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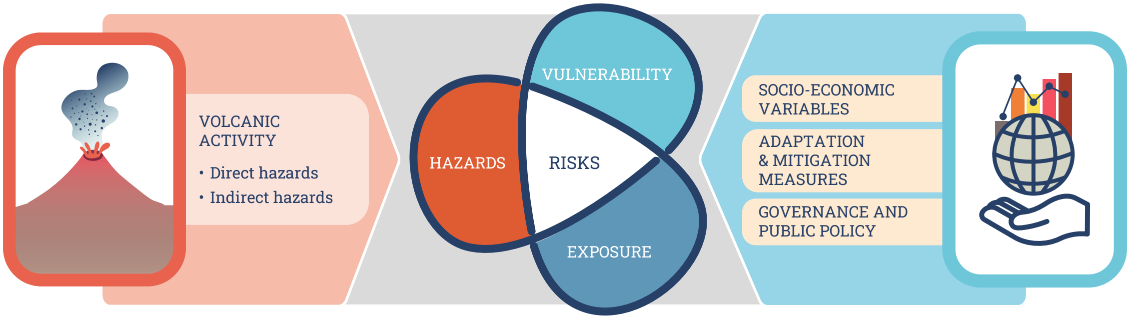
What is Volcanic Risk?

Volcanic risk is defined as the possibility of adverse consequences for life, property, infrastructure and the environment due to volcanic activity. Thus, when referring to volcanic risk, one must consider both the hazard of the natural phenomenon, i.e., the probability of occurrence of a given volcanic event, and the vulnerability and exposure of society and the ecosystem to this volcanic hazard, including the susceptibility to damage, its economic value, and the capacity to cope and adapt.

Figure 1 Venn diagram of volcanic risk



(*) Diagram modified from the 5th Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), the UN body for assessing the science related to climate change.

Currently, more than 800 million people around the world live in the vicinity of active volcanoes and may be directly affected by volcanic eruptions. Mitigating the impact of future volcanic hazards requires an adequate forecast and early warning system for an impending eruption, which in turn requires a detailed understanding of the geological processes that control volcanic activity. In this report, we review and analyse such volcanic hazards, their assessment and the associated risk management in the long and short term, as well as during a volcanic crisis.

11.

Volcanic eruptions, why do they occur and where do they happen?

A volcano is a geological structure formed by the eruption of magma to the Earth's surface. Magma, composed of molten rock, solid rock fragments, minerals and dissolved gases, escapes through the Earth's crust in a volcanic conduit, usually creating a crater. This process, known as volcanic eruption, can give rise to a variety of geological morphologies, such as cinder cones, tephra (volcanic rock) rings, stratovolcanoes, collapse calderas, lava domes or fields.

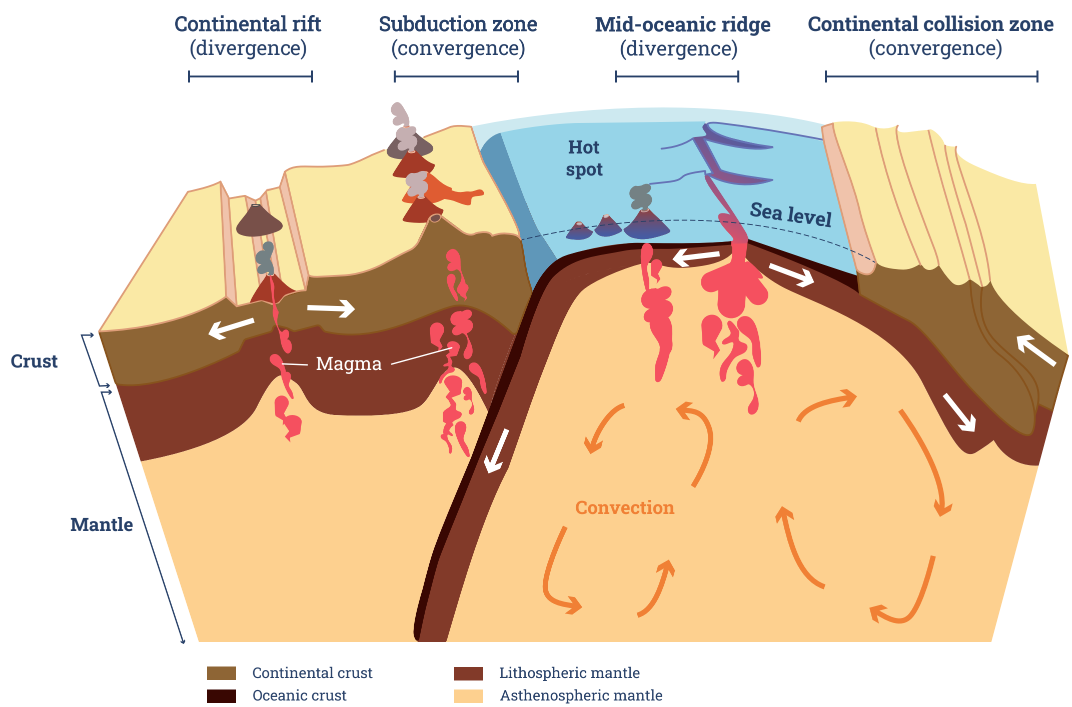
Fissure eruption at Piton de la Fournaise (France). / STÉPHANIE BARDE-CABUSSON

Volcanic eruptions are the result of a series of geological processes involving the generation, ascent and emission of magma to the surface. Thus, magma forms in the Earth's interior, where pressure and temperature conditions are suitable for melting the rocks of the mantle and, in some cases, the Earth's crust. Being less dense than the surrounding solid rock, magma manages to rise to the surface through fractures and faults (fractures accompanied by displacement) in the Earth's crust. Thus, although on

Example of an eruption at Mount Bromo volcano (Indonesia). / XAVIER BOLÓS

the geological time scale and even on the human scale, volcanic eruptions may appear to be relatively brief events, ranging from a few days to years, in reality, they are the result of geological processes that extend over hundreds of thousands or even millions of years. Volcanoes are an integral part of the Earth's evolution and have had, have and will have significant impacts on landscapes, ecosystems and human societies.

Figure 2 Volcanoes and plate tectonics

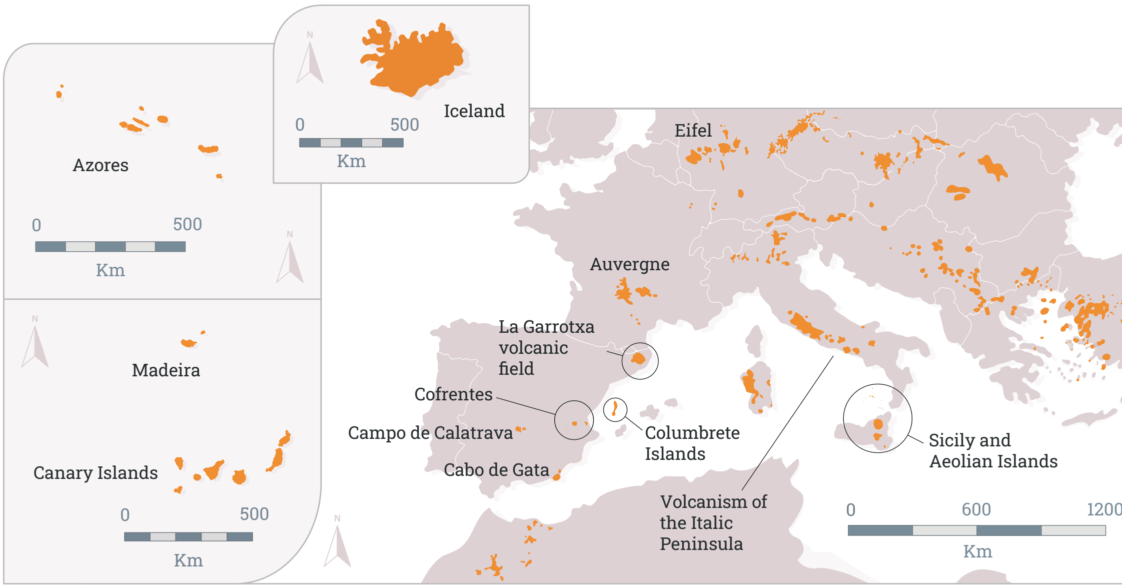


The global distribution of volcanism on the planet is not random, but is directly related to global dynamics. Active volcanoes are found where pressure and temperature conditions, or changes in the chemistry of the Earth's mantle favour the melting of the mantle and the formation of magma. This occurs mainly in two tectonic settings, convergent or divergent plate boundaries. That is, where the movement of tectonic plates causes them to collide and one sinks under the other (subduction zones) or move apart (in ridges and rift zones). Volcanic activity is mostly concentrated at the margins of ocean basins, particularly in the belt around the Pacific, the Atlantic ridge and the African rift. Finally, a modest percentage of the planet's volcanism is located within tectonic plates (intra-plate zones), such as in the Hawaiian Islands or Yellowstone in the United States, where intense volcanic activity occurs. Although the processes that give rise to this type of volcanism are still under scientific debate, one of the most widely accepted is the hotspot hypothesis.

Among the various active volcanic areas in Europe, Iceland is particularly noteworthy, with intense volcanic activity due to its location on the Mid-Atlantic ridge and a hotspot. In Italy and Greece, volcanism occurs mainly along subduction zones, where some of Europe's most famous (and destructive) volcanoes are found, with Etna in Sicily being one of the most active in the world. In the Azores Islands (Portugal), located at a triple point where the Terceira rift connects with the Mid-Atlantic Ridge, there have also been numerous signs of volcanic activity over the last centuries. Finally, the volcanic areas of Auvergne (France) and Eifel (Germany), considered active, are associated with the European Cenozoic rift system, which extends for more than a thousand kilometres from the North Sea coast to the Mediterranean, also generating volcanism in the Iberian Peninsula.

In Spain, the Canary Islands, specifically Tenerife, Lanzarote, El Hierro and La Palma, have been affected by volcanic activity since the beginning of the historical period (end of the 16th century), that is, since there are written chronicles after the conquest of the islands. Many of the eruptions that have occurred in the archipelago, such as Timanfaya (Lanzarote, 1730), the underwater volcano Tagoro (El Hierro, 2011-2012) or Tajogaite (La Palma, 2021) have caused significant economic losses and a great social impact. As far as peninsular Spain is concerned, the most recent volcanism (less than 15,000 years ago) is located in the Garrotxa Volcanic Field (Catalonia) and in the Calatrava Field (Castilla la Mancha), both also associated with the European Cenozoic rift.

Figure 3 Map of the distribution of geologically recent (Neogene-Quaternary) volcanism in Europe and the Mediterranean area (MODIFIED BY BERGER AND BODEN, 1994)



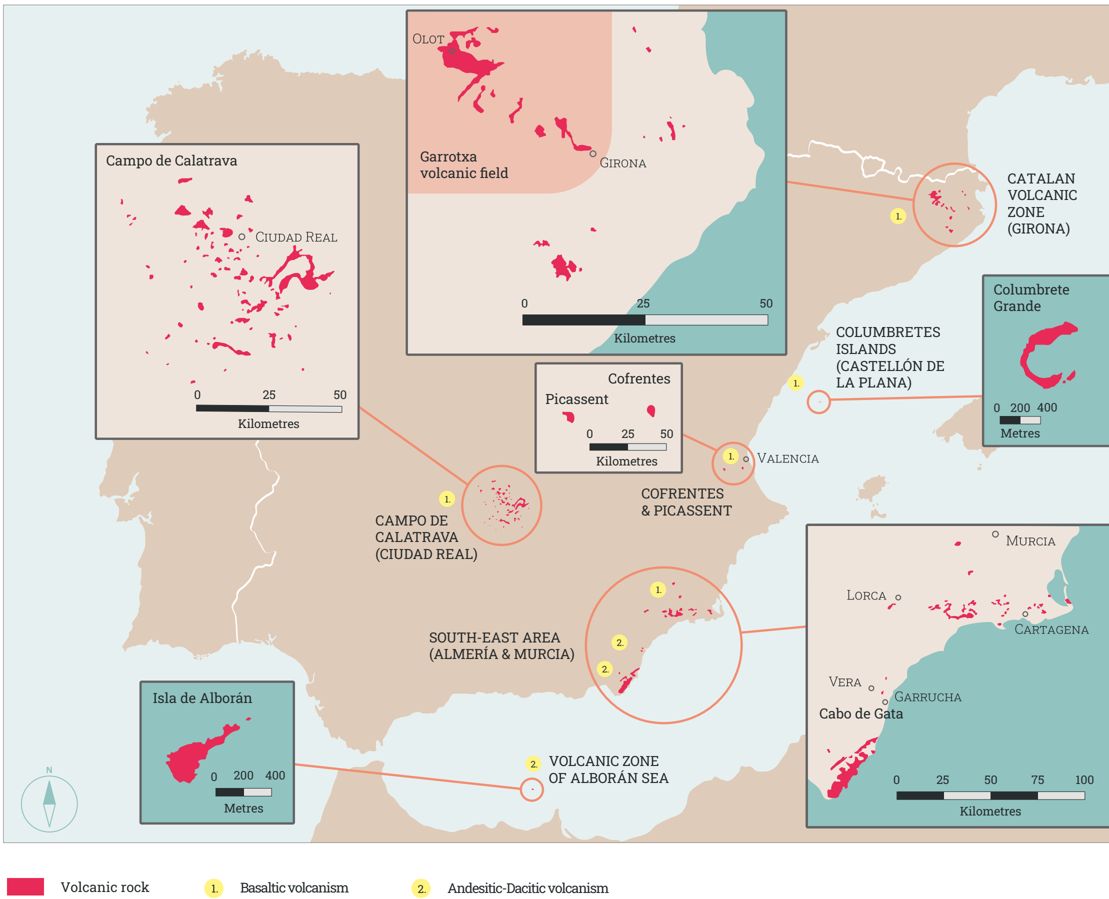
Even though the volcanism is older, although geologically recent, it is interesting to note the Columbretes Islands (Castellón), the Cofrentes volcano (Valencia) and the strip of southeast peninsular Spain, between Cabo de Gata (Almería) and the Mar Menor, as well as Alboran Island. It is also worth noting that Spain has the Gabriel de Castilla and Juan Carlos I Antarctic bases, located respectively within 35 kilometres of the active volcano on Deception Island (South Shetland Islands, Antarctica). During the austral summer, both bases host numerous research projects and scientific, technical and logistical personnel from institutions from Spain and other countries.

The contrast between the scale of geological time and human perception of time highlights the enormous temporal difference between long geological processes, and the brevity of human life and the advance of civilisation. This contrast underlines the

Figure 4 Historical volcanic eruptions in the Canary Islands

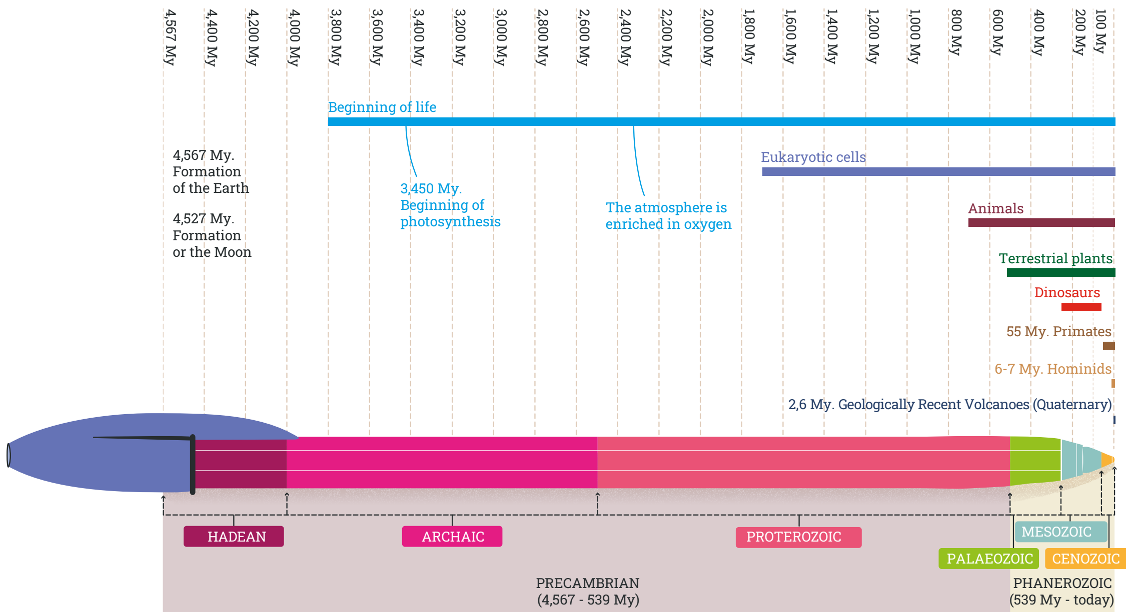
challenge of understanding, addressing and managing geological phenomena, such as volcanic processes. This is evidenced by the concept of active volcanism, which considers a volcano, or volcanic zone, to be active when its last eruption occurred in the Holocene (within the last 11,000 years or so) or when geological conditions since the last eruption have not changed. In other words, even if the last eruption occurred more than 11,000 years ago, if the conditions for magma to be generated and reach the surface remain the same, a new eruption cannot be completely ruled out. While those 11,000 years represent a brief instant in the evolution of the planet, they are perceived as an eternity on the human time scale, which often results in a low perception of risk, or false sense of security, in those populations close to a volcanically active area but who have not experienced an eruption in the last centuries or millennia.

Figure 5 Geologically recent volcanic areas (Neogene-Quaternary) in the Iberian Peninsula



In volcanology, the most crucial and, in turn, the most challenging questions to answer revolve around determining when, where and how a new eruption will occur, as they will condition the associated risks and the strategies for their study and management. In this context, it is essential to differentiate between two main types of volcanism: polygenetic and monogenetic. Polygenetic volcanoes can experience multiple eruptions over

Figure 6 Simplified geological time scale on a biro



thousands or even millions of years (e.g., Teide in Tenerife, Vesuvius and Etna in Italy, and Mount St. Helens in the USA), concentrating their activity around a single large (kilometres high) main volcanic edifice. This type of volcanism is usually associated with large volumes of magma stored a few kilometres below the surface, so the magnitude of eruptions can be colossal. In contrast, in monogenetic volcanism, each eruption produces a new volcanic edifice. Unlike polygenetic volcanoes, once the eruption is over, monogenetic volcanoes do not reactivate again, which means that they are much smaller structures, reaching only a few hundred metres in height (for example, the volcanoes Croscat in Catalonia, Chinyero in Tenerife and Paricutín in Mexico). A characteristic of monogenetic volcanism is that it results in a clustering of numerous volcanoes, forming volcanic fields with tens or hundreds of volcanic edifices that can cover large

Teide, a polygenetic volcano. / NIEVES SÁNCHEZ

geographical areas of 100 to 50,000 square kilometres. Examples are the volcanic fields of Garrotxa, with 600 km^2; Calatrava, with 5000 km^2; or Michoacán-Guanajuato in Mexico, with more than 40,000 km^2. This means that, despite the smaller size and potential impact of monogenetic eruptions, the uncertainty surrounding the location of future eruptions represents a challenge for volcanic hazard assessment.

During an eruption, either of a polygenetic or monogenetic volcano, there may be more explosive phases of activity, dispersing volcanic material and injecting gases into the atmosphere or ocean, or effusive phases, emitting lava flows. The occurrence of each of these phases is mainly conditioned by the chemical composition of the magma, its gas content and its emission rate. When the volcanic conduit opens, the magma decompresses, causing the volcanic gases, hitherto dissolved in the liquid due to the pressure, to expand and form bubbles. The explosion of these gas bubbles fragments the magma to a greater or lesser extent, generating droplets of various sizes that are propelled outwards

The Garrotxa Volcanic Field, with dozens of monogenetic volcanoes. / XAVIER BOLÓS

(pyroclasts). A similar phenomenon occurs when we open a bottle of champagne or beer and the gas dissolved in the liquid expands and generates foam. In some eruptions, this degassing can be gentle, with little fragmentation of the magma, leading to an effusive phase characterised by lava fountains and lava flows. When degassing is violent, the magma breaks up into particles of various sizes which, once cooled in the atmosphere, solidify into volcanic ash, lapilli, blocks or bombs. During these more energetic, so-called explosive eruptive phases, eruptive columns and ash clouds are formed. Although, as a first approximation, eruptions can be categorised as either effusive or explosive, there is an almost continuous spectrum of mixed eruptions, manifesting both types of activity.

The explosiveness of an eruption can also increase when magma encounters groundwater or surface water (e.g., lakes, groundwater, seawater or ice) during its ascent. Such eruptions are called hydromagmatic or hydrovolcanic eruptions and occur when very hot magma (commonly between 700 and 1300 degrees)

Fragmentation and pyroclast formation during the 2021 eruption of the Tajogaite volcano in La Palma. / ORIOL OMS Y XAVIER BOLÓS

comes into contact with low-temperature water. This produces a violent reaction capable of generating extremely energetic explosions. This process is similar to that which occurs when, during cooking, water droplets accidentally fall into a pan of hot oil. The latter, comparable to magma in an eruption, transfers its heat to the water, which instantly vaporises. This steam expands and fragments the oil, which sprays out of the frying pan at high speed. In the case of volcanic phenomena, the oil droplets expelled would be magma. This type of eruption generates significant clouds of steam, with large quantities of volcanic ash, among many of the other volcanic hazards detailed below.

Effusive activity of the Tajogaite volcano of 2021 in La Palma. / XAVIER BOLÓS

The most explosive hydromagmatic activity is typically seen when eruptions occur in lakes, in glacial areas due to the interaction of magma with meltwater, in shallow coastal waters (less than 50 metres deep) and in groundwater (aquifer) sites, in which case it is known as phreatomagmatic activity.

Conversely, when volcanic activity occurs in intermediate or deep marine waters (deeper than 200 metres), eruptions are mostly effusive or low explosive. Following the above analogy, a higher percentage of water rapidly cools the hot oil, reducing the explosiveness of the interaction, which may be zero. This fact, together with the pressure exerted by the water column, explains the low explosiveness of submarine eruptive activity at great depth, which will be given solely by the characteristics of the magma itself. These types of eruptions are difficult to observe, although sometimes floating lava globes or pumice emissions can be seen, as well as yellow or green spots on the surface of the sea.

Phreatomagmatic eruption at Poás volcano in Costa Rica. / GEOFFROY AVARD - OVISCORI

Submarine eruption in El Hierro with the town of La Restinga in the background. / XAVIER BOLÓS

12.

Volcanic hazards: a natural phenomenon

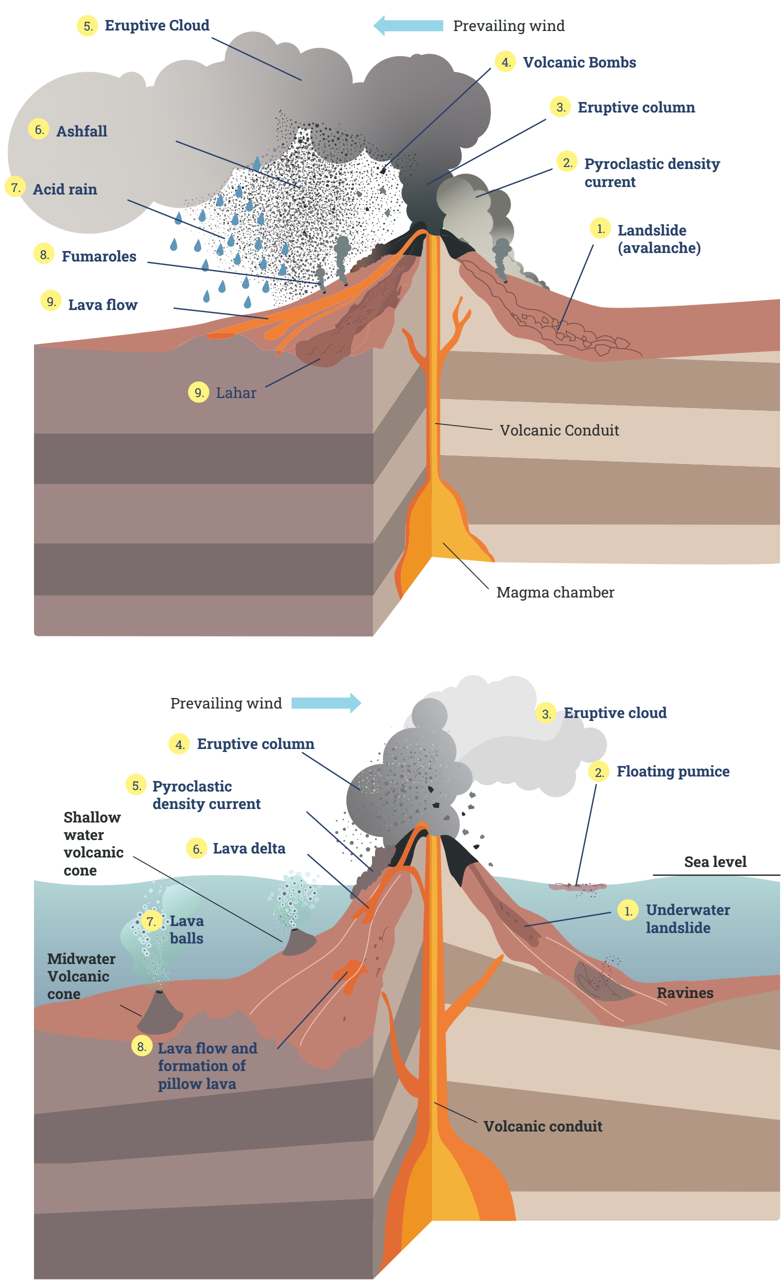
Volcanic hazards result from activity occurring at the volcano, or in the volcanic zone, before, during or after an eruption. They can be classified as direct and indirect, and can often occur simultaneously or cascade, reflecting the complexity and interconnectedness of the different hazards associated with volcanic activity.

Direct volcanic hazards are those that derive directly from volcanic activity and primarily occur during an eruption, although many can manifest themselves even before and after the release of magma to the surface. Indirect volcanic hazards, on the other hand, are secondary consequences of volcanic activity.

Direct hazards

- **Lava flows** in subaerial environments can generally be of two types:
    - **Aa:** They have a rough texture, move slowly and form thick lava flows. Their temperature usually ranges from 700°C at the surface to 1000°C in the interior.
    - **Pahoehoe:** They reach 1200°C throughout their thickness, are smooth and flow rapidly, creating characteristic rope-like shapes (cordate lava) as they cool. In underwater environments (e.g., the ocean floor, a deep lake or a water-filled cavity within a glacier), lava cools rapidly into lobes, giving rise to pillow lava.

Figure 7 Volcanic hazards on land and at sea



Pahoehoe lava at Piton-de-la-Fournaise (France). / STÉPHANIE BARDE-CABUSSON

- **Eruptive column,** or ash plumes, can rise several kilometres into the stratosphere.

Photo of an eruptive column of the Tajogaite volcano in 2021 in La Palma. / NIEVES SÁNCHEZ

- The **ash cloud and ash fall** disperse and accumulate fine material around the volcano, in the atmosphere and in the sea.

Photo of ash fall from the Tajogaite volcano in 2021 on La Palma. / ORIOL OMS Y XAVIER BOLÓS

- **Pyroclastic density currents** (or pyroclastic flows and surges) result from a lateral explosion, the collapse of part of the volcano or the partial collapse of the eruptive column. They consist of flows composed of a variable amount of gases, blocks and ash, which descend the slopes of the volcano at speeds of up to 700 kilometres per hour and temperatures of up to 1000°C.

Pyroclastic density currents at Fuego volcano in Guatemala, (1 July 2015) (Image Conred Guatemala). / LICENSE: CC BY-NC-ND 2.0 DEED - ATTRIBUTION-NONCOMMERCIAL-NODERIVS 2.0 GENERIC

- **Gases,** widely present before, during and after eruptions, can be released throughout the area of volcanic activity, either by diffusion throughout the terrain, in the eruptive cloud and plume, or by forming point source vents, which can reach 400°C. Volcanic gases consist mainly of water vapour, carbon dioxide (CO_2), and sulphur dioxide (SO_2), with hydrogen sulphide (H_2S), hydrogen fluoride (HF) and carbon monoxide (CO) in smaller quantities.

Fumaroles in Vulcano, Aeolian Islands, Italy. / STÉPHANIE BARDE-CABUSSON

Indirect hazards

- **Lahars**, mudflows, which are created when water from heavy rainfall or melting ice or snow washes away volcanic deposits in its path.

Lahar produced by the Fuego volcano of Guatemala (2018). / EDGAR ANTONIO BARRIOS, OBSERVADOR DE INSIVUMEH

- **Seismicity** generated mainly during the ascent of magma, which breaks up rock as it passes through the earth's crust. Occasionally, the most intense earthquakes can be felt by the population near the volcano.

- **Rockfalls** and **landslides** as a consequence of volcanic seismicity or other processes favouring terrain instability.

Rockfall on La Palma, 2021. / INÉS GALINDO Y MIGUEL LLORENTE

- **Tsunamis** of volcanic origin are triggered when a volcanic slope collapses into a body of water or due to the entry of pyroclastic density currents into the water.

- **Fires** caused, for example, by the high temperatures of lava flows or pyroclastic density currents.

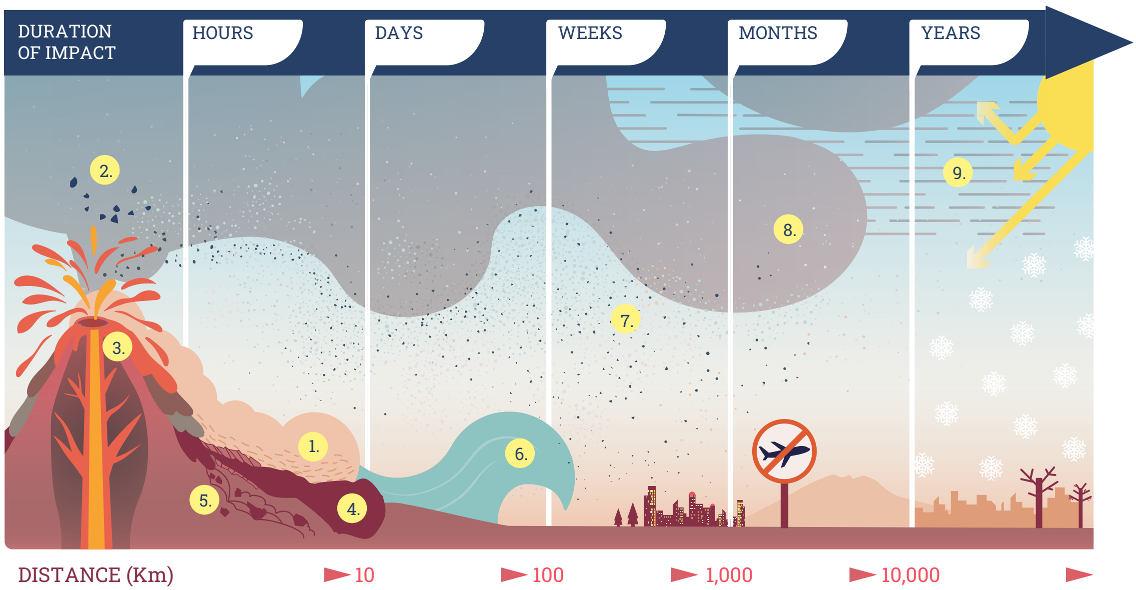
- **Acid rain** and **pollution** due to the presence of volcanic gases in the atmosphere and the leaching of chemical compounds of volcanic origin into the soil and water bodies or water column (e.g., aquifers, lakes, marine environment, etc.).

Effects of acid rains on the vegetation on the flanks of the Turrialba volcano in Costa Rica, 2018. / XAVIER BOLÓS

It is important to note that both direct and indirect volcanic hazards can occur as a consequence of each other and can interact with each other, increasing the magnitude, severity and spatial extent of their impact. For example, in 2003 the volcanic dome (protrusion due to the accumulation of viscous lava) of the Soufrière Hills volcano (Montserrat Island, Lesser Antilles) collapsed as a result of heavy rainfall and seismic activity of the volcano, generating pyroclastic density currents, phreatomagmatic explosions and tsunamis.

The relationship and interaction between different hazards are defined under the concept of **multi-hazard management of disaster risk**, a notion adopted by new international initiatives to achieve the goals of the Sendai Framework for Disaster Risk Re-

Figure 8 Duration and extent of volcanic hazard impact



1. Pyroclastic density currents.
2. Volcanic bombs.
3. Lava flows.
4. Lahars.
5. Landslides.
6. Tsunamis.
7. Ashfall.
8. Ash cloud and volcanic aerosols.
9. Stratospheric aerosols: climate impacts.

**Image adaptation from The Economist*

duction 2015-2030. Multi-hazard management requires a specific, transdisciplinary approach to assessing the risks that separate analysis of each individual hazard does not allow.

Volcanic hazards have a variable impact in terms of severity, duration and spatial extent. For example, a lava flow can have severe consequences at the local level, such as the destruction of infrastructure or houses (e.g., in the case of the Tajogaite volcano on La Palma), but little or no impact at the global level. On the other hand, when volcanic aerosols (gases and tiny solid particles) reach the upper layers of the atmosphere during an explosive eruption, they can modify the global climate. The 1991 eruption of Pinatubo (Philippines), the second largest eruption of the 20th century, triggered, on average, a decrease in global temperature of about 0.5°C between 1991 and 1993. This, along with many other examples of eruptions over the past centuries, or even millennia, illustrate how the impact of a volcanic eruption transcends borders and continents, underlining the importance of international coordination of early warning systems and volcanic risk management plans at the global level.

In the case of submarine eruptions, which account for the majority of volcanic activity on Earth, they do not usually pose a great risk because they generally occur in deep areas (deeper than 600 metres). However, it should be noted that these eruptions, and dyke intrusions, can destabilise undersea slopes or cause collapses that can trigger the formation of tsunamis.

As will be discussed in detail in the second part of the report, one of the fundamental pillars of volcanic risk management is to assess the potential environmental and socio-economic impact of future eruptions in order to implement the necessary mitigation measures. In terms of the environmental impact of volcanic eruptions, burning of vegetation, change of soil acidity, contamination of water sources, among many other processes, cause major disturbances in the ecosystems near the volcano. For example, during submarine eruptions, the injection of volcanic materials and heat generate important physical-chemical and biological anomalies in the marine environment, leading to massive mortality of organisms. However, once the eruptive phase is over and the degassing phase begins, the same volcano will release large concentrations of inorganic nutrients, heat and gases into the marine environment, producing the physical and chemical conditions necessary for the process of ecosystem recolonisation to occur at a much faster rate than under normal conditions.

Impact of the ash fall in the 2021 eruption of the Tajogaite volcano in La Palma / XAVIER BOLÓS

From a socio-economic point of view, the effects of a volcanic eruption can last for years or decades and, in some more extreme cases, the affected areas never recover their previous socio-economic situation. In the short term, before and during the eruption, volcanic activity impacts on the economy and crucial infrastructure during a crisis. Lava flows block communication and evacuation routes, while ash accumulation can collapse roofs, underground buildings and other structures, disrupt telecommunications and disrupt power supplies.

With more than 70 active volcanoes or volcanic areas in France, Greece, Italy, Portugal and Spain alone, the question is not whether there will be new eruptions in Europe, but where, how and when they will occur. It is important to consider that the risk associated with volcanic activity in Europe is not only limited to areas close to volcanoes. Historically, some eruptions have

Impact of the lava flows in the 2021 eruption of the Tajogaite volcano in La Palma. / INÉS GALINDO

triggered socio-economic and political conflicts in neighbouring countries, such as the eruption of Laki (Iceland, 1783), which is believed to have contributed to triggering the French Revolution due to global cooling and the food shortages it caused. More recently, the hydromagmatic eruption of the Eyjafjallajökull volcano (Iceland, 2010) produced large ash clouds which, pushed by the wind towards central and southern Europe, posed a threat to air travel, triggering one of the biggest recent aviation crises with the cancellation of more than 100,000 flights and economic losses valued at more than 4 billion euros.

During the 20th and 21st centuries, Spain has been affected by the dispersion of ash and aerosols from international eruptions, as well as by volcanic eruptions in the Canary archipelago. During the eruption of the Tajogaite volcano (La Palma, 2021), lava flows covered more than 1200 hectares, destroying 1676 buildings, large areas of crops (more than 370 hectares), more than 70 kilometres of roads and numerous livestock farms, and also affected the marine ecosystem where they reached the coast. The emission of volcanic gases and ash caused air quality problems, and gas emissions are still a problem in some areas, even years after the eruption. In addition, during the eruption, the abundant presence of ash in the atmosphere intermittently caused the temporary closure of airspace for several days, affecting hundreds of local, national and international flights, with consequent economic and personal damage. The damage assessment transmitted from the national authorities to the European Parliament has been estimated at more than 1 billion euros. There is no doubt that this eruption has had serious consequences for the local economy, but also social and cultural consequences, and has caused, for example, the loss of roots and cultural identity in the population of the most affected areas.

The eruption of the Tagoro volcano (El Hierro, 2011-2012) had a much smaller economic impact as it occurred at sea, relatively far from the coast, and at sufficient depth not to generate hydromagmatic explosive events that could have affected nearby coastal areas. On the other hand, the marine impact was considerably much greater than during the Tajogaite eruption in La Palma, since, in this case, the volcano was completely submerged and all the lava and gases were emitted directly into the sea. Marine fauna and flora were significantly affected, as well as the usual economic activities of the area (fishing, diving and tourism). However, one of the main dangers included the landslides caused by earthquakes in El Hierro before, during and even several years after the end of the eruption, forcing the evacuation of several areas of the island and the cutting off roads.

The two examples cited are the most recent, but the eruptions that have occurred in recent centuries in the Canary Islands, such as Timanfaya (Lanzarote, 1730-1736) or Garachico (Tenerife, 1706), caused the death of more than 20 people and great material damage. In some cases, these had a great socio-economic impact and involved the relocation of major ports, giving rise to new towns, or forcing emigration, among other things.

All these eruptions have been characterised by low explosivity. However, it cannot be ruled out that hydromagmatic or much more explosive eruptions may occur in the Canary Islands in the future, for example, in relation to the Teide volcano (Tenerife). An eruption of Teide, which is considered to be active, could be devastating on a local scale and even have global effects.

Moreover, taking into account current scientific information, the occurrence of future activity in some volcanic areas of the national territory such as the Garrotxa Volcanic Field (Catalonia), the Calatrava Volcanic Field (Castilla-La Mancha) or the Columbretes Islands (Valencia) cannot be ruled out. Although the only recorded past impact of this volcanism is through the geological record, an eruption today in any of these areas could have terrible effects in the region and nationally. In Spain, in addition to the risks from volcanoes within its territory, the volcanic threat also comes from explosive eruptions of European and other volcanoes.

13.

Living among volcanoes: the human factor in risk

DESPITE their potentially devastating power, the force of nature unleashed during an eruption has never left humans indifferent. Since ancient times, volcanoes have been considered places of worship, the home of gods and demons, or areas where mystical energy is concentrated, attracting and inspiring artists and writers. However, it has mainly been the properties of volcanic soils for cultivation, the resources associated with geothermal energy and the concentration of raw materials (minerals and rocks) useful for the construction of infrastructures (blocks, aggregates, cements), the manufacture of ornamental elements, jewellery, or the construction of tools and utensils, among other applications, that have brought many civilisations closer to volcanoes. Moreover, nowadays, geotourism is a fundamental economic value in volcanic areas, since an important part of the local population is dedicated, directly or indirectly, to this economic activity. The medicinal benefits of the thermal waters or volcanic muds and the great beauty of the volcanic landscapes attract millions of visitors who enjoy the local products and their culture, intimately linked to their geology. This is why many of the world's active volcanoes have some kind of measure to protect their natural environment and, in some cases, are recognised by UNESCO as World Heritage Sites or Global Geoparks for their natural, scientific, educational and tourist value.

Today, under the umbrella of the Sustainable Development Goals defined by the United Nations, technological development and energy needs have focused on volcanic territories. On the one hand, because hydrothermal volcanic activity can generate mineral deposits with high concentrations of strategic metals essential for the production of technological devices and, on the other hand, because the heat provided by magmatic chambers constitutes an unlimited source of energy (on a human scale) that can be exploited to obtain geothermal energy (heat and electricity).

Sightseeing at Stromboli volcano, Aeolian Islands, Italy.
/ STÉPHANIE BARDE-CABUSSON

Human occupation of active volcanic territories due to demographic expansion, geotourism activities and the exploitation of material and energy resources poses significant challenges in terms of volcanic risk management, development and land-use planning, as well as preparedness for future emergencies.

According to definitions established by the United Nations Office for Disaster Reduction (UNDRR), **volcanic risk** is defined as the potential loss, including both damage and total destruction, of life and assets that a society or community could suffer in a specific period of time. Risk is determined probabilistically as a function of hazard, exposure, vulnerability and capacity.

In one aspect, **exposure** relates to the physical proximity of communities and infrastructure to active volcanoes, as well as their degree of interaction with volcanic areas, including human activities such as agriculture, urbanisation and tourism. In another aspect, **vulnerability** is understood as those conditions, determined by physical, social, economic or environmental factors or processes, that increase the susceptibility of an individual, community or assets to the impacts of volcanic hazards. Finally, the concept of **capacity** includes all the strengths, attributes and resources available in an organisation, community or society that allow for managing and reducing risk and increasing resilience.

Thus, volcanic risk assessment integrates the identification and characterisation of potential hazards (including information on their location, intensity, frequency and probability), the analysis of exposure and vulnerability (considering physical, social, health, environmental and economic dimensions) and the evaluation of the effectiveness of current capacities to cope with likely risk situations and the search for possible alternatives to cope with them. All these aspects, as well as the actions to be taken for risk reduction, are detailed in the next part of the report.

Hellisheiði Geothermal Power Plant in Iceland, 2023. / XAVIER BOLÓS