We are IntechOpen, the world's leading publisher of Open Access books
Built by scientists, for scientists

Chapter 1

Introductory Chapter: Volcanoes - From Their Geological and Geophysical Setting to Their Impact on Human Health

Gemma Aiello

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.78541

1. Introduction

This is the introductory chapter of the book "Volcanoes: Geological and Geophysical Setting, Theoretical Aspects and Numerical Modelling, Applications to Industry and Their Impact on the Human Health". In this chapter, the research themes studied in this book have been introduced referring to the geological and geophysical setting of volcanoes, pertaining, in particular, to the correlation between seismic and volcanic activity in volcanic edifices of Southern Italy (Somma-Vesuvius) carried out on a regional scale, the volcanic emissions of the submarine edifice of the Tagoro volcano (Canary Islands, Atlantic Ocean) and the corresponding implications on the chemical and physical properties of the oceanic water, the volcanological studies on the base of the volcanoes and the discovery of a new volcanic edifice, namely the Hiyamizuyama volcano, allowing to evaluate the long-term variations of volcanic and magmatic processes in Northeastern Japan, the volcanic eruptions in Indonesia, a land hosting 147 volcanoes (76 active volcanoes) spreading along the islands of Java, Lesser Sunda, Sumatra and Celebes and mostly characterised by stratovolcanoes and finally, the geologic, petrographic and geodynamic study of the layered gabbroids of Pekulney Ridge, a complex volcanic structure located in Northeastern Russia. Moreover, in this book, significant theoretical aspects and numerical modelling of volcanoes have been addressed, including, in particular, the volcanic dynamics of the convective heat and of the mass transfer in the seismo-focal areas of the Kamchatka Region, including the related volcanic arcs, the modelling of the elastic deformation of volcanoes through the development of computational tools for inverse analyses of geodetic data, which have evidenced the mechanical complexity of the volcanic systems, and finally, the mechanical aspects of the magmatic chambers and their relationships with the fluxing of CO_2, referring to the Yellowstone magmatic chamber, whose large volume has required additional large volumes of magmas and fluids in order to trigger volcanic eruption. In this book, significant applications of volcanic studies to the industry have also been presented, focusing, in particular, on the use of volcanic scorias (VS) and natural pozzolans as cement replacement in the construction industry based on the concrete mixes by analysing their setting times, the compressive strength, water permeability and chloride penetrability and, moreover, on the use of volcanic glasses as adsorbents for industrial aims and scopes, being materials displaying a low thermal conductivity, a low density and a high resistance to fire and perlite aggregate plasters. The volcanic glasses have also been often used as starting materials in the synthesis of clay minerals, as smectites and zeolites. The impact of volcanoes on human health is significant, referring to both the volcanic deposits and to volcanic emissions. In this book, the impact of volcanic emissions on human health has been mainly examined, highlighting that exposure to volcanic emissions can influence the health of people living in the surroundings of the volcano in many ways (dermal and ocular irritation, cardiologic and pulmonary exacerbations and cancer). Moreover, volcanic ashes which have been deposited in a subaqueous environment may produce significant variations in the chemistry of the surface waters and may increase the risk of exposure to metals by drinking that water.

Volcanoes represent geological structures forming on the Earth's surface in the zones where an emission of magma verifies, that is, a volcanic eruption [1]. Many volcanoes have an outer shape of a conical mountain, constructed through the superimposition of the erupted products. The inner part of the cone is crossed by one or more volcanic conduits, representing the last tract of magma uprising. These conduits open outward through the craters. When the magma uprising happens for a long time along the same conduit, the products of different volcanic eruptions accumulate around the same, forming a central volcano. After that the volcanic eruption terminates and the volcanic conduit remains empty; the volcanic crater occurs as a deep cavity. Along the central conduit the uprising of new magma may become very difficult in a high volcano or having the conduit filled by solidified magma. The magma tends to accumulate and pushes along the walls of the volcano up to fracture them. The fractures and faults represent one way out on the flanks or at the base of the volcanic cone, where parasitic vents consequently form.

Volcanoes may have different shapes and dimensions, strictly related to the type of eruptive activity. The effusive eruptions tend to grow a volcano through the accumulation of superimposed lava flows. The explosive eruptions may, on the contrary, remove whole parts of volcanoes. A stratovolcano is typically formed by the superimposition of volcanic products erupted by both explosive and effusive eruptions. The flanks of these volcanoes have steep slopes. Remnants of previous craters, partially destroyed by the strongest explosive phases, have often been individuated. The dimensions of the stratovolcanoes are often relevant but smaller than the ones of shield volcanoes. Important examples of stratovolcanoes in Italy are represented by the Etna [2–4] and Vesuvius [5–7] volcanoes, while between the largest volcanoes of the world there is the Fujiyama volcano (Japan) [8–10].

The Neapolitan volcanic district is composed of the Phlegraean Fields volcanic complex, by the Somma-Vesuvius volcanic complex and by the Ischia Island volcanic complex. In this book, geophysical studies on the Somma-Vesuvius have been presented, referring, in particular, to the correlation between the volcanic activity and the seismic activity. The geological and geophysical setting of these volcanic districts will be discussed in dedicated sections of this chapter.

Important studies of this book deal with the Tagoro submarine volcano, located in the Canary Islands (Atlantic Ocean), and with the effects of the volcanic eruptions on the physical and chemical composition of the oceanic water. The Tagoro submarine volcano is a deeply studied site up to recent times. Significant results have been obtained on the submarine volcanic eruptions of El Hierro Island, referring to the physical and chemical perturbation and to the biological activity [11].

In 2017, Danovaro et al. [12] have recently studied the same volcano, publishing an article in Nature Ecology and Evolution, establishing that a submarine volcanic eruption leads to a novel microbial habitat. Near the top of the volcanic cone, marine exploration has revealed the occurrence of massive mats of white filaments. Microscopic and molecular analyses have revealed that these filaments are made of bacterial trichomes colonised by epibiotic bacteria. Surrounding biology suggests that these microorganisms can drive the restart of biological systems after submarine volcanic eruptions.

In this book, the exploration of the base of a Japanese volcano will be presented, the active stratovolcano of Mt. Zao, located in Northeastern Japan. More than 100 active volcanoes occur in Japan, representing about 10% of volcanoes of the world. They are located in correspondence with the so-called Pacific Ring of Fire, whose occurrence is controlled by important geological processes of subduction among plates. The Japanese region is located at the junction of the Pacific, Philippine, Eurasian and North American plates. Five main subduction zones occur. The Pacific plate descends under the North American plate forming the Kuril and the Japan trenches and controlling the formation of the Northeast Honshu and Kurile volcanic arcs to the north. On the other side, the Philippine plate undergoes subduction beneath the Eurasian plate, controlling the formation of the Ryukyu and Southwest Honshu volcanic arcs. Contemporaneously, the Pacific plate undergoes subduction beneath the Philippine plate, controlling the formation of the Izu-Bonin-Mariana volcanic arc. An important seismic activity is associated with these geodynamic processes, often triggering large tsunamis.

In particular, the Zao volcano, studied in this book, is located in the Northern Honshu volcanic district and is a complex volcanic edifice, characterised by an eruption style that is mainly explosive (phreatic) [13]. In the Honshu volcanic district, the Zao volcano is the most active volcanic edifice. It is composed of several stratovolcanoes, which divide the Pacific Ocean from the Japanese Sea. The older parts of the volcanic edifice are represented by the Ryuzan volcano in the western sector of the volcanic district and by the Byobu volcano and by the Fubo volcano, which are located in the southern sector of the volcanic district [13].

In this book, the characteristics of volcanic eruptions in Indonesia have also been discussed. The Indonesian region hosts about 147 volcanoes [14]. The archipelago is made up of more than 13,000 islands, spreading over a large area, and represents the country having the greatest number and density of active volcanoes [14]. The most prominent geological structure is represented by the Sunda Volcanic Arc, resulting from related geological processes of subduction, involving the lithosphere of the Indian Ocean and the Asian Plate. The Andaman Islands, genetically related to the geodynamic and volcanic processes, are characterised by short spreading centres. On the other side, the Banda volcanic arc is formed as a result of the westwards-directed subduction of the Pacific Ocean. Proceeding northwards, the geodynamic setting becomes more and more complex, due to the individuation of multiple subduction zones, N–S trending [14].

In this book, another important research topic is represented by the Pekulney Ridge, located in Northeastern Russia. The Pekulney segment is characterised by a N–S trending portion of the Pekulney-Zolotogorskaya system, which, in its modern tectonic setting, is occupied by the Pekulney Ridge [15]. Its tectonic setting is characterised by several assemblages of the Late Jurassic-Early Cretaceous island arc (Parautochtone), its deformed pre-Late Mesozoic basement and Neoautochtone [15]. The tectonic setting of plagiogranites, coupled with their location, has indicated that they were intruded in the fore arc of the Pekulney segment of the Pekulney-Zolotogorskaya system. This intrusion was contemporaneous with the accretion of the oceanic-volcanic cherty complex and with the subduction and the island arc magmatism during Early Cretaceous times [15].

2. Geological and geophysical settings of volcanoes

In this book, several significant contributions dealing with the geological and geophysical setting of volcanoes have been presented. The study volcanoes are located in several places of the world (Vesuvius volcano, Southern Italy; Zao volcano, Northeastern Japan; Tagoro volcano, Canary Islands, Atlantic Ocean; Indonesian volcanoes, Indonesia; Pekulney Ridge volcanic complex, Northeastern Russia).

The geological and geophysical settings of volcanoes, as a general rule, are important research topics in the volcanological research. It is a broad research topic and many studies have been developed in these research fields, including the determination of the tectonic setting of basic volcanic rocks through the use of trace element analyses [16], the presentation of comprehensive geochemical data sets of recent volcanic rocks from the Mariana Islands, providing volcanological constraints on the timing and the nature of fluxes from the subducting slab [17] and the development of new methods to measure the deformations on volcanoes using interferometric synthetic aperture radar (INSAR) persistent scatterers [18].

The Somma-Vesuvius volcano is one of the most important morphological lineaments occurring in the Naples Bay, typically facing the town of Naples and representing, in some way, its symbol. Studies have been conducted deeply regarding its eruptive events, the recent seismicity involving the surroundings of the volcano, the geochemistry of the volcanic deposits and the volcanic hazard related to the volcano [5–7, 19–23]. The geological setting of the Somma-Vesuvius volcano has been simplified by the stratigraphy of the "Trecase 1" deep exploration well [24]. This well, located on the Vesuvius volcano, has drilled several volcanic complexes, respectively, located below and above the Campanian Ignimbrite deposits, representing an important volcanic marker of the Campania Plain and dating back to 37 ky B.P. In particular, at the bottom of the well Mesozoic dolomites have been drilled (2068–1885 m), belonging to the paleogeographic unit known as "Piattaforma Campano-Lucana" *Auct.* [25, 26]. These carbonate deposits are overlain by tertiary continental calcareous conglomerates, interlayered with marine sediments. The tertiary deposits are, in turn, overlain by lavas and tuffites of the ancient Somma volcano, Pleistocene in age, alternating with marine deposits. These volcano-sedimentary deposits are overlain by the Campanian Ignimbrite pyroclastic flow deposits. At the top of the well, post-35 ky B.P., subaerial lavas and pyroclastics of Somma and Vesuvius volcanic edifices have been drilled.

3. Theoretical aspects and the numerical modelling of volcanoes

In this book, theoretical aspects of volcanoes have been pointed out through numerical modelling, referring, in particular, to the dynamics of volcanic systems (convective heat and mass transfer) in seismo-focal zones of the Kamchatka Region (Asia), to the analysis of the deformation of volcanic systems through finite element models and to the mechanical aspects referred to the magma chambers and corresponding implications on the flux of the CO_2.

The convective heat transfer is represented by the transfer of heat through the movements of fluids. This mechanism involves an integration between the conduction, represented by the diffusion of the heat, and the advection, represented by the transfer of the heat through the fluid flow.

The heat transfer by convection may be expressed through a basic relationship:

$$Q = hA\left(T_a - T_b\right) \tag{1}$$

In this relationship Q is the transferred heat/unit time, A is the area of the object, h is the coefficient of heat transfer, T_a is the temperature at the surface of the object and T_b is the temperature of the fluid.

The heat and mass transfer in volcanic systems have been deeply investigated. In particular, the chemical mass transfer in magmatic systems has been studied through the elaboration of a thermodynamic model, which takes into account the liquid–solid equilibrium in the volcanic systems, occurring both at elevated temperatures and pressures [27].

The convective heat transfer has been discussed through the mathematical formulation of numerical models, which have been applied to the geothermal systems [28]. The geothermal reservoirs are often characterised by vertical normal faults. The comprehension of the processes of convection to a large scale has been obtained through the idealisation of the reservoir as a porous medium. The thermal anomalies, which are genetically related with the transfer of heat, have been detected through surface manifestations, aerial infrared surveys, geochemical analyses and exploration wells [28].

A tool methodology has been constructed in the case of volcanic and hydrothermal systems in order to estimate the heat release and the carbon dioxide degassing [29]. In the construction of this methodology, theoretical aspects have been clarified. Referring to the hydrothermal and volcanic emissions, the released energy represents a main component in the balance of energy of quiescent volcanoes. These balances have been often derived calculating the mass balance at crater lakes. They have also been estimated in the volcanic systems without crater lakes (Vulcano, Solfatara, Nisyros, Somma-Vesuvius and Ischia), ranging between 0.23 and 1.39×10^8 W. These estimates were carried out through measurements of CO_2, volcanic and hydrothermal in origin, which has been released through soil diffusion emission.

In this theoretical context the heat flux represents a linear function of the soil thermal gradient, which is proportional to the thermal conductivity [29]. The field and laboratory methods have included the CO_2 soil flux measurements, the temperature measurements along vertical profiles and the samples of fumaroles within the degassing areas. A physical modelling has been applied in order to simulate heat and fluid flow. The used geothermal simulator has accounted for the transport of heat and has been applied also to the degassing of the Solfatara crater at the Phlegraean Fields [30, 31].

The methodology of Chiodini et al. [29] has allowed us to estimate the amount of energy, which is released from volcanic and hydrothermal systems. The use of CO_2 as a tracer of the degassing process has allowed us to find a linear relationship between the fumarolic ratios of the fluids and the ratios of temperature in the shallow part of the soil.

The analysis of deformation in volcanic systems has been deeply studied, taking into account the development of new technologies and methodologies, including INSAR scatterometric measurements.

Hooper et al. [18] have developed a new method, based on the INSAR scatterer in order to analyse the crustal deformation occurring in volcanic systems. This method is based on the spatial correlation of the phases in order to observe the volcanic deformation, representing a geological process varying during geological time. The developed algorithm is based on the removal of the residual topographic component of flat phases of the interferograms and on phase correlation, both spatial and temporal.

The INSAR analysis has been applied also to volcanoes located in Alaska, analysing all available synthetic aperture radar (SAR) images of Okmok acquired during 1997–2008 by three different satellite sensors to investigate inter-eruption deformation patterns [32].

Another tool methodology in studying the deformation of volcanic systems is represented by satellite imagery, allowing for a global coverage of volcanoes, often not systematically surveyed, so providing probabilistic analyses which link the deformation with the volcanic eruption [33]. Taking a sample of 198 volcanoes, which were systematically observed in the last 18 years, 54 volcanoes have undergone a significant deformation and 25 of them erupted [33]. In such a framework the satellite technology applied to the monitoring of deformation in volcanic systems allows for the applications of probabilistic approaches, implying the hazard decisions and strategic development.

Significant studies on the relationships between volcanic activity and seismicity in volcanic settings have been recently furnished based on differential interferometric synthetic aperture radar co-seismic measurements [34]. These measurements have been collected at Ischia (Southern Italy) and regard, in particular, that the earthquake source model of the Casamicciola earthquake occurred on 21 August 2018 [34]. The integration of geophysical data (seismological data, global positioning system, Sentinel 1 and Cosmo-Skymed) has indicated the occurrence of E–W trending normal faults, dipping southwards and located at depths of 800 m [34].

4. Application of volcanoes to the industry

In this book, the applications of studies on volcanoes to the industry are also presented. In particular, they deal with the use of volcanic scorias as cement replacement and with the volcanic glasses or obsidians and their use as adsorbents.

Volcanic scorias as cement replacement deal with the use of natural pozzolans, representing a common technique in the construction industry and having economic, ecologic and performance benefits. The advantages and the disadvantages of the use of volcanic scoria as cement replacement in concrete mixes in terms of fresh and hardened concrete properties have been shown. The chemical and mineralogical composition of volcanic scoria samples collected from 36 countries has been presented. The effects of using volcanic scoria as cement replacement on some past, mortar and concrete properties, such as the setting times, the heat of hydration, the compressive strength, the water permeability and the chloride penetrability, have been studied. The improvement in resistance against the chemical attack of volcanic scoria-based cement mortar has also been highlighted. Some estimation equations depending on the data available in literature have been derived from the analysed data. The modification of the microstructure of VS-based cement paste has been confirmed, as well.

Volcanic glasses and their use as adsorbents have been studied in detail. The capacity of adsorption of perlite is explained through the occurrence of hydroxyl groups on the surface of the perlite. As a consequence, the silicon atoms maintain their coordination attaching to the monovalent hydroxyl groups; they form silanol groups, whose chemical reactions have been explained. The adsorption of cations and anions has also been explained. The heavy metals represent the most important pollutants harming the aqueous environment and damaging the health of human beings, animals and plants. These metal ions tend to accumulate in the living organisms, provoking different diseases and disorders and having the possibility to be diluted but not destroyed. The ions of heavy metals cause serious health implications on the vital organs of human beings and animals, if they are consumed above certain threshold concentrations. The removal of these toxic metals may be performed through the chemical precipitation, the extraction of solvents, the exchange of ions, the reverse osmosis and nanofiltration. Due to its use as an adsorbent, perlite represents a material having a high potential, due to its low cost and high availability.

The application of volcanoes to the industry are numerous and have been resumed by Dehn and McNutt [35], delineating the use of volcanic materials in commerce and industry. Some key terms need to be clarified in order to improve the understanding of volcanic materials in the industry, as treated in this book, such as the absorbent, representing a material taking up, assimilating or incorporating liquids through pore interstices, the obsidian, representing a black glassy rock, often of a rhyolitic composition, undergoing a process of devitrification and forming crystal structures, and the pozzolan, a siliceous volcanic ash used to create hydraulic cement [35].

The explosive volcanic products tend to form aggregates, having a low density, and are often vesicular, giving good insulating qualities. Among the industrial processes, the manufacture of perlite is designed to enhance these characteristics. The lava flows and the welded ignimbrites represent cost-effective building materials. Moreover, the concrete constructed from volcanic cinders is a good insulator if compared with the normal concrete, due to the high vesicularity of the cinders used in its manufacture. The vesicles tend to resist the heat's transfer, making it difficult for thermal energy to move through the block [35].

The modern uses of volcanic rocks in the industry range from the mining of volcanogenic minerals for manufacturing and lubricants to their use as construction materials. In the industrial use, the aggregates represent broken pieces of rocks, including the volcanic aggregates, the cinders and the scorias, used for both the construction of roads and the production of building materials. The aggregates may be used as loose aggregates, refractories and absorbents [35].

Perlite represents a volcanic glass, which is highly hydrated and is generally used as a lightweight aggregate. Moreover, perlite has some special uses, as the substitute of sands in lightweight wall plaster and their use in ceramic production, fillers and filters. On the other side, the refractories are materials which are not deformed or damaged by high temperatures. Consequently, they are used to make firebricks, crucibles, insulation and furnace linings. The ingredients of refractories also include the pumices and the clays, while bentonite has been used as a binder during production [35].

The use of volcanic materials in the construction industry is widespread, including the massive stones, providing good building materials, especially lavas and ignimbrites, having high strengths and insulating qualities, the concrete and the cinder blocks, used in creating concrete prefabricated parts for buildings. Moreover, some soft volcanic rocks, such as ignimbrites, have been used for tunnelling, storage and housing (Japan, Ischia, Herculaneum of Pompei and New Guinea) [35].

5. Impact of volcanoes on human health

In this book, the impact of volcanoes on human health has also been considered, dealing, in particular, with the impact of volcanic emissions on human health. As it has been clarified from the authors, the health effects of volcanic emissions depend on their physical and chemical characteristics and by the corresponding toxicological properties, as a consequence of the inhalation of particles directly emitted from the active volcanoes or through the re-suspension of the soil ashes during the cleaning task after the eruption. The effects on human health derived from such an exposure can be classified as acute and chronic.

The health impact of volcanic emissions represents an intriguing research topic and has been studied by different authors. In particular, studies of the respiratory health effects of different

http://dx.doi.org/10.5772/intechopen.78541

types of volcanic ash have been undertaken only in the last 40 years and mostly since the eruption of Mt. St Helens in 1980. This review of all published clinical, epidemiological and toxicological studies, and other work known to the authors up to and including 2005, highlights the sparseness of studies on acute health effects after the eruptions and the complexity of evaluating the long-term health risk (silicosis, non-specific pneumoconiosis and chronic obstructive pulmonary disease) in populations from prolonged exposure to ash due to persistent eruptive activity [36].

Volcanoes and their eruptions can result in a wide range of health impacts, arguably more varied than in any other kind of natural disaster. At least 500 million people worldwide live within the potential exposure range of a volcano that has been active in recorded history. Many volcanic and geothermal regions are densely populated and several are close to major cities, threatening local populations. Volcanic activity can also affect areas hundreds or thousands of kilometres away, as a result of airborne dispersion of gases and ash or even on a hemispheric to global scale due to impacts on climate. Healthcare workers and physicians responding to the needs of volcanic risk management might therefore find themselves involved in scenarios as varied as disaster planning, epidemiological surveillance, treating the injured or advising on the health hazards associated with long-range transport of volcanic emissions [37].

A health hazard assessment of exposure to soil gases (carbon dioxide and radon) was undertaken in the village of Furnas, located in the caldera of an active volcano. A soil survey to map the area of soil gas flow was undertaken, gas emissions were monitored at fumaroles and in eight houses and a preliminary radon survey of 23 houses in the main anomaly area was performed. Potential volcanic sources of toxic contamination of air, food and water were also investigated, and ambient air quality was evaluated. About one-third (41 ha) of the houses were located in areas of elevated carbon dioxide soil degassing [38].

Millions of people are potentially exposed to volcanic gases worldwide, and exposures may differ from those in anthropogenic air pollution. A systematic literature review found few primary studies relating to health hazards of volcanic gases. SO_2 and acid aerosols from eruptions and degassing events were associated with respiratory morbidity and mortality but not childhood asthma prevalence or lung function decrements. Accumulations of H_2S and CO_2 from volcanic and geothermal sources have caused fatalities from asphyxiation. Chronic exposure to H_2S in geothermal areas was associated with increases in the nervous system and respiratory diseases. Some impacts were on a large scale, affecting several countries (e.g., Laki fissure eruption in Iceland in 1783–4). No studies on health effects of volcanic releases of halogen gases or metal vapours were located. More high-quality collaborative studies involving volcanologists and epidemiologists are recommended [39].

Volcanoes provide a conduit by which magma—the molten rock, gases and water within the Earth—may interact with human biological systems. Because of the range of materials that are ejected during eruptions, the consequent effects on the human health are different. Contact may occur dramatically and immediately for people living close to the vent, such as from pyroclastic density currents or the emission of large projectiles. Alternatively, effects on health may occur slowly or at great distances from the volcano as a result of dispersal of volcanic material such as ash and aerosols [40].

A time-averaged inventory of subaerial volcanic sulphur (S) emissions was compiled primarily for the use of global S and sulphate modellers. This inventory relies upon the 25-year history of S, primarily sulphur dioxide (SO_2), measurements at volcanoes. Subaerial volcanic SO_2 emissions indicate a 13 Tg/a SO_2 time-averaged flux, based from an early 1970s to 1997 time frame. When considering other S species present in volcanic emissions, a time-averaged inventory of subaerial volcanic S fluxes is 10.4 Tg/a S. These time-averaged fluxes are conservative minimum fluxes since they rely upon actual measurements. The temporal, spatial and chemical inhomogeneities inherent to this system gave higher S fluxes in specific years. Despite its relatively small proportion in the atmospheric S cycle, the temporal and spatial distribution of volcanic S emissions provides disproportionate effects at local, regional and global scales [41].

Fluid geochemistry monitoring in the Azores involves the regular sampling and analysis of gas discharges from fumaroles and measurements of CO_2 diffuse soil gas emissions. Main degassing areas under monitoring are associated with hydrothermal systems of active central volcanoes in S. Miguel, Terceira and Graciosa islands. Fumarole discharge analysis since 1991 show that apart from steam these gas emissions are CO_2 dominated with H_2S, H_2, CH_4 and N_2 in minor amounts. Mapping of CO_2 diffuse soil emissions in S. Miguel Island leads to the conclusion that some inhabited areas are located within hazard-zones. At Furnas village, inside Furnas volcano caldera, about 62% of the 896 houses are within the CO_2 anomaly, 5% being in areas of moderate-to-high risk. At Ribeira Seca, on the north flank of Fogo volcano, few family houses were evacuated when CO_2 concentrations in the air reached 8 mol%. To assess and analyse the CO_2 soil flux emissions, continuous monitoring stations were installed in S. Miguel (2), Terceira and Graciosa islands. The statistical analysis of the data showed that some meteorological parameters influence the CO_2 flux. The average of CO_2 flux in S. Miguel stations ranges from 250 g/m^2 /d at Furnas volcano to 530 g/m^2 /d at Fogo volcano. At Terceira Island, it is about 330 g/m^2 /d, and at Graciosa, it is 4400 g/m^2/d [42].

Passive samplers were used to measure the atmospheric concentrations of SO_2 naturally emitted at three volcanoes in Italy (Etna, Vulcano and Stromboli) and of H_2S naturally emitted at three volcanic/geothermal areas in Greece (Milos, Santorini and Nisyros). The measured concentrations and dispersion patterns varied with the strength of the source (open conduits or fumaroles), the meteorological conditions and the area topography. At Etna, Vulcano and Stromboli, SO_2 concentrations reach values that are dangerous to people affected by bronchial asthma or lung diseases (>1000 μg m^{-3}). H_2S values measured at Nisyros also exceed the limit considered safe for the same group of people (>3000 μg m^{-3}). The data obtained using passive samplers represent time-averaged values over periods from a few days up to 1 month, and hence concentrations probably reached much higher peak values that were potentially also dangerous to healthy people. The present study provides evidence of a peculiar volcanic risk associated with tourist exploitation of active volcanic areas. This risk is particularly high at Mt. Etna, where the elderly and people in less-than-perfect health can easily reach areas with dangerous SO_2 concentrations via a cableway and off-road vehicles [43].

Author details

Gemma Aiello

Address all correspondence to: gemma.aiello@iamc.cnr.it

Institute of Marine and Coastal Environment (IAMC), National Research Council of Italy (CNR), Napoli, Italy

References

[1] Simkin T, Siebert DL. Volcanoes of the World. 2nd ed. Tucson, Arizona: Geoscience Press, Inc.; 1994. p. 349. ISBN 0-945005-12-1

[2] Coltelli M, Del Carlo P, Vezzoli L. Discovery of a plinian basaltic eruption of Roman age at Etna volcano, Italy. Geology. 1998;**26**(12):1095-1098

[3] Coltelli M, Del Carlo P, Vezzoli L. Stratigraphic constraints for explosive activity in the past 100 ka at Etna volcano, Italy. International Journal of Earth Sciences. 2000;**89**:665. DOI: 10.1007/s005310000117

[4] Branca S, Coltelli M, Groppelli G, Lentini F. Geological map of Etna volcano, 1:50,000 scale. Italian Journal of Geosciences. 2011;**130**(3):265-291

[5] Cassano E, La Torre P. Geophysics. In: Santacroce R, editor. Somma-Vesuvius. Roma, Italy: CNR, Quaderni De La Ricerca Scientifica; 1987

[6] Santacroce R. Somma-Vesuvius. Roma, Italy: CNR, Quaderni De La Ricerca Scientifica; 1987

[7] Castellano M, Buonocunto C, Capello M, La Rocca M. Seismic surveillance of active volcanoes: The Osservatorio Vesuviano seismic network (OVSN-Southern Italy). Seismology Research Letters. 2002;**73**:177-184

[8] Nakamura K. Volcanoes as possible indicators of tectonic stress orientation—Principle and proposal. Journal of Volcanology and Geothermal Research. 1977;**2**:1-16

[9] Acocella V, Neri M. Dike propagation in volcanic edifices: Overview and possible developments. Tectonophysics. 2009;**471**(1-2):67-77

[10] Togashi S, Terashima S. The behavior of gold in unaltered island arc tholeiitic rocks from Izu-Oshima, Fuji, and Osoreyama volcanic areas, Japan. Geochimica and Cosmochimica Acta. 1997;**61**(3):543-554

[11] Fraile Nuez E, Gonzalez-Dvila M, Santana-Casiano JM, Astergui J, Alonso Gonzalez IJ, Hernandez-Len S, Blanco MJ, Rodriguez-Santana A, Hernandez-Guerra A, Gelado-Caballero MD, Eugenio F, Marcello J, de Armas D, Dominguez-Yanes JF, Montero MF,

Laetsch DR, Vlez-Belch P, Ramos A, Ariza AV, Comas-Rodriguez I, Bentez-Barrios VM. The submarine volcano eruption at the island of el hierro: Physical-chemical perturbation and biological response. Scientific Reports. 2012;**2**(486). DOI: 10.1038/srep00486

[12] Danovaro R, Canals M, Tangherlini M, Dell'Anno A, Gambi C, Galderic L, Amblas D, Sanchez-Vidal A, Frigola J, Calafat AM, Pedrosa R, Rivera J, Rayo X, Corinaldesi C. A submarine volcanic eruption leads to a novel microbial habitat. Nature Ecology and Evolution. 2017;**1**(0144):1-8

[13] https://www.volcanodiscovery.com/zao.html

[14] https://www.volcanodiscovery.com/indonesia.html

[15] Luchitskaya MV, Morozov OL, Palandzhyan SA. Plagiogranite magmatism in the Mesozoic island-arc structure of the Pekulney Ridge, Chukotka Peninsula, NE Russia. Lithos. 2005;**79**(1-2):251-269

[16] Pearce JA, Cann JR. Tectonic setting of basic volcanic rocks determined using trace element analyses. Earth and Planetary Science Letters. 1973;**19**(2):290-300

[17] Elliott T, Plank T, Zindler A, White W, Bourdon B. Element transport from slab to volcanic front at the Mariana arc. Journal of Geophysical Research, Solid Earth. 1997; **102**(B7):14,991-15,019

[18] Hooper A, Zebker H, Segall P, Kampes B. A new method for measuring deformation on volcanoes and other natural terrains using InSAR persistent scatterers. Geophysical Research Letters. 2004;**31**:L23611. DOI: 10.1029/2004GL021737

[19] Esposti Ongaro T, Neri A, Todesco M, Macedonio G. Pyroclastic flow hazard at Vesuvius from numerical modelling II. Analysis of local flow variables. Bulletin of Volcanology. 2002;**64**:178-191

[20] Mastrolorenzo G, Palladino D, Vecchio G, Taddeucci J. The 472 A.D. Pollena eruption at Somma-Vesuvius (Italy) and its environmental impact at the end of Roman Empire. Journal of Volcanology and Geothermal Research. 2002;**113**:19-36

[21] Saccorotti G, Ventura G, Vilardo G. Seismic swarms related to diffusive processes: The case of Somma-Vesuvius volcano, Italy. Geophysics. 2002;**67**:199-203

[22] Scarpa R, Tronca F, Bianco F, Del Pezzo E. High-resolution velocity structure beneath mount Vesuvius from seismic array data. Geophysical Research Letters. 2002;**29**:2040. DOI: 10.1029/2002GL015576

[23] Todesco M, Neri A, Esposti Ongaro T, Papale P, Macedonio R, Santacroce R. Pyroclastic flow hazard at Vesuvius from numerical modeling. Bulletin of Volcanology. 2002;**64**: 155-177

[24] Brocchini F, Principe C, Castradori D, Laurenzi MA, Gorla L. Quaternary evolution of the southern sector of the Campanian plain and early Somma-Vesuvius activity: Insights from the Trecase well. Mineralogy and Petrology. 2001;**73**:67-91

[25] D'Argenio B, Pescatore TS, Scandone P. Schema geologico-strutturale dell'Appennino meridionale (Campania e Lucania). Quaderni dell'Accademia Nazionale dei Lincei, Problemi Attuali di Scienza e Cultura. 1973;**183**:49-72

[26] Bigi G, Cosentino D, Parotto M, Sartori R, Scandone P. Structural Model of Italy. Monografie Progetto Finalizzato Geodinamica. Roma, Italy: CNR; 1992

[27] Ghiorso MS, Sack RO. Chemical mass transfer in magmatic processes IV. A revised and internally consistent thermodynamic model for the interpolation and extrapolation of liquid-solid equilibria in magmatic systems at elevated temperatures and pressures. Contributions to Mineralogy and Petrology. 1995;**119**(2-3):197-212

[28] Cheng P. Heat transfer in geothermal systems. Advances in Heat Transfer. 1979;**14**:1-105

[29] Chiodini G, Granieri D, Avino R, Caliro S, Costa A, Werner C. Carbon dioxide diffuse degassing and estimation of heat release from volcanic and hydrothermal systems. Journal of Geophysical Research. 2005;**110**:B08204

[30] Chiodini G, Todesco M, Caliro S, Del Gaudio C, Macedonio G, Russo M. Magma degassing as a trigger of bradyseismic events: The case of Phlegrean fields, Italy. Geophysical Research Letters. 2003;**30**(8):1434

[31] Todesco M, Chiodini G, Macedonio G. Monitoring and modelling hydrothermal fluid emission at La Solfatara (Phlegrean fields, Italy): An interdisciplinary approach to the study of diffuse degassing. Journal of Volcanology and Geothermal Research. 2003;**125**:57-79

[32] Lu Z, Dzurisin D, Biggs J, Wicks C Jr, McNutt S. Ground surface deformation patterns, magma supply, and magma storage at Okmok volcano, Alaska, from InSAR analysis: 1. Intereruption deformation, 1997-2008. Journal of Geophysical Research. 2010;**115**:B00B02. DOI: 10.1029/2009JB006969

[33] Biggs J, Ebmeier SK, Aspinall WP, Lu Z, Pritchard ME, Sparks RSJ, Mather TA. Global link between deformation and volcanic eruption quantified by satellite imagery. Nature Communications. 2014;**5**(3471). DOI: 10.1038/ncomms4471

[34] de Novellis V, Carlino S, Castaldo R, Tramelli A, De Luca C, Pino NA, Pepe S, Convertito V, Zinno I, De Martino P, Bonano M, Giudicepietro F, Casu F, Macedonio G, Manunta M, Cardaci C, Manzo M, Di Bucci D, Solaro G, Zeni G, Lanari R, Bianco F, Tizzani P. The 21 August 2017 Ischia (Italy) earthquake source model inferred from seismological, GPS and DInSAR measurements. Geophysical Research Letters. 2018;**45**:2193-2202. DOI: 10.1002/2017GL076336

[35] Dehn J, McNutt SR. Volcanic Materials in Commerce and Industry. Chapter 74, in the Encyclopedia of Volcanoes. Elsevier Science Publishers; 2015. pp. 1285-1294

[36] Horwell CJ, Baxter PJ. The respiratory health hazards of volcanic ash: A review for volcanic risk mitigation. Bulletin of Volcanology. 2006;**69**(1):1-24

[37] Hansell AL, Horwell CJ, Oppenheimer C. The health hazards of volcanoes and geothermal areas. Occupational and Environmental Medicine; **63**(2):149-156. DOI: 10.1136/oem.2005.022459

[38] Baxtera PJ, Baubron JC, Coutinoc R. Health hazards and disaster potential of ground gas emissions at Furnas volcano, Sao Miguel, Azores. Journal of Volcanology and Geothermal Research. 1999;**92**(1-2):95-106

[39] Hansell A, Oppenheimer C. Health hazards from volcanic gases: A systematic literature review. Archives of Environmental Health: An International Journal. 2004;**59**(12):628-639. DOI: 10.1080/00039890409602947

[40] Weinstein P, Horwell CJ, Cook A. Volcanic emissions and health. In: Selinus O. (Ed.) Essentials of Medical Geology. Springer, Dordrecht, 2013

[41] Andres RJ, Kasgnoc AD. A time-averaged inventory of subaerial volcanic sulfur emissions. Journal of Geophysical Research. 1998;**103**(D19):25251-25261. DOI: 10.1029/98JD02091

[42] Ferreira T, Gaspar J, Viveiros F, Marcos M, Faria C, Sousa F. Monitoring of fumaroles discharge and CO_2 soil degassing in the azores: Contribution to volcanic surveillance and public health risk assessment. Annals of Geophysics. 2005;**48**(4-5):787-796

[43] Aiuppa A, Bellomo S, Brusca L, Calabrese S, Kyriakopoulos K, Liotta M, Longo M, D'Alessandro W. Sulphur-gas concentrations in volcanic and geothermal areas in Italy and Greece: Characterising potential human exposures and risks. Journal of Geochemical Exploration. 2013;**131**:1-13