Review article: Brief history of volcanic risk in the Neapolitan area (Campania, Southern Italy): A critical review

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Abstract
The presence of three active volcanoes (Vesuvius, Campi Flegrei and Ischia Island) along the coast of Naples did not contained the huge expansion of the urbanised zones around them. On the contrary, since the Greco-Roman era, volcanoes have featured among the favourite sites for people colonising the Campania region. The stable settlements around Vesuvius, Campi Flegrei caldera and Ischia were progressively enlarged, attaining maximum growth rate between 1950 and 1980. Between 1982 and 1984, Neapolitans faced the last and most dramatic volcanic crises, which occurred at Campi Flegrei (Pozzuoli), without an eruption. Since that time, volcanologists have focused their attention on the problem of risks associated with eruptions in the Neapolitan area, but a systematic strategy to reduce the very high volcanic risk of this zone is still lacking. A brief history of volcanic risk in the Neapolitan district is narrated here in an effort to provide new food for thought for the scientific community that works for the mitigation of volcanic risk in this area.

Keywords: Neapolitan volcanoes, volcanic risk, volcanic hazard, risk mitigation, human settlements.

1. Introduction

The region surrounding Naples is one of the most-risky volcanic areas in the world, due to the presence of three active volcanoes, Vesuvius, Campi Flegrei caldera and the Island of Ischia, which it is inhabited by more than 1,500,000 people, directly exposed to the risk (Alberico et al., 2011; Carlino, 2019) (Fig. 1). These volcanoes are capable of generating a wide range of eruptions, from gentle lava flow to those triggering catastrophic effects and were active in historical times (the last eruption occurring in 1944 at Vesuvius, in 1538 at Campi Flegrei and in 1302 at Ischia). Larger eruptions at Vesuvius have devastated entire territories around the volcano, up to a distance of 10–20 km from the vent, as was observed in 79 AD (Pompei) and 1,800 BC (Avellino), respectively. At least two large caldera-forming eruptions occurred at Campi Flegrei, (the Campania Ignimbrite (CI), ~39 ka, and the Neapolitan Yellow Tuff (NYT), ~15 ka, which involved the entire Campania Plain, such as the case of the CI event. At Ischia, a large eruption occurred about 55 ka ago, while the subsequent activity was mostly confined within the island (de Vita et al., 2010; De Vivo et al., 2006; Mastrolorenzo et al., 2006; Piochi et al., 2005). In Figure 2, a sketch of the eruptive history of Vesuvius, Campi Flegrei and Ischia is presented (Piochi et al., 2005).

On one hand, volcanoes and their activity produced fertile soils for farming, hot waters and lakes for human recreation, raw materials and natural inlets along the coast for sea navigators (Carlino et al., 2010a; Scarpati et al., 2016). These features make the Neapolitan area a favourable site for human settlements and the development of a local economy. However, volcanic activity has greatly devastated the area and left behind many victims (Scarpati et al., 2013). The city of Naples itself stands on various volcanic centres and, in particular, on the extended deposits of the NYT eruption (~15 ka); this eruption triggered the collapse of the present Campi Flegrei caldera (~~Isaia et al., 2009;~~ Scarpati et al., 2013), the eastern rim of which is the site where an important residential area of the city (the *Posillipo hill*) stands (Fig. 3). Analysing the most crucial historical moments that marked the relationship between humans and Neapolitan volcanoes is fundamental to understanding why so many people are nowadays residing in such a hazardous area. On the other hand, we need to also analyse the development of the research in volcanology and its impact in mitigating the risk of this highly inhabited area. In the long history of relations between humans and Neapolitan volcanoes, a few notable milestone events must be mentioned: the Pompei 79 AD eruption, reconstructed by the letters of Plinian the Younger; the eruption of Vesuvius of 1631 which, after almost 500 years of quiescence, ushered a long period of continuous volcanic activity ending in 1944; the systematic exploration of Pompei (buried by the 79 AD event) starting from 1748; the foundation of the "Osservatorio Vesuviano" (Vesuvius Observatory) under the Bourbons domination in 1841; the eruption of Vesuvius in 1944, which closed the activity of the volcano and the unrests crises at Campi Flegrei caldera in 1970–72 and 1982–84 (Barberi et al., 1984; Cubellis et al., 2015; ~~Giacomelli et al., 2003;~~ Perrotta & Scarpati, 2009; ~~Scandone et al., 2008~~). Particularly, in this paper, the latter two crises at Campi Flegrei will be discussed, as they occurred during a challenging time in the field of earth science and when volcano-monitoring networks were being improved and policies for management and prevention of the risks in the Neapolitan area altered (Carlino, 2019). Starting from that time, the problem of volcanic hazard and risk in the Neapolitan area has been systematically treated by several authors, trying to quantify the equation of the risk: *risk = hazard x vulnerability x exposed value* (see Blong, 1996 and the references therein). A larger part of the studies has been aimed at assessing the hazard and, to a lesser extent, the risk (see, for instance, Mastrolorenzo et al., 2006; Petrosino et al., 2004; Scandone et al., 1993) and the risk perception of communities exposed to potential volcanic activity (Carlino et al., 2008; Ricci et al., 2013). On the other hand, the primary drivers of vulnerability may be socio-economic, cultural and political, and so policy changes and reduction of social inequality are more important than merely measuring vulnerability itself. As discussed later, this topic encompasses social and policy sciences rather than volcanology. Other authors have debated the criteria adopted to identify the most risked area in the Neapolitan volcanic district (e.g. the red zones), criticising the emergency plan of Vesuvius or proposing an alternative perspective to reduce the risk (De Natale et al., 2020; De Vivo et al., 2010; Dobran, 2000, 2007; Matsrolorenzo et al., 2006; Rolandi, 2010). Although this district has been becoming increasingly vulnerable for about 50 years, only in recent times (starting from early 2000) have attempts been made to reduce its exposed values, though unsuccessfully. Possibly, a more general analysis, from both the historical and scientific points of view, to understand the reasons why the attempts to reduce the volcanic risk in the Neapolitan area have systematically failed is necessary. This paper does not intend to examine such a complex issue, which deserves a wider, longer and multidisciplinary discussion, but sparing a thought for this topic is essential. This paper reports a brief history of volcanic risk in the Neapolitan area and an account of recent studies and policies adopted to reduce the risk. As it will be shown, new proposals to mitigate the volcanic risk of this area could be ineffective if we do not analyse the reasons why previous attempts have failed. Furthermore, it is important to define, as clearly as possible, the role of volcanologists in facing volcanic emergency and risk education policies in this highly urbanised area.

2. The ~~progressive~~ first human settlements of Neapolitan volcanoes

The history of Neapolitan volcanoes harks back to before the birth of Christ, when the first stable population settled in the plain along Vesuvius and the Campi Flegrei caldera (Pappalardo, 2007). The great Greek geographer Strabo (64 B.C.–19 A.D) provided in his work "Geography" one of the first descriptions of the Campania Plain and its surroundings, commenting on the splendour of these places, dominated by the presence of Vesuvius and bordered by mountains extending along the sea forming the Gulf of Naples (Strabone, XIV-XXIII A.D.). The first and most ancient human settlements in Campania date back to the Palaeolithic period, primarily along the coasts of the Sorrento Peninsula. ~~According to Mastrolorenzo et al., (2006), , t~~The first evidence of disrupted human activity due to volcanic eruption in this area dates back about 3,800 years (Mastrolorenzo et al., 2006)~~.~~. This is in fact the age of an ancient Bronze Age village near Nola, about 11 km north of Mount Vesuvius, where archaeologists excavated a human village with several findings in a state of excellent conservation. A massive explosion of Vesuvius (the Avellino eruption, 3,800 years ago) had sealed the village beneath hot ash (Mastrolorenzo et al., 2006), in a fate similar to that of Pompei~~i~~ a few thousand years later. That was when the natural environment of Vesuvius showed a less friendly face, and humankind was confronted with unexpected adversities. In fact, the geology and the landscape of Campania were the chief attractions for the populations colonising this area, which

Romans later called “Campania felix” (from Latin “felix” = lucky, happy) (Montone, 2010). The expression derives not only from the beauty of the place but also from its soil, made fertile by the volcanic activity, the presence of streams and the gentle climate. The broad river and coastal plains, the modest mountain ranges overlooking them, the steam and the various volcanic areas, the thermal waters and natural coastal inlets to protect sailors – all combined together to transform the area into the crossroads of different civilisations (Carlino, 2019). The Campi Flegrei area is also linked to a myth, possibly due to the suggestion recalled by the continuous emission of hot steam and the boiling of mud pots. It was there, along the Lake of Averno (a volcanic crater close to the city of Pozzuoli), that the ancients placed the cave of the Cumaean Sibyl (motioned in the famous literary work “L’Eneide” of Virgilio) and the entrance to the afterlife (Azcuy, 2013). This crater lake exhaled vapours and volcanic gases that probably kept some animals away, from which it derived its Greek name, “aoèrnov”, that is, “without birds”. Following the migration of the Etruscan population, from central Italy to the Campania plain from the 9th to the 5th century B.C., the first early urban centres were established (Maiuri, 1957). These immigrants predominantly settled in the fertile lowlands of the Campanian Plain, along the rivers or close to the river-mouths. With the arrival of the Greeks and the development of maritime trade, the inhabitants of Campania migrated towards coastal areas and started settling in the volcanic areas of Ischia (called “Pithecusae”) and, later, of Campi Flegrei and Vesuvius (D’Ascia, 1867). The Greeks arrived between the 9th and 8th centuries B.C., from a long and narrow island close to the coast of modern-day south-east Greece, namely Euboea. On the Phlegrean side, ancient signs of stable habitation dating to between the 7th and 6th centuries B.C. were discovered in the Rione Terra, the old town in present-day Pozzuoli (Pappalardo, 2007). The historical centre of this town stands on a small volcanic promontory that, at that time, played host to a modest Cumaean mooring. Between 529 and 528 B.C., some Samnite exiles, banned by the tyrant Polycrates, founded a colony on the promontory named Dikaiarchia, meaning “Just Government”, integrated into a territory still controlled from Cumae (Annecchino, 1996). In 194 B.C., the Romans transformed this small colony into a town called Puteolis (hereafter Pozzuoli), thus named for its abundance of thermal springs. The town soon became an imposing port and warehousing area for large quantities of foodstuffs. Earlier, the Greeks had moved eastwards, forming the first inhabited elements of the city of Naples (called Pharthenophe), between Mount Echia (Fig. 3), an upland of volcanic origin, and the island of Megaride where Castel dell’Ovo stands today (Ghirelli, 2015). The Greek population was faced with the hazard of volcanoes on the island of Ischia. In fact, their migration from Ischia towards the coast of Campania was possibly influenced by the eruptions in the western and southern parts of the island from the 5th century B.C. onwards. Amidst the lavas and the ash of the 5th century B.C. eruption and close to the port of Ischia, an old ground level was excavated containing potsherds and other archaeological finds from the 6th and 5th centuries B.C., demonstrating the existence of an ancient Greek settlement destroyed in the eruption (Carlino et al., 2010a). Strabo bore witness to the eruptions in the Greco-Roman era, writing: "*...in ancient times a series of extraordinary events took place on the island of Pithecusae. [...] when Mount Epomeo, which rises in the middle of the island, was shaken by earthquakes and erupted fire and (again) swept away everything that lay between itself and the shore and into the sea. At the same time a part of the ground, reduced to ash and thrown upwards, fell back onto the island like a maelstrom and the sea retreated for a distance of three stadia (about 500 m) and, flowing back shortly afterward, flooded the island, extinguishing the fire. Such was the deafening noise that the inhabitants of the mainland fled from the coast to the inner regions of Campania*." The towns of Naples and Pozzuoli and the villages in the Vesuvius area, such as Pompe~~i~~i, were expanding rapidly, with its citizens having to deal with the adverse forces generated by the volcanic nature of the area. While in historical times (starting from the former civilised human settlements), the Campi Flegrei caldera and the island of Ischia generated small eruptions, the Vesuvius, contrarily, demonstrated its power with the 79 A.D. eruption, which seriously affected the cities of Pompei and Ercolano and the southern part of the volcano (Giacomelli et al., 2003). During the longest period of expansion of the Western Roman Empire, the cities around the volcanoes had expanded progressively. The volcanic activity of Ischia in the early centuries before Christ and its insular nature had, however, contained its demographic expansion. On the other hand, the quiescence of the Campi Flegrei in eruptive terms did not imply that the volcanic nature of these places had been forgotten; the continuous puffs of steam and the hot thermal springs served as haunting symbols. However, in the minds of the people at least, the hostile nature of these places, sometimes sinister, was associated with the mood of the gods and not the actual nature of the area itself (Carlino, 2019). In this emerged the perception of natural disasters as divine punishments for humankind, a view that remained rooted in culture up to the 17th century (Cocco, 2012).

3. Towards a modern view of volcanoes

With Galileo Galilei (1564–1642), a gradual change in the approach to the study of earth science and the risk related to natural phenomena occurred. A crucial moment in the history of volcanic risk in the Neapolitan area came in 1631 when, after a long quiescence, Vesuvius awoke with an explosive (sub-plinian) eruption, beginning an almost continuous eruptive activity that ceased only in 1944 at the end of World War II (Cocco, 2012; Kilburn & McGuire, 2001; Rosi et al., 1993). However, here too a theological meaning was attributed to this calamitous event, as an expiation of punishments. In this sense, the eruption of 1631 symbolised an event that, in the coming centuries, affected not only volcanology but also other political, sociological, literary and, above all, religious disciplines (Scarth, 2009). Although Aristotelian science still dominated in the 17th century, it was also the beginning of its end as a result of the works of the Galileans and Cartesians (Fiorentino, 2015).

The period witnessed immense cultural transformations, with new impulses in the field of scientific research with the introduction of the experimental method by Galileo (Rossi, 2020). Further support and impetus to the scientific revolution were lent by the foundation of the Royal Society of London in 1662 and of Acadèmie Royale des Sciences in Paris. Although this revolution determined a new perspective that views losses as resulting from the effects of extreme natural events, religious terms of reference remain a vital element for a significant portion of Neapolitan people in the perception of volcanic eruptions (Chester et al., 2008, 2015).

Actually, the Vesuvius eruption of 1631 was the first event that focused attention on the problem of volcanic risk. In fact, the suggestion to mitigate the volcanic risk at Vesuvius was first formally proposed by the viceroy of Naples, Emmanuele Fonseca, in 1632. The viceroy placed an epigraph in the town of Portici (in the Granatello area), inviting the local population to abandon the Vesuvius area and recalling the catastrophic effects of the 1631 eruption. Many years later, for this inscription, the expression "*the paradox of Granatello*" was coined by Nazzaro (2001), referring to the reluctance of Vesuvians to consider the risk (Nazzaro, 2001; Gugg, 2018).

The continuous activity of Vesuvius pushed many scholars and artists to visit the volcano (during the famous Grand Tour epoch) and, at the urging of few intellectuals, the idea of a volcano observatory was born gradually (Luongo, 1997). Particularly, an important impetus came from Sir William Hamilton (1730–1803), who arrived in Naples in 1764 as the British "Envoy Extraordinary to the Kingdom of the Two Sicilies". Hamilton's amateur activity inspired the intuition of active volcano surveillance and later, in 1841 (under the Bourbon Kingdom), the first volcanological observatory in the world was founded, the Vesuvius Observatory (Cubellis et al., 2015). It was a great moment for the Neapolitan School of Volcanology. Then, the interest of this new institution was mainly devoted to the observation of the eruptive activity and to the development of new instruments to monitor the volcano dynamic, such as the electromagnetic seismograph designed by Luigi Palmieri (1855–1896) (Palmieri, 1880). Thus, the attention was mainly directed at the volcanic hazard.

4. Volcanic risk increase

~~Later on, w~~With the increase of population in Neapolitan area~~,~~ the problem of volcanic risk grew critical, because of the exponential ~~increase~~rise of the exposed value. The increase of population in the Neapolitan volcanic district was possibly sustainable, with respect to volcanic risk, up to the economic boom of Italy following the Second World War (Carlino, 2019). Immediately after this war, western civilisation suffered a long economic crisis. A global-scale response to the crisis was the activation of the Marshall Plan (the European Recovery Program, lasting from April 1948 to December 1951), whose aim was the creation of stable economic conditions to guarantee the survival of democratic institutions. The plan contributed to the renewal of the western European chemical, engineering and steel industries and to a rise in gross national products between 15 and 25% (The Marshal Plan; https://www.history.com/topics/world-war-ii/marshall-plan-1). The demographic increase in the province of Naples and the consequent expansion of urban areas since the end of the Second World War have been largely influenced by the country's economic choices following the Industrial Revolution, a process beginning in the 19th century. For instance, the first mechanical plants began in Pozzuoli in Campi Flegrei where, in 1885, a factory for the construction of naval artillery was set up. The increase of population and postwar industrial activity mainly involved the Vesuvius area in conjunction with the volcano's quiescent state following its most recent eruption in 1944 (Carlino, 2019). The Campi Flegrei were also affected by a migratory flow (albeit to a lesser extent) particularly in the districts of Fuorigrotta and Bagnoli (located inside the caldera), reflecting a strong phase of urban growth, especially following the expansion of the Bagnoli industrial area in 1954 (Andriello et al., 1991). The social and environmental change within the Campi Flegrei area had been drastic and often sudden, but the area around Vesuvius was even more badly affected. This latter came under attack from rampant "cementification" not following any town planning criteria, especially concerning the volcanic risk. In the westernmost sector of the volcano, at the border with the eastern outskirts of Naples, oil refineries and various mechanical industries were developed along the coastal strip, while between Portici and Torre Annunziata, residential areas expanded enormously (D'Aprile, 2014). Agricultural land in many areas was converted into construction sites so that the landscape of farming and forestry use was transformed into a typically urban, densely populated environment, contrasting sharply with Vesuvius in the background. Between the 1950s and 1990s, the entire Vesuvius area witnessed uncontrolled speculative building with an exponential increase in residential areas, so as to make unrecognisable the boundaries between the towns that, especially in the coastal sector, became merely an expanse of housing and villas (Carlino, 2019; Luongo, 1997). In the whole metropolitan area belonging to Naples, an increase of 1,000,000 residents occurred between 1950 and 1980 (Censimento Popolazione Città Metropolitana Napoli, 1861–2001). In this chaotic growth, the architectural beauties around Vesuvius leftover from the time of the Grand Tour, the historic villas, were engulfed and new buildings covered the lava flows arising from Vesuvius's most recent activity (Lancaster, 2008). This was a bad sign of the decline of local culture and of the corruption of the political establishment (Berdini, 2010; Curci et al., 2018).

With the onset of globalisation and the expansion of international markets, the industrial activities in the areas of Campi Flegrei went bankrupt. This definitively closed Bagnoli's industrial district in 1992 leading to an attempt to reclaim the area, with numerous halts and course changes, taking place in the sector east of the city of Naples closer to Vesuvius. Meanwhile, the unbroken quiescence of Vesuvius since 1944 gradually transformed the volcano from a perceived risk to a "passive" actor in the landscape. This step resulted in inevitable demographic growth that did not take the security implications into account while the boom in the construction industry extended the cities around the volcano with increasingly invasive settlements. Between 1950 and 1981, the town of Portici alone, now one of the most densely populated places in the world, saw the population rise from just over 30,000 to about 84,000 (ISTAT Censimento popolazione e abitazioni). The cities around Vesuvius extended centripetally, approaching more and more frequently the areas repeatedly affected by recent eruptions. If the quiescence of Vesuvius has caused a progressive decline in the perception of volcanic risk, the territorial management policies until the end of the last century have continuously postponed to posterity the issue of the risks involved in spite of the continual efforts of the scientific community (Carlino et al., 2008). Only relatively recently, following the unrest in the Campi Flegrei caldera in 1982–84, scientists, local authorities and the Civil Protection faced the problem of excessive anthropic pressure in the Neapolitan volcanic area, but an organic plan for decongesting one of the areas of the greatest volcanic risk is still lacking.

~~3.~~5. The last experience of volcanic emergency in the Neapolitan district: Pozzuoli 1970–1984

A fundamental moment in the history of volcano emergency in Campania was the episode of volcanic unrest of Campi Flegrei caldera affecting the town of Pozzuoli in 1970–72 and 1982–84, respectively. During those years, the ground of the town experienced the maximum cumulative uplift of about 3 meters, forcing the local authorities to evacuate the town during both episodes (Barberi et al., 1984). By the beginning of the 1970s, the phenomenon of *bradyseism* (a Greek origin word which describes the up and down movement of the ground) was largely forgotten, since the last time it had occurred was more than 400 years before when an uplift of about 20 m culminated in the eruption of Monte Nuovo in 1538, the most recent volcanic event at Campi Flegrei (Di Vito et al., 2016). In 1970, monitoring networks for volcano surveillance did not exist in the area. In fact, the inversion in the movement of the ground was signalled by fishermen, who suddenly managed to pass with their small boats beneath an arch at the entrance of the small harbour of Pozzuoli while standing, while it had normally been necessary to bend down (Carlino, 2019). The uplift, in the first phase, was almost aseismic, while the Vesuvius Observatory decided to undertake a new elevation survey performed by the engineers of the Genio Civile to estimate the real amount of the ground uplift. The results indicated that the floor of the Serapeum of Pozzuoli (a ruin of an ancient Roman market) had risen by about 0.70 m since the last surveys and that the area affected by this phenomenon included the entire town (Longo, 2019; Luongo, 2013). The concern about the volcano uplift focused the attention on the hazard related to a possible eruption. There was no consensus among scientists; thus, scientific meetings took place to understand the possible evolution of the phenomenon might and the associated volcanic risk. Experts such as the volcanologists Alfred Rittman and Izumi Yokoyama participated in the debate together with the researchers of Vesuvius Observatory. However, the physical model adopted by the Japanese researchers associated the observed uplift with a high probability of an eruption. In 1972, the centre of Pozzuoli was evacuated, although the unrest was characterised by a modest seismic activity, while the maximum uplift was about 1.7 m and ended without eruption (Yokoyama, 1970). The evacuees were placed in the new Toiano district, whose construction was accelerated during the final stages of the bradyseismic episode. The 1970–72 bradyseism crisis, possibly was not handled in a transparent way, and this experience was complicated by the lack of sufficient knowledge about the physics of the volcano phenomenon (Longo, 2019). This last fact, along with the virtual absence of a monitoring network, determined the decision to evacuate the centre of Pozzuoli, although the perceptible signs of a possible eruption were low, and all the local residents criticised this decision. Nonetheless, it was during that period that earth science experienced new important studies and projects, also strengthening the monitoring networks and the assessment of seismic and volcanic hazards in the world.

Following the Campi Flegrei caldera unrest of 1970–72, the Italian peninsula was severely tested with the devastating earthquakes of Friuli in 1976 (leaving about 1,000 people dead and more than 100,000 displaced) and the one in Campania-Basilicata in 1980 (with about 3,000 deaths and 280,000 dis- placed) (Boschi & Bordieri, 1998). Subsequently, a National Civil Protection service was established in Italy. Thus, when a new bradyseismic crisis occurred in Pozzuoli in 1982, the scientific community and the national and local authorities were better prepared to handle the emergency (Luongo, 2013). The Vesuvius Observatory had strengthened its surveillance network so that, throughout 1972–1981, it was possible to record a tendency to ground subsidence and a new uplift in 1982. In the summer of that year, it became clear that a new episode of bradyseism was underway (Cannatelli et al., 2020). It was most dramatic compared to the previous one. Continuous and significant seismic activity was recorded since spring 1983. Pozzuoli was shaken by hundreds of seismic events a day, while the population was frightened by the roars accompanying the earthquakes and the continued ground movements which wrought widespread damage on the city's ancient buildings. A further increase of seismic activity occurred between September and October 1983, peaking on 4th October with a shallow magnitude 4.0 earthquake, spreading panic among the population, damaging several buildings in the historic centre of Pozzuoli and being clearly felt in Naples (Branno et al., 1984). The ground uplift in the Pozzuoli area reached a maximum rate of the order of centimetres per day. The main concern about the situation was primarily related to the damage to the buildings caused by the shallow earthquakes (2–3 km in depth). Accordingly, the

Vesuvius Observatory and the National Group for Volcanology, responsible for surveillance, presented a seismic hazard map of the Phlegraean area, demonstrating that the level of risk in the historical centre of Pozzuoli had become very high, especially because of the high vulnerability of the buildings at risk (Luongo, 2013). A further concern related to the possibility of an eruption, for which the recorded uplift and the seismic activity appeared as clear precursors, although the likelihood of an eruption was considered low by the director of the Vesuvius Observatory. On 1st April 1984, a new dramatic seismic crisis, with continuous swarms throughout the morning, hit the town of Pozzuoli. At this stage, the problem of the evacuation was faced, also considering the possibility of an eruption inside the caldera of Campi Flegrei. In collaboration with the Central Government, the evacuation plan was drawn up and, following the meetings between monitoring staff and civil defence authorities it was decided to evacuate about 25,000 people from the centre of Pozzuoli. The evacuees were relocated to the new settlement area of Monteruscello, which was built in a few years, a few kilometres north-west of the centre of Pozzuoli, considered a safer area than the coastal strip.

During the 1984 emergency, an effective communication system was established between the monitors, the Civil Protection Service and the citizenry, and the crisis was handled with maximum transparency, especially in light of the 1970 experience (Luongo, 2013). Particularly, the monitoring info-centre, close to Pozzuoli, was activated to ensure the correct management and spreading of information about the ongoing events. Meanwhile, as the plan was actualised the unrest seemed to decrease in intensity, and in December 1984 the uplifting and seismic activity ceased, marking the end of the crisis (Barberi & Carapezza, 1996). Pozzuoli remained for few years like a “ghost town” while local and central governments were deciding on the future of the city. Pozzuoli was later rebuilt without limiting the anthropic pressure that should have been contained within thresholds that would make the volcanic risk acceptable. Today, the municipality of Pozzuoli has about 82,000 residents, representing a coveted residential site for Neapolitan people.

~~4.~~6. The debate about the volcanic risk in the Neapolitan area

The subject of volcanic risk and its mitigation in the Neapolitan area has very important implications because this zone involves at least 1,500,000 people who are potentially exposed to a very large eruption (Mastrolorenzo et al., 2006). Otherwise, given the long history of volcanic risk in the

Neapolitan area and the current very high risk of the area, two preliminary inquiries are required: i) can we find a new paradigm or an alternative plan to reduce the high risk? and ii) how feasible is it in the Neapolitan area? We do not have a unique response to the questions, but to analyse the issue, we have to revert to the last Campi Flegrei caldera unrest between 1982 and 1984, culminating in the evacuation of the town of Pozzuoli (Barberi & Carapezza, 1996). After this event, a strong debate ensued (among scientists, citizens and politicians) about the possible solutions to reduce the volcanic risk in the densely inhabited Neapolitan area.

Between 1980 and 1990, the problem of volcanic risk in the Neapolitan area was considered by the National Group of Volcanology (GNV) (see De Vivo et al., 2010 and references therein), while the one of territorial planning was discussed during several Italian workshops, and the few solutions focused primarily on two actions (Leone, 1987; Ulisse, 1984): i) the short-term one with the preparation of the evacuation plans, ii) the long-term one, which provided the actions and methods, aimed to reduce the demographic pressure in the riskiest areas. ~~As highlighted by Leone (1987), t~~The latter is not simple, because it cannot be forced, while developing a new organisational set-up of the whole Campania Region would be necessary by planning a "new geography" (Leone, 1987) of the services industry and the productive activities, allowing a spontaneous relocation of the residents from the risk areas.

After the last Campi Flegrei caldera unrest ended in 1984, the volcano rested again (up to 2005), but not the debate about volcanic risk. Later, responding to the solicitations and concerns emanating from the scientific and institutional world, and following the foundation of the Italian Civil Protection, the attention was mainly focused on Vesuvius, the most inhabited volcano of the district. The volcanic risk in this area was evaluated by Scandone et al., (1993), in terms of human losses, and according to the equation: *Risk = Exposed Value* × *Vulnerability* × *Hazard* (Blong, 1996). The authors evaluated the hazard based on the entire history of the volcano and identified the events likely to cause loss of human lives as those with Volcanic Explosivity Index (VEI) >~3. Later on, the first evacuation plan for the Vesuvius area was released by the Civil Protection in 1995.

After its foundation in 1999, the Istituto Nazionale di Geofisica e Vulcanolgia (INGV) became the reference scientific institution for the Civil Protection, to assess the volcanic hazard and continuously update it for Neapolitan volcanoes. As regards Vesuvius, the extension of the most hazardous zone (i.e. the Red Zone) involves about 600,000 inhabitants, who must be evacuated in case of eruption (Protezione Civile: Update of the National Emergency Plan for Vesuvius). The extension of the Red Zone was obtained considering a medium energy scenario for the next eruption (a sub-plinian eruption) such as the one in 1631. The emergency plan for Vesuvius foresees a part of the population spontaneously moving away from the Red Zone during the pre-alarm phase (Fig. 1). Depending on the state of the volcano, the actions to be taken are defined within the emergency plan by the different levels of alertness in which the scientific and monitoring activities are decided upon depending on the assessment of the hazard. The lowest level (a "green" alert level) corresponds to the quiescence of the volcano, during which there are no significant changes in the parameters being monitored. If these changes are detected, however, the protocol provides for a transition to a level of attention ("yellow"), during which there is an intensification of monitoring activities and a more frequent assessment of the condition of the volcano by the Civil Protection agency and the Italian Commissione Grandi Rischi (Major Risks Commission). The levels above this are those of pre-alarm ("orange") and alarm ("red"), which, for the latter, involve the evacuation of the population from the Red Zone. The Vesuvius evacuation plan has been updated and modified during the time. At present, at least three days (compared to the previous three weeks) would be required to effectively evacuate 600,000 inhabitants. This should correspond to the actual possibility of forecasting the eruption with this level of forewarning. The last choice was also based on the forecasting experiences of the 1980 Mt. Saint Helens (USA) and 1991 Pinatubo (Philippine) eruptions (Pinatubo Volcano Observatory Team, 1991; Swanson et al, 1983). The plan posed, among the scientific community, a number of concerns and criticisms about the actual possibility of forecasting the next eruption in advance and evacuating at least 600,000 people at risk. In the framework of this debate, an alternative plan to mitigate the volcanic risk of Vesuvius area was proposed by Flavio Dobran (*Vesuvius 2000 plan*, Dobran 2006, 2007). Although the first work of Flavio Dobran was published in 2006, the dissemination of his plan took place a few years earlier, with an intense information campaign around the Vesuvius area. More than an emergency or evacuation plan, *Vesuvius 2000* proposed a new paradigm of development to reduce the risk of the area. The main intention of this proposal was "*…to produce guidelines for transforming high-risk areas around Vesuvius into safe and prosperous communities. This would be accomplished through interdisciplinary projects involving engineers, environmentalists, urban planners, economists, educators, geologists, sociologists, historians, and the public*" (Dobran, 2007). Among the general aims of *Vesuvius 2000* plan, the decreasing of the resident population density in the most-risky areas was proposed, as well as improving the resistance of the buildings to seismic shaking, the quality of infrastructure and the resilience of urban centres. Furthermore, Dobran (2006, 2007) showed that given the strong historical and social connection between "Vesuvius people" and their land, the diminishing of urban pressure in most of the risky zones represented a very long-term aim, needing a complete social, cultural, urbanistic and economic reconsideration of the Vesuvius area and surroundings. This long-term action will minimise the economic and social costs of the evacuation of people from the red zone in case of an eruption. The great challenge of the ambitious *Vesuvius 2000* plan was therefore that people around the volcano acquired the awareness of the environment in which they lived and participated in the solution of this difficult conundrum (Dobran, 2006).

After the solution proposed by Dobran (2006, 2007), a wide literature about the methods and the actions devoted to reduction and management of volcanic risk, and also of natural risks in general, was proposed by different authors, and in which most detailed descriptions of the limits of each solution and the case history were reported (Barcklay et al., 2008, 2015; Chester et al., 2000; Donovan and Oppenheimer, 2016; Fearnley et al., 2017; Jenkins & Haynes, 2011; Hansjürgens et al., 2008; Hicks et al., 2014; Hossain et al., 2017; Newhall & Punongbayan, 1996; Papale, 2017; Peterson et al, 1993; Petrazzuoli & Zuccaro, 2004; Petrosino et al., 2004; Small & Naumann, 2001; Spence et al., 2007; Usamah & Haynes, 2012; Wisner, 2003). Furthermore, some of the above researches also demonstrate that a volcanic resettlement program must be directed by meaningful consultation with the impacted community, as also suggested by Dobran (2006), which also shares in the decision making.

What happened in the period following the first releasing of the Vesuvius emergency plan and of the alternative paradigm *Vesuvius 2000* proposed by Flavio Dobran? The latter was not welcomed by the political establishment and remained a mere proposal. On the other hand, the former (the institutional one) only partially guaranteed the restraint or decreasing of anthropic pressure around the volcano. To deal with this problem, a new plan called *Vesuvìa* (https://www.viveretraivulcani.it/il-progetto-vesuvia/) was approved in 2003 by the Campania Region (Legge regionale n. 21/2003, "Legge del Vesuvio", http://www.sito.regione.campania.it/leggi_regionali2003/lr21_2003.htm). The intent of this project was to lighten the demographic pressure around the Vesuvius volcano. This intent would be promoted by offering economic incentives (up to 30 thousand euros) to the population (living in the red zone) willing to relocate themselves outside the dangerous areas. The project expects to reduce the number of people living in the red zone over a period of about 20 years by evacuating at least 100,000 people from this zone (Gugg, 2018). A further aim of *Vesuvìa* was also the reconversion of available buildings into tourist reception facilities, to create an opportunity of valorisation of the great cultural and natural heritage of the Vesuvius volcano. (http://www.cngeologi.it/wp-content/uploads/2017/08/Casa-Italia_Rapporto-sicurezza-rischi naturali-patrimonio-abitativo.pdf). Three years from the launch of the project, there was a reduction of residents in the red zone of only 0.1%, prompting the promoters of the project to abandon the endeavour. It was a resounding flop. The reasons for the failure were described by Gugg (2018). Among the reasons reported, the lack of involvement of the mayjors and the local communities in the development of the project was probably the most critical. Additionally, as also described by the *Vesuvius 2000* plan (Dobran 2006, 2007), a relocation of people from the red zone outside the Vesuvius volcano is very unlikely without long-term economic and social policies stimulating Vesuvius people to move to safer zones. It is clear that in a complex social, cultural and urban context such as that of Naples and surroundings, the choice to reduce the volcanic risk by relocating a part of people in the red zones (Campi Flegrei and

Vesuvius) outside the most-risky areas and by increasing the volcanic perception is a very gruelling challenge (Carlino, 2019). Furthermore, the policies to improve the vulnerability of edifices against disasters (and reduce the risk) have rarely been adopted in Italy, as demonstrated for instance by heavy damages suffered by many cities after moderate earthquakes recently (Valensise et al., 2017). The main issues, in this case, are related to the actual perception of risk in general (as well as of volcanic risk in particular), but mainly to the morals and personal profit of politicians in taking specific actions to reduce the risk and to other social and political problems of the Neapolitan area (Carlino et al., 2008; Donovan and Oppenheimer, 2015; Donovan, 2019; Luongo, 1997). For instance, political timescales generally limit the amount of capital invested in the volcanic risk reduction. Basically; as reported by Donovan (2019), "*if a politician is only in power for 4 years*" (and this time is the best case in Italy!) "*the probability of an eruption at a particular volcano within that timeframe is usually very low, and so, the personal-political cost-benefit analysis indicates that there are more socially acceptable policies to invest in*". This is possibly one of the main reasons why a long-term plan for risk reduction such as *Vesuvius2000* was rejected by the political establishment. The example reported by Donovan (2019) appears particularly true for the Neapolitan area, where the volcanic risk increased exponentially during the last 50 years, and no policies have contained this trend. This aspect was also debated by De Vivo et al., (2010) who stated that while the Italian Civil Protection tries to convince people to dislocate from the risk zone, it does not take a stand against the illegal buildings in the red zone. Otherwise, from the institutional point of view, the latter problem does not involve Civil Protection, because the management control of illegal buildings and their compliance with the seismic risk primarily involves the municipalities (*Decreto Legislativo 18 agosto 2000, n. 267; Testo unico delle disposizioni legislative e regolamentari in materia edilizia, d.P.R. n. 380/2001*). In this regard, the seismic risk associated with the volcano-tectonics earthquakes is not neglectable as well, at least for Campi Flegrei and Ischia. A representative case is the Island of Ischia. In 1883, the island was hit by a moderate and shallow earthquake (with magnitude around 4.5, Cubellis and Luongo, 1998), which devastated its northern sector (Casamicciola town) and had more than 2300 victims (Carlino et al., 2010b). This event was followed by an almost seismic silence, up to 2017. At least during the last 25 years, the scientific community urged the island local authorities and the municipality of Casamicciola to take actions favouring the mitigation of seismic risk in the island (Cubellis and Luongo, 1998; Luongo et al., 2012). However, this message went unnoticed, up to 21 August 2017, when an M_L4.0 earthquake occurred in Casamicciola town and caused two ~~victims~~deaths, tens of injuries and heavy damage in the upper part of the municipality (De Novellis et al., 2018). From the above considerations, it appears that conciliating the emergency plans, drawing the red zones of volcanoes, and regulating for the seismic risk, with the actual economic and land-use planning policies in the Neapolitan area are a hard purpose to attain.

Recently, in August 2016, the emergency planning for the volcanic risk of the Campi Flegrei was updated (Protezione Civile: Update of the National Emergency Plan for Campi Flegrei), and the area of the new Red Zone to be evacuated as a precautionary measure in case of an eruption, was defined, together with the Yellow Zone, which is potentially exposed to a high concentration of falling ash (Fig. 1). As for Vesuvius, the Red Zone and the Yellow Zone were defined by the Civil Protection in agreement with the Campania Region and based on the indications provided by the scientific community. As a whole, and considering that an emergency plan for the island of Ischia (Gulf of Naples) is still lacking, about 1,000,000 people could be directly affected by a moderate to large eruption (VEI 3–4) in the red zones of Campi Flegrei and Vesuvius, respectively. The high number of people exposed to the risk and the uncertainty in eruptions forecasting (Sparks, 2003) motivated some authors to criticise the evacuation plans and the risk reduction policies in the Neapolitan district (De Natale et al., 2020; Rolandi, 2010). Particularly and recently, De Natale et al. (2020) have questioned how the very high volcanic risk in the Neapolitan area can be effectively mitigated. The authors focused the attention on two evacuation-related problems: i) the extremely high number of people to evacuate in case of an impending eruption; ii) the lack of plans today to rehabilitate such a high number of evacuated people (600,000 and 700,000 for Campi Flegrei Caldera and Vesuvius, respectively). ~~The analysis of De Natale et al. (2020) is not new, since their main conclusions, as well as the weaknesses they highlighted in respect to the present emergency plans, were already stated by other authors, and in particular by Dobran (2006, 2007, *Vesuvius 2000* plan).~~ It is important to highlight that some works criticising the evacuation plans (De Natale et al., 2020; Dobran 2006) do not exclude their effectiveness if a number of actions to mitigate the risk are carried on. Unfortunately, what we have seen during the last 40 years of volcanic risk management in the Neapolitan area is a predominance of emergency policies in respect to that of prevention. The result is that the present volcanic risk, given the current high values of society, appears ~~non-acceptable~~unacceptable.

~~5.~~7. The role of volcanologists

In the framework of the discussed topics, a fundamental issue is the role of volcanologists in managing volcanic risk and crises. It was, in many cases, misinterpreted by people living in the Neapolitan area. The role and responsibilities of volcanologists in volcanic hazard evaluation, risk mitigation and crisis response have been outlined by the International Association for Volcanology and Chemistry of the Earth's Interior (IAVCEI). Their main responsibility is to improve the scientific knowledge of volcanoes to better understand how they work and provide the most robust eruption forecasts, and to educate the local and global community (mainly exposed to eruptions) to the volcanic risk, making people more perceptive of the risk itself. The latter is fundamental to evoking an amenable response from people to an evacuation (IAVCEI, 2016). Anyway, the main task of volcanologists is to provide as robust a forecast of an eruption as possible. It is well-known how problematic it is to obtain a clear picture of the progression of volcano processes during unrests and to understand what the actual state of the volcano is (critical state or not). In general (but not always), as the eruption approaches the number and the amplitude (or energy) of geophysical and geochemical signals increases, the uncertainty in the forecast should decrease (Carlino, 2019; Decker, 1986; Kilburn, 2003; Robertson et al., 2016; Sparks, 2003; Sparks & Cashman, 2017;) (Fig. 4). An unsolved question is whether, and at what moment, the volcano approaches the critical state during an unrest; that is the moment when the physical processes occurring within the volcano are irreversible and the volcano erupts (Fig. 4). This is the most critical issue because the promulgation of a false alarm or a missed alarm will adversely affect 600,000–1,500,000 people living in the Neapolitan area (De Natale et al., 2020). The problem of false alarms and of uncertainty in volcano forecast is chronic in volcanology and also relates to communications and managing the expectations that a population have of scientific capacity over long term. The uncertainty in anticipating eruptions may reflect the complexity of volcanic systems, the level of monitoring networks and the complex multidisciplinary decision-making process during a volcanic crisis (Winson et al., 2014; Harris, 2015b). During the last 20 years, the monitoring networks for the surveillance of the Vesuvius, Campi Flegrei and Ischia volcanoes have been greatly improved, reaching one of the best standards worldwide (www.ov.ingv.it). This effort should correspond to a reduction of the uncertainty in forecasting the next eruption although it depends on the capacity of volcanologists to correctly decipher the volcano signals. Beyond the efforts of scientists to improve their understanding of volcanic processes and provide more robust forecasts, communicating the systemic uncertainty of the forecast to the public is fundamental. This can be done effectively only with a proficient direct communication network between volcanologists and the media (Haynes et al, 2008; Winson et al., 2014).

7.1 Volcanologists and media

The relationship between volcanologists and media ~~This~~ is also a very important topic, particularly when the communication of an ongoing volcanic crisis involves large metropolitan areas like Naples and its surroundings. The example of what occurred during the 1982–84 unrest is emblematic of this view. During that crisis, a unique channel of communication was established between the Vesuvius Observatory and the press while the observatory was continuously communicating with the Minister for the Coordination of the Civil Protection (Luongo, 2013). The activation of the information centre for the citizens of Pozzuoli and the straight link between the latter and the direction of the Vesuvius Observatory generated confidence among people. How would it have turned out if the same crisis had happened today? The unrest and the evacuation at Pozzuoli occurred in an era without the internet and social media (Facebook, Twitter and WhatsApp) which, nowadays, represent the main rapid dissemination channels of news and information. Furthermore, the "tabloidization" of the news has also resulted in the use of strong, exaggerated words, headlines and images to support a particular frame (Harris, 2015a). Social media platforms are disruptors of traditional communication, opening up new opportunities for scientists to communicate (Dong et al., 2020) but, on the other hand, bestowing the right to evaluate or criticise scientific decisions on everyone. This could lead to misinterpretations or distortions of scientific broadcasts and information and, consequently, to false alarms or unjustified panic among the population, in case of a volcanic crisis (Harris, 2015a). This circumstance, albeit not related to a volcanic crisis, occurred recently before the commencement of the Campi Flegrei Deep Drilling Project, at Campi Flegrei, a project aimed at scientifically investigating the caldera (Carlino, 2019). The project worried many local residents about the possible disturbance that the scientific drilling would unleash in the volcanic system. Just before the onset of the drilling, the declarations spreading on social networks and newspapers assumed an increasingly alarming tone (sometimes to the limit of the paradoxical) such as to seriously worry the municipal administration of Naples, which had cleared the drilling. The climax was reached in October 2010 when the national newspaper "Il Mattino" led with the front-page title: "If you touch the volcano, Naples will explode" (Carlino, 2019, page 265). The project was temporarily suspended by the Naples administration to further clarify its aim and associated risk. This fact highlights that the position of volcanologists in communicating the hazard and the risk in densely inhabited regions like Naples is very tricky because the communication occurs within a complex social system where many people exposed to the risk are involved. Furthermore, a number of studies demonstrate that Neapolitans have a low perception of risk and a low level of risk education (Carlino et al., 2010b; Ricci et al., 2013).

As a whole, beyond the effort that scientists are expending to improve the robustness of the volcanic eruptions forecast, a further effort is necessary to promulgate the culture of volcanic risk and promote open debates with the local population and authorities. In other words, volcanologists should be more present on the territory (not only during an ongoing volcanic unrest) and they should be an open book, not an acquired skill (Fearnley et al., 2017; Goodstain, 2010). This approach is fundamental to improving the confidence of people in a scientific institution such as INGV.

~~6.~~8. Conclusions

The past experiences concerning the management of volcanic risk in the Neapolitan area reveal the complexity of devising a collaboration around the active volcanoes of Vesuvius, Campi Flegrei caldera and Ischia Island to reduce the risk in such densely inhabited areas. The history of volcanic risk in this area demonstrates the tendency to not consider, or to underestimate, the risk (which otherwise is a human attitude). Nonetheless, we cannot reduce the problem of the high volcanic risk of the Neapolitan area to this latter consideration only. The present development of the urbanised areas around the volcanoes of Naples is the result of a very long history and stratification of different cultures and populations that settled the Neapolitan area and its surroundings as a scenic and useful place to live, since the Bronze Age. This history left a huge cultural heritage in its wake but also a demanding socio-economic condition, especially around Vesuvius. Thus, as also highlighted by Galliard (2008), in many cases the historical and cultural heritage and political economy remain of much greater importance and may override the choice of people in the face of volcanic hazards. This fact emphasises the importance of understanding the complex contexts of the Neapolitan area in proposing policies to reduce volcanic risk. It appears evident, for instance, that the choice of people not to relocate themselves outside the red zone of Vesuvius and to remain in their native towns, despite the perceived threats, has little to do with volcanic activity. This point, already discussed by Galliard (2008), suggests that, in such a complex social context, the policies for volcanic risk mitigation need to go far beyond only prevention of relatively rare events. A different and more general approach is thus required, and rational access and the use of resources to adapt the social and economic development of the area to its natural vocation should be aimed at. This is a long-term objective conflicting with the short-sighted policies adopted by the Campania Region and the Central Government. Consequently, the proposals to re-convert the riskiest areas of Neapolitan volcanoes into lower-risk zones using a different (and long-term) paradigm of development (e.g. Dobran, 2006, 2007) are struggling to take off. Simultaneously, the proposed economic incentives (*Vesuvìa* project) to relocate people from the red zone (at Vesuvius) towards safer areas was a failure as well. Accordingly, these failures first have to do with a wrong territorial policy, and secondly with the volcanology.

Furthermore, at least during the last 25 years, the policies for the reduction of volcanic risk in the Neapolitan area have been disconnected from their natural, social and politico-economic context. This is possibly the result of a not so holistic approach to the problem of volcanic risk reduction which, particularly in this area, is unavoidable and, on the contrary, requires an openly discussed method between academics of all disciplines, policymakers and stakeholders (Don~~v~~ovan, 2019). The most recent history of Neapolitan volcanoes is also interesting for disaster development trajectories in other countries. Actually, the mistakes – particularly those of not linking risk with development practice – are being repeated all over the world in hazard-prone areas. This fact highlights the importance of risk-sensitive development practices, that incorporate scientific advice, urban planning, social study and so on (Barclay et al., 2008; Donovan and Oppenheimer, 2014).

-Finally, after about 40 years of debates around the volcanic risk in the Neapolitan area, an analysis of the reasons why the strategies aimed to reduce the risk in this area systematically failed is required. This step is necessary to propose more reliable solutions for the risk reduction in a very large and urbanised territory such as that of Neapolitan volcanoes. A further effort is also required by Neapolitan scientists to connect the territorial governance structures and local (at risk) communities to the scientific network. In this framework, scientists must pay further attention to avoid politicisation of volcanology when advising the authorities (Donovan, 2019).

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Figure captions

Fig.1. The Neapolitan volcanic area with the three active volcanoes, Vesuvius, Campi Flegrei caldera and the Island of Ischia. The limits of the red zones of the evacuation plans for Vesuvius and Campi Flegrei caldera are reported, respectively (from www.protezionecivile.gov). ~~More than~~About 1,000,000 of people are living in both the red zones. A plan for the island of Ischia is currently in progress (base map is from Google Earth). The box below shows the inhabitants density map of the Neapolitan area (from regione.campania.it)

Fig. 2. A timeline of volcanic activity history at Vesuvius, Campi Flegrei and Ischia Island. The most important eruptions are reported. Red and blue color indicates increasing and decreasing of volcanic activity, respectively (after Piochi et al., 2005).

Fig. 3. The city of Naples with the location of the eruptive vents associated with different eruptive periods. The dotted line represents the eastern boundary of the caldera of Campi Flegrei (modified after Scarpati et al., 2013 and Carlino, 2019; base map is from Google Earth).

Fig. 4. A qualitative sketch describing the possible state of a volcano approaching an eruption and its forecast reliability. For a quiescent volcano the reawakening is generally associated with the onset of seismic activity indicating the variation of stress field within the volcano. The latter is generally due to circulation of pressurized fluids in the crust and, eventually, to magma migration at shallow level.

This dynamic is accompanied by others precursors (ground deformations and variation of fluids emission) which make the forecast more reliable as the eruption is approached. The point at which the volcano overcomes the critical state, is the moment (t?) in which the physical processes occurring within the volcano are irreversible, that is to say the volcano will erupt. Volcanologists cannot predict the time (t?) because the processes are chaotic and the forecast has a probabilistic nature (after, Carlino, 2019).

Figures


Italy
CF caldera
Naples
Vesuvius
Pozzuoli
Procida Island
Gulf of Naples
Ischia Island
Sorrento Peninsula
N
20 km

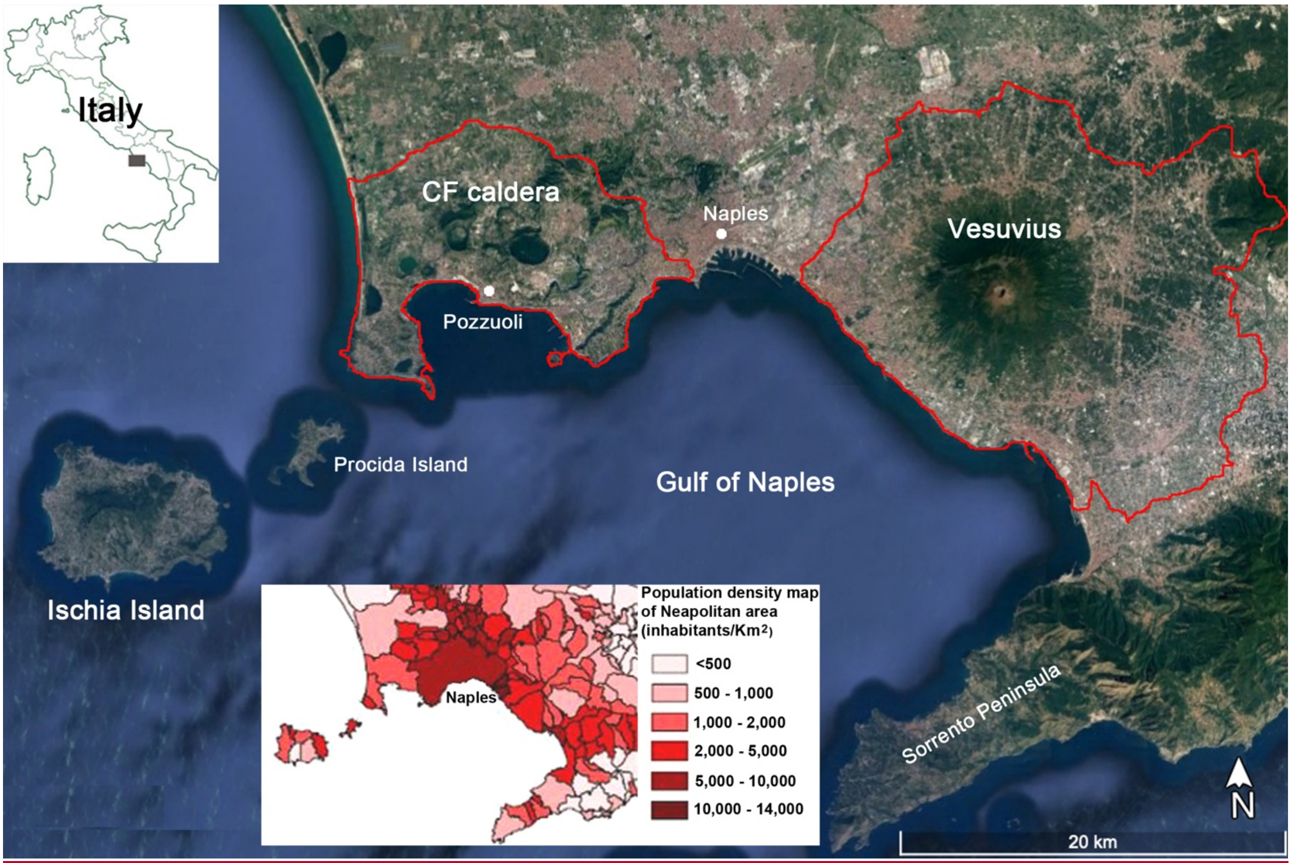
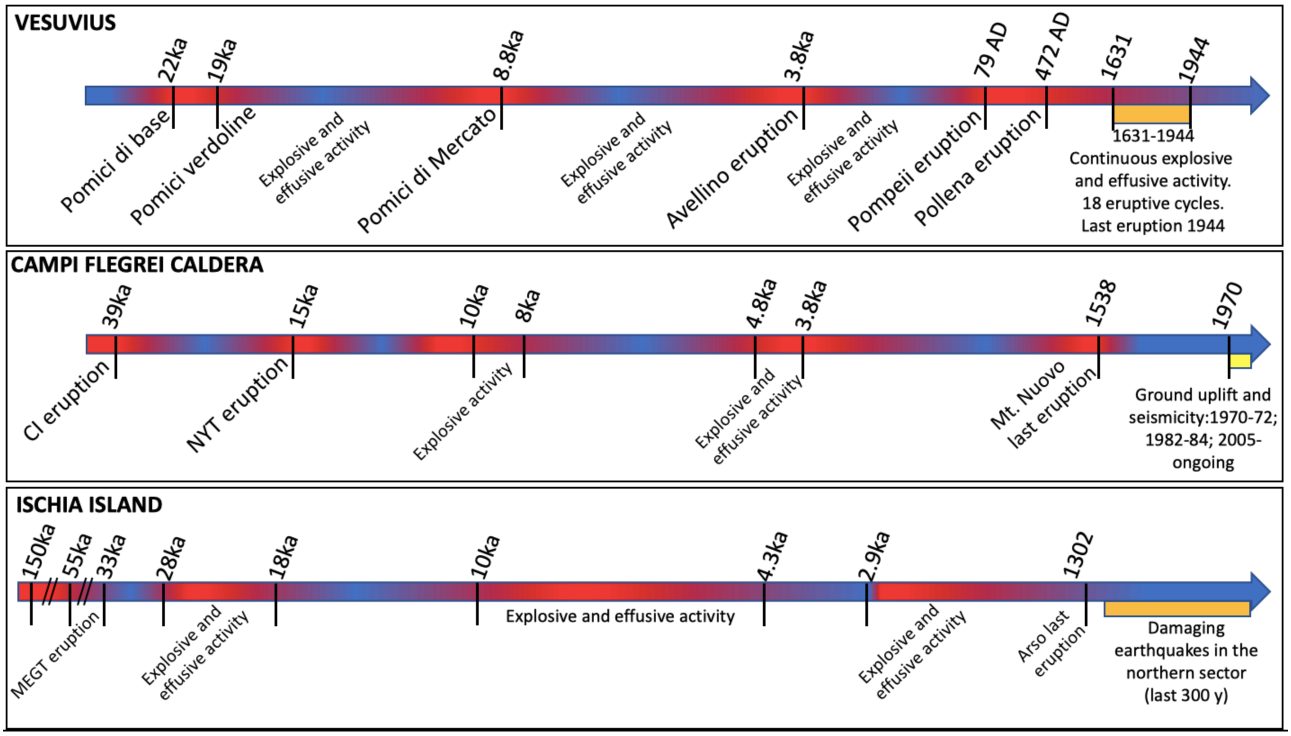
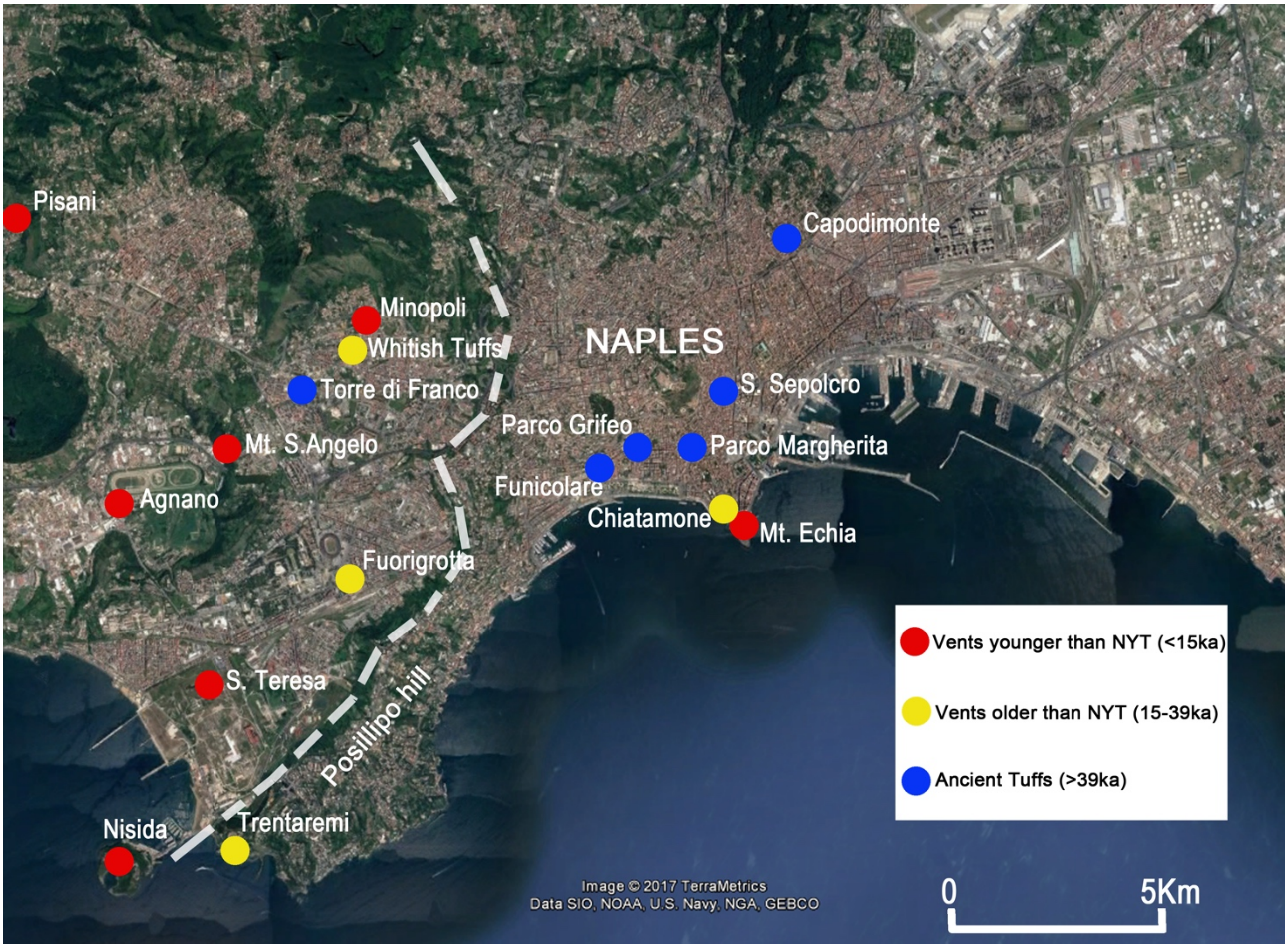

Italy
CF caldera
Naples
Vesuvius
Pozzuoli
Procida Island
Gulf of Naples
Ischia Island
Population density map of Neapolitan area (inhabitants/Km2)
<500
500 - 1,000
1,000 - 2,000
2,000 - 5,000
5,000 - 10,000
10,000 - 14,000
Naples
Sorrento Peninsula
N
20 km

Fig.1



VESUVIUS
22ka
19ka
8.8ka
3.8ka
79 AD
472 AD
1631
1944
Pomici di base
Pomici verdoline
Explosive and effusive activity
Pomici di Mercato
Explosive and effusive activity
Avellino eruption
Explosive and effusive activity
Pompeii eruption
Pollena eruption
1631-1944
Continuous explosive and effusive activity.
18 eruptive cycles.
Last eruption 1944
CAMPI FLEGREI CALDERA
39ka
15ka
10ka
8ka
4.8ka
3.8ka
1538
1970
CI eruption
NYT eruption
Explosive activity
Explosive and effusive activity
Mt. Nuovo last eruption
Ground uplift and seismicity:1970-72; 1982-84; 2005-ongoing
ISCHIA ISLAND
150ka
55ka
33ka
28ka
18ka
10ka
4.3ka
2.9ka
1302
MEGT eruption
Explosive and effusive activity
Explosive and effusive activity
Explosive and effusive activity
Arso last eruption
Damaging earthquakes in the northern sector (last 300 y)

Fig.2



Pisani
Capodimonte
Minopoli
Whitish Tuffs
Torre di Franco
NAPLES
S. Sepolcro
Parco Grifeo
Mt. S.Angelo
Parco Margherita
Agnano
Funicolare
Chiatamone
Mt. Echia
Fuorigrotta
S. Teresa
Posillipo hill
Nisida
Trentaremi
Vents younger than NYT (<15ka)
Vents older than NYT (15-39ka)
Ancient Tuffs (>39ka)
Image © 2017 TerraMetrics
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
0
5Km

Fig. 3

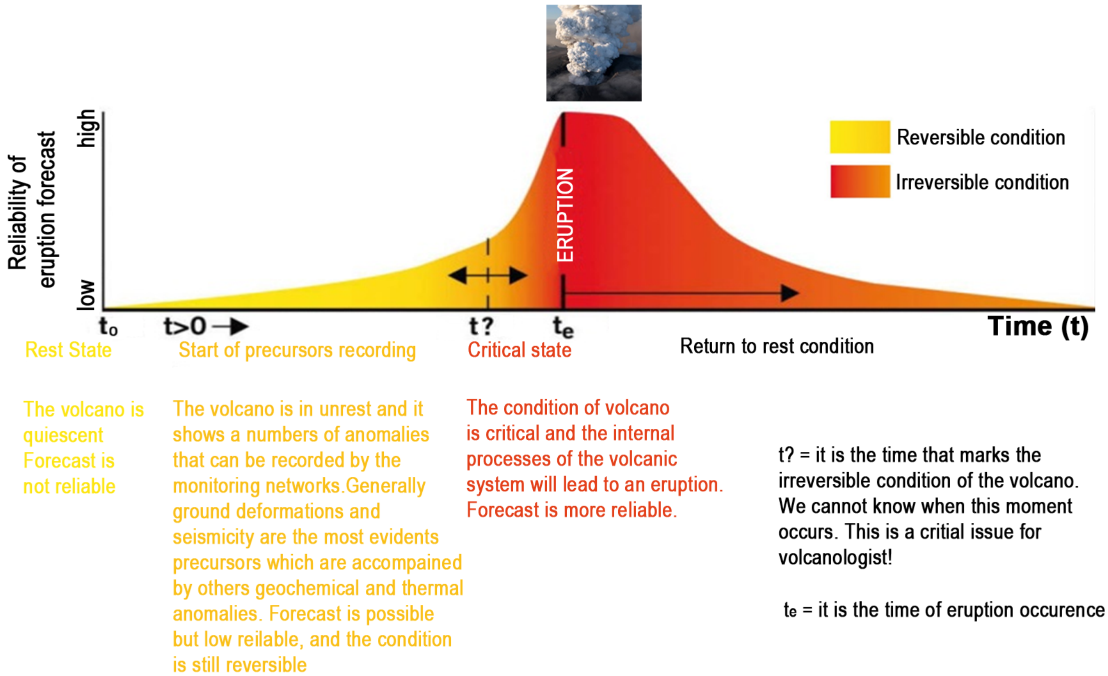


Fig.4

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