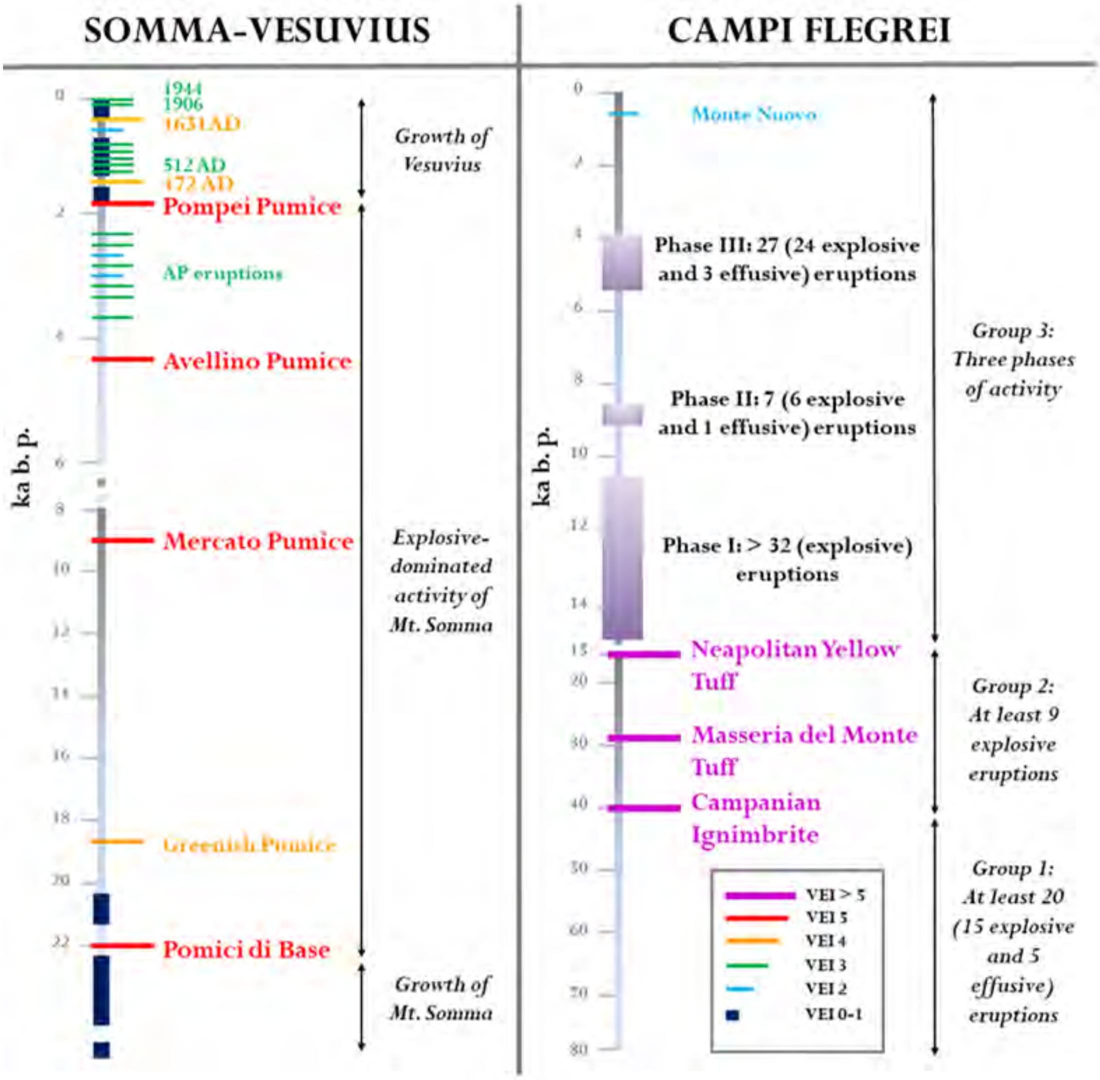

Figure 9. Schematic chronograms of volcanic activity of Somma-Vesuvius and Phlegraean Fields as recorded by stratigraphic successions. At Somma-Vesuvius in the last 22,000 years, four plinian caldera-forming eruptions and at least three major sub-Plinian eruptions occurred. The last cycle of open conduit activity started after 1631 and lasted until 1944. At Phlegraean Fields, volcanic activity started more than 80,000 years ago and includes the large caldera-forming Campanian Ignimbrite eruption and the second major caldera-collapse eruption of the Neapolitan Yellow Tuff. The only eruption in historical times occurred in 1538 AD. For Phlegraean Fields VEIs of the last 14,000 years eruptions are not indicated.

The Phlegraean Fields caldera (Phlegraean Fields, literally 'burning fields'), provides a classic example of how unrest can have a large impact on local communities. Volcanic unrest phenomena (ground uplift and seismicity) occurred during 1982-1984 years caused significant building damage and led to the evacuation of residents from the central part of Pozzuoli town. The Phlegraean Fields caldera (Figure 10) is considered among the most dangerous volcanoes in Europe, as it has been the source of the largest eruption in the whole Mediterranean area: the Campanian Ignimbrite eruption, dated about 40,000 years ago. According to recent studies, this eruption, which emitted a huge amount of ash and volcanic gas into the atmosphere, caused a lowering of the Earth's temperature by several degrees for many years, a real volcanic winter, which contributed to the disappearance of the Neanderthals. A second large eruption dates back 15,000 years ago, with the emplacement of the Neapolitan Yellow Tuff, on which much of the city of Napoli was built (Figure 9).

Figure 10. The figure shows part of the Phlegraean Fields caldera at whose centre is the city of Pozzuoli, in the foreground. Some of the monogenetic volcanoes formed during the last ten thousand years of volcanic activity are visible. The image shows the high urbanization of the caldera. In particular, in its centre, the crater of the Astroni (formed about 3,800 years ago), today a natural park and the Piana di Agnano from which the Plinian eruption of Agnano Montespina occurred (about 4,100 years ago); below on the left the bigger crater of Gauro (formed about 10,000 years ago).
Source: DTM by Laboratory of Geomatics and Cartography, INGV Osservatorio Vesuviano.

Today, the active volcanic area includes a 12-kilometre-wide caldera depression centred in the city of Pozzuoli. In the last 15,000 years, it was the site of a monogenetic (that is, a volcano built up by a single eruption) volcanic activity producing about 70 eruptions (with variable VEI, spanning from 0 to 5), concentrated mainly in discrete epochs separated by long periods of quiescence. The last of these eruptions occurred in 1538 AD, after more than 3,000 years of rest, and in one week led to the birth of a new volcanic cone, the Monte Nuovo, about 130 m high. Since then, many towns have developed inside the caldera, which is currently inhabited by more than 350,000 people.

After a long period of subsidence following the last eruption, in the last decades the caldera showed signs of potential reactivation characterized by episodes of ground uplift, shallow seismicity, significant increase in hydrothermal degassing, and changes in fluid geochemistry (Figure 11). In the Phlegraean Fields caldera the characteristic phenomenon of the slow lifting or lowering of the ground is called bradyseism (Figure 12).

Figure 11. Sampling of fumaroles at Pisciarelli, in the Phlegraean Fields Caldera.
Source: Photograph by Emanuela Bagnato.

The main bradyseismic crises occurred in 1970-72 and 1982-84 and were accompanied by several thousands of earthquakes and 3.5 m of total ground uplift, forcing the inhabitants of Pozzuoli city centre to evacuate. An ongoing unrest phase, resulting until now in a ground uplift of 85 cm in the central sector of the caldera and few thousands of earthquakes, has prompted the Italian Civil Protection Department to shift the Phlegraean Fields volcano alert level from base ("green") to warning ("yellow") at the end of 2012.

Figure 12. The Temple of Serapis, a Roman market located not far from the Pozzuoli coast line. The ruins of this Macellum (which dates back to the end of the 1st century AD) have been fundamental for the reconstruction of the ground movements (bradyseism, from the greek bradius = slow and seismos = movement), due to the presence on the three standing marble columns of lythodome's holes (marine molluscs that live in a coastal environment at the limit between high and low tide) that testify the maximum subsidence of the area.
Source: Photograph by Fabio Sansivero.

The island of Ischia, in the Phlegraean Fields district, is the emerging part of an extensive volcanic system, which rises over 1,000 m from the sea level. At Ischia, volcanism began before 150,000 years ago and has continued intermittently, with quiescent periods lasting centuries to millennia, until the last Arso eruption in AD 1302. The volcano is at base level of alert and is currently characterized by fumarolic and hydrothermal activity, on which a thriving economy is based. A moderate seismicity is also linked to its volcanic nature, which can cause heavy damage since the hypocentres are very shallow. A recent example is the 3.9 magnitude volcano-tectonic earthquake that occurred on August 21th, 2017 at Casamicciola Terme town. The most destructive earthquake of the last centuries occurred in 1883 and completely destroyed the same town, killing 2,313 people. The island is densely populated, with more than 60,000 inhabitants distributed in less than 50 km^2. During tourist seasons this population increases substantially.

Due to the high volcanic hazard and the densely populated urban context, the Neapolitan volcanoes have been the terrain to develop complex risk mitigation strategies aimed at emergency planning. Important information to forecast the future behaviour of the volcanoes derives by an accurate and in-depth analysis of the magmatic and eruptive history, as well as numerical simulations of expected eruptive phenomena. On this basis, the volcano science community has defined the possible pre-eruptive and eruptive scenarios of future eruptions and the areas that will eventually be affected by the effects of volcanic activity. In addition, the monogenic nature of the past Phlegraean Fields eruptive activity implies the uncertainty in the precise location of the future eruptive vent, a new volcano could grow at any place inside the 12 km wide caldera. This knowledge represents the basis for identifying the perimeter of areas potentially subject to dangerous phenomena, adopted in emergency planning by the National Department of Civil Protection in Italy.

The National Plans of Civil Protection for Somma-Vesuvius and Phlegraean Fields include as reference scenario for both the volcanoes, which is an explosive eruption of medium size. This scenario is characterized by three main stages corresponding to different hazard and risk areas: a first phase of "fallout", with the development of a very high (tens of km) and sustained eruptive column associated with the fall of pyroclastic fragments in the downwind sectors (the so-called yellow zone), a second phase of eruptive column collapse with generation of pyroclastic flows (affecting the so-called red zone) and a third phase with abundant precipitation and generation of mud flows.

The impact associated with the first phase consists mainly in the collapse of the roofs in the urbanized area around the volcanoes. At this latitude, stratospheric winds mostly blow eastward. This considerably reduces the hazard of ash fallout for the 1 million inhabitants' city of Naples in case of an explosive eruption of Somma-Vesuvius, located in the eastern sector of the city. However, Naples is highly exposed to ash fallout produced by an eruption from Phlegraean Fields, located in the western sector.

Nevertheless, the maximum risk derives from the passage of pyroclastic flows (second phase). These are clouds of ash and volcanic gas that flow at high speed an d temperature along the volcano flanks and can reach considerable distances in a few minutes, destroying everything along their path. In the areas closest to the vent, due to their high density and speeds (100 km/h), pyroclastic flows are able to knock down even modern reinforced concrete buildings. At greater distances the pyroclastic flows slow down and lose part of their ash load, so the impact force is reduced while the temperature remains always above the survival limits. Recent studies show, in fact, that during the Plinian eruption in 79 AD the unfortunate inhabitants of the towns of Herculaneum and Oplontis (located 5-6 km from Vesuvius), as well as those of Pompeii (10 km from Vesuvius), died of thermal shock due to the high temperature (300-600 °C) of the pyroclastic flows.

In case of medium-high intensity explosive eruptions, the pyroclastic flows coming from Phlegraean Fields and from Somma-Vesuvius can reach the city area of Naples, such as demonstrated both by the volcanic successions present in the metropolitan area, and by the results of numerical calculations that simulate the passage of pyroclastic flows on the current volcanic morphologies. Due to the high impact of pyroclastic flows, the only countermeasure for safeguarding the population remains the complete evacuation of the risk zone at the very onset of the volcanic crisis and before the eruptive phase occurs.

Despite the high volcanic hazard of the Neapolitan area, the resident population does not perceive the volcanic risk as relevant. In the last decades in-depth studies of volcanic risk perceptions have been carried out for inhabitants of the Neapolitan area. The results for the Vesuvius population demonstrates that people are aware of the threat of a future eruption and worried about it, but they feel more concerned by the problems they daily face, such as unemployment and crime. Moreover, 80 % of the sampled population believe that Vesuvius will not erupt within the next 10 years. The study also highlights that knowledge of the Vesuvius Emergency Plan is not widespread. Consequently, trust in public officials and in the success of the plan is low, as well as self-confidence to deal with such an emergency. On the other hand, a positive note is the great confidence in scientists. More recently, another survey has shown that Vesuvius Red Zone inhabitants are more aware about volcanic threat than Vesuvius Yellow Zone ones. This different perception was to be expected, given that they have been most affected by the Vesuvius eruptive activity in recent times.

For Phlegraean Fields caldera inhabitants, as for those of Vesuvius, volcanic hazard is not spontaneously mentioned as a major problem facing the community and is more associated with Vesuvius volcano than with the Phlegraean Fields caldera. However, when asked about the specific issue, citizens expressed serious concern about the volcanic threat and its effects on their community. Only 17 % of the population sample is aware of the existence of the Phlegraean Fields Emergency Plan, and 65 % said that they have not received enough information about the possible effects of an eruption. Nonetheless, citizens feel sufficiently confident in being able to face an eruption but have low confidence in local authorities and civil protection.

Finally, probably because an emergency plan has not yet been implemented, the volcanic hazard perception of a small sample of inhabitants of the island of Ischia is very low, so low that some of them believe they are included in the risk maps for Vesuvius.

All these issues pose a challenge to emergency management in the whole Neapolitan area and highlight the need of an accurate educational and raising awareness campaign about volcanic hazard and emergency plan, which builds knowledge, motivation and coping abilities. Moreover, for both Somma-Vesuvius and Phlegraean Fields areas, citizens ask for their involvement in emergency planning and in particular in preparedness measures. It follows that a participatory process should be established in the construction and update of future emergency plans.

Volcanic hazards and risk management in Iceland

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Introduction

Volcanic activity is common in Iceland and eruptions, usually lasting days to weeks, happen on average once every three years. Even though some eruptions cause substantial damage, most eruptions do not. This is mainly because Iceland is very sparsely populated with on average only 3-4 people per square kilometer and most live in SW-Iceland, just outside the boundary of the volcanically active zone. However, the threat from volcanic eruptions is ever present in Iceland where authorities and monitoring institutions need to be on constant alert. This level of alertness, and the fact that locals in general are well-aware of the potential dangers posed by volcanoes, is the key to successful co-existence of people and volcanoes in Iceland. In this article the background and the main characteristics of volcanism in Iceland are explained. Recent examples of volcanic crises are presented, the monitoring outlined, damage and losses discussed and some lessons from the volcanic activity in the last several decades are given.

Iceland is very sparsely populated with about 380,000 people living in a country of just over 100 thousand km^2. One consequence of this is that despite frequent volcanic eruptions, fatalities are not common. Only two deaths can be traced directly to volcanic activity (scientist hit by a falling lava block in 1947 and gas poisoning in 1973) in the last 100 years.

Geological setting

The geological setting of Iceland is highly unusual (Einarsson, 2008). It is located on a mid-oceanic ridge where two of the large tectonic plates that make up the earth's surface drift apart from one another with an average rate of opening of 2 cm per year (Figure 1). The western part belongs to the North American Plate while the eastern part belongs to the Eurasian Plate, the plate that includes Europe and the largest part of Asia. In addition, a mantle plume beneath Iceland rises from deep within the Earth's mantle. This combination of a tectonic plate boundary and a mantle plume is the reason for the existence of Iceland. It also explains why volcanic activity in Iceland produces about four times as much magma as does a comparable section of the Mid-Atlantic Ridge outside Iceland.

The oldest rocks in Iceland are 16-18 million years old (Figure 1), found in the northwest and eastern parts on the island. The plate boundary is manifested as a 40-80 km wide volcanic zone that cuts across Iceland from the southwest to the northeast. Volcanic activity is confined to these zones. In South Iceland the plate spreading is distributed on two near-parallel zones. In the southwest is the Western Volcanic Zone, merging with the Mid-Atlantic Ridge offshore. From the center of Iceland lies the Eastern Volcanic Zone, extending beyond the coast in South Iceland. The plate boundary in North Iceland is represented by the Northern Volcanic Zone.

Within the volcanic zones volcanic features are arranged into volcanic systems (Figure 1). Each system is elongated along the volcanic zone and is 30-190 km long and 10-30 km wide. Most volcanic systems have a central volcano in the middle and fissure swarms extending along the volcanic zones in both directions. The central volcanoes are typically 20-30 km in diameter, rise 500-1000 m above their surroundings with a caldera in the centre. Most volcanic eruptions occur within the central volcanoes, where the erupted magma ranges from basalts through intermediate compositions to rhyolites. Volcanic activity is less frequent on the fissure swarms and the erupted magma is all basaltic.

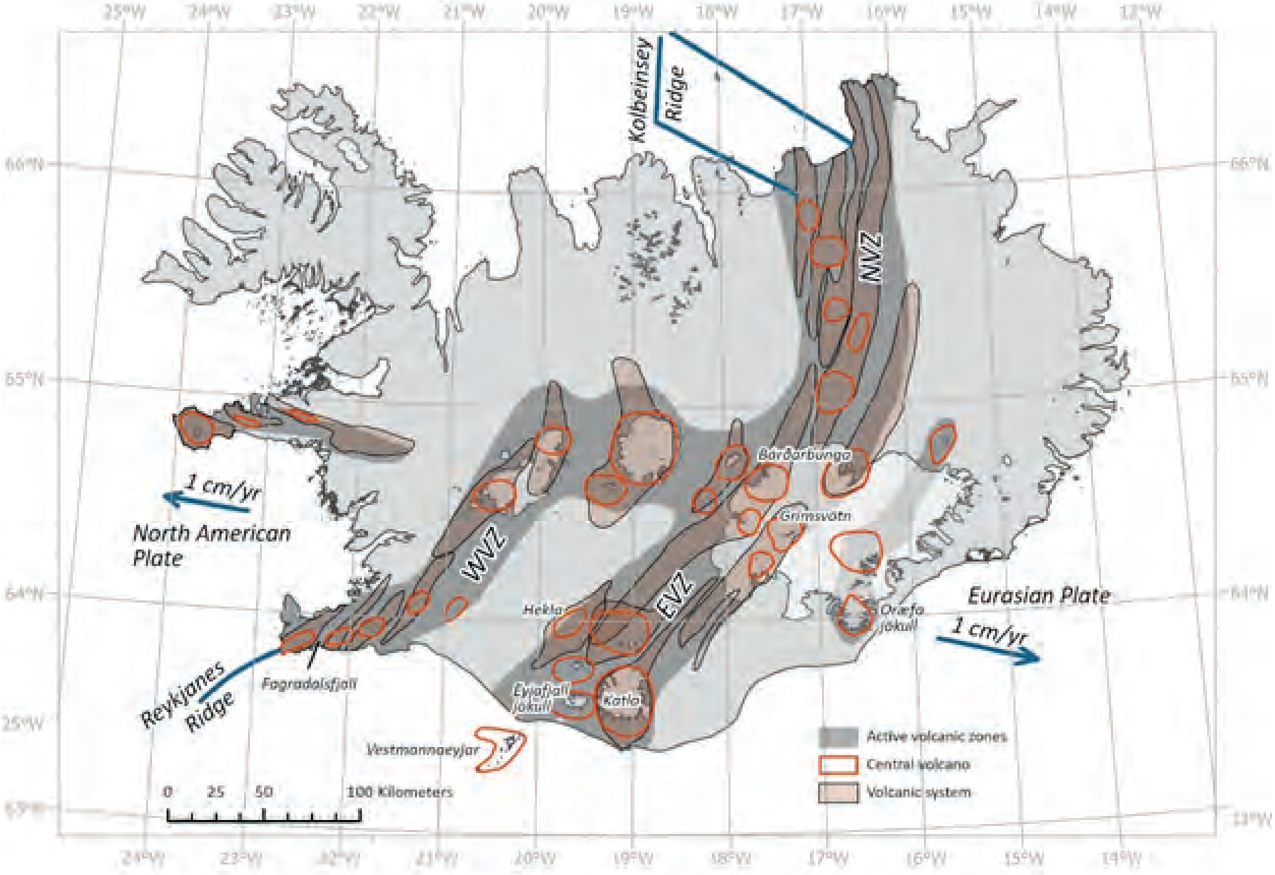

Figure 1. Plate boundaries, volcanic zones, volcanic systems and central volcanoes in Iceland.

Iceland is located at about 65°N and has a cool temperate maritime climate with relatively high precipitation. About 10 % of the island is covered with glaciers. This includes substantial parts of the volcanic zones. Consequently, about 50 % of all volcanic eruptions in Iceland take place within the glaciers or on high volcanoes with considerable ice cover (Larsen, 2002). This combination implies that volcano-ice interaction is very common, with volcanic eruptions or geothermal activity in glaciated areas, melting ice and causing volcanogenic floods.

The combination of volcanic activity associated with rifting along the plate boundary, the existence of large central volcanoes where magma can evolve in the crust, and the highly variable environmental conditions between ice-covered and ice-free areas, implies that volcanic activity in Iceland covers a very broad spectrum. Basaltic, mostly effusive fissure eruptions occur on the fissure swarms, but high groundwater levels and ice cover can result in highly explosive hydromagmatic activity in some parts of the country and offshore. Within the central volcanoes, activity can range from frequent, relatively small basaltic eruptions, to occasional large-volume explosive eruptions.

According to a recent estimate by Thordarson and Larsen (2007) 79 % of all magma is erupted as basalt, 16 % is of intermediate composition and 5% is silicic. Some eruptions are mixed, produce both lava and tephra and some produce only lava. About 80 % of eruptions in Iceland are mostly explosive. This contrasts sharply with e.g. Hawaii and most other places where basalts are dominant. This importance of basaltic explosive activity is mostly due to the widespread occurrence of magma-water interaction, within the glaciers, in parts of the rift zones where groundwater levels are very high and lakes are common. Moreover, occasionally eruptions occur in the shallow ocean off the coast of Iceland.

Magnitude and frequency of volcanic eruptions in Iceland

The most common type of activity are explosive or effusive eruptions within central volcanoes, with the four volcanic systems of Hekla, Katla, Grímsvötn and Bárðarbunga being the most active. The majority of eruptions are of moderate size, but they include some large explosive eruptions. Less common are large eruptions on the fissure swarms like the one that occurred in Holuhraun in central Iceland in 2014-2015 (Pedersen et al., 2017).

Apart from the largest events, estimates of erupted volume are uncertain for eruptions that occurred more than 100 years ago. Table 1 provides numbers on the 22 confirmed eruptions of the last 50 years; the average interval between eruptions in this period is 2.3 years. Out of these, less than 0.1 km^3 of magma was erupted in 10 eruptions, nine produced between 0.1 and 0.25 km^3, with the largest events producing respectively 0.45 km^3 and 1.4 km^3. It is possible that the number of the smallest events is not complete, as a few very minor events may have occurred beneath the glaciers in this period. A more general overview of recurrence times of events, based on the known eruption history in the last 1,100 years, is given in Table 2. Estimates of production rate indicate that on average 7-8 km^3 of magma is erupted every 100 years (Thordarson and Larsen, 2007). The largest eruptions have recurrence times of 250-1000 years. They are principally of two types: (1) Major flood basalt eruptions producing up to 20 km^3 of lava, and (2) very large explosive eruptions that may produce up to 10 km^3 of tephra.

Since the settlement of Iceland, over 1,100 years ago, only four lava flows are responsible for up to half of the total magma erupted in this period. This includes the large Laki lava. It was formed in 1783-1784, during a major rifting event in the Eastern Volcanic Zone, covering 600 km^2. This eruption caused great hardship at the time and the associated high volcanic gas concentrations and disturbance to weather patterns caused widespread disruption in many parts of the northern hemisphere (Thordarson and Self, 2003).

Volcano	Year	Deposits	Magma composition	Eruption type	Lava area (km^2)	Lava bulk volume km^3	Tephra volume (DRE) km^3	VEI	Insured loss - Present day value (million EUR)
Fagradalsfjall (1)	2021	lava	basalt	Effusive	4.85	0.15		1	
Holuhraun 2014-2015 (2)	2014	lava	basalt	Effusive	84	1.44		1	
Grímsvötn (3)	2011	tefra	basalt	Explosive	0		0.27	4	2.1
Fimmvörðuháls (4)	2010	lava	basalt	Effusive	1.3	0.02		1	
Eyjafjallajökull (5)	2010	tefra/lava	intermediate	Explosive	0,6	0.02	0.18	3	2.5
Grímsvötn (6)	2004	tefra	basalt	Explosive	0		0.05	3	
Hekla (7)	2000	lava/tefra	intermediate	Mixed	15	0.095		2	
Grímsvötn (8)	1998	tephra	basalt	Explosive	0		0.05	3	
Gjálp (9)	1996	tefra	intermediate	Sub-Glacial	0		0.45	2	9.6
Hekla (7)	1991	lava/tefra	intermediate	Mixed	25	0.24	0.01	3	
Krafla, September (10, 11)	1984	lava	basalt	Effusive	24	0.13		1	
Grímsvötn (8)	1983	tefra	basalt	Explosive	0		0.01	2	
Krafla, November (10, 11)	1981	lava	basalt	Effusive	17	0.05		1	
Krafla, January-February (10, 11)	1981	lava	basalt	Effusive	6.3	0.032		1	
Krafla, October (10, 11)	1980	lava	basalt	Effusive	11.5	0.035		1	
Krafla, Jully (10, 11)	1980	lava	basalt	Effusive	6	0.025		1	
Krafla, March (10, 11)	1980	lava	basalt	Effusive	~1	0.003		1	
Hekla 1980-1981 (7)	1980	lava	intermediate	Mixed	25	0.17	0.026	3	
Krafla, September (10, 11)	1977	lava	basalt	Effusive	<1	0.002		1	
Krafla, April (10, 11)	1977	lava	basalt	Effusive	~1			1	
Krafla, December (10, 11)	1975	lava	basalt	Effusive	<1	<0.001		1	
Vestmannaeyjar (12)	1973	lava/tefra	basalt	Mixed	3.2	0.23	0.02	2	260-330*

(1) Pedersen et al. 2021, (2) Pedersen et al. 2017, (3) Hreinsdóttir et al. 2013, (4) Edwards et al. 2012, (5) Gudmundsson et al. 2012, (6) Oddsson et al. 2012, (7) Pedersen et al. 2018, (8) Gudmundsson 2005, (9) Gudmundsson et al. 2004, (10) Einarsson 1991, (11) Sæmundsson 1991, (12) Einarsson, 1974.

* The Vestmannaeyjar eruption occurred prior to the establishment of NTI. The loss has been estimated based on the existing coverage, provide by NTI as today.

Table 1. Volcanic eruptions in Iceland 1973-2021.

All eruptions - volume erupted (lava and tephra)	
Volume (DRE) km^3	Years
<0.03	5-10
0.03 - 0.1	10
0.1- 0.3	10
0.3 - 1.0	20-40
1-3	~250
3-10	~500
>10	~1000

Explosive eruptions (Volcanic Explosivity Index)	
VEI	Years
1	5-10
2	10-20
3	10
4	30-50
5	100-200
6	~1000
7	no known eruptions

DRE: Dense rock equivalent = total material erupted compacted to the density of solid rock.
VEI: Volcanic Explosivity Index, based on plume height and bulk (total) volume of airborne material (tephra) erupted:
VEI 1 < 0.001 km^3 < VEI 2 < 0.01 km^3 < VEI 3 < 0.1 km^3 < VEI 4 < 1 km^3 < VEI 5 < 10 km^3 < VEI 6 < 10 km^3.
The bulk volume of tephra is often about ~three times the DRE volume, as tephra has high porosity.
(Table modified from Gudmundsson et al. 2008).

Table 2. Recurrence times of eruptions in Iceland.

Volcanic hazards in Iceland

Iceland is very sparsely populated with about 380,000 people living in a country of just over 100 thousand km2. One consequence of this is that despite frequent volcanic eruptions, fatalities are not common. Only two deaths can be traced directly to volcanic activity (scientist hit by a falling lava block in 1947 and gas poisoning in 1973) in the last 100 years. The principal hazards (Figure 2) are: (1) Tephra fallout, (2) lava flows, (3) jokulhlaups (flooding caused by volcanic or geothermal activity under glaciers), (4) gas pollution, (5) Pyroclastic density currents, and (6) lightning.

Tephra fallout

The majority of explosive eruptions in Iceland are basaltic and take place within the glaciers, most frequently in the Grímsvötn volcano (Larsen 2002, Thordarson and Larsen, 2007; Gudmundsson et al., 2008). Most of these eruptions are of modest size (<0.1 km3, Volcanic Explosivity Index = 3 – see Table 2), with magma-water interaction being an important driver of magma fragmentation resulting in eruption plumes and the spread of ash layers. Most of these eruptions have relatively little effect in inhabited areas due to the remote location of the source volcano. Substantial explosive eruptions, (VEI 4) occur approximately once every 30-50 years. Larger eruptions (VEI 5) occur once every 100-200 years.

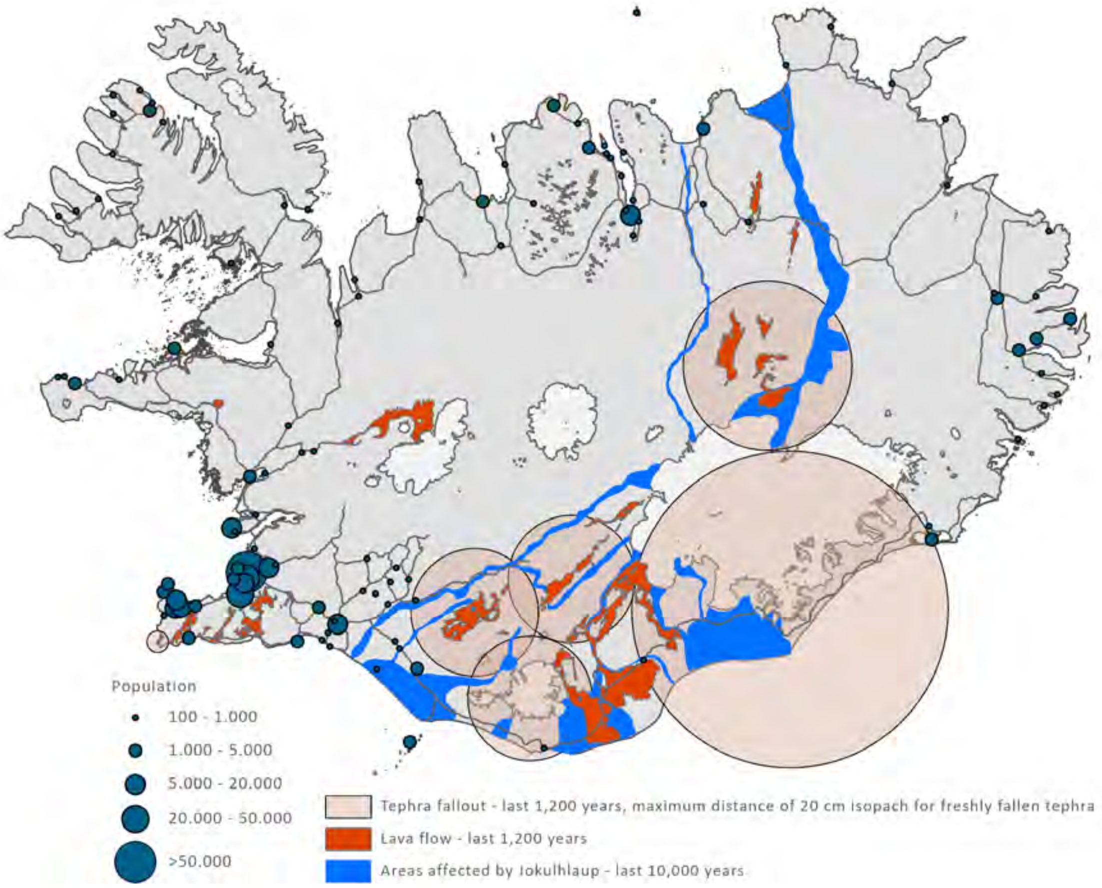

Figure 2. Population centres, main roads and areas that can be seriously affected by explosive eruptions and jokulhlaups according historical and geological records (after Gudmundsson et al., 2008).

Lava flows

Lava flows formed in the last 100 years cover more than 200 km^2 of land. However, most of this lava is formed in the highlands or in uninhabited regions and therefore do not cause damage. There are exceptions to this, notably the eruption on the island of Heimaey in Vestmannaeyjar. No casualties or injuries occurred, and the inhabitants were successfully evacuated from the island. However, during the five months of the eruption, about 400 buildings were destroyed and there was extensive damage to infrastructure and disruption to the local economy. The most recent eruption on the Reykjanes Peninsula in March-September 2021 occurred only 8 km from the nearest town. However, there was no damage to buildings or infrastructure.

Jokulhlaups

Jokulhlaups (floods) caused by release of meltwater from glaciers in Iceland are mainly of two types: (a) release of meltwater that accumulates beneath the glacier due to melting by geothermal activity, (b) large scale events caused by melting during eruptions. Type (a) is much more common, with such events occurring on average every 1-2 years. Damage is usually minor. However, frequent geothermally induced jokulhlaups can change vegetated land to wasteland susceptible to sandstorms as observed in one region in SE-Iceland. Type (b) is less common but may result in major flooding, as occurred in the catastrophic jokulhlaup during the eruption of the ice-covered Katla volcano in 1918 (peak discharge estimated as high as 300,000 m^3/s). Other examples include a major jokulhlaup in SE-Iceland caused by the Gjálp eruption in 1996 and several much smaller floods during the eruption of Eyjafjallajökull in 2010. These floods may destroy bridges, roads, and other infrastructure, but usually occur in uninhabited floodplains.

Gas pollution

During large effusive eruptions large amounts of volcanic gasses may be released into the atmosphere. This is principally Sulphur dioxide (SO_2) which in high concentrations is harmful to people. Gas pollution is therefore monitored, and warnings given depending on concentrations during eruptions (Barsotti et al., 2020). During the large eruption of Holuhraun in 2014-2015, high concentrations occurred occasionally in towns up to 100 km away from the eruption site, causing temporary halt to outdoor work.

Pyroclastic density currents

During large explosive eruptions, pyroclastic density currents (PDCs) are a major hazard in some volcanic regions around the world. They form when eruption plumes collapse and the hot volcanic tephra and gasses flow outwards away from the volcano, devastating everything in their path. PDCs occur in Iceland but most are small and do not reach much beyond the area close to the vents. However, in the very large but infrequent VEI 5-6 eruptions PDCs may reach inhabited areas. The latest eruption where PDCs reached inhabited farmland was in the eruption of Öræfajökull in 1362. However, with increased tourism the danger from PDCs to hikers on Hekla volcano is increasing, as precursors to eruptions on Hekla are very short (~1 hour or less).

Lightning

During explosive eruptions lightning may be a serious hazard to people. This especially applies where the magma interacts with water. Notable examples are eruptions in Katla volcano, which happen on average once every 50 years. Lightning may also damage power lines and other such infrastructure. Two people were killed by lightning during the eruption of Katla in 1755, but no other fatalities due to this hazard are known in Iceland.

Volcanic monitoring and response

Networks of seismometers and GPS stations monitor volcanic regions around Iceland. These are mainly operated by the Icelandic Meteorological Office (IMO), providing real-time data (seismic), and same-day updates on the status of deformation at selected volcanoes (the GPS-station network). A network of real-time gauging stations in glacial rivers monitor discharge and geothermal signals in the rivers. These networks are publicly accessible on the web-page of IMO (https://vedur.is). The IMO also has C- and X-band radars to track eruption plumes. Air quality and gas concentrations are monitored by the Environment Agency of Iceland. During unrest and volcanic activity, response is coordinated by the Civil Protection Department of the Icelandic Police Commissioner. During volcanic unrest and activity, expertise is sought widely and active collaboration on monitoring and assessment exists between the IMO and the Nordic Volcanological Center at the Institute of Earth Sciences, University of Iceland. An informal Science Advisory Board of the Civil Protection Department holds frequent meetings during unrest, over the last two years exclusively as online meetings.

Case stories – last 50 years

Vestmannaeyjar (1973)

On the 23rd of January 1973 a 1,600 m long volcanic fissure opened only 300 m from the nearest houses in the town of 5,000 inhabitants on this island off the south coast (Einarsson, 1974). A battle was fought between man and the lava in order to protect the harbour and the houses in town. Both cooling of the lava with seawater as well as diversion dikes and retention dams were used. The combination was a success even though a part of the town was lost.

Dams and dikes were made from the available material that was mainly of low density, including tephra from the eruption. The diversion dikes held to the end of the eruption but the retention dam (with lava flow perpendicular to the structure) broke on 18th of March at which time the lava front had risen up to twofold the height of the dam that was about 25 m high at its highest point (Jónsson, 2013).

The cooling of the lava started along the same line as the diversion dike at the lava edge using firehoses. As the lava started to threaten the entrance to the harbour, seawater was also pumped from ships onto the lava front especially the northwesternmost part of the lava nearest to the harbour. In order to cool not only the lava front but also its interior, a pipe was placed on top of the still moving lava allowing the water to reach some further 200 m inside the lava margin. Bulldozers and similar heavy machinery had to be used to place the pipe, but as this was slowly advancing a'a lava[1], it was possible to operate such machines on the cool uppermost rubble covering the hot interior. This risky operation seemed to slow down the progression of the lava. Based on the first successes using available pumps, 32 large pumps were acquired from the USA and a cooling of the lava field on a major scale started. During this latter cooling phase some 5,7 million tons of seawater was pumped onto about 0,45 km^2 of lava surface, i.e. the part of the lava closest to town and the entrance to the harbour (Jónsson & Matthíasson, 1974).

The highly fractured surface of the slow-moving a'a lava resulted in a relatively large cooling area and thus efficient cooling. Additionally, this type of lava is in many cases easier to control with dikes and dams as the high viscosity and yield stress allows the lava to raise high above obstructions without overtopping them.

Gjálp (1996)

This eruption took place under an initially 600-750 m thick ice and lasted 13 days in October 1996 (Gudmundsson et al, 2004). It broke through the ice cover after 31 hours of eruption. However, the resulting explosive eruption was relatively minor causing no damage, as the eruption site is more than 60 km away from the nearest inhabited area. The subglacial eruption on the other hand was large, producing 400-500 m high mountain beneath the ice. The eruption melted more than 3 cubic kilometers of ice and all this meltwater was stored for five weeks in the subglacial lake within the Grímsvötn caldera, 10 km to the south.

All this meltwater was then released in a major jokulhlaup that reached peak discharge of approximately 50,000 m^3/s. The jokulhlaup swept away one of the main bridges (Figure 3) and caused additional extensive damage to the main ring road, closing it for some weeks afterwards. No farms or towns were in danger as the flood plain has been uninhabited for hundreds of years.

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(1) 'A'ā (also spelled aa) is one of three basic types of flow lava. 'A'ā is basaltic lava characterized by a rough or rubbly surface composed of broken lava blocks called clinker.

Figure 3. The jokulhlaup resulting from the eruption in Gjálp in 1996. The bridge was destroyed by the large icebergs carried with the floodwater.
Source: Photo by Magnús T. Gudmundsson.

Eyjafjallajökull (2010)

The infamous explosive eruption of Eyjafjallajökull in 2010 began on the 14th of April, following a smaller effusive flank eruption at Fimmvörðuháls (Gudmundsson et al, 2012). The continuous eruption lasted 39 days, with minor occasional activity in the following two weeks.

The eruption (Figure 4) occurred during a period when the prevailing wind direction was towards Europe. Ash clouds were blown towards Europe resulting in this moderate-sized eruption becoming a global event, causing the cancellation of over 100,000 passenger flights in Europe and across the North Atlantic. Jokulhlaups occurred repeatedly in the first 2-3 days. However, existing flood barriers withstood the impact, and by cutting flow paths for

Figure 4. The Eyjafjallajökull eruption in May 2010.
Source: Photo by Magnús T. Gudmundsson.

the floodwaters through the main highway, damage to the bridge on the ring-road was avoided. Recently adapted response plans for volcanic eruptions in the area were applied, including three short-duration evacuations. Locally, ash fall caused minor losses to nearby farms.

Grímsvötn (2011)

On the 21st of May 2011 the largest explosive eruption in Iceland for several decades began in Grímsvötn, the ice-covered volcano in the western central part of the Vatnajökull ice cap. An area to the south of the volcano was heavily influenced by temporary ash cover. Most of the economic losses were suffered by farmers and were uninsured. Insured losses at farms were for the most part only minor, such as damage to metal cladding, windowpanes, external walls and floor finishing. Despite being much larger, the overall impact of Grímsvötn 2011 was much less than that of the Eyjafjallajökull eruption a year earlier. The main reasons for this were firstly more favourable wind patterns, resulting in only minor distribution of tephra towards Europe, and secondly, the duration of the explosive eruption in Grímsvötn was only a few days, short compared to the 39 days of Eyjafjallajökull.

Bárðarbunga-Holuhraun (2014 - 2015)

The largest eruption in Iceland since the large Laki eruption in 1783-84 took place in the central highlands over six months between September 2014 and February 2015. The volume of lava erupted was 1.4 km^3, covering 84 km^2 (Pedersen et al., 2017). This eruption was a consequence of a major rifting event when a 40 km long segment of the volcanic zone rifted apart by 2 m. The magma came from underneath the central volcano Bárðarbunga where the caldera subsided by 65 meters. Such caldera collapses are not common but may happen once every 100-200 years in Iceland. The last major rifting episode prior to Holuhraun occurred in 1975-1984, the Krafla fires in North Iceland, with major rifting, dike intrusions and repeated eruptions. However, the eruptions at Krafla were an order of magnitude smaller than the eruption at Holuhraun.

Due to the remote location of the Holuhraun in the highlands at the northern margin of Vatnajökull ice cap, no damage to houses or infrastructure occurred. The danger of the eruptive fissure extending towards south and beneath the glacier was taken seriously, and large parts of the highlands were closed for travel due to the possibility of major flooding. Sulphur dioxide emission was very high, making a large area around the eruption dangerous. The remote location and the timing of the eruption in autumn/winter with higher winds than in summer contributed to making the effects of this eruption smaller than it could have been. Nevertheless, high gas concentrations caused disruption at times. On a few occasions people in towns more than 100 km away from the eruption site were instructed to stay indoors.

Fagradalsfjall (2021)

On the evening of 19th of March 2021, a volcanic eruption started in a small valley in the Fagradalsfjall Mountain on the Reykjanes Peninsula in SW-Iceland, only 8 km from the nearest town, close to various important infrastructure and with more than 75 % of the total population of Iceland living less than 40 km away from the site.

The eruption was preceded by an intense earthquake swarm (thousands of earthquakes, the largest of magnitude 5.7) starting 23 days before the onset of the eruption accompanying intense ground deformation as a 9 km long dyke intrusion formed in the crust.

By all standards it was of low intensity producing only lava (Figure 5). The most recent surface measurements of the lava, from the 30th of September 2021, show that the lava has covered about 4,85 km^2 of land and the volume of the lava is about 0,15 km^3 (Pedersen et al. 2021; Institute of Earth Sciences, University of Iceland, 2021). Currently (1st of December 2021), no activity has been detected since the 18th of September.

Figure 5. The lava flow in Fagradalsfjall on the 15th of September 2021, view towards north. The town of Reykjavík can be seen in the distance. On the left is the diversion dike built to prevent the lava flowing westwards.
Source: Photo by Björn Oddsson.

Extensive work took place in the days preceding the eruption on possible measures to minimize damage to infrastructure and populated areas in the event of an effusive eruption as an explosive eruption was considered improbable in this area. This work included mapping of infrastructure and available machinery for possible protection work through e.g. the possible construction of protection dams and diversion dykes; this work was aided by the use of computer modelling of possible direction and extent of lava flows. As things turned out, the eruption occurred at favorable location. Considerable volumes would need to erupt and fill valleys in the vicinity of the eruption site before the lava would advance sufficiently to cause damage.

Computer modeling of lava flow evolution to help predict the evolution of the lava field was done from the start, with simulations adjusted to observed effusion rates (Figure 6). Lava viscosity and yield strength had to be adjusted from time to time as the eruption evolved. For example, around 19th of May the flow shifted from being dominantly a'a to pahoehoe[2] resulting in changes to modeling parameters. As different software have different strengths and weaknesses, using more than one lava modeling software proved to be beneficial.

Five protection works were constructed: Three retention dams and two diversion dikes. Additionally, three Work Site Protection Barriers (WSPB) were made to protect the site where the actual dam or dike was being built.

The first two WSPB (1.5 to 2 m high) delayed the advance of the a'a lava, allowing the lava front to rise some 2 to 4 m above the barriers. After the lava changed to pahoehoe (Figure 7), the more fluid lava advanced as soon as it overtopped the barriers.

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(2) Pāhoehoe (from Hawaiian [pa:'howe'howe], meaning "smooth, unbroken lava"), also spelled pahoehoe, is basaltic lava that has a smooth, billowy, undulating, or ropy surface.

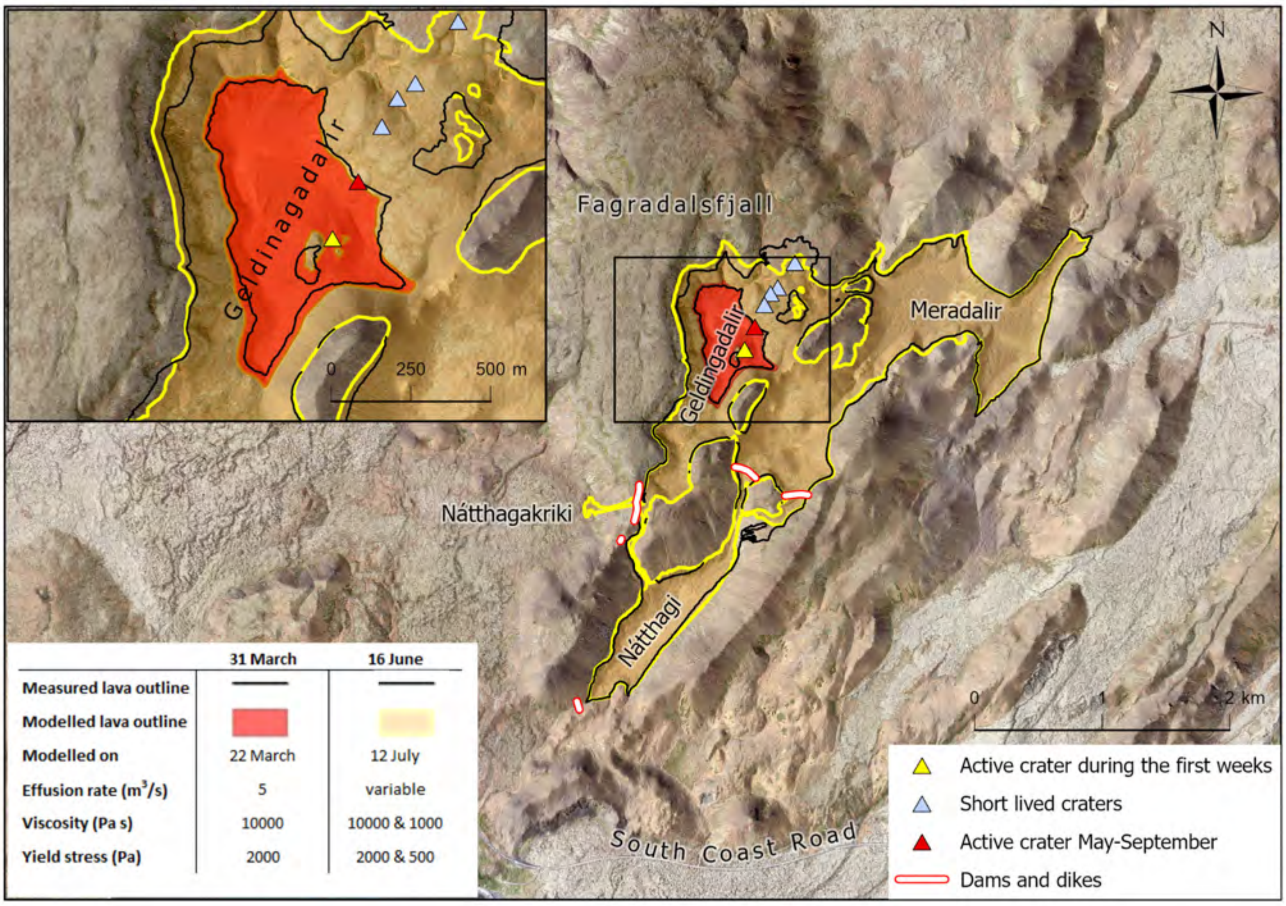

Figure 6. Comparison of measured and simulated lava extent for the eruption in Fagradalsfjall in 2021. Simulated lava extent from Verkís Consulting Engineers, simulated in HEC-RAS. The measured lava outline is based on data from Icelandic Institute of Natural History, Institute of Earth Sciences, University of Iceland, and National Land Survey of Iceland.

The diversion dikes are located along a ridge aimed at preventing the lava to flow towards west. The dikes did prevent such overspill on three occasions but by that time the lava was so high that they might not have withstood a fourth one.

The experience of these efforts shows that the progression of lava can be influenced by dams and diversion dikes. The dams delay the advance and are much more effective against the more viscous a'a flows while diversion dikes can have an important effect on the direction of propagation, e.g. where lava flows down from a topographic high.

Insurance against volcanic risk

Following the volcanic eruption in Vestmannaeyjar, the Icelandic government established the National Relief fund to compensate building owners for their loss. Three years later the fund was replaced by the Natural Catastrophe Insurance of Iceland (NTI), which was founded as a public undertaking by a special Act of the Alþingi (parliament) of Iceland. NTI functions as an insurance company collecting premiums for insurance cover. The purchase of catastrophe insurance for earthquake, volcanic eruption, snow avalanches, landslides and floods is compulsory for all buildings; as well as for contents that have been insured against fire. Buildings are insured according to their valuation for fire as assessed by the Property Registry Office and contents are insured according to their owners' self-assessment. Since fire insurance of buildings is compulsory in Iceland, all buildings are likewise insured against natural perils covered by the programme. The catastrophe cover is a stand-alone policy; the fire insurance companies collect the premiums alongside fire premiums in exchange for a collection fee. There is a single premium of 0.25 ‰.

Figure 7. Emergency heightening of the eastern dam, one day before overtopping.
Source: Photo by Ari Guðmundsson.

Infrastructure i.e. waterworks, geothermal heating systems, sewage systems, electric installations, bridges, harbour installations, and ski-lifts, which are not normally insured against fire, are separately insured (premium 0.2 ‰) with the institution.

The policy only insures against direct losses resulting from the above-mentioned catastrophes. There is a deductible of 2 % for each loss as well as a minimum deductible.

A special resource fund (Bjargráðasjóður) was initially founded in the early 20th century. The fund is an independent institution, owned equally by the Icelandic government and the Farmers Association of Iceland. The fund obtains its resources from the government budget. One of the main functions of the fund is to financially support farmers who have suffered losses related to natural catastrophes (including volcanic eruptions). The scheme includes properties, fences, grass-fields, and powerlines, related to the agricultural industry. The fund does not support losses which are insurable, e.g., by the NTI.

Even though there is a compulsory insurance against volcanic eruption provided by the NTI, and a special resource fund in place, protection is not complete. As an example, business interruption is not covered by the private insurance companies nor the NTI. The comprehensive car insurance policy, provided by the private insurance companies likewise does not include volcanic eruptions.

Concluding remarks

Volcanic activity in Iceland is both frequent and sometimes causes high magnitude events. Sizeable parts of the country are affected in some events, notably by fallout of ash in explosive eruptions. The co-existence of glaciers and volcanoes creates flooding hazards when ice is melted by geothermal activity or during eruptions. Population density is very low and the highlands, where most of the activity takes place, is unpopulated. As a result, most small to moderate-sized events cause little or no damage. However, there are occasions where eruptions take place near or almost within populated areas as the example from Vestmannaeyjar in 1973 vividly shows.

One of the main lessons from the last 50 years is that preparedness is all important. Response plans need to be ready beforehand, to be used in the event of a volcanic eruption. The basis of response plans has to be sound scientific knowledge of the hazards. This includes detailed studies of the characteristics of previous eruptions, recurrence times, types and magnitudes of events expected for each volcano.

The following points summarize some of the elements that form the basis for preparedness and response in Iceland:

1. Rigorous basic and applied research of the volcanoes and their products provides the vital information on which any response is based.
2. Response plans, including any mitigating measures possible to reduce the impacts of events that for Iceland can range from lava flows to floods of glacial meltwater.
3. Active dialogue with local inhabitants, informing them of scientific results and ensuring their involvement in response plans.
4. Effective and effortless collaboration between researchers, engineers and both local and national civil protection authorities is all important when it comes to minimizing material and economic losses.
5. A sound insurance system for natural disasters enhances resilience in society to such events.

Acknowledgements

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Volcanic eruption risk management in Japan

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Volcanic activities in the Japanese archipelago

With 111 active volcanoes, Japan ranks 4th in number, after the United States, Russia and Indonesia. Although Japan's share of global land area is 0.25 %, it houses 7 % of active volcanoes.

The Japanese archipelago is situated where four tectonic plates meet, which describes why earthquakes and volcanic eruptions occur so frequently. Active volcanoes are aligned with the plate boundaries, and many of which are found in parallel to the trench formed by the Pacific Ocean Plate sinking underneath the Japanese archipelago. Similar alignment is visible along the Nankai Trough formed by the Philippine Ocean Plate. There are three types of eruptions, namely magmatic, phreatomagmatic and phreatic eruptions observed. In terms of volcanic products, they are classified in seven types; volcanic ash & lapilli, ash deposits, volcanic gas, debris & mud flow, lava flow, pyroclastic flow, and sector collapse & debris avalanche.

Japan Meteorological Agency (JMA) defines five Volcanic Alert Levels based on the target area and actions to be taken which are described using actionable keywords.

At Alert Level 5, there is a risk of massive eruption that calls for an evacuation. Currently, there is no volcano with Alert Level 4 or 5. There are three classified as Level 3 and five classified as Level 2.

Volcanic warning system in Japan

Out of the 111 active volcanoes, 47 are subject to constant surveillance and observation.

Japan Meteorological Agency (JMA) defines five Volcanic Alert Levels based on the target area and actions to be taken which are described using actionable keywords.

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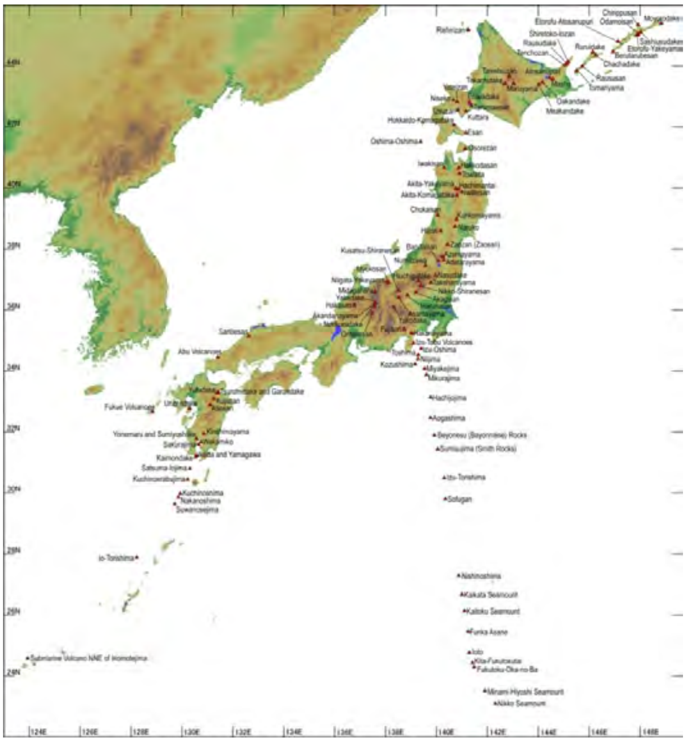
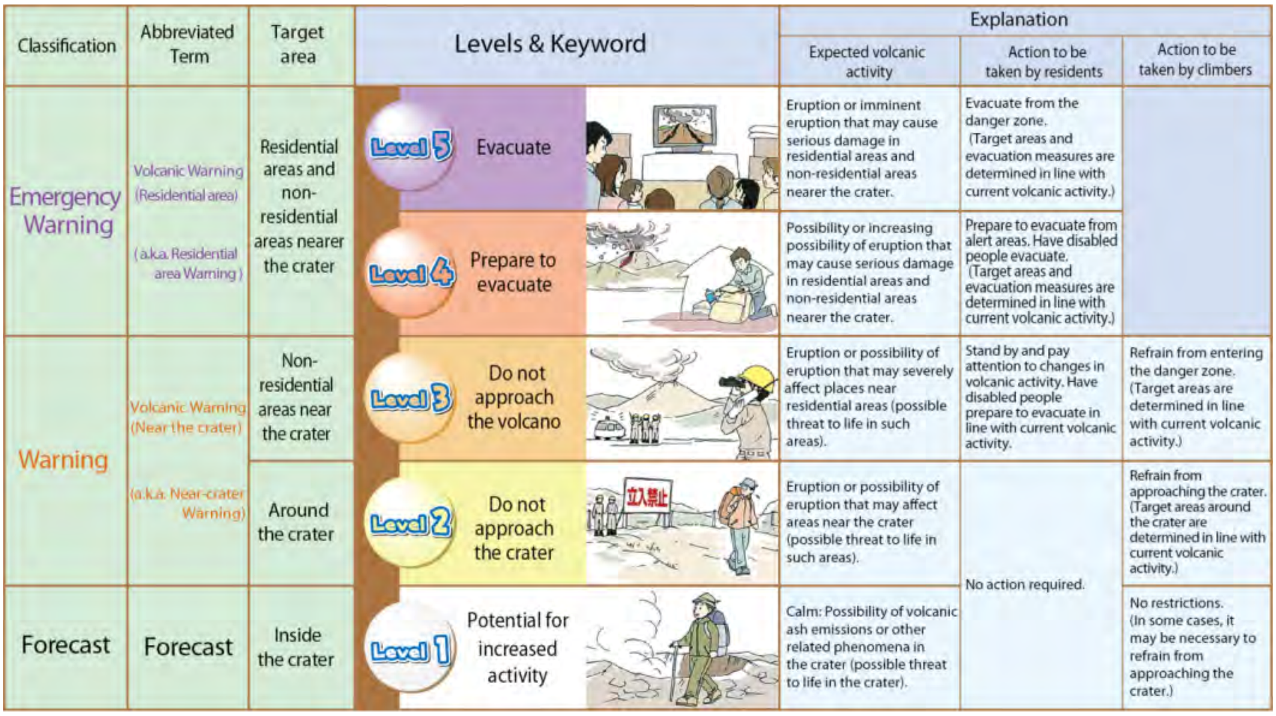


Figure 1. Active volcanoes in Japan.
Source: Japan Meteorological Agency (JMA).



Classification	Abbreviated Term	Target area	Levels & Keyword		Explanation		
					Expected volcanic activity	Action to be taken by residents	Action to be taken by climbers
Emergency Warning	Volcanic Warning (Residential area) (a.k.a. Residential area Warning)	Residential areas and non-residential areas nearer the crater	Level 5	Evacuate	Eruption or imminent eruption that may cause serious damage in residential areas and non-residential areas nearer the crater.	Evacuate from the danger zone. (Target areas and evacuation measures are determined in line with current volcanic activity.)	
			Level 4	Prepare to evacuate	Possibility or increasing possibility of eruption that may cause serious damage in residential areas and non-residential areas nearer the crater.	Prepare to evacuate from alert areas. Have disabled people evacuate. (Target areas and evacuation measures are determined in line with current volcanic activity.)	
Warning	Volcanic Warning (Near the crater) (a.k.a. Near-crater Warning)	Non-residential areas near the crater	Level 3	Do not approach the volcano	Eruption or possibility of eruption that may severely affect places near residential areas (possible threat to life in such areas).	Stand by and pay attention to changes in volcanic activity. Have disabled people prepare to evacuate in line with current volcanic activity.	Refrain from entering the danger zone. (Target areas are determined in line with current volcanic activity.)
		Around the crater	Level 2	Do not approach the crater	Eruption or possibility of eruption that may affect areas near the crater (possible threat to life in such areas).	No action required.	Refrain from approaching the crater. (Target areas around the crater are determined in line with current volcanic activity.)
Forecast	Forecast	Inside the crater	Level 1	Potential for increased activity	Calm: Possibility of volcanic ash emissions or other related phenomena in the crater (possible threat to life in the crater).		No restrictions. (In some cases, it may be necessary to refrain from approaching the crater.)

Figure 2. Volcanic Alert levels.
Source: JMA.

Major historical volcanic eruptions and lessons learned

The following three eruptions are notable cases which prompted policy discussions.

Unzendake

Figure 3. Unzendake.
Source: JMA.

Unzendake, located in the Nagasaki prefecture in Kyushu Island, has been active for 500 thousand years. In modern days, the vapor eruptions occurred between 1990 and 1991 are remembered. Most notably, the eruption on 3 June, 1991 accompanied large amount of pyroclastic flow which traveled in excess of 100 km/h, leading to 43 fatalities. Volcanic ash-turned debris flow that followed caused serious damage to the nearby township. At one point, the debris flow flooded 579 households. Volcanic ash reached not only the city of Shimabara but also Nagasaki.

Prior to the event, the destructive nature of the pyroclastic flow was little known. As it turned out, pyroclastic flow extended to an area broader than ash deposits. The situation forced local residents to evacuate, and its peak, the number of evacuees reached 11,000. It was only in 1995 that eruption ceased, by when 9,400 pyroclastic flows were observed. It prolonged the days needed for evacuation.

The number of fatalities is often cited to emphasize the tragic nature of the event. However, it should be noted that the director of the observatory appropriately released warning to the local residents one week prior to the event which saved the lives of 200 to 300. The victims were those who knowingly stayed in the hazardous area despite the warning. Therefore, the event is recognized as a case which proved the value of effective volcanic risk management.

Usuzan

Usuzan is located in the south-western section of Hokkaido, the northern-most island of the archipelago. It is known to have existed for around 110 thousand years. In recent decades, it erupted on 31 March, 2000, followed by another the day after at a different section of the volcanic system. Collectively, the events caused damage to manufacturing facilities and residential properties in the local township, forcing approximately 16,000 residents and tourists to evacuate. The alert was made in time for the evacuation, leaving no case of injury or fatality.

The successful conduct of evacuation is attributed to the inherited knowledge of the precedent that earthquakes occurred prior to eruption and the existence of dedicated volcanic scientists who played a critical role in alerting local government offices in a timely manner.

Figure 4. Usuzan.
Source: JMA.

Ontakesan

The biggest lesson Japan has learned over the recent decades is the eruption of Ontakesan, which is situated on the border of the Nagano and Gifu prefectures in the central part of Honshu Island. On 27 September, 2014, Ontakesan erupted and left 63 people deceased or missing, making it the worst fatal eruption post World War 2. As a famous climbing spot, there were more than 200 climbers around when the eruption occurred. It took the form of phreatic eruption which is considered less predictable in comparison to magmatic eruption. Reportedly, increase in volcanic earthquakes was observed between 10 and 11 September, 2014, which led to the issuance of "Explanatory information on the state of volcanic activities." As there was no other irregular symptoms besides earthquakes, no change was made to the Volcanic Alert Level 1 "normal," which was actually defined as "calm in terms of volcanic activity, however dangerous in the crater."

Figure 5. Ontakesan.
Source: JMA.

The tragic event prompted the launch of the Working Group on Promoting Volcanic Disaster Prevention Measures, convened by the Central Disaster Prevention Conference's Disaster Prevention Execution Committee. The Working Group responded by proposing remedial measures to the volcanic disaster prevention system, which was published on 26 March, 2015. The proposals covered the following six themes; 1) enhancing national volcanic risk management system, 2) strengthening observation capabilities and upgrading technical evaluation methodologies, 3) implementing a clearer disaster communication system, 4) introducing an appropriate evacuation protocol, 5) promoting education and knowledge sharing on volcanic eruption risks, and 6) strengthening research on volcanoes and developing human resources.

How insurance coverage is offered

In Japan, volcanic eruption risks are covered in conjunction with earthquake risks, although there are some exceptions. Most notably, volcanic ash is typically excluded under commercial property extensions, as insurers tend to avoid overwhelming accumulation of the said risk. The chart below summarizes how volcanic eruption losses are covered under major lines of business.

Line of Business	Coverage Part	Volcanic Ash	Other than Volcanic Ash	Description on Volcanic Ash coverage
Commercial Property (Coverage Extension)	Endorsement	Excluded	Covered	N/A
Residential Property (Fire following EQ)	Standard	Resultant Fire only	Resultant Fire only	Only losses resulting from fire due to attachment or accumulation of volcanic ash are covered
Personal Auto (Note)	Endorsement	Total Loss only	Total Loss only	There are cases where only total loss due to surface scratch or acidification are covered
Personal Accident	Endorsement	Covered	Covered	For example, health issues to eye, nose, throat or bronchus due to attachment or inhalation of volcanic ash
Marine Cargo	Standard	Covered	Covered	Losses to cargos such as completed vehicles due to surface scratch or acidification from volcanic ash are covered
Inland Cargo	Endorsement	Covered	Covered	Losses to cargos such as completed vehicles due to surface scratch or acidification from volcanic ash are covered
Aviation	Standard	Covered	Covered	For example, third party liability losses caused by engine malfunction or property damage resulting from suctioning volcanic ash

Note: Only in case where endorsement on total vehicle loss from earthquake, volcanic eruption and tsunami is in place.

Figure 6. Insurance coverage for volcanic eruption risks in Japan.

With limited cases of catastrophic volcanic eruptions since the initiation of commercial insurance business, there has been no recorded case where insurance payment has generated public debate. Nevertheless, volcanic eruption risks, particularly ash fall, can cause widespread economic loss, whose potential impact calls for close attention in terms of risk assessment and accumulation control.

Assessment of volcanic eruption risk

Based on the understanding that volcanic eruption can cause wide-scale socio-economic damage, the insurance industry in Japan has been conducting research over the years. The following description illustrates a study run by the General Insurance Rating Organization of Japan (GIROJ) in 2019. The study entitled "Assessment on the degree of volcanic disaster risk based on historical eruption" focused on two aspects; damageability per type of volcanic eruption loss, and volcanic hazard assessment based on historical eruption record.

Out of the 111 active volcanoes identified, the study focused on 86 volcanoes with relatively credible eruption record. It took into account 125,000 years of eruption record for large-scale eruptions (Volcanic Explosivity Index 6 and above) and 15,000 years for ordinary eruptions (VEI 5 and below).

The scope of volcanic phenomena covered volcanic ash, lava flow, debris avalanche and ash deposits for hazard assessment. In case of significant eruptions, they normally accompany several types of phenomena, such as volcanic ash, pyroclastic and lava flows. As such the study created hazard maps per each event. Having screened 86 active volcanoes, hazard maps for 105 eruption events representing 32 volcanoes were generated.

Damageability per type of volcanic eruption loss

In assessing damageability per type of volcanic eruption loss, the extent of damage to residential properties was classified in four categories; "total loss," "massive loss," "half loss" and "partial loss," per each eruption phenomenon. As for pyroclastic flow, lava flow, debris avalanche and formation of crater, total loss damageability for both wooden and non-wooden structures are considered as 1.0. In terms of damage to buildings due to volcanic ash accumulation, probability of total loss to wooden structure was set as 1.0 for accumulation of 1m, 0.5 for 50 cm, 0.3 for 30 cm, and 0.1 for 10 cm. Figures for non-wooden structure was imported from flood statistics, with understandably smaller ratios for each. The degree of volcanic ash accumulation and damageability to structures is summarized in the chart below.

Volcanic ash accumulation	Typical consequences
1 cm	Driving a car becomes difficult. Public transportation is affected.
2 cm	Many people sense bronchial disorder.
2-3 cm	Public transportation system ceases.
10 cm	Damage to old wooden structures, such as roof collapse.
20-30 cm	Most wooden structures suffer from damages.
50 cm	More than half of wooden structures collapse.
1 m	Most wooden structures collapse.

Figure 7. Volcanic ash accumulation and its consequences to structures.
Source: General Insurance Rating Organization of Japan (GIROJ).

Ash deposits have more destructive effect as they fall from high above. A sizable ash deposit can pierce through a residential roof which is likely to result in total loss. Probability of total structural loss due to ash deposit is summarized as follows.

Distance from Crater	Ratio of Total Structural Loss
0-1 km	0.17
1-2 km	0.034
2-3 km	0.0079
3-4 km	0.00035

Figure 8. Ratio of total structural loss due to ash deposits.
Source: GIROJ.

Assessment on the degree of volcanic disaster risk based on historical eruption

Now that the hazard maps developed from historical eruption and damageability per type of loss are available, assumption on the number of damaged households per eruption event can be lead by applying a 250 m mesh number of household which is available from the Government census data. Dividing the sum of damaged households by the number of years of consideration (15,000 years for ordinary eruptions and 125,000 years for large-scale) yields the number of yearly damaged households. Applying the formula to all 105 eruption events, and summing up the results produces total number of damaged households per year. By denominating the result, national average degree of volcanic disaster risk can be obtained. The following chart summarizes the result.

Category of Eruption	Damaged Households (A)	Annual Average Damaged Households (B) B=A/No. of years of consideration	Annual Average Damage Ratio per Household (C) (per mille) C=B/D x 1,000
Ordinary Eruption (No. of years of consideration: 15,000 years)	2,939,256	196	0.0037
Large-scale Eruption (No. of years of consideration: 125,000 years)	69,572,590	557	0.0104
Ordinary + Large-scale Combined	-	753	0.0141
National Total Households (2015 Census) (D)			53,331,797

Figure 9. Summary of volcanic disaster risk assessment.
Source: GIROJ.

Volcanic eruption risk management

Act on Special Measures for Active Volcanoes

As discussed in Section 3.3, the 2014 eruption of Ontakesan prompted national-level discussion to strengthen disaster risk management on volcanic activities, which culminated in the revised Act on Special Measures for Active Volcanoes. The Act consists of three pillars which are 1) redefining precautionary evacuation in volcanic disaster alert communities, 2) strengthening mutual co-operation among volcanic research institutions and development of volcanic expert resources, and 3) mandating local governments and climbers to exercise preventive effort by themselves.

On the first pillar that involves redefining precautionary evacuation, the national government retains the right to designate volcanic disaster alert district. Once designated, the relevant local government is required to set up and organize Volcano Disaster Prevention Council, comprising representatives from local government, local meteorological observatory, district development bureau, Japan Ground Self-Defense Force, law enforcement, fire marshal, volcano science, and tourism business. The Act also requires relevant local governments to define the following four items; 1) protocol to collect and disseminate information on volcanic activities, and alert the public, 2) elements to be incorporated as standards in municipal-level disaster prevention meetings, 3) issues to be considered in coordinating evacuation and rescue across community boundaries, and 4) other issues that involve precautionary evacuation system to prevent fatality or bodily injury from volcanic eruption in the designated alert district.

The second pillar requires both national and local governments to make effort in reinforcing facilities and organizations to conduct research and observation on volcanic activities in enhancing mutual cooperation among universities and think tanks in parallel to nurturing and securing human resources equipped with the needed expertise. It is also identified that the central government must promote research on scientific technologies in the field of predicting volcanic activities.

The third pillar focuses on climbers. The revised Act mandates not only relevant local governments to make effort in collecting information on climbers but also climbers themselves to gather information on the probability of volcanic eruption and to take measures necessary to enable smooth and expeditious evacuation at times of emergency including securing means to contact with local offices.

Currently 49 volcanoes, which involve 23 prefectures, are designated as disaster alert districts.

Advancing volcano research and human resources development

In response to the revised Act, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) launched the “Integrated Program for Next Generation Volcano Research and Human Resource Development” as a ten-year plan starting in 2016. The program aims at promoting integrated volcano research encompassing observation, forecasting and countermeasures through unifying volcano observation data, and nurturing sound volcano researchers. The program focuses on developing four areas of expertise which are; volcanic observation data sharing system, cutting-edge volcano observation technology, forecasting technologies for volcanic eruptions, and volcano disaster countermeasure technology. In parallel to promoting researches, there is a project to form a consortium for volcano research and human resource development, since volcano researchers are scattered throughout the country.

Assessing the risk of ash fall

Despite the concentration of active volcanoes, the country has not experienced massive eruption that accompanies ash fall in modern days. However, the record tells that there were eruptions resulting in wide-area ash fall, such as Hoei eruption at Mt. Fuji in 1707 and Taisho eruption at Sakurajima in 1914. Nevertheless, the question of how to respond to potential challenges ash falls may bring about was left unanswered by the revised Act as discussed earlier.

To advance the discussion, the Disaster Management Implementation Committee of the Central Disaster Management Council established Working Group on Countermeasures for Wide-Area Ash Falls from Major Volcanic Eruptions in August 2018. There was growing concern over how highly industrialized and populated cities can maintain their function under accumulated ash fall. The Working Group was therefore tasked to study how city infrastructure may be affected by severe ash fall and what measures should be in place, to facilitate governments both national and local develop their disaster management protocols. The Working Group responded by publishing its findings in the report "Countermeasures for Wide-Area Ash Falls from Major Volcanic Eruptions -With Mt. Fuji's Eruption as a Model Case," which was released in April 2020.

The Working Group's study was based on three hypothetical wind patterns following Mt. Fuji's eruption. The existence of Mt. Fuji's eruption record, including the one in 1707 which affected Edo, nowadays Tokyo, made it the choice of scenarios.

Learning from past experiences, likely impacts of ash fall on public services are summarized as follows.

Railways	Above-ground railways stop operating even with small amount of accumulation.
Roadways	2-wheel drive vehicles are immobilized with 10 cm or greater accumulation under dry condition, or 3 cm or greater under wet condition.
Daily Necessities	Food, drinking water and other essential items are sold out in populated communities.
Transportation	Commuters are stranded due to paralysis of public transportation and resultant road congestion.
Electricity	Power outage with 0.3 cm or greater accumulation under wet condition. Even under dry condition, power generation is impaired with 2-3 cm accumulation.
Telecommunication	Phoneline congestion occurs soon after eruption.
Water Supply	Original water sources suffer from contamination, making tap water undrinkable.
Drainage	Clogged drainpipe causes overflow of drainage.
Buildings	Wooden houses collapse with 30 cm or greater accumulation under wet condition.
Human Health	Irritation to eyes, nose, throat or bronchi.

Figure 10. Impacts of ash fall on public services.

How to secure means of transportation is considered critical in the recovery process, which involves evacuation of inhabitants and delivering daily necessities. Under the wind pattern with the potential to affect the largest population and asset value, it would take three days before ash removing equipment reach essential public services to start sweeping arterial roadways.

The treatment of collected ash also needs to be figured out beforehand. Recent precedents saw ash disposed at designated waste treatment site or used for landfill. Under the worst case scenario, the amount of ash could be as much as 490 million cubic meters.

The report recommends relevant government offices and infrastructure operator to work closely with each other to put in place countermeasures to minimize losses and prevent social turmoil from happening.

Revising Mt. Fuji hazard map

Mt. Fuji Volcano Disaster Countermeasure Council was established in June 2012 by three surrounding prefectural governments, Yamanashi, Shizuoka and Kanagawa. The Council's work has centered around revising Mt. Fuji hazard map which was originally prepared in June 2004 by national government offices in response to a series of low-frequency earthquakes observed underneath the mountain.

The revised Mt. Fuji hazard map has two components; a drill map which illustrates volcanic activities such as lava and pyroclastic flow assisted by numeric simulation, and a probability map which is an overlay of historical drill maps to visualize maximum spread and minimum arrival time of each volcanic activity in a comprehensive manner to depict the area with potential hazards.

As such, volcano hazard map is fundamental to crafting an effective means of disaster prevention. The Council therefore set up a three-year work plan to revise Mt. Fuji hazard map, and published the outcome in March 2021. The revision incorporated several upgrades such as; 1) increased the estimated crater range, 2) expanded the scope of historical study from 3,200 years to 5,600 years, 3) enhanced the granularity of topography to 20 m mesh from 200 m for lava flow and 50 m for pyroclastic flow, 4) increased the lava flow amount following massive eruption from 700 million cubic meters to 1.3 billion cubic meters, 5) increased the pyroclastic flow amount from 2.4 million cubic meters to 10 million cubic meters, and 6) updated historical record on sector collapse.

The state of predictive technologies

The Coordinating Committee for Prediction of Volcanic Eruptions, under the auspices of Japan Meteorological Agency and established in 1974, is composed of scientists and experts from public offices. The Committee convenes twice a year to update each other with activities of the 47 selected volcanoes. In the aftermath of the 2014 Ontakesan eruption, the Committee launched the "Study Group on the Systematic Volcano Observation" aiming at strengthening the monitor of active volcanoes. The Committee utilizes Global Navigation Satellite Systems (GNSS) which are useful in detecting precursors of an eruption by monitoring change in ground inflation or deflation of volcanic edifices which are driven by magmatic activity.

Figure 11. Mt. Fuji.
Source: JMA.

Future considerations

The unpredictable and case-specific nature of volcanic eruption risk makes it especially challenging for one to justify costs and resources to invest in advanced researches and hire dedicated experts to take precautionary measures against catastrophic events in the future. Even in Japan, it was under the Act on Special Measures for Active Volcanoes that recognized the importance of capacity building. The national effort to invest more in research and to nurture volcano researchers is a welcome step forward, however, deserves further public attention to scale up the effort.

The insurance industry has been accumulating knowledge in assessing volcanic eruption risk, both through industry organization and on individual company level. For instance, offering assistance to corporates and local municipal governments in designing their business continuity plan has been conducted as part of insurance companies' daily business practice. Volcanic eruption has attracted greater attention among corporates operating in the Tokyo metropolitan area for their potential exposure to ash fall, which calls for an appropriate business continuity plan in place. It is expected that the industry contribute further to the national effort to better prepare for the next catastrophic eruption event by making the most of its risk evaluation capabilities.

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Volcanic risk management and insurance in New Zealand

Jo Horrocks and Annah Chisholm
The Earthquake Commission | Kōmihana Rūwhenua

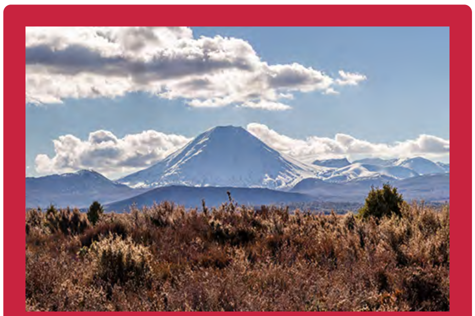
Introduction

New Zealand volcanologists, emergency managers, and insurers watched the unfolding eruption in La Palma, Canary Islands, this year with interest, well aware such a scenario could happen in this country.

New Zealand hasn't experienced a damage-causing eruption like that seen in La Palma over the last few weeks. Nor has it experienced events like the lava flows from Kilauea, Hawaii, in 2018, the volcanogenic tsunami caused by Anak Krakatoa, Indonesia, in 2018, or the widespread ashfall seen at Taal Volcano, Philippines, in 2020, and Calbuco volcano, Chile, in 2015. But we know it could happen, and we are actively preparing for that eventuality.

In this article we discuss recent experience with volcanic events in New Zealand, the state of volcano science and understanding, and multi-agency preparedness for such events. We cover New Zealand's public-private model of insurance, including insurance coverage of volcanic events; we discuss a recent review of operational policy, seeking to ensure the lessons learned from the Canterbury Earthquake Sequence claims management experience are applied to other hazards. Finally, we look at New Zealand's risk and loss modelling capability, including how we are trying to quantify likely losses from future volcanic events.

The Earthquake Commission is New Zealand's public insurer. As well as providing 'first-loss' insurance cover for natural disasters, we also invest in natural hazard research, including how to reduce the impact of hazards, build resilience, and protect the wellbeing and prosperity of New Zealanders.



While a range of Government agencies and private sector organisations work to reduce volcanic risk and plan and prepare for volcanic activity, New Zealand is fortunate to also have very high insurance coverage for volcanic impacts.

New Zealand has two major public insurance schemes: the Accident Compensation Corporation (ACC) which insures anyone in New Zealand (regardless of residency or citizenship status) with 'no-fault' personal injury cover, and the Earthquake Commission (EQC) which provides cover for residential property (homes and residential land) against natural disaster damage (including volcanic eruption). In addition to the Government-run schemes, vehicle, commercial, and agricultural interests are covered through the private insurance market.

Recent volcanism in New Zealand

While we haven't experienced property damage resulting from a volcanic eruption for many years, New Zealand has not been without its volcanic crises and tragedies. On 9 December 2019, Whakaari/White Island, an offshore volcano in the Bay of Plenty region (Figure 1) erupted, killing 22 tourists. The eruption generated an ash plume and pyroclastic surge (super-hot, fast-moving ash cloud) that affected the entire crater area. Two tour parties were caught in the blast. As well as the fatalities, 25 more suffered serious injuries, and the eruption required a weeks' long response and recovery effort. The tragedy re-started a national conversation on volcanic risk management and communication, and it renewed authorities' planning and preparedness efforts.

In reality, New Zealand is relatively well-served by volcano science, risk assessment, planning, preparedness, and education, having had frequent small-scale reminders of the power of volcanoes over recent decades.

The eruption of Mt Ruapehu in central North Island in 1995-96 was a particular wake-up call. Several explosive eruptions over two years caused ballistics, lahars, tens of kilometres-high ash plumes, and extensive ashfall across several regions. The eruption didn't cause substantial damage, but was enough of a reminder about what could happen, and it initiated a wave of research, planning, and preparedness by a range of agencies.

Since then, there have been several smaller eruptions, as well as some large earthquakes, costly flood and storm damage, wildfires, tsunami, landslides, and drought in New Zealand: natural hazards are well known to the country.

New Zealand is situated on the "Ring of Fire", a geographic belt encircling the Pacific Ocean and containing about 90% of the earth's volcanoes. The country has three main types of volcanoes (Figure 1): stratovolcanoes such as Ruapehu, or its cousins Tongariro, Ngauruhoe, Taranaki, and Whakaari, which are all capable of small-to-moderate eruptions, generally from a single location (e.g., Leonard et al., 2021; Cronin et al., 2021; Kilgour et al., 2021); caldera volcanoes, such as Taupō, Okataina, and Rotorua, which have a history of infrequent but moderate-to-large eruptions, including, on rare occasions, super-eruptions (e.g., Barker et al., 2021); and volcanic fields such as Auckland and Bay of Islands in Northland, where small eruptions can occur over a wide geographic area, and generally in a new location every time (e.g., Hopkins et al., 2021). Multiple types of eruptions can occur at each of the volcanoes, and the eruption type can vary minute to minute. Each volcano has its own challenges of risk assessment, monitoring and detection, hazard types, and exposed population and assets.

Figure 1. Location of active volcanoes in New Zealand. Source: GNS Science.

Volcano science, research, and monitoring in New Zealand

New Zealand's relative advantage when it comes to its natural hazard risk, is our long history of investment in science and research, in particular the geological, marine, and hydro-meteorological sciences. This investment in science means we know a lot about our natural environment, the ground beneath us, and the natural processes that can affect us. It means we have a robust evidence base on which to inform our natural hazard risk management policy and practice. It also means we have an authoritative, evidence-based voice in international markets, in particular, in the international reinsurance market.

At the core of almost all geoscience research is scientific observations of the earth. For the last twenty years, these observations have been provided in real-time by GeoNet, New Zealand's geohazards monitoring system. The GeoNet Programme was established in 2001 by the Earthquake Commission, GNS Science, and Land Information New Zealand (LINZ). It resulted from the recognition that the risk to New Zealand's population and economy from geological hazards is significant, and that a robust evidence base is needed to understand and manage these hazards. GeoNet now comprises a network of more than 700 sensors nationwide, as well as the 24/7 National Geohazards Monitoring

Centre, automated software applications, a data management and storage centre, and skilled technical and scientific staff. The programme detects, interprets, and archives key geophysical data about New Zealand, and provides real-time, open source, public data and information about the hazards around us.

For New Zealand volcanoes this monitoring incorporates several strands of observation and measurement, including:

- **Visual observations –** a network of remotely-operated cameras to supplement in-person observations and observation flights.
- **Seismic monitoring –** provided by the core national seismic network, supplemented by regional networks for specific volcanoes.
- **Chemical analyses –** airborne and ground-based gas monitoring, and groundwater, fumarole, crater lake, and thermal spring water chemistry to detect changes in the behaviour of the volcanoes and their associated geothermal systems.
- **Ground deformation –** geodetic levelling, continuous Global Positioning System (GPS), and Interferometric Synthetic Aperture Radar (INSAR) satellite monitoring to measure changes to the land surface that may be the result of magma, hydrothermal, and/or magmatic fluids in the volcanic system.

In addition to this continuous monitoring capability, a number of volcanic risk management and resilience research platforms are currently in operation across the country (Figure 2). These platforms aim to deliver end-to-end volcanic crisis research; from understanding volcanic processes, assessing hazards, impacts, and risks, readiness and response processes, through to community resilience.

A key feature of the platforms, especially at the regional (volcanic centre) level, is the multi-disciplinary and multi-stakeholder nature of the programme of activity. Even the platforms with a primary science/research purpose tend to include a range of stakeholders, from central and local government, emergency management authorities, risk managers and communicators, representatives from infrastructure, business, and local tangata whenua (indigenous people). The overriding purpose is collaboration and coordination on matters of volcanic risk management, and co-creation of research objectives and knowledge needs. The platforms allow a common understanding of the volcanic hazard and risk, common planning scenarios and frameworks, and coordinated risk communication and education.

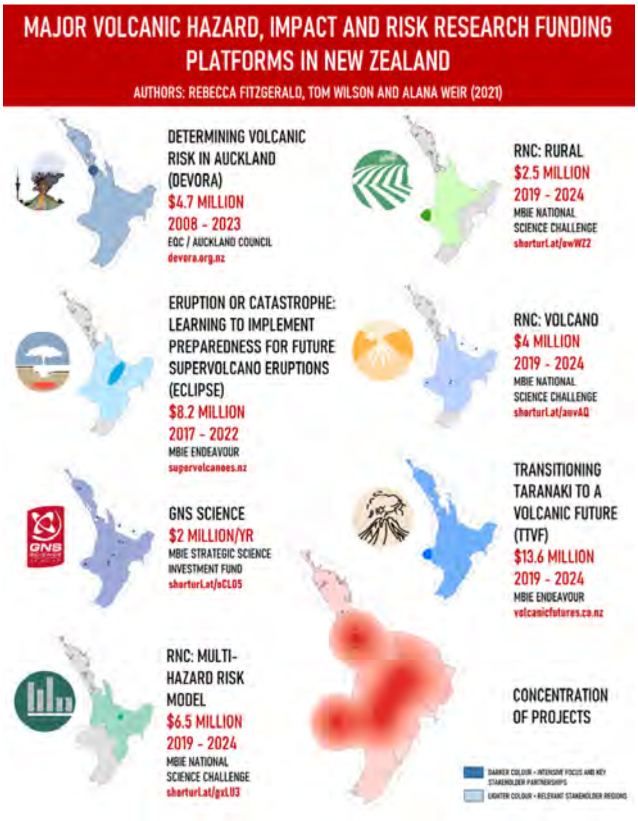


Figure 2. Major volcanic hazard, impact and risk research platforms New Zealand.
Source: Fitzgerald et al., 2021.

At a national level, the New Zealand Volcano Science Advisory Panel is a mechanism for ensuring the provision of authoritative science advice when volcanic activity is affecting New Zealand, through trans-disciplinary and multi-institution collaboration. The Advisory Panel was established in 2008 with representatives of each research institution and hosted by the National Emergency Management Agency. It has played a role in recent volcanic crisis such as Whakaari (2019) and Te Maari (2012) to ensure consistent communication to decision-makers, stakeholders and the public, and coordinate post-event research.

Insurance coverage of volcanic impacts in New Zealand

While a range of Government agencies and private sector organisations work to reduce volcanic risk and plan and prepare for volcanic activity, New Zealand is fortunate to also have very high insurance coverage for volcanic impacts.

New Zealand has two major public insurance schemes: the Accident Compensation Corporation (ACC) which insures anyone in New Zealand (regardless of residency or citizenship status) with 'no-fault' personal injury cover, and the Earthquake Commission (EQC) which provides cover for residential property (homes and residential land) against natural disaster damage (including volcanic eruption). In addition to the Government-run schemes, vehicle, commercial, and agricultural interests are covered through the private insurance market.

Coverage of natural disaster damage: About the Earthquake Commission

EQC was initially established as the Earthquake and War Damages Commission in 1944 in response to the economic recovery (or lack thereof) of communities affected by the seismically-active period that occurred in New Zealand between 1929 and 1942. The Earthquake and War Damages Commission provided insurance on an indemnity basis for any property in New Zealand with fire insurance. In 1956 the scope of the legislation was expanded to include landslip and volcanic eruption. Cover for residential land, including structures essential for maintaining access to and utility of the land (e.g. retaining walls, bridges, and culverts) was added in the 1970s.

In 1993 the Earthquake and War Damages Commission Act was re-established as the Earthquake Commission Act 1993 ('EQC Act'), covering damage resulting from earthquake, natural landslip, volcanic eruption, hydrothermal activity, tsunami, and natural disaster fire occurring as a consequence of the above. EQC also covers damage caused by storms or floods to residential land (only).

The maximum amount of insurance available under the EQC scheme is NZD150,000 (1) per residential dwelling (i.e. a single home). EQC covers the first NZD150,000 of damage; if claimants have natural disaster damage that exceeds this amount, their private policy may respond and 'top up' their insurance cover. Damaged residential land is covered for its market value and damaged retaining walls, bridges and culverts are covered for their indemnity value.

What does EQC consider to be 'natural disaster damage'?

For EQC insurance to apply to any particular insured property, the loss or damage to that property must be:

- as a direct result of natural disaster; and
- physical, i.e. has actually occurred; or
- expected to happen in the near future (as considered by EQC) – referred to as 'imminent damage'.

Physical loss or damage as a direct result of natural disaster is a common and well-understood insurance concept. 'Imminent damage' is a unique feature of the EQC scheme and caters to those circumstances where there is an inevitable 'more to come' in terms of natural disaster damage. This component of EQC insurance presents some unique considerations in relation to damage arising from volcanic eruptions, and the type of damage EQC may consider 'imminent' as a direct result of that eruption.

Insurance lessons from other natural hazard events in New Zealand

Prior to 2010, EQC managed around 2000-4000 claims per year, with semi-regular spikes in volume related to natural disaster events. The highest claim numbers received by EQC was around 10,000 claims, in 1968, as a result of the Inangahua Earthquake in New Zealand's South Island.

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(1) 1This amount will increase to NZD300,000 from 1 October 2022.

In 2010, a magnitude 7.1 earthquake occurred in Darfield, Canterbury, starting the Canterbury Earthquake Sequence. The sequence included the Christchurch Earthquake of 22 February 2011, which, tragically, resulted in the loss of 185 lives. The Canterbury Earthquake Sequence resulted in widespread property damage across the city of Christchurch, surrounding towns and rural areas: EQC received over 450,000 claims in 16 months. Given the high rate of insurance penetration in New Zealand, the Christchurch Earthquake of February 2011 would become the second largest insurance loss in history, globally, for a seismic event (Source: Munich Re datacentre).

The Canterbury Earthquake Sequence presented a number of complexities for claims management, including:

- multiple damage-causing events, including four 'major' earthquakes, and thousands of smaller aftershocks, making it hard for EQC and insurers to pinpoint exactly when damage occurred to a property;
- damage that went 'undiscovered' for some period of time (for example, subsurface damage to drainage infrastructure);
- damage that only eventuated over longer timeframes (for example, caused by land 'settling' from liquefaction processes);
- a two-tier system of assessment where EQC first quantified the loss, and then the private insurer quantified theirs. At times these assessments did not always align, and gaps in insurance cover were identified between EQC and private insurance cover;
- a system of 'managed repair' where homeowners had limited control and which presented unique liability and operational concerns for EQC;
- several areas of the city where entry was prohibited for a prolonged period of time, resulting in delays to damage identification or making damage assessments difficult;
- the capability and capacity needed for EQC to scale up from ~4,000 claims per year, to 450,000 claims over 16 months; and
- many judicial decisions, resulting in an evolving understanding of EQC's coverage.

Some of the above issues are unique to EQC, being either event-specific, or a result of the public-private model of insurance in New Zealand. However, many of the issues highlight transferable lessons that can be applied to other natural hazards, in New Zealand or overseas. In particular, they highlight the importance of a thorough understanding of the natural hazard in question, and the unique environment in which it may occur – *before* a loss-causing event happens.

This is in large part the rationale for EQC's ongoing investment in natural hazard research. However with the above lessons in mind, EQC recently embarked on a phase of operational policy review, with a view to ensuring the lessons from the Canterbury Earthquake Sequence were properly considered for other natural hazard events – including volcanic eruption.

EQC and coverage of volcanic eruption: previous experience and lessons

EQC's most meaningful interaction with volcanic eruption claims was the 1995-96 eruption of Mt Ruapehu. 203 claims were made to EQC. All were for damage relating to ashfall; almost 90% of the claims related to the claimants' roofs, with 28 related to corrosion of metal roof surfaces.

The EQC Act sets the same baseline cover regardless of the natural hazard faced. This means that EQC can utilise the EQC Act to set out the response process. However, it must undertake careful operational planning to ensure that the features of a particular natural hazard interact with the insurance available under the EQC Act effectively.

EQC worked closely with the New Zealand Volcanic Science Advice Panel to review these settings and add clarity, where needed. The review of the volcanic eruption policy included:

Issues of definition

The EQC Act specifically includes 'volcanic eruption', with no further definition of that term. Further, there were concerns the term 'eruption' was too narrow, and did not adequately consider sub-hazards, for example, ground deformation, steam, gas, or lahars. An early consideration therefore was improving this definition and interpretation.

New Zealand's geohazards monitoring system, GeoNet, makes a distinction between volcanic eruption and volcanic activity. Volcanic eruption is considered to occur when eruption hazards are observed near the vent; volcanic activity can include unrest and volcanic environment hazards, which could include (but are not limited to): steam eruptions, volcanic gases, earthquakes, landslides, uplift, subsidence, changes to hot springs, and/or lahars and mudflows (Figure 3).

In some cases, these hazards are covered by EQC in their own right, as a defined natural disaster under the EQC Act (e.g. earthquake). Where hazards are not distinctly covered in their own right, EQC insurance may not apply. EQC is currently working with the wider insurance industry and the New Zealand Treasury to understand the implications of this.

Issues of timing

EQC claim lodgements are timebound, which means EQC needs to understand at what point a volcanic eruption actually begins (and ends). In New Zealand, we use a system of Volcanic Alert Levels to define the current status of each volcano (Figure 3). The Alert Levels range from 0 to 5, and are intended as a descriptor of what's happening at the volcano, and as a guide for response. EQC considers that a volcanic eruption has occurred when GeoNet has raised the Volcanic Alert level to level 3, 4 or 5. If a wider definition of volcanic activity is eventually agreed, the start and end point would change accordingly.

	VOLCANIC ALERT LEVEL	VOLCANIC ACTIVITY	MOST LIKELY HAZARDS
Eruption >	**5**	**Major volcanic eruption**	Eruption hazards on and beyond volcano*
Eruption >	**4**	**Moderate volcanic eruption**	Eruption hazards on and near volcano*
Eruption >	**3**	**Minor volcanic eruption**	Eruption hazards near vent*
Unrest >	2	Moderate to heightened volcanic unrest	Volcanic unrest hazards, potential for eruption hazards
Unrest >	1	Minor volcanic unrest	Volcanic unrest hazards
>	0	No volcanic unrest	Volcanic environment hazards

An eruption may occur at any level, and levels may not move in sequence as activity can change rapidly.

Eruption hazards depend on the volcano and eruption style, and may include explosions, ballistics (flying rocks), pyroclastic density currents (fast moving hot ash clouds), lava flows, lava domes, landslides, ash, volcanic gases, lightning, lahars (mudflows), tsunami, and/or earthquakes.

Volcanic unrest hazards occur on and near the volcano, and may include steam eruptions, volcanic gases, earthquakes, landslides, uplift, subsidence,changes to hot springs, and/or lahars (mudflows).

Volcanic environment hazards may include hydrothermal activity, earthquakes, landslides, volcanic gases, and/or lahars (mudflows).

Ash, lava flow, and lahar (mudflow) hazards may impact areas distant from the volcano.

> Figure 3. New Zealand Volcanic Alert Level Table.
> Source: GNS Science.

Issues of scope of coverage

The Canterbury Earthquake Sequence, including various judicial decisions, made it clear that the scope of coverage for any particular hazard needs to be as transparent and specific as possible. With this in mind, EQC reviewed its coverage of volcanic impacts.

EQC now considers that it needs to be prepared to manage claims for damage arising from:

- heat damage from proximity to lava flow;
- impact damage from ballistics;
- degradation of finishes due to prolonged exposure to chemically reactive volcanic ash, aerosol, acid rain or gas;
- roof or gutter deformation or collapse due to ash inundation;
- compromised effluent disposal fields due to ash inundation;
- total loss of the building due to destruction from a volcanic eruption.

Issues related to repeated or ongoing events

A key complexity of the Canterbury Earthquake Sequence was its ongoing nature, including repeated damage-causing aftershocks. A volcanic eruption may be similar: because of the nature of an eruptive episode, an individual property may be damaged by several eruptions or volcanic hazards in any given period. This could mean that insurers may need to respond to multiple events.

Schedule 3 of the EQC Act stipulates that an EQC claim may only be lodged when the property has been damaged by the natural disaster in question. Any subsequent damage that occurs within 48 hours (or in the case of natural disaster fire, seven days) of the initial damage to the property from any natural disaster insured by EQC, is subject to one claim cap (i.e. NZD150,000) and excess. In any given eruptive episode, the EQC cap may reinstate over consecutive or separate 48 hour periods.

When assessing the damage to a property, EQC must also consider whether any further damage is 'imminent’ as a result of the natural disaster that has occurred. For volcanic eruption this could include, for example, indicators of ground deformation or a landslide that may cause future damage to land or property. A tricky feature of this type of assessment (in relation to volcanic eruption damage) is how assessors would quantify potential corrosion damage from exposure to corrosive elements over a sustained period of time. EQC continues to work to understand how best to approach this.

Issues of operational process

In addition to considerations around coverage and timing, EQC also reviewed its readiness to manage a volcanic crisis. Key considerations were:

- policy and processes for assessors working in potentially dangerous areas;
- approach to managing claims in exclusion zones;
- technology that could enable smarter assessment;
- approach to, and coverage of clean-up costs, including preventative clean-up;
- coordination and collaboration with partner agencies and key science experts;
- how EQC can better support customers and communities in their response to and recovery from volcanic crises;
- risk communication and public education; and
- EQC’s role in reducing risk from volcanic activity.

One of the biggest advances for insurance delivery in New Zealand was on 30 June 2021 with the introduction of the Natural Disaster Response Model (NDRM). Building on the learnings of the Canterbury Earthquake Sequence and other smaller natural disaster claims events, the NDRM is an agreement between EQC and private insurers for the latter to manage and settle all EQC claims up to the relevant cap in conjunction with the private insurance claim.

EQC has worked to develop capability with insurers to enable them to perform this function, including to build a common understanding of natural hazard scenarios, and readiness for different events.

EQC is fortunate to have close relationships with the science and research community in New Zealand, including access to quality science advice for volcanic hazard risk management. The above policy reviews were greatly aided by working in close partnership with the science community to fully understand impacts and develop clear definitions and criteria. Work to better define our operational policies and approach is ongoing and EQC is committed to working with its business partners to share the knowledge it has access to.

A step further: assessing impacts and modelling losses from volcanic events in New Zealand

Like other insurers, EQC utilises deterministic and probabilistic loss modelling to quantify likely losses from hazards. New Zealand has had a mature probabilistic hazard model for earthquakes (National Seismic Hazard Model, NSHM) for many years, with four iterations completed over the last 30 years (Smith and Berryman, 1986; Stirling et al., 1998, 2002, 2012), and a major revision currently in progress (Gerstenberger et al., 2020). However, modelling for other hazards, including volcanic hazard, is not as well advanced.

Development of a national probabilistic volcanic hazard model is a priority for EQC, both for its use in loss modelling (for insurance and reinsurance purposes), and for informing disaster risk reduction and resilience initiatives. A national model would sit alongside other national hazard models – currently in various stages of development – to allow robust comparison between perils and inform national hazard risk management and governance.

Quantifying probabilistic volcanic hazard has been discussed and conceptualised by New Zealand scientists for many years (e.g., Stirling et al., 2017). Single-hazard models have been created, such as the national volcanic ashfall model (Hurst and Smith, 2010) but a nationwide, multi-hazard model (i.e., including other volcanic hazards such as lava flows, lahars, pyroclastic density currents, ballistics, or debris avalanches) has yet to be developed.

There are many challenges associated with the development of a national probabilistic model. These include: characterisation of the eruption magnitude and frequency of all actual and realistic volcanic sources (including probabilistic determination of sources in the case of the Field volcanoes; Bebbington, 2013a) preferably in a time-varying model (Bebbington, 2013b); determination of the statistical dependence between hazards, given many of the volcanic hazards are linked within the volcanic system; the need for uniform definition and metrics for all sources, hazards, and return periods; determining the utility and outputs of such a model, especially for building standards; consideration of communication issues, including the information needs of decision-makers, propagation of model outputs into other decision-making tools, and management and communication of uncertainties; and, the funding required to progress the wide variety of research needed to make the model a reality. However, the consensus of the scientific community in New Zealand is that the time is right to make a determined effort towards this goal, given the rare opportunity presented by the number of volcanic hazard and risk focussed research platforms currently underway (Figure 2).

EQC has been utilising its natural hazard research funding to progress some of the early stages required in this work. This includes, crucially, the steps needed to move from hazard, to risk, to loss.

A three-year deterministic volcanic loss modelling project for eight Auckland Volcanic Field (AVF) eruption scenarios (Figure 4) has recently been completed. The project utilised the most detailed, realistic eruption scenarios ever considered for the AVF (Hayes et al., 2018). The scenarios were co-produced by volcanologists, risk scientists and emergency managers and consider a diverse but credible suite of eruption styles, across eight eruption locations, including multiple volcanic hazards in time and space. This provides a vastly more realistic and accurate estimation of the likely impacts from an AVF eruption.

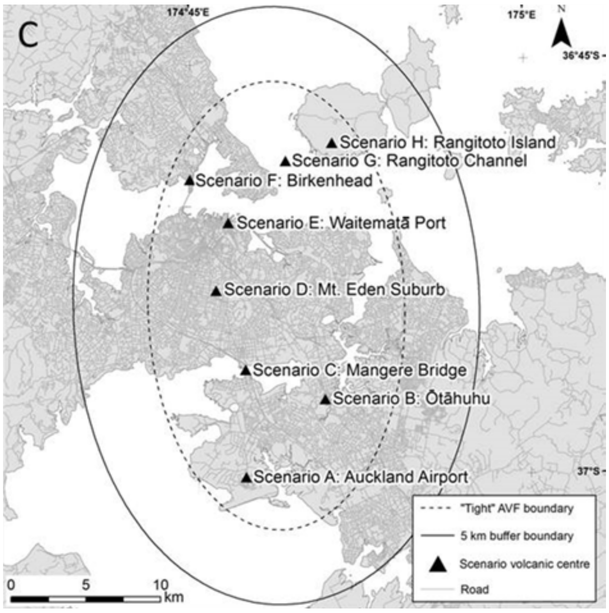

Figure 4. Location of Auckland Volcanic Field eruption scenarios.
Source: Hayes et al., 2018.

The AVF research contained four main phases:

1. development of a preliminary suite of hazard models and associated hazard intensity measures for those volcanic perils expected in Auckland (edifice formation, lava flow, pyroclastic density currents, ballistics, tephra, and gas);
2. amalgamation and curation of digitally-available asset data for Auckland buildings, infrastructure and people (previously this data could best described as ad hoc and key datasets tended to be split across different institutions);
3. development of a suite of Auckland-specific fragility models for assessment of direct impacts to the Auckland built environment (with a focus on buildings) for tephra fall, ballistics, pyroclastic density currents, and lava flows; and
4. testing of tephra fall, ballistics, pyroclastic density currents, and lava flow fragility models for a future AVF eruption scenario through a novel (deterministic) multi-volcanic-hazard impact assessment.

The results from the study showed loss estimates from the eight AVF eruption scenarios for buildings and associated clean-up costs ranged from NZD1.5B (eruption vent location on Rangitoto Island) to NZD63B (eruption vent in dense inner city suburb and heavy tephra fall across 90% of city) (Figure 4, Figure 5; Wilson et al., 2021). Building losses for all scenarios were dominated by pyroclastic density currents near the eruption vent, and tephra fall (when present) more generally. There is considerable variability in losses from the different scenarios, controlled mostly by location of eruption (exposure) and the type and size of particular volcanic hazards (namely pyroclastic density currents). Clean-up costs were shown to be high, which may be something that insurers haven't considered, if this is part of their mandate.

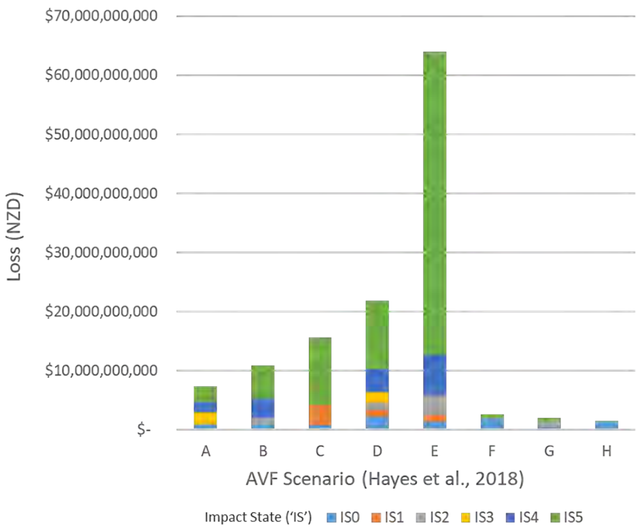

Figure 5. Modelled losses by AVF scenario.
Source: (Wilson et al., 2021.

The Auckland multi-volcanic-hazard loss model represents a considerable advance for the field. It demonstrates the feasibility of a multi-hazard model, and the utility of such a model for volcanic hazard risk management, including in the cost-benefit analysis of mitigation options (for example, the mitigation of tephra fall impacts where roof cleaning and/or bracing may provide damage control). There is clear benefit to considering dynamic multi-hazard impacts, due to the compounding nature of the impact. The model is already of substantial use to local government and emergency management authorities in the Auckland region, where more than a quarter of New Zealand's population lives on a volcanic field.

The next step is to develop this work into a national model. A new three-year phase is now in progress (as of 2021), and is focussed on three main objectives:

1. developing the framework, including methodology, for moving the existing deterministic multi-hazard (AVF) model, to a probabilistic multi-hazard model;
2. scoping the application of probabilistic loss models to Taranaki, Ruapehu, and Tongariro (stratovolcanoes) and Taupō Volcanic Zone (caldera volcanoes); and
3. developing the framework for a New Zealand Volcanic Hazard Risk Model (NZVHRM) and successfully incorporating it into New Zealand's probabilistic loss modelling platform (RiskScape).

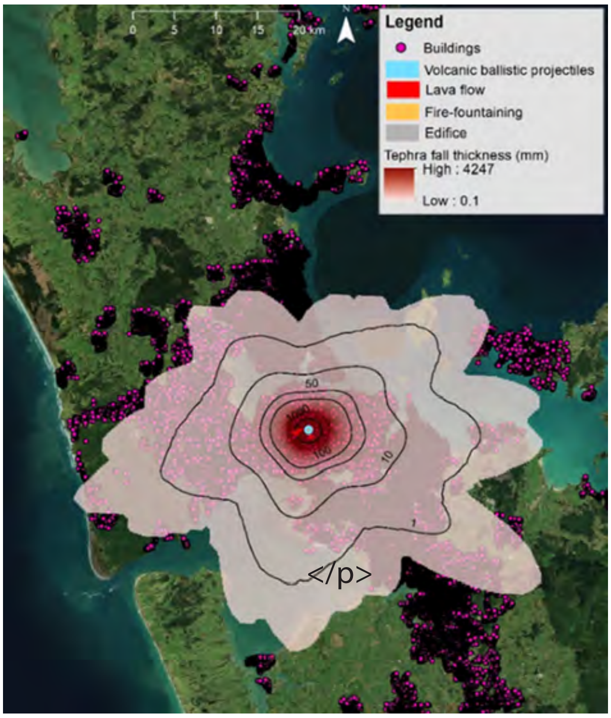

Figure 6. AVF scenario 'D'.
Source: Hayes et al., 2018.

An alternative approach to volcanic risk and impact assessment, potentially bridging the gap between the two dominant approaches (deterministic and probabilistic modelling; Marzocchi and Bebbington, 2012), is also being advanced in a New Zealand context. Ang et al. (2020) developed a hybrid, pseudo-probabilistic hazard model for the AVF, derived from a range of dynamic eruption scenarios. Weir et al. (in press, 2021) present a modular framework for stakeholder co-creation of multi-hazard, multi-phase eruption scenarios that incorporate spatial and temporal dependencies between hazards. The dynamic, hybrid approaches are thought to mitigate some of the limitations of both deterministic approaches (limited in the characterisation of multi-phase, multi-hazard risk, and uncertainty) and probabilistic (complex in development, use, and interpretation). The hybrid approach provides scientifically-credible scenarios that incorporate multi-phase complexity and uncertainty, but still provide a clear, effective knowledge-sharing mechanism for end users, particularly risk and emergency managers (Weir et al., in press, 2021). While potentially too nuanced for use in insurance and reinsurance calculations, these methods hold great potential for better hazard risk management and major event preparedness.

Conclusion

New Zealand's geographic position on the subducting plate boundary between the Australian and Pacific plates means the country is particularly prone to natural hazards such as earthquakes, tsunamis, floods, landslides and volcanoes. The country's volcanoes are mostly well characterised and understood thanks to a long history of volcano science as well as comprehensive indigenous knowledge and oral histories. Despite a history of small-to-moderate eruptions over the last 25 years, some with devastating loss of life, there has not been a large or widespread damage-causing eruption for many decades.

As a nation, we know, however, it is a case of when, not if, the next 'big one' will come. This is reflected in the end-to-end approach to volcanic hazard risk management activity in the country: comprehensive volcano monitoring through GeoNet, New Zealand's geohazards monitoring system, a wealth of investment in volcanology and volcanic risk research programmes, a series of regional and national multi-disciplinary platforms designed for stakeholder collaboration and coordination, an advanced risk and loss modelling capability, and insurance coverage via public and private insurance providers. New Zealand's emergency management authorities are also well-tested through a series of exercises and natural hazard events over the last 10-15 years.

Volcanoes never fail to surprise, though, as the Spanish authorities on La Palma can surely attest. The goal in New Zealand is to understand our risk to the greatest possible extent, and plan and build capability and capacity for adaptive response. Learning from others, as in this volume, is a critical additional step, helping to put us in the best possible position to anticipate and manage any volcanic crises that come our way.

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Volcanic activity and insurance in Portugal

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Director, Property and Engineering Insurance
MDS Group

Capelinhos Volcano eruption

Saturday, 27 September 1958, Azores. The ground had been shaking non-stop for 12 days. Some 200 tremors had been recorded, none with an intensity higher than V on the Mercalli scale. Suddenly, at 6:45 a.m., the ocean started to boil about 300 metres off Capelinhos Point.

Activity increased over the next three days, with black jets of volcanic ash shooting into the air to heights of more than 1,000 metres and a cloud of water vapour reaching altitudes of over 4,000 metres. After a few days, the ejection of gases and pyroclasts decreased in intensity and was quickly followed by violent explosions that expelled projectiles of lava and released large quantities of ash into the air, destroying crops and forcing the population to evacuate the areas closest to the volcano, while torrents of lava spilled into the ocean.

Property insurance coverage in Portugal typically includes property damage caused by volcanic eruptions under the category of seismic events and their repercussions, one being earthquakes. Lost earnings due to events of this type may be covered by business interruption insurance, which can be taken out together with seismic damage coverage.

Accumulating debris formed a small island that grew to 100 metres in height and came to be known as Ilha Nova, or New Island. In periods of calm the new island was eroded away by the ocean, and in the months when the volcano was active, new islets kept forming and then being washed away.

After erupting for seven months, a tongue of land opened up in the ocean at the eastern part of the volcanic cone, where fountains of incandescent lava could be seen shooting up various metres into the air.

Thirteen months after it appeared, the volcano started to lose strength, and the last effusion of lava took place on 24 October 1959.

This volcano, the Capelinhos Volcano on Faial Island in the Azores, is the one most inhabitants of the Azores and most Portuguese remember because of the destruction it caused and the wave of emigration it produced.

However, the last volcanic eruption recorded in the islands took place in 1998 off Terceira Island, near Serreta parish. This submarine eruption caused no damage.

Volcanic activity in the Azores

There are 26 active volcanos in the Azores, eight of which are submarine volcanoes. Only one of the nine islands in the archipelago, Santa María, does not have an active volcano. All the others have volcanoes that are currently dormant but could awaken at any time. There are no other volcanoes in Portugal.

Seismic and volcanic activity in the Azores is constantly monitored by the Centre for Seismovolcanic Information and Surveillance of the Azores [*Centro de Informação e Vigilância Sismovulcânica dos Açores (CIVISA)*] and by the Research

Figure 1. Eruption of the Capelinhos Volcano on Faial Island, Azores.
Source: nit.pt

Institute for Volcanology and Risk Assessment [*Instituto de Investigação em Vulcanologia e Avaliação de Riscos (IVAR)*]. They use three networks covering the entire island group, one for seismic activity, one for geochemical analysis of gases, and GNSS (global navigation satellite system).

Insurance sector exposure to volcanic activity

There is no reliable information concerning transfer of the 1958 volcanic eruption in the Azores to the insurance market.

Like certain other European countries, Portugal does not currently have a special catastrophe compensation fund or specific covers for seismic damage. Despite various attempts along these lines, private insurance is the only coverage option available.

Property insurance coverage in Portugal typically includes property damage caused by volcanic eruptions under the category of seismic events and their repercussions, one being earthquakes. Lost earnings due to events of this type may be covered by business interruption insurance, which can be taken out together with seismic damage coverage.

It should be noted that purchasing seismic damage cover is optional in Portugal.

Premiums in the insurance market are priced on the basis of a specific rate set and recommended by the Portuguese Association of Insurers [Associação Portuguesa de Seguradores (APS)] according to the type of property insured, where it is located, and when it was built. Virtually no insurer operating in Portugal retains the bulk of its seismic damage exposure (and hence its volcanic damage exposure) in its portfolio but instead opts to transfer it to international reinsurance markets. Common excesses for earthquakes and volcanic eruptions stand at between 2% and 5% of the insured sum for each property exposed, which means that seismic and volcanic risks cannot be transferred wholly to the insurance, and the insured parties themselves have to bear part of the risk.

Unfortunately, as it is in the vast majority of insurance markets, the protection gap is quite large, made worse in Portugal by the low degree of insurance culture, the low perception of risk (even in the Azores), and low purchasing power. This last factor is aggravated by the fact that earthquake and volcanic eruption covers are considered to be quite expensive, since comparatively they may cost more than the other customary multirisk property insurance covers. It should be noted that there is no legal requirement to purchase seismic/volcanic eruption damage insurance covers.

In areas with the greatest exposure, like the Azores, many insurers, international insurers in particular, try to minimise underwriting seismic and volcanic risk covers as much as possible, above all for older buildings. The upshot is low penetration by seismic damage and volcanic risk covers and a sizeable protection gap, which could potentially be made smaller by establishing a seismic damage or volcanic risk fund based on a public-private sector association and making those covers compulsory.

Covers for natural events, a category that includes volcanic eruptions, can be purchased as part of car insurance, especially in the case of own damage covers, hence this national insurance line offers a broader product range and is more competitive. The same is true for personal accident insurance.

Sixth Symposium of the Aon España Foundation's Catastrophe Observatory «Catastrophes and their Cost»

Pedro Tomey
President of the Catastrophe Observatory and Director General of the Aon España Foundation

The sixth Symposium of the Aon España Foundation's Catastrophe Observatory, "Catastrophes and their Cost", was held at the National Civil Defence School in Madrid on 25 November with His Majesty King Felipe VI acting as President of Honour. At the Symposium the Aon España Foundation presented a report on the cost of catastrophes in Spain (2016-2020) and the repercussions of Storm Filomena during the pandemic. The report had been prepared by Aon Reinsurance Solutions in cooperation with the Spanish Civil Defence Corps and with the participation of Spain's Insurers Association (UNESPA from the Spanish abbreviation), the *Consorcio de Compensación de Seguros* (CCS), the agricultural insurance provider Agroseguro, the Spanish insurers' Research Cooperative (ICEA from the Spanish abbreviation), the Spanish Red Cross, the Spanish Emergency Military Unit (UME from the Spanish abbreviation), the ONCE Foundation for the Blind and the Disabled, and researchers from the Aon Foundation's Catastrophe Studies Programme *[Cátedra de Catástrofes]*.

The ranking of disasters with the highest economic cost was topped by the cut-off low that occurred in Alicante and Murcia in September 2019, with an impact of 1,319 million euros. The next highest was the storm Gloria in January 2020 that covered all of mainland Spain, reaching a cost of 843 million euros. The third most expensive was the flooding and storms in southeastern Spain in December 2016, which did 272.72 million euros worth of damage.

The ten largest disasters accounted for losses amounting to 3,540 million euros, 30.5% of the overall estimated economic cost.

The Observatory also announced the establishment of the Annual Disaster Barometer, an original, innovative analysis presenting the statistical details of the disasters that have occurred in Spain during the previous year, to be drawn up by the Observatory itself.

The Symposium was attended by representatives of the Civil Defence Corps, Aon Reinsurance Solutions, the Madrid City Council, *Consorcio de Compensación de Seguros*, the Spanish Emergency Military Unit, the Spanish Red Cross, Spain's National Geographic Institute [*Instituto Geográfico Nacional*], and researchers from our Catastrophe Studies Programme. The participants reviewed the natural disasters that have occurred in 2021, for instance, storms produced by cut-off lows, earthquakes, forest fires, and the volcanic eruption on La Palma.

Leonardo Marcos, Director General of the Civil Defence Corps, welcomed the participants; Pedro Tomey, President of the Aon España Foundation's Catastrophe Observatory, reviewed the Symposium's objectives; and Isabel Goicoechea Aranguren, Under Secretary of Spain's Ministry of the Interior, closed the sessions.

The cost of natural catastrophes in Spain (2016-2020)

Juan Antonio Sánchez Utrilla, Aon Reinsurance Insurance's Chief Data Analytics Officer, presented a report on the cost of natural disasters in Spain (2016-2020), which totalled 12,067 million euros, an average annual cost of 2,413 million euros.

The year with the highest cost was 2019, at 3,120 million euros, followed by 2020 at 2,616 million euros, 2018 at 2,438 million euros, 2017 at 2,284 million euros, and 2016 at 1,610 million euros.

Pedro Tomey, President of the Observatory, noted that "this is the first study of its kind produced in Spain, setting forth an analysis of the most important catastrophes recorded between 2016 and 2020".

The cost calculation included the impact on the budget, subsidies and aid, as well as repercussions on household economies and the agricultural sector.

By sector, the agricultural sector was hardest hit, accounting for 35% of the losses. Next were households, which accounted for 31.6% of the total cost. Budgetary appropriations for the Civil Defence Corps, the Spanish Emergency Military Unit, and the Red Cross plus subsidies and aid paid out by the Civil Defence Corps accounted for 4.13% of the total.

The cost of the catastrophes considered covered by insurance between 2016 and 2020 was 6,290 million euros, 41.3% of the total estimated cost, an average of 1,258 million euros per year. Insurance coverage in the agricultural sector represented 38.38% of the total, in the rest of the sectors coverage was 20%.

The uninsured costs came to 5,274 million euros, i.e., a protection gap of insured losses to uninsured losses of 45.6% on average over the period considered.

Civil Defence Corps subsidies and aid between 2016 and 2020 totalled 32 million euros, an average yearly cost of 6.56 million euros. Budgetary appropriations for Civil Defence, the Emergency Military Unit, and the Red Cross came to 438 million euros, an average of 87.8 million euros a year.

The report also included a special section on the economic impact of Storm Filomena in January 2021. Its economic cost was 1,157 million euros, of which 505 million euros were insured and the remainder uninsured.

Ranking of disasters with the highest economic cost

The ranking of disasters with the highest economic cost was topped by the cut-off low that occurred in Alicante and Murcia in September 2019, with an impact of 1,319 million euros. The next highest was the storm Gloria in January 2020 that covered all of mainland Spain, reaching a cost of 843 million euros. The third most expensive was the flooding and storms in southeastern Spain in December 2016, which did 272.72 million euros worth of damage.

The ten largest disasters accounted for losses amounting to 3,540 million euros, 30.5% of the overall estimated economic cost.

Cost of natural catastrophes in Spain - 2016-2020

The 10 largest events in the last 5 years

Year	Date	Place	Cause	Estimated Economic Cost (million €)
2019	11-15 September	Alicante and Murcia	Flood - cut-off low	1,319.14
2020	19-21 January	Peninsula (widespread) and Balearic Islands	Windstorm (Gloria)	843.72
2016	16-22 December	SE Spain	Flood and windstorm	272.72
2017	1-7 February	Tarragona	Windstorm (Kurt)	266.71
2018	February 2018	Asturias, Basque Country and Pyrenees	Snow	183.39
2020	4-5 November	Valencia	Flood	179.45
2018	18-21 October	Catalonia, Balearics, Andalusia and Valencia	Flood	140.71
2017	December 2017	Peninsula (widespread) and Balearic Islands	Flood and windstorm (Ana)	121.71
2018	November 2018	Catalonia, Valencia and Murcia	Flood	115.82
2019	18-22 December	Peninsula (widespread)	Storms Elsa and Fabien	96.24

- The two largest events in 2016-2020 period have ocurred in the last two years, storm Gloria and cut-off lows in September 2019
- Both episodes represent themselves 61.1% of the estimated economic cost of the 10 major events
- The 10 largest events accumulate a total of € 3,540 million, which represents 30.5% of the overall estimated economic cost

Source: Aon's Reinsurance Solutions, UNESPA, ICEA, Consorcio de Compensación de Seguros, Agroseguro
Figures updated in million euros as of 2021

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Storm Filomena in Madrid

At the Symposium, José Antonio Martínez Páramo, General Coordinator of the Environment Area for the Madrid City Council, said that 1.25 million tonnes of snow fell over 30 straight hours. "Also, an additional 9,000 tonnes of waste that could not be picked up by refuse trucks piled up in the streets while traffic in the city was completely shut down. The underground was the only transportation we could use, and it was an escape valve", he added.

There are five million trees in Madrid. In all, 1.7 million of them are cared for by the City Council, and 800,000 of those were damaged by Storm Filomena. In the end, 80,000 could not be saved and had to be cut down. The cost to the city government was 46 million euros for tree management alone, 30 million in the Casa de Campo Park.

Annual Disaster Barometer

Pedro Tomey, President of the Catastrophe Observatory, announced the creation of an Annual Disaster Barometer for Spain to quantify the impact of disasters and to compile and organise criteria with a view to being able to implement preventive measures, respond appropriately, and mitigate damage.

The new Barometer will inventory catastrophes and draw up metrics concerning the socio-economic impact of disasters, their repercussion on critical infrastructure, the personal injuries and material damage they cause, their impact on the most vulnerable populations, and resilience. In Tomey's words, «This Barometer will be the first of its kind in Spain and will help bridge the statistical and analytical gap in disaster studies extant in Spain, thus giving society new tools to protect itself from catastrophic events and mitigate their impact. Thanks to the new Barometer, we will be able to develop a severity-based classification for catastrophes and design a full map with a focus on the most critical locations».

The Annual Disaster Barometer's Scientific and Advisory Committees

The new Barometer will be backed by a Scientific Committee to choose catastrophes based on parameters to be set by the Committee itself, draw up questionnaires and conduct surveys, select and assess data for each disaster collected from designated sources, follow up metrics with participating institutions and organisations, oversee the work carried on by researchers and consultants, validate conclusions, and if appropriate, join in any public presentation of the Barometer.

Representatives of Aon España Foundation, Aon Reinsurance Solutions, the Analistas Financieros Internacionales (Afi) firm, Agroseguro, *Consorcio de Compensación de Seguros*, Spain's Engineering Institute [*Instituto de la Ingeniería de España*], and the Catastrophe Studies Programme (Comillas Pontifical University and the University of Navarre's Tecnun School of Engineering) will all be members of the Scientific Committee. There will also be an Advisory Committee composed of the First Responders that are members of the Catastrophe Observatory, the Civil Defence Corps, the Spanish Red Cross, and the Spanish Emergency Military Unit.

Consorcio de Compensación de Seguros in 2021: volcanic eruptions

During his presentation to the Symposium concerning the volcanic eruption on the island of La Palma, Alejandro Izuzquiza, the Director of Operations of CCS, reported that «2,300 claims for compensation have been received and 50 million euros have already been paid out». CCS estimated that the total payout will come to more than 95.5 million euros. Izuzquiza pointed out that the extent of insurance coverage on La Palma is rather low.

He explained that the following criteria were used to process insurance claims:

- Where stipulated in the policy, the replacement value will be paid out, irrespective of whether the insured will be able to rebuild the property or not.
- As a rule, compensation will be paid for the entire contents of buildings that have been destroyed, even where the insured may have been able to save some possessions.
- Uncertified information extracts from the Land Register will be ordered by the CCS as proof of ownership of properties that have been destroyed.
- Insurance companies and insurance brokers will be asked to furnish supporting documents to expedite payouts.
- For purposes of calculating the statutory 7-day waiting period from the issue date of the policy, the date of loss will be taken to be not the starting date of the eruption (19 September) but the date on which the damage to each insured property took place.
- The tolerance limit for potential overinsurance of destroyed homes will be 20%.

Disasters and the Civil Defence Corps

Francisco Ruiz Boada, the Civil Defence Corps' Deputy Director General of Prevention, Planning, and Emergencies, reported that "the catastrophic event management system has tallied 4,253 events to date in 2021, compared with 849 in 2020 and 1,012 in 2019, in other words, the growth curve is becoming steeper". The highest risks in 2021 were seismic activity, with 494 cases, and forest fires, with 579 cases. He noted that the National Civil Defence System "is cognisant of the need to be prepared for evolving, cross-cutting emergencies" and underlined that in the case of disasters, «rather than diverging, the competencies of the national and regional governments complement each other».

He also stressed the need for policies that will more fully inform the population and raise self-reliance and that the National Prevention Network has put in place a National Response Mechanism to address this.

Spanish Red Cross and catastrophes

Íñigo Vila, Director of Emergencies of the Spanish Red Cross, reported that the organisation's work on the island of La Palma was proceeding in a highly professional manner and that «events like the Cumbre Vieja Volcano should help raise our awareness that civil defence starts with each of us as individuals».

The Spanish Emergency Military Unit and the La Palma volcano

Lieutenant-Colonel Jorge Serra Llopart reported that 239 soldiers, 75 vehicles, and 4 drones have been deployed for the operation in response to the La Palma eruption. The Unit's mission has been to provide support and coordination for the emergency management authority, carry out reconnaissance flights, monitor the progress of lava flows, measure air quality, take samples, provide support for evacuations, help move belongings, and remove ash.

Volcano monitoring and warnings in the La Palma eruption

Carmen López Moreno, Director of the National Geographic Institute's Central Geophysical Observatory, spoke on managing volcanic emergencies: «There have been 13 eruptions in the past 500 years, and La Palma was the island that was most likely to undergo an eruption». She added that, «The problem is not explosivity or the size of the eruption, the eruption has not been particularly large. The problem is that it has taken place in a heavily populated, prosperous area

located some distance from the ocean. In this respect it is unlike the Teneguía eruption in 1971, which flowed directly into the ocean and did little damage. This time there were homes located quite near to where the eruption started». In her opinion the preventive measures that had been taken had made it possible to evacuate the population and «had been a great success».

«Shortly before the eruption started, we were able to predict where it would take place, and we have not suffered any loss of life, only economic damage and the misfortune of losing one's home and livelihood».

Qualitative evaluation of the effect of catastrophes on critical infrastructure: The case of Storm Filomena

«There was a cascade effect that ultimately affected infrastructure in a number of ways», said Marcos Borges, Professor at the University of Navarre's Tecnun School of Engineering, one of the headquarters of the Aon España Foundation's Catastrophe Observatory. «Transportation infrastructure was most affected, highways were made impassable, vehicles were abandoned, the food supply was impaired both at its source and by being unable to reach consumers. Many streets were blocked, doctors had trouble reaching their workplaces, ambulances were unable to pass», he reported.

At the border. Migrations forced by climate change

Víctor Pérez Segura, a researcher at the Aon España Foundation's Catastrophe Observatory at the ICAI-ICADE Comillas Pontifical University, noted that extreme weather episodes, rising temperatures, rising ocean temperatures, desertification, and rising sea levels will have social repercussions such as harsh living conditions, impacts on fisheries, impacts on agriculture and livestock raising, and land loss.

Management by the CCS of losses caused by the La Palma volcanic eruption in 2021

María Flavia Rodríguez-Ponga Salamanca, Director General
Francisco Espejo Gil, Deputy Director for Studies and International Relations
Consorcio de Compensación de Seguros

At 2:10 p.m. local time on 19 September 2021, on the island of La Palma in the Canary Islands, the Cumbre Vieja volcano erupted through the western slope of the ridge at a site known as Cabeza de Vaca, at an elevation of some 800 m above sea level and at a distance of some 5 km from the ocean as the crow flies. Lava flows started to affect properties practically from the very outset, because the eruption took place in a populous area with many single homes spread over the land, some towns, many crops, and even some industry.

The seismic activity in the days before of the eruption and certain other factors, such as land deformation, allowed a previous emergency management facilitating the timely evacuation of residents and tourists.

As of that date, CCS had paid out 73,484,337 euros as compensation for 419 homes (totalling €62,948,909), 75 motor vehicles (totalling €275,210), 48 business and office premises (totalling €9,845,083), and 5 industrial properties (totalling €415,135). If the conditions of the eruption do not change, CCS estimates that the amount of this loss, the first time in its history that it has had to deal with this type of risk, will ultimately come to about 180 million euros.

As of 16 December, the volcano appears to be showing signs that the eruption has come to an end. Up until this moment, lava flows have covered a total land area of 1,237.3 hectares (Figure 1) and have destroyed a total of 2,988 buildings according to the Copernicus-EMS service.

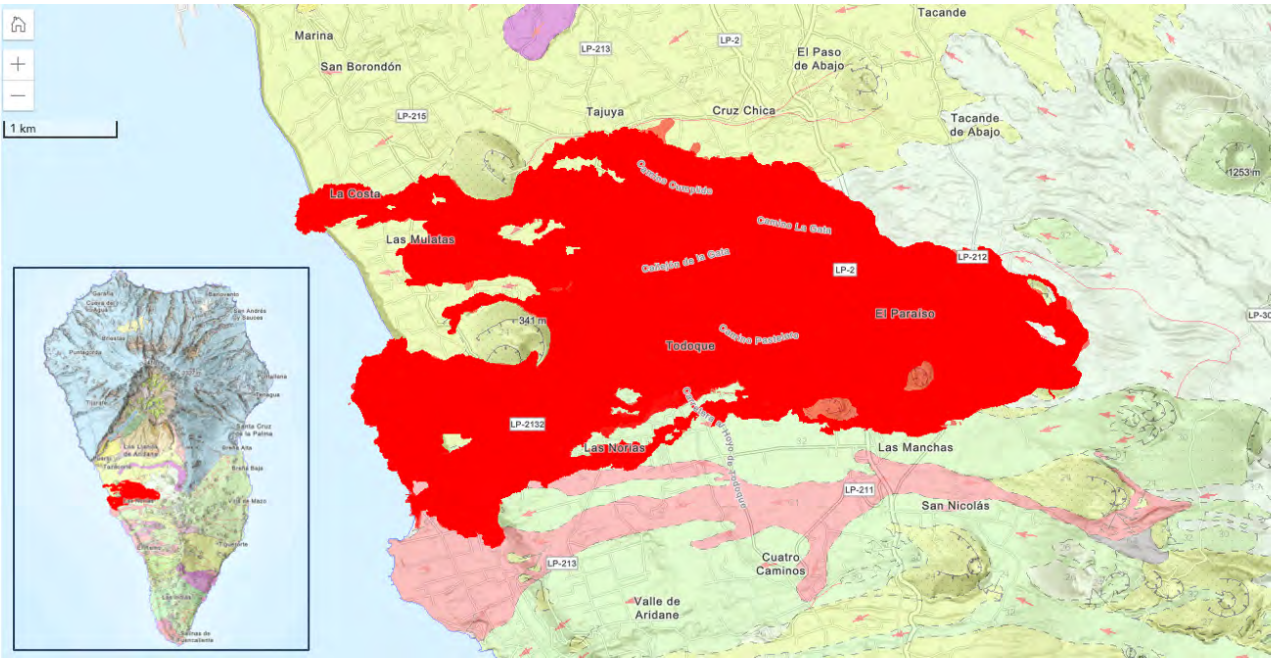

Figure 1. Areas affected by lava flows as of 16 December 2021.
Source: Spanish Geological Survey [IGME]-Spanish National Research Council [CSIC].

The day after the eruption began, on 20 September, the Consorcio de Compensación de Seguros (CCS) issued its first informative note, reminding that volcanic eruptions were one of the perils covered by the extraordinary risk insurance scheme and that the CCS would cover damage to insured property. In that note CCS therefore announced that damage to homes or condominiums, motor vehicles, office premises, commercial establishments and service facilities, other non-industrial buildings, industry, and civil works and infrastructure, whether publicly or privately owned, would be covered by CCS, provided that the property in question was insured.

By 22 September, just three days after the eruption started, CCS had already received the first 40 claims for losses, and these were immediately assigned to claims adjusters. CCS put on extra staff at its Call Centre and kept the lines open on weekends. It should be noted that claims may also be submitted on the CCS' website at all times without restriction, or through the Call Centre, which operates according to a schedule that can be expanded when demand is high, as on this occasion. To complicate matters, this event coincided with numerous episodes of flooding on the southern and eastern coast of mainland Spain.

CCS' policy is to handle claims made under the extraordinary risk insurance scheme within specified time limits, and under that policy the first indemnities for losses are to begin to be paid out within the first 10 days of an event. This case has been no exception, and as of 30 September more than 600,000 euros had already been paid out for damage to homes.

This event has, however, had certain special features. CCS allows claims for losses to be made by the insured, or by the original insurer or the broker on behalf of the insured, and this was also done in this case. Nevertheless, on the assumption that in many instances the documents of the insured had been destroyed inside the insured buildings, on this occasion CCS recommended that claims be filed by brokers or the insurers, because they also had the documents needed to start processing claims. CCS has thus, ex officio, carried out a good part of the procedures before the Land Registry Office, credit institutions and insurance companies to obtain information and clarifications, avoiding the policyholders having to do them.

Another special circumstance peculiar to this event is that in most cases the adjusters have not been able to inspect the properties that suffered the losses, because access had been cut off for obvious safety reasons on account of continuous overlap of lava flows. This has made it necessary to resort to using information obtained by satellite and by drones and then superposing the information collected on the cadastral survey maps to identify properties. Total losses of the properties were verified in most of these cases (Figures 2 and 3). More conventional claims adjustment has been possible in many cases where the damage has been caused by ashfall.

CCS also announced the conditions for indemnifying losses, namely, the usual for extraordinary risks: indemnification up to the limit of the sum insured in the original policy. Business interruption or losses because homes had been made uninhabitable were also covered if included in the original policy. Indemnities for damage to commercial and industrial properties and civil engineering works would be subject to the statutory deductible of 7%.

It was also announced that ashfall damage that could be confirmed by claims adjusters (Figure 4) would also be considered to be eruption damage and indemnified accordingly, including the cost of cleaning up the insured property.

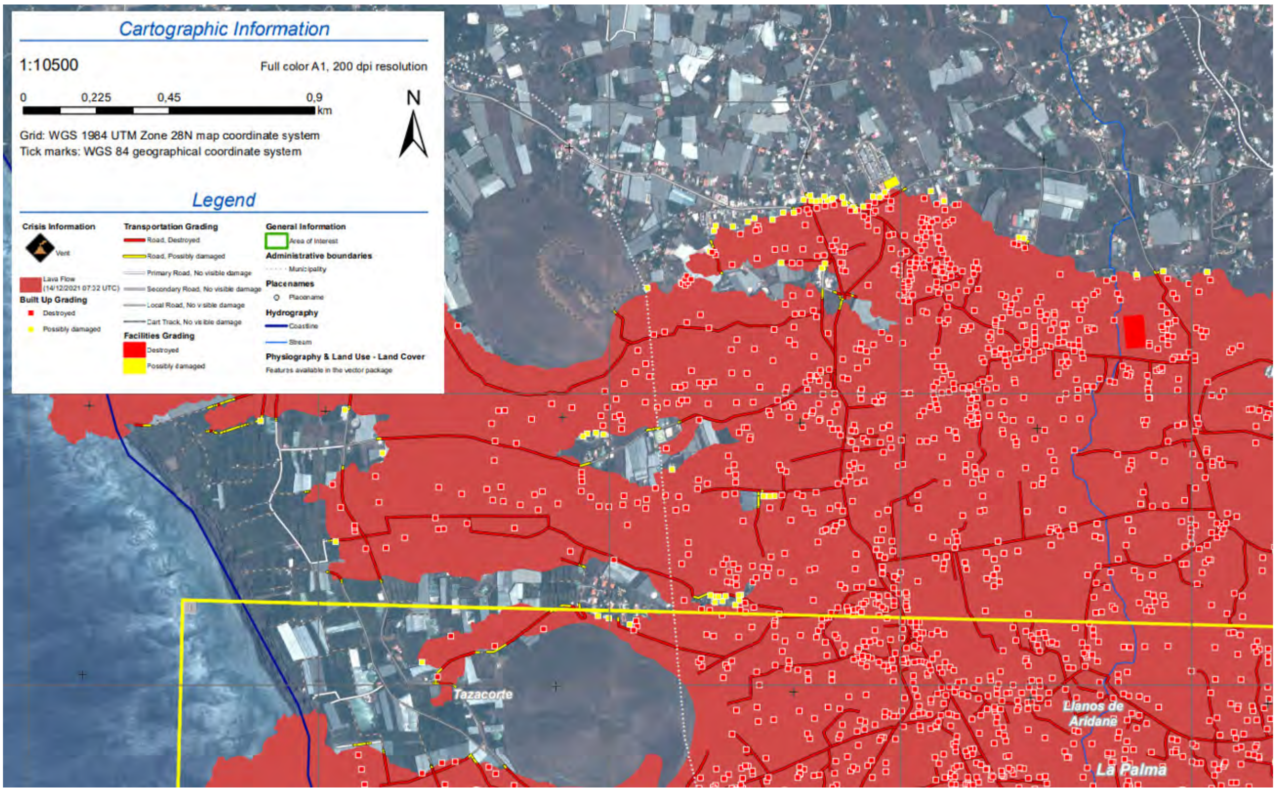

Figure 2. Example of visualisation of areas and properties destroyed (shown in red) or affected (shown in yellow) by the lava flows.
Source: Copernicus-EMS.

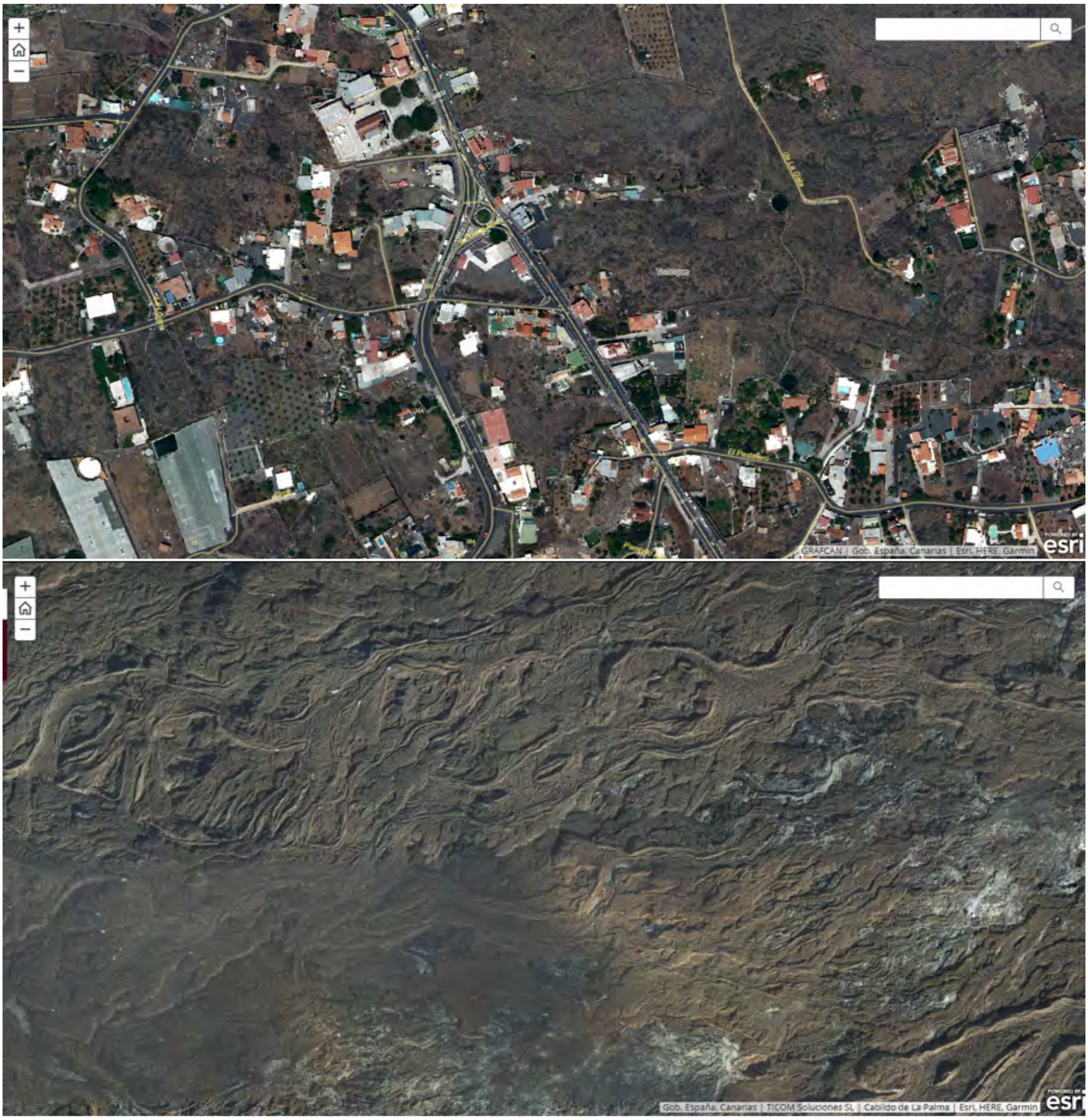

Figure 3. Before and after the eruption in the vicinity of Todoque in the municipality of Los Llanos de Aridane. Source: La Palma Island Government viewer.

According to law, there is a 7-day waiting period from when an insurance policy has been signed or the sums insured under a pre-existing policy have been modified and entry into force of the CCS' extraordinary risk covers or of the updated policy terms under the extraordinary risk insurance scheme. CCS decided to take, as a general rule, the date on which the lava or ash damaged each individual property as the date of the loss, where a date could be established, instead of the starting date of the eruption.

By 16 December 2021 CCS had received a total of 2,632 claim applications for 2,160 homes; 201 motor vehicles; 252 business, hotel, and office premises; and 18 industrial properties spread among all the island's municipalities (Figure 5). Damage in the areas closest to the volcano's vents (Llanos de Aridane, El Paso, and Tazacorte) was caused mainly by lava flows. In the other areas damage was caused chiefly by ashfall and seismic activity. In 44% of cases claim applications were submitted by insurers and in 34% of cases by brokers, both acting on behalf of the insured who had suffered the losses. In 22% of cases the claims were submitted directly by the insured. By method of submission, 54% of claims have been filed using the CCS' website and 46% through the Call Centre.

Figure 4. Ash build-up.
Source: CCS.

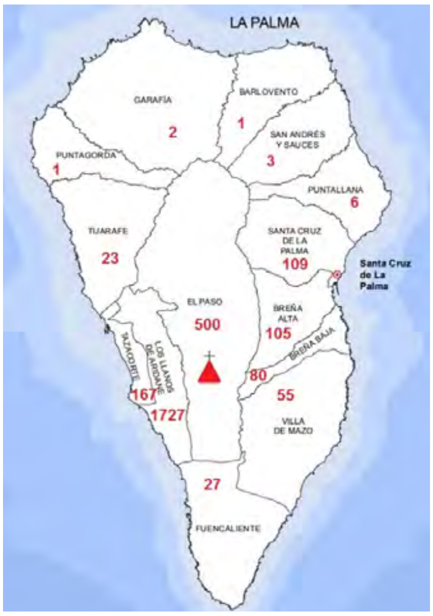

Figure 5. Source of the claims submitted to the CCS by municipality as of 16 December 2021.
Source: CCS.

As of that date, CCS had paid out 73,484,337 euros as compensation for 419 homes (totalling €62,948,909), 75 motor vehicles (totalling €275,210), 48 business and office premises (totalling €9,845,083), and 5 industrial properties (totalling €415,135). If the conditions of the eruption do not change, CCS estimates that the amount of this loss, the first time in its history that it has had to deal with this type of risk, will ultimately come to about 180 million euros.

Figure 6. The new Cumbre Vieja Volcano (La Palma) on 17 December 2021.
Source: CCS.

Acknowledgments: To the Geological Survey of Spain (IGME), to the Spanish Emergency Military Unit (UME) and to the other bodies and security forces of the State, for their work in the management of this eruption and for facilitating the work of the Consorcio de Compensación de Seguros in claims handling.

Review of valuations of volcanic risk. How they apply to the La Palma event

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Introduction

Coverage of volcanic eruptions by Spain's *Consorcio de Compensación de Seguros (CCS)* dates back to issue of the Spanish Law on recasting the Property and Accident Insurance Catastrophe Compensation Funds into a single "Insurance Compensation Fund" also covering Livestock, Forestry, and Agricultural Insurance [*Ley de 16 de diciembre de 1954 sobre refundición de los Consorcios de Compensación de Riesgos Catastróficos sobre las Cosas y de Accidentes Individuales en un solo "Consorcio de Compensación de Seguros" e integrando en el mismo los Seguros Agrícolas, Forestales y Pecuarios*].

That Law provided that one of the Consorcio's functions would be to serve as a compensation fund for non-personal risk insurance lines covering losses to insured risks produced by unusual or exceptional causes not covered by ordinary private insurance policies.

> The order of magnitude of the exposed sum insured on the island of La Palma in 2013, 4,876 million euros for property damage and pecuniary losses, 4,464 and 412 million euros, respectively, reported in the AON Benfield study, was consistent with the exposure on the island of La Palma in 2021, 5,316 million euros for property damage and pecuniary losses based on SIR (insurers' extraordinary risk surcharge reporting system) data.

The Decree of 13 April 1956 approving the Implementing Regulations for the Law of 16 December 1954 stipulated that the 'extraordinary' risks covered would explicitly cover volcanic eruptions.

There is no record of any losses covered by CCS for this reason until the volcanic eruption on La Palma in September 2021, because the eruption at El Hierro in October 2011 took place under the ocean and did not cause any covered damage, and there is no record of any damage caused by the eruption of the Teneguía Volcano in October 1971.

Even though CCS has not had to face an event of this kind until now, in recent years a series of approximations into the cost that would arise in the event of a possible volcanic eruption event have been performed.

This study compares the three available approximations estimating the cost of damage from volcanic eruptions in Spain covered by the Fund with the projected cost of the current La Palma event based on updated data as of 11 December 2021.

Valuations of volcanic risk

The three valuations available to the Fund were prepared by:

- Consorcio de Compensación de Seguros.
- The Spanish Geological Survey [*Instituto Geológico y Minero de España (IGME)*].
- AON Benfield, an external consultant engaged by CCS.

The methodology used and the results obtained by each of these valuations are briefly described below.

Valuation performed by CCS

"EXPANDED VALUATION OF THE ECONOMIC IMPACT OF CATASTROPHIC RISKS ON CCS", report from February 2014

The purpose of this study was to estimate the risk to CCS represented by its coverage of catastrophic events in Spain under the exceptional risk insurance scheme in terms of both expected loss rates and potential deviations to that rate and to assign a probability of occurrence.

The records on historical eruptions in the Canary Islands span 16 eruptions over the period from 1430 to 2012 (583 years) affecting La Palma, Tenerife, Lanzarote, and El Hierro.

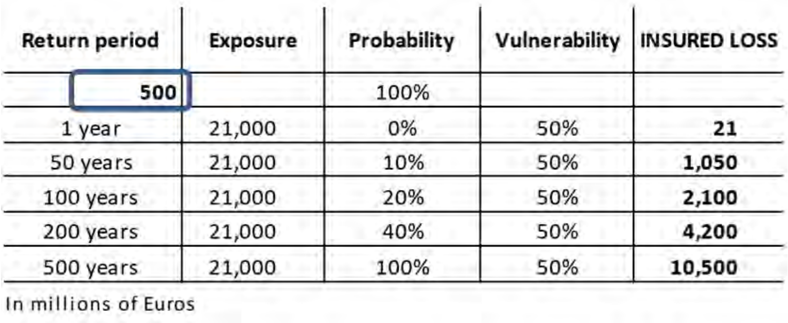
Island	Year	Eruption	Time span
La Palma	1430/1440?	Tacande or Montaña Quemada	?
	1585	Tehuya	19 May-10 Aug
	1646	Martín or Tigalate	2 Oct-21 Dec
	1677-1678	San Antonio	17 Nov-21 Jan
	1712	El Charco	9 Oct-3 Dec
	1949	San Juan or Nambroque	24 Jun-30 Jul
	1971	Teneguía	26 Oct-18 Nov
Tenerife	1492	Boca Cangrejo	?
	1704/1705	Siete Fuentes	31 Dec-4-5 Jan
		Fasnia	5-16 Jan
		Arafo	2 Feb-27 Mar
	1706	Garachico or Montaña Negra	5 May-13 Jun
	1798	Chahorra or Narices Del Teide	9 Jun-14-15 Sep
	1909	Chinyero	18-27 Nov
Lanzarote	1730-36	Timanfaya	1 Sep-16 Abr
	1824	Tao or Clérigo Duarte	31-Jul
		Nuevo Del Fuego or Chinero	29 Sep-5 Oct
		Tinguatón or Volcán Nuevo	16-24 Oct
El Hierro	1793	Lomo Negro	?
	2011-2012	South of La Restinga (offshore)	10 Oct-5 Mar

Table 1. Historical record of volcanic eruptions in the Canary Islands.
Source: "GeoMEP: Loss model by geological hazards. Technical Memory." Spain's Geological Survey (IGME) and CCS - May 2014.

Reliable data on the damage caused by the various events being extremely hard to obtain, a historical simulation was run based solely on one extreme event, i.e., the Timanfaya eruption in 1730, which was assigned a return period of 500 years and an impact equal to the destruction of 50% of the insured property on the island of Lanzarote.

Accordingly, the following assumptions were taken as the basis for this assessment: (i) only one event occurs every 500 years; (ii) the event takes place on the island of Lanzarote; (iii) it destroys 50% of the insured sums exposed on the island; and (iv) the insured sums exposed on the island total 21,000 million euros.

On that basis, it follows that quantification of the risk (Risk = Exposure x Vulnerability x Probability of occurrence) was:

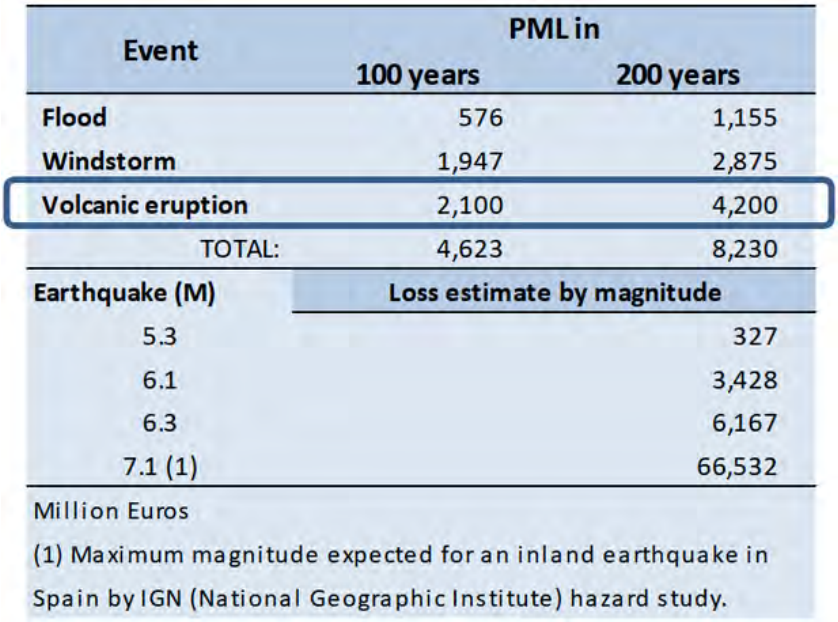


Return period	Exposure	Probability	Vulnerability	INSURED LOSS
500		100%		
1 year	21,000	0%	50%	**21**
50 years	21,000	10%	50%	**1,050**
100 years	21,000	20%	50%	**2,100**
200 years	21,000	40%	50%	**4,200**
500 years	21,000	100%	50%	**10,500**

In millions of Euros

Table 2. CCS valuation of volcanic eruption risk in Spain. (Lanzarote scenario).

The assessment results are set forth in the following Table, which compares the relative importance of volcanic eruptions to such other hazards as floods, storms, and earthquakes.



Event	**PML in**	
	100 years	**200 years**
Flood	576	1,155
Windstorm	1,947	2,875
Volcanic eruption	2,100	4,200
TOTAL:	4,623	8,230
Earthquake (M)	**Loss estimate by magnitude**	
5.3		327
6.1		3,428
6.3		6,167
7.1 (1)		66,532

Million Euros

(1) Maximum magnitude expected for an inland earthquake in Spain by IGN (National Geographic Institute) hazard study.

Table 3. Probable Maximum Losses (PML) by return period.
Source: "Expansion of the loss assessment of catastrophic risks for Consorcio de Compensación de Seguros" - February 2014.

Valuation by the Spanish Geological Survey (IGME)

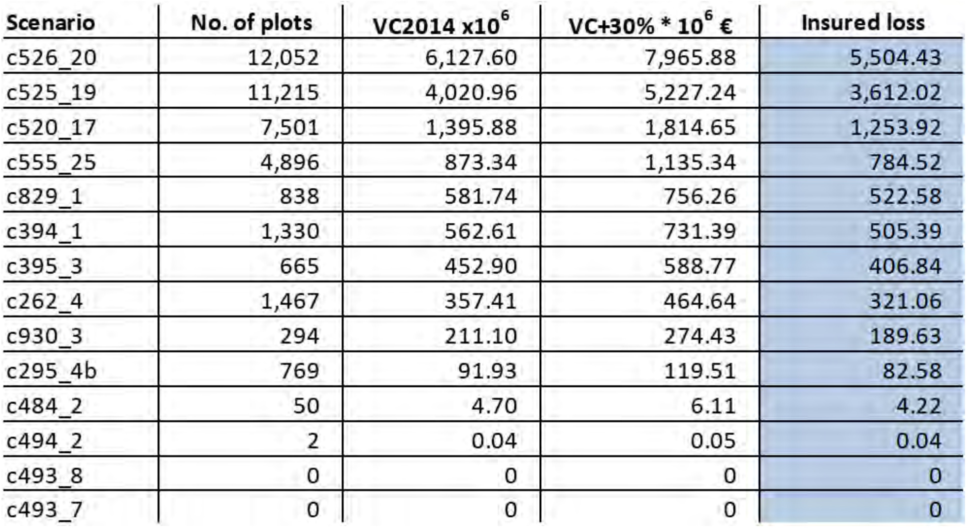
«GeoMEP: ASSESSMENT MODEL FOR LOSSES DUE TO GEOLOGICAL HAZARDS», report on the Canary Islands from May 2014

This assessment of volcanic eruptions was based on the premise of lava flows. A total of 14 scenarios were considered, all on the island of Tenerife.

No reconstruction or repair ratio was used for volcanic risk, because damage was assumed to be total and the cost equal to the assessed value of the properties plus contents in each of the selected scenarios.

Study assumptions: (i) 14 scenarios on the island of Tenerife were selected, all sharing the attribute of being areas with moderate to high vulnerability; (ii) the scenarios ranged from minor to maximum expected damage; (iii) all were considered to have the same probability of occurrence (threat level), not specified, hence there was no association between the loss rate and the return periods; (iv) exposure was restricted to each of the 14 scenarios, so vulnerability was 100% of exposure.

The results of this assessment yielded insured losses of **between 0 and 5,504 million euros, depending on the area (scenario)** concerned:



Scenario	No. of plots	VC2014 x10^6	VC+30% * 10^6 €	Insured loss
c526_20	12,052	6,127.60	7,965.88	5,504.43
c525_19	11,215	4,020.96	5,227.24	3,612.02
c520_17	7,501	1,395.88	1,814.65	1,253.92
c555_25	4,896	873.34	1,135.34	784.52
c829_1	838	581.74	756.26	522.58
c394_1	1,330	562.61	731.39	505.39
c395_3	665	452.90	588.77	406.84
c262_4	1,467	357.41	464.64	321.06
c930_3	294	211.10	274.43	189.63
c295_4b	769	91.93	119.51	82.58
c484_2	50	4.70	6.11	4.22
c494_2	2	0.04	0.05	0.04
c493_8	0	0	0	0
c493_7	0	0	0	0

Table 4. Insured loss by scenario concerned.
Source: "GeoMEP: Loss model by geological hazards. Technical Memory." Spain's Geological Survey (IGME) and CCS - May 2014.

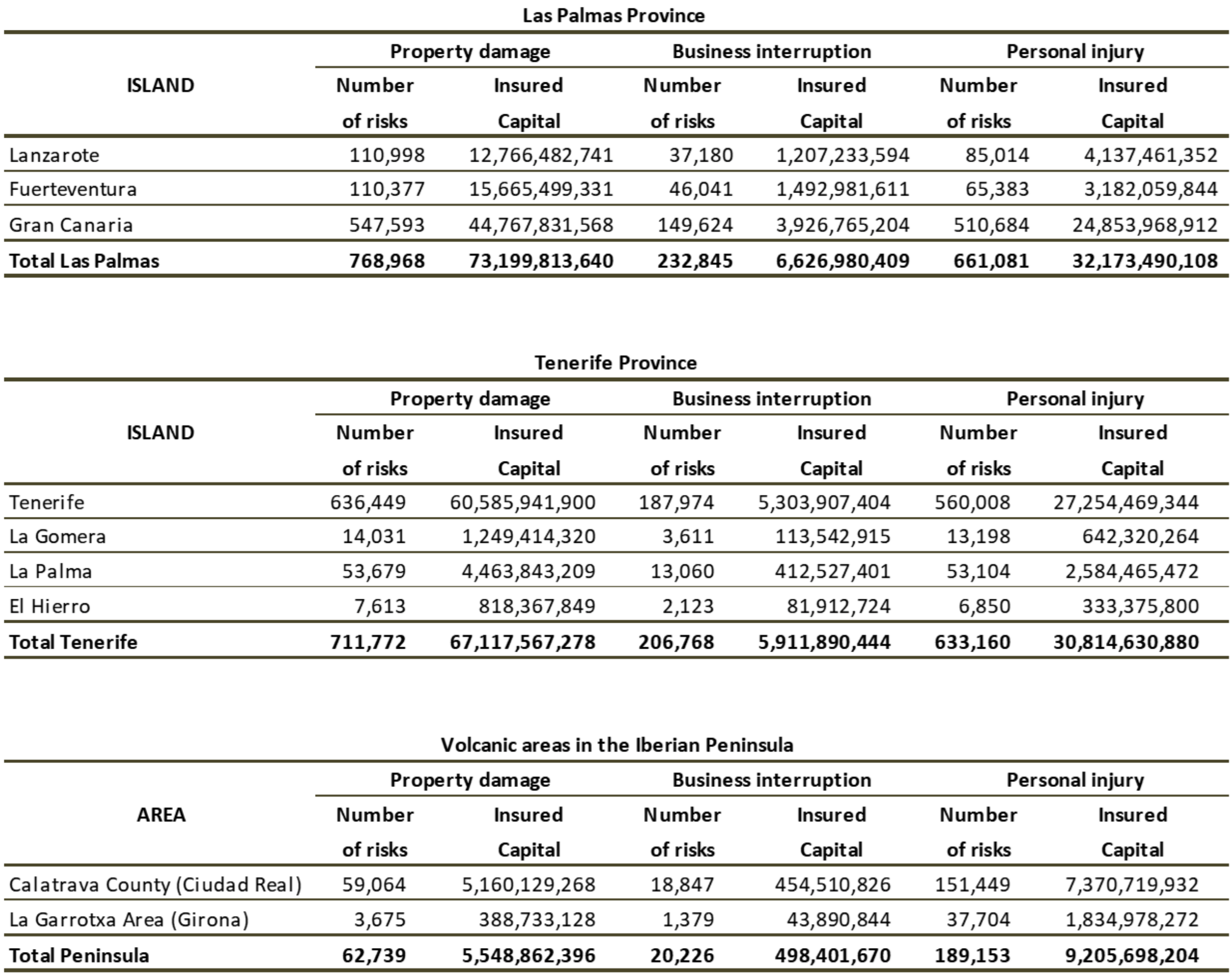
Aon Benfield valuation

«CONSORCIO DE COMPENSACIÓN DE SEGUROS: VALUATION OF CATASTROPHE HAZARDS», report from July 2014

This study suggested that volcanic eruptions were a hazard that had not benefited from commercial modelling and classified it as the most dangerous of all the natural perils covered by CCS in terms of the ratio of losses to the exposed sums insured.

The study used a combined experience-exposure approach.

It was based on the following total exposure to volcanic risk in Spain in 2013:



Las Palmas Province

ISLAND	Property damage		Business interruption		Personal injury	
	Number of risks	Insured Capital	Number of risks	Insured Capital	Number of risks	Insured Capital
Lanzarote	110,998	12,766,482,741	37,180	1,207,233,594	85,014	4,137,461,352
Fuerteventura	110,377	15,665,499,331	46,041	1,492,981,611	65,383	3,182,059,844
Gran Canaria	547,593	44,767,831,568	149,624	3,926,765,204	510,684	24,853,968,912
Total Las Palmas	**768,968**	**73,199,813,640**	**232,845**	**6,626,980,409**	**661,081**	**32,173,490,108**

Tenerife Province

ISLAND	Property damage		Business interruption		Personal injury	
	Number of risks	Insured Capital	Number of risks	Insured Capital	Number of risks	Insured Capital
Tenerife	636,449	60,585,941,900	187,974	5,303,907,404	560,008	27,254,469,344
La Gomera	14,031	1,249,414,320	3,611	113,542,915	13,198	642,320,264
La Palma	53,679	4,463,843,209	13,060	412,527,401	53,104	2,584,465,472
El Hierro	7,613	818,367,849	2,123	81,912,724	6,850	333,375,800
Total Tenerife	**711,772**	**67,117,567,278**	**206,768**	**5,911,890,444**	**633,160**	**30,814,630,880**

Volcanic areas in the Iberian Peninsula

AREA	Property damage		Business interruption		Personal injury	
	Number of risks	Insured Capital	Number of risks	Insured Capital	Number of risks	Insured Capital
Calatrava County (Ciudad Real)	59,064	5,160,129,268	18,847	454,510,826	151,449	7,370,719,932
La Garrotxa Area (Girona)	3,675	388,733,128	1,379	43,890,844	37,704	1,834,978,272
Total Peninsula	**62,739**	**5,548,862,396**	**20,226**	**498,401,670**	**189,153**	**9,205,698,204**

Table 5. Distribution of risks and sums insured across volcanic regions.
Source: "CCS: AON Benfield risk assessment." July 2014.

Accordingly, exposure to property damage and pecuniary losses (exposure of individuals was not contemplated) in Spain as a whole in 2013 came to around 160 billion euros.

External data taken from the Smithsonian Institution were used to ascertain frequency, as set out below:

Volcanic area	Event Number	Considered time span	Return period	Probability
La Garrotxa	0	n.d.	n.d.	0.0105%*
Calatrava County	1	5144	5144	0.0196%
La Palma	13	6864	528	0.1894%
El Hierro	7	6804	972	0.1029%
Tenerife	45	9564	213	0.4705%
Gran Canaria	11	6609	601	0.1664%
Fuerteventura	0	n.d.	n.d.	0.0105%*
Lanzarote	4	1464	366	0.2732%
Total Canary Islands	**80**	**9564**	**120**	**0.8365%**
Total Spain	**81**	**9564**	**118**	**0.8469%**

* For the volcanic areas of La Garrotxa and Fuerteventura, being no likely events documented, we apply a probability of at least one event in 9564 years (equal to the longest considered time span).

Table 6. Frequency of events – Volcanic eruptions.
Source: "CCS: AON Benfield risk assessment." July 2014.

The Volcanic Explosivity Index (VEI), a scale of from 0 to 8, was used for vulnerability and yielded the following percentage values:

VEI	% of total loss of insured value
0	0.0001%
1	0.0010%
2	0.1000%
3	1%
4	10%
5	100%
6	100%
7	100%
8	100%

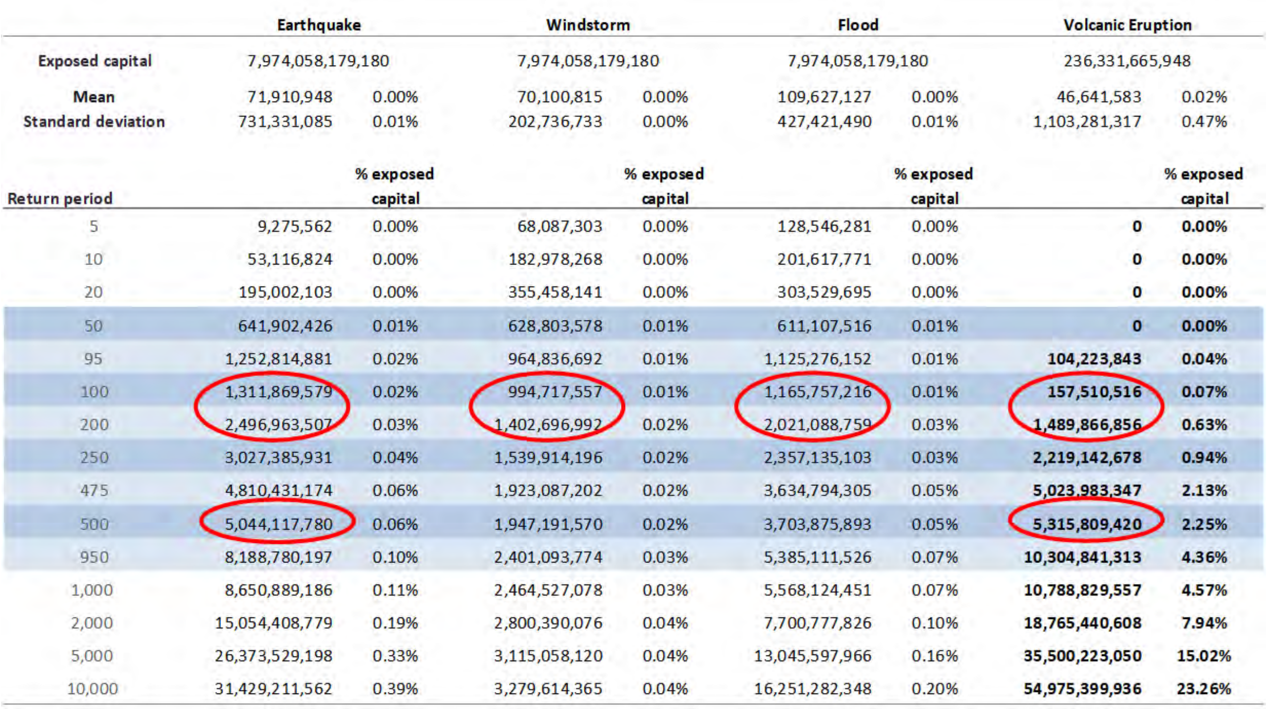
Table 7. Vulnerability according to the VEI.
Source: "CCS: AON Benfield risk assessment." July 2014.

The average for Spain was 2 on the VEI scale:

VEI	No. of eruptions	Areas
0	2	El Hierro and Tenerife
2	11	La Palma, El Hierro, Tenerife and Lanzarote
3	2	Tenerife and Lanzarote
4	1	Tenerife
Total	**16**	**Mean VEI: 2**

Table 8. Mean vulnerability in Spain.
Source: "CCS: AON Benfield risk assessment." July 2014.

The following table sets out the results obtained by this study for all hazards for Spain as a whole by type of damage (property damage, business interruption, and personal injury).

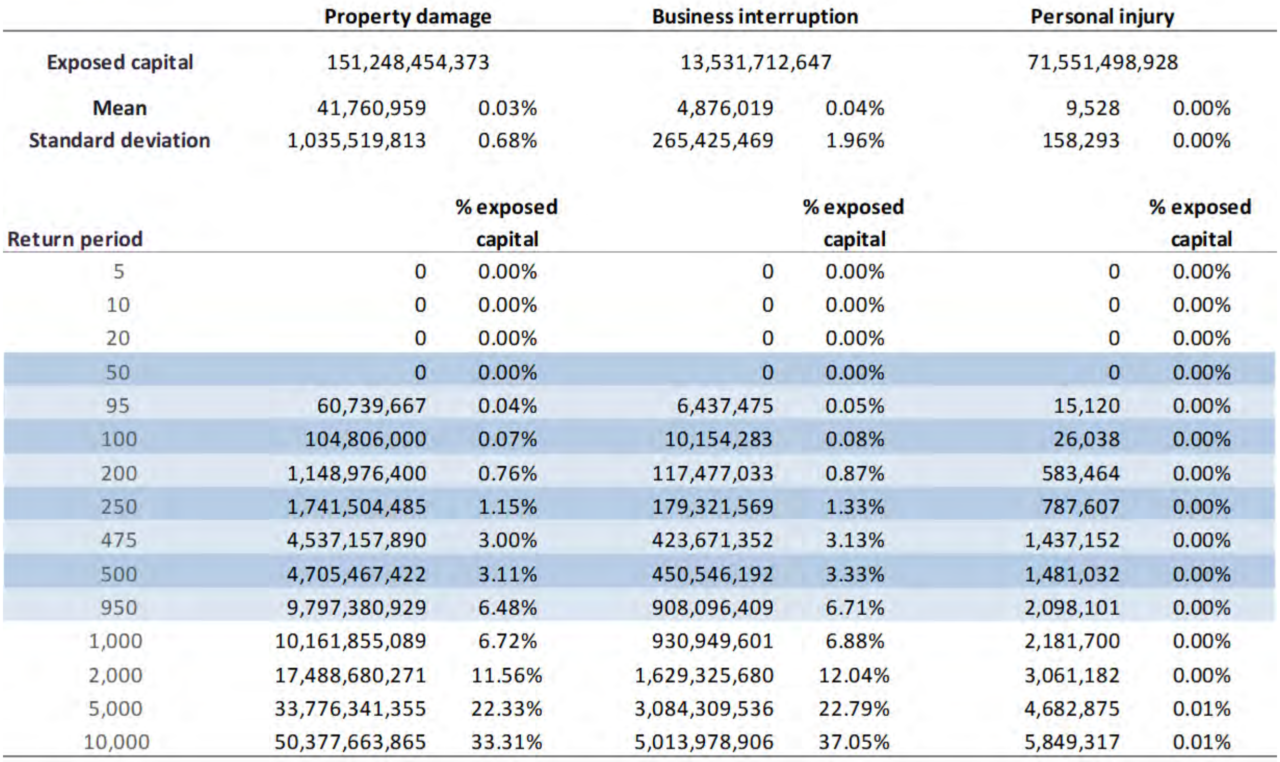


	Earthquake		Windstorm		Flood		Volcanic Eruption	
Exposed capital	7,974,058,179,180		7,974,058,179,180		7,974,058,179,180		236,331,665,948	
Mean	71,910,948	0.00%	70,100,815	0.00%	109,627,127	0.00%	46,641,583	0.02%
Standard deviation	731,331,085	0.01%	202,736,733	0.00%	427,421,490	0.01%	1,103,281,317	0.47%
Return period		**% exposed capital**		**% exposed capital**		**% exposed capital**		**% exposed capital**
5	9,275,562	0.00%	68,087,303	0.00%	128,546,281	0.00%	**0**	**0.00%**
10	53,116,824	0.00%	182,978,268	0.00%	201,617,771	0.00%	**0**	**0.00%**
20	195,002,103	0.00%	355,458,141	0.00%	303,529,695	0.00%	**0**	**0.00%**
50	641,902,426	0.01%	628,803,578	0.01%	611,107,516	0.01%	**0**	**0.00%**
95	1,252,814,881	0.02%	964,836,692	0.01%	1,125,276,152	0.01%	**104,223,843**	**0.04%**
100	1,311,869,579	0.02%	994,717,557	0.01%	1,165,757,216	0.01%	**157,510,516**	**0.07%**
200	2,496,963,507	0.03%	1,402,696,992	0.02%	2,021,088,759	0.03%	**1,489,866,856**	**0.63%**
250	3,027,385,931	0.04%	1,539,914,196	0.02%	2,357,135,103	0.03%	**2,219,142,678**	**0.94%**
475	4,810,431,174	0.06%	1,923,087,202	0.02%	3,634,794,305	0.05%	**5,023,983,347**	**2.13%**
500	5,044,117,780	0.06%	1,947,191,570	0.02%	3,703,875,893	0.05%	**5,315,809,420**	**2.25%**
950	8,188,780,197	0.10%	2,401,093,774	0.03%	5,385,111,526	0.07%	**10,304,841,313**	**4.36%**
1,000	8,650,889,186	0.11%	2,464,527,078	0.03%	5,568,124,451	0.07%	**10,788,829,557**	**4.57%**
2,000	15,054,408,779	0.19%	2,800,390,076	0.04%	7,700,777,826	0.10%	**18,765,440,608**	**7.94%**
5,000	26,373,529,198	0.33%	3,115,058,120	0.04%	13,045,597,966	0.16%	**35,500,223,050**	**15.02%**
10,000	31,429,211,562	0.39%	3,279,614,365	0.04%	16,251,282,348	0.20%	**54,975,399,936**	**23.26%**

Table 9. Distribution of Maximum Loss per Event (extraordinary risks).
Source: "CCS: AON Benfield risk assessment." July 2014.

This Table describes the weight of each of the main extraordinary risks covered by CCS.

The loss data included personal injury, though as shown by the following Table, personal injuries caused by volcanoes are of limited consequence:



	Property damage		Business interruption		Personal injury	
Exposed capital	151,248,454,373		13,531,712,647		71,551,498,928	
Mean	41,760,959	0.03%	4,876,019	0.04%	9,528	0.00%
Standard deviation	1,035,519,813	0.68%	265,425,469	1.96%	158,293	0.00%
Return period		**% exposed capital**		**% exposed capital**		**% exposed capital**
5	0	0.00%	0	0.00%	0	0.00%
10	0	0.00%	0	0.00%	0	0.00%
20	0	0.00%	0	0.00%	0	0.00%
50	0	0.00%	0	0.00%	0	0.00%
95	60,739,667	0.04%	6,437,475	0.05%	15,120	0.00%
100	104,806,000	0.07%	10,154,283	0.08%	26,038	0.00%
200	1,148,976,400	0.76%	117,477,033	0.87%	583,464	0.00%
250	1,741,504,485	1.15%	179,321,569	1.33%	787,607	0.00%
475	4,537,157,890	3.00%	423,671,352	3.13%	1,437,152	0.00%
500	4,705,467,422	3.11%	450,546,192	3.33%	1,481,032	0.00%
950	9,797,380,929	6.48%	908,096,409	6.71%	2,098,101	0.00%
1,000	10,161,855,089	6.72%	930,949,601	6.88%	2,181,700	0.00%
2,000	17,488,680,271	11.56%	1,629,325,680	12.04%	3,061,182	0.00%
5,000	33,776,341,355	22.33%	3,084,309,536	22.79%	4,682,875	0.01%
10,000	50,377,663,865	33.31%	5,013,978,906	37.05%	5,849,317	0.01%

Table 10. Distribution of Maximum Loss per Event (volcanic eruptions).
Source: "CCS: AON Benfield risk assessment." July 2014.

Data for the La Palma eruption in 2021

In this section are shown, separately, exposure data on the Island of La Palma, that is to say, the value of insured property damage and business interruption and, on the other hand, the currently known losses in property damage from the 2021 eruption process.

Insured value in property damage and business interruption on the island of La Palma

CCS' risk exposure was estimated based on data from the insurers' extraordinary risk surcharge reporting system (abbreviated SIR after the Spanish, "sistema de información de recargos") as of 31 July 2021 and was put at:

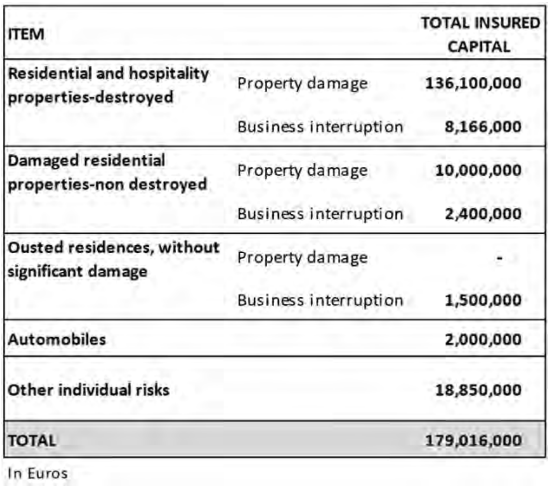
- Property damage exposure in the whole Island of La Palma 2021 = 5,124 million euros.
- Business interruption exposure in the whole Island of La Palma 2021 = 192 million euros.
- **Property damage plus business interruption exposure in the whole Island of La Palma = 5,124 + 192 = 5,316 million euros.**

It includes all categories (residential, business, other property, and motor vehicles) but not individual life and accident cover exposures.

It shows that the order of magnitude of the exposed sum insured on the island of La Palma in 2013, 4,876 million euros for property damage and pecuniary losses, 4,464 and 412 million euros, respectively, reported in the AON Benfield study, was consistent with the exposure on the island of La Palma in 2021, 5,316 million euros for property damage and pecuniary losses based on SIR data.

Actual loss on insured properties from the 2021 volcanic eruption in La Palma.

The expected loss for CCS from the eruption event of the last quarter of 2021 in La Palma, that at the moment of writing is showing clear signs of being near its end, after the information updated on 11 December 2021, comes to:



ITEM		TOTAL INSURED CAPITAL
Residential and hospitality properties-destroyed	Property damage	136,100,000
	Business interruption	8,166,000
Damaged residential properties-non destroyed	Property damage	10,000,000
	Business interruption	2,400,000
Ousted residences, without significant damage	Property damage	-
	Business interruption	1,500,000
Automobiles		2,000,000
Other individual risks		18,850,000
TOTAL		179,016,000

In Euros

Table 11. Projected cost of the volcanic eruption on La Palma.

Property damage and pecuniary losses from risks not affected by lava flows, or business interruption losses from individual risks are not included, therefore the total cost for CCS is expected to be higher than this figure.

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