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VESUVIUS–CAMPIFLEGREI PENTALOGUE

Resilience and Sustainability Framework for Neapolitan Area

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Abstract. VESUVIUS–CAMPIFLEGREI PENTALOGUE is a resilience and sustainability framework for the Neapolitan area with two active volcanoes Vesuvius and Campi Flegrei (Phlegraean Fields). These volcanoes produce small and large eruptions that can affect several million people living in Naples and surrounding towns. The framework requires abandoning the evacuation plans that aim at deporting several million people all over Italy before the impending eruptions and the achievement of five key objectives of resilience and sustainability that makes possible the cohabitation of the population with volcanoes in security and prosperity. The pentalogue calls for the establishment of three danger zones around the volcanos: exclusion nuclei containing the craters, resilience belts surrounding the exclusion nuclei, and sustainability areas beyond the resilience belts. The built environments in the resilience and sustainability areas are required to conform to special construction codes to mitigate the effects of the eruptions and establishment of extensive volcanic risk information and educational campaigns. The achievement of these objectives depends on interdisciplinary and transdisciplinary collaborations and involvement of suitable investors for producing territorial interventions.

Keywords: Vesuvio, Vesuvius, Campi Flegrei, Phlegraean Fields, hazard, risk, resilience, sustainability

1. Introduction

The Neapolitans managed to cohabit with Vesuvio (Vesuvius) and Campi Flegrei (Campi Phlegraei, Phlegraean Fields) volcanoes for several millennia by rebuilding their habitats after the eruptions and built unique culture that contributed significantly to Western Civilization. Both of these volcanoes can produce explosive eruptions with the fall of ash from the eruption columns and propagation of deadly pyroclastic flows from the collapses of these columns. During the past 30,000 years of activity Vesuvius produced a dozen of large plinian eruptions

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with each ejecting several cubic kilometers of material, and in between of these eruptions produced an order of magnitude smaller explosive eruptions that terminated with effusive activities [1]. Campi Flegrei is 10-100 times more powerful volcano than Vesuvius and during the past 60,000 years produced two super eruptions on whose deposits the city of Naples is built [2]. This volcano can also produce Vesuvius-type eruptions and the geologists estimated that on average it erupts every 5-6 centuries [3].

The urbanization around the Neapolitan volcanoes is, however, preventing reliable assessments of erupted material and the development of credible eruption scenarios requires the development of complex multicomponent and multiphase physical-chemical-mathematical models and their computer implementations [4, 5]. The current ground uplift at Campi Flegrei and occasional rise of seismicity bellow Vesuvius [6] are of concern to the population and the Civil Protection (Protezione Civile) and Osservatorio Vesuviano (Vesuvius Observatory) keep assuring the people that "eveything is under control". But what exactly is *under control* is never specified.

Vesuvius and Campi Flegrei Evacuation Plans [7, 8] were politicized by the geologists with the objective of forcefully resettling several million people around the volcanoes in different Italian regions prior to the impending eruptions. This strategy requires reliable eruption forecasting that may be available only 2-3 days preceding the eruption [9, 10], adequate infrastructure and public order to produce reliable exodus from the territory that frequently shakes before the eruptions, willingness on the part of the evacuees to abandon their homes and properties, and willingness of hosting communities to absorb the refugees that will produce socio-economic and cultural consequences. The architects of these massive deportation plans failed, however, to conduct an exhaustive *feasibility study* of such a complex socio-technical undertaking and the institutionalization of these plans is preventing the development of resilience and sustainability for Neapolitans [11]. The criticisms of Vesuvius and Campi Flegrei evacuation plans have been available since 1995 [12], but neither the national nor the European Union authorities have found it necessary to support the development of *prevention strategies* that aim to produce the cohabitation of Neapolitans with their volcanos in security and prosperity.

VESUVIUS 2000 [13] is a proposed feasibility study that aims to achieve this cohabitation, or resilience and sustainability for Neapolitans, and requires interdisciplinary and transdisciplinary collaborations. Its central objective is directed at producing the *security culture* instead of the *emergency culture* promoted by the current evacuation plans. The development of this framework was proposed in 1995 through a proposal to the European Union [14] and it rejection was contested through the European Parliament without success[1] [15]. Once developed

[1] During the preparation of VESUVIUS 2000 proposal the European earth science community was invited to participate on the project but the Italian geologists opted instead to support Vesuvius and Campi Flegrei Evacuation Plans under the leadership of then Undersecretary of Civil Protection Franco Barberi and Director of Vesuvius Observatory Lucia Civetta.

for the Vesuvius area such a feasibility study could also have been developed for Campi Flegrei with some important modifications that require the considerations of super eruptions of this volcano. When dealing with complex social and technical issues the feasibility studies are necessary before implementing policies, not only to account for the interests of different actors but also for attracting the investors for successfully implementing territorial interventions.

TVESUVIUS 2000 was elaborated to stress its five key objectives and was named VESUVIUS PENTALOGUE [16], and this work summarizes its extension to the volcano of Campi Flegrei. The resulting framework for both volcanoes is called VESUVIUS–CAMPIFLEGREI PENTALOGUE and includes plinian-type eruptions for both volcanoes and super eruptions of Campi Flegrei. The development of this feasibility study requires several years to complete and even more time for achieving territorial interventions, while the normal life of Neapolitans is maintained with minimal disruptions and the volcanos remain dormant.

2. VESUVIUS–CAMPIFLEGREI PENTALOGUE

VESUVIUS–CAMPIFLEGREI PENTALOGUE requires the achievement of the following five key objectives:

1. The current National Emergency Evacuation Plans for the populations of Summa-Vesuvius and Campi Flegrei areas, which would create massive dispersions all over Italy of the current 1-2 million inhabitants living within the immediate danger zones of the volcanos, are both problematic and unacceptable. Further collaborative efforts (studies, discussions, workshops) among institutional representatives, scientists, as well as the communities at risk, are required, in order to:
   A. Select *temporary settlements* for some of these inhabitants within the areas much closer to their native homeland, until the volcanic crises subside;
   B. Minimize the effects of the eruptions on the built environment.
2. A continuing close cohabitation of the populations with the volcanos should be the crucial cultural point to be pursued, whenever possible, together with an overall risk reduction; this can be accomplished through a much more accurate identification of:
   A. Volcanic hazards (earthquakes, tephra falls, pyroclastic flows, bombs and missiles, mudflows, tsunamis);
   B. Vulnerabilities (civil construction practices, infrastructure systems, cultural patrimonies);
   C. Exposed values (with particular regard to people, strategic buildings, schools, heritage).

   To achieve this identification, a redefinition of the *danger zones* around Summa-Vesuvius and Campi Flegrei is required, as follows:
   a. An *exclusion nucleus* (*nucleo di esclusione*) should be established for each volcano that prohibits all future human settlements and discourage the existing ones;

b. A *resilience belt* (*cintura di resilienza*), housing most of the current population, should be established for each volcano, where:
   i. All structures (new and existing) conform to special construction codes based on *maximum plausible seismic and volcanic actions scenarios*;
   ii. Comprehensive scenario evacuation plans for the population within this belt should be implemented as backup strategies;

c. A *sustainability area* (*area di sostenibilitá*) should be established for each volcano beyond the resilience belt, allowing for both *sustainable practices* and *temporary resettlements* of the resilience belt citizens; if this area is sustainable, it is consequently resilient to future eruptions;

d. For the Campi Flegrei area, the exclusion nucleus, resilience belt, and sustainability areas should be established for both plinian and super eruptions of this volcano.

The three zones for each volcano should be urgently identified as follows:

a. Activating further multidisciplinary studies, researches, projects, with the cooperation among International and Italian scientists, institutional representatives, and communities at risk;

b. Enhancing the rule of law to fight illegality, guarantee the strict control of public funds, foster the transparency of local administrators, ensure the effectiveness of emergency and risk mitigation strategies.

3. The built environment construction codes for the populations of danger zones should be established utilizing:
   A. Plinian for Vesuvius and plinian and super eruptions for Campi Flegrei volcano scenarios;
   B. Scenario-based seismic hazard assessment and zonation;
   C. Dynamic structural analysis;
   D. Global volcanic simulations of thermo-fluid dynamic eruption processes capable of modeling the durations of *entire* eruptions.

4. The volcanic risk information and education should involve:
   A. An effective volcanic risk information campaign and active public preparedness strategy should be implemented for exclusion nuclei, resilience belts, and sustainability areas surrounding Summa-Vesuvius and Campi Flegrei.
   B. A Volcanic Risk Education Safety Program should be implemented in all schools located within each of the above areas surrounding the volcanos.

5. The political authorities, scientific community, and organizations participating on pentalogue framework should produce:
   A. A *memorandum of understanding* that univocally establishes an effective collaboration;
   B. Periodic progress reports that keep the populations informed on the progress leading to the realization of pentalogue objectives.

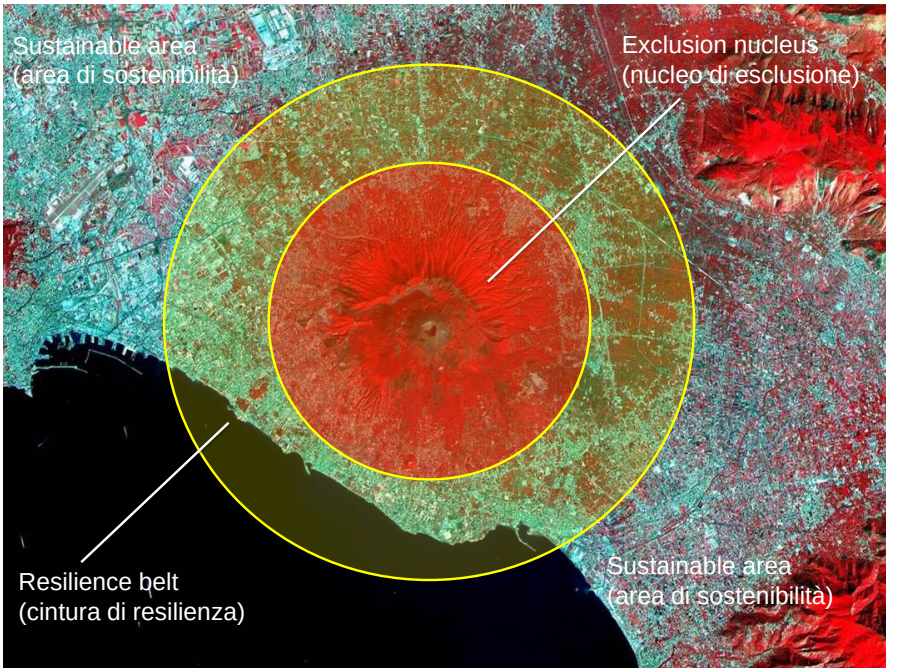

Figure 1. Schematic illustration of exclusion nucleus, resilience belt, and sustainability area for plinian eruptions of Summa-Vesuvius volcano [12].

3. Discussion

Figure 1 illustrates the exclusion nucleus, resilience belt, and sustainability areas for plinian eruptions of Summa-Vesuvius volcano, Fig. 2 is an illustration of similar areas for plinian eruptions of Campi Flegrei volcano, and Fig. 3 illustrates these areas for the super eruptions of Campi Flegrei volcano. The boundaries of different areas shown in the illustrations are provisional and their true nature can only be determined by achieving the above five pentalogue objectives. For Vesuvius there is only one exclusion nucleus, one resilience belt, and one sustainability area that account for the plinian eruptions of this volcano, whereas for Campi Flegrei there are two exclusion nuclei, two resilience belts, and two sustainability areas that account for the expected short-term plinian eruptions (order of 1000 years) and long-term super eruptions (order 10,000 years) of this volcano.

The achievement of five pentalogue objectives requires collaborations of engineers, earth scientists, educators, economists, populations surrounding the volcanoes, and governmental and nongovernmental organizations of the territory. This collaboration is, however, difficult to achieve because each group tries to maintain the group identity and mistrusts disciplines that are unknown to the group [17]. The acceptance of a new paradigm is for many incommensurable and

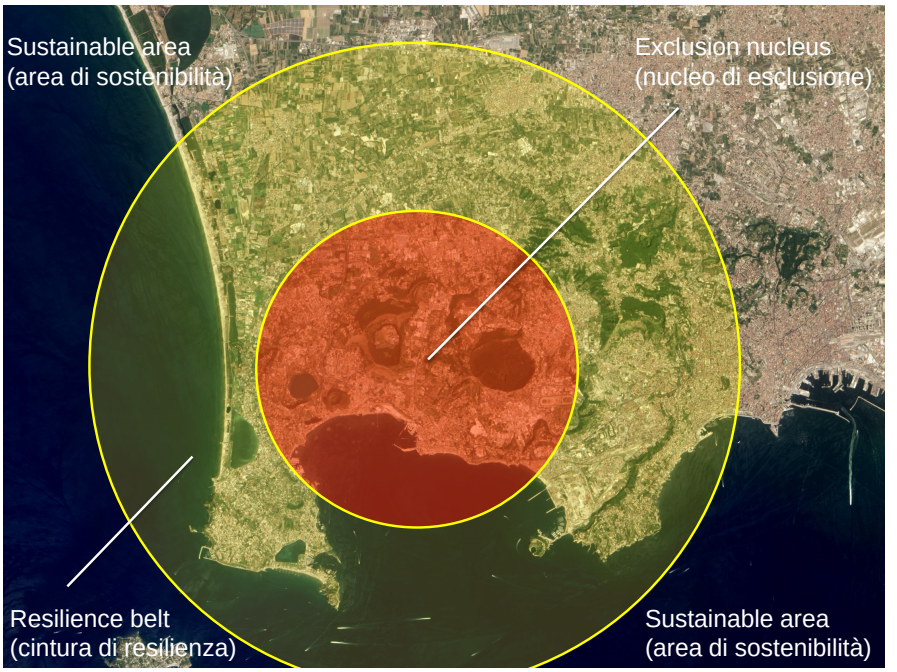

Figure 2. Schematic illustration of exclusion nucleus, resilience belt, and sustainability areas for plinian eruptions of Campi Flegrei volcano [12].

requires challenging the entrenched habits of mind until the sharing of paradigm becomes contagious and unproblematic [13]. Incommensurability is therefore a blindness or a "barrier" to seeing what the other side is saying.

Massive displacements of people from their habitats is problematic, not only for those being displaced but also for the authorities that must prepare and manage the exhodus in an orderly manner and the hosting communities that must accept the refugees. This strategy is thus in conflict with the *preservation of the sense of belonging* as required by one of the central pillars of sustainability [18], because the people who participate in culture building want to conserve their culture or group identity. VESUVIUS–CAMPIFLEGREI PENTALOGUE is consistent with this principle of sustainability whereas the evacuation plans of Vesuvius and Campi Flegrei are not.

The pentalogue requires a reorganization of the Neapolitan area to ensure that the future eruptions can only produce minimal socio-economic, cultural, and political consequences, and not only locally but also nationally and within other countries of the European Union if some Neapolitan refugees journeys across the Italian border. The explosive nature of Neapolitan volcanoes cannot be underestimated and by developing emergency evacuation plans for the eruptions of these volcanoes that are below the powers of plinian and super eruptions

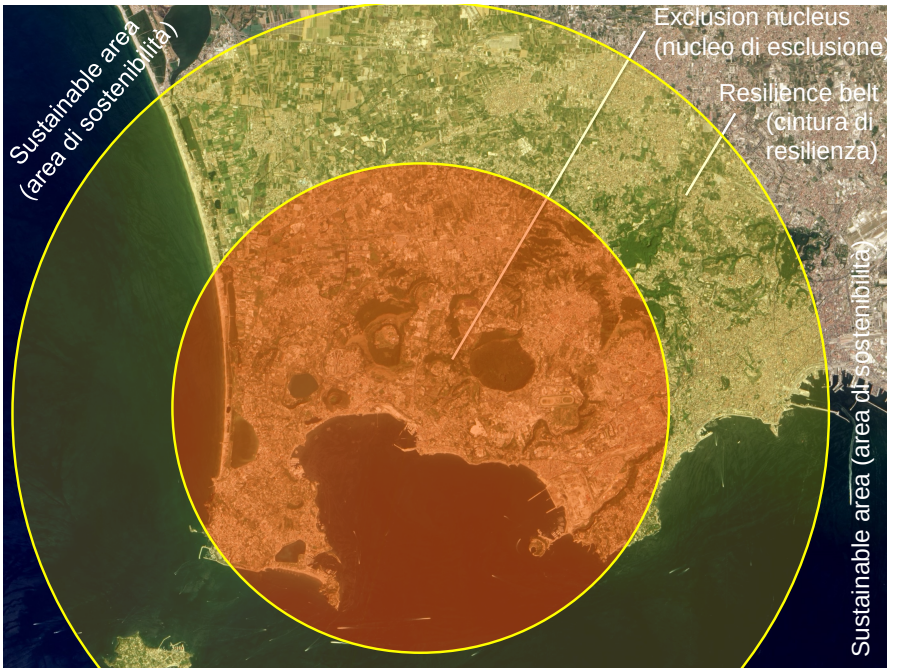

Figure 3. Schematic illustration of exclusion nucleus, resilience belt, and sustainability areas for super eruptions of Campi Flegrei volcano [12].

is another myopic vision of the architects and promoters of such plans. The VESUVIUS–CAMPIFLEGREI PENTALOGUE risk mitigation framework for the Neapolitans does not underestimate this vision and fully confronts the social and technical requirements that are necessary to seriously confront the eruptions of Vesuvius and Campi Flegrei.

The powers of these volcanoes, require, however, that within certain distances from the craters all human activities connected with the normal conduct of life should be prohibited. These are the *exclusion nuclei* of the pentalogue and must be carefully determined through the simulations of eruption scenarios, since any activity conducted in these nuclei risk of being destroyed. Surrounding the exclusion nuclei are the *resilience belts* where the built environments must conform to special construction codes. All constructions in the resilience belts should be able to withstand the eruptions with minimal damage to the built environment and the displaced people from these areas should be able to return and rebuild. While it should be possible for some people of resilience belts to remain in these belts during the eruptions, this should be evaluated very carefully through the extensive simulations of scenarios to ensure that no safety measures have been abused. The resilience belts should have the ability to *react* or respond appropriately in time, the ability to *monitor* their own states and the environments that

interact with them, the ability of certain *intelligence* that allows them to learn and take actions when necessary. Resilience is, therefore, a capacity to recover from the difficulties, whereas the *sustainability areas* must have an ability to be maintained at a certain level or levels prior, during, and after the perturbing effects of their environments.

The resilience and sustainability areas of the pentalogue have an extraordinary technical component (objective 3 of the pentalogue) that requires professional engineering and urban planning competences. A precise knowledge of volcanic deposits around the volcanoes is essential in order to understand their past behavior and for verifying the volcanic and seismic scenario models in limited circumstances. As noted earlier, the volumes and compositions of these deposits are uncertain and need to be better understood and verified through independent geological investigations [11]. The volcanic scenario models require integrations of different volcanic processes: Magma accumulation and differentiation in magma chambers, magma ascent in volcanic conduits and interactions with underground aquifers, dispersions of volcanic products above the vents of volcanoes and along their slopes with built environment during the plinian and column collapsing phases of eruptions [4]. A Global Volcanic Simulator is being developed to accomplish this task with the objective of simulating the entire eruptive process, from start to finish [17, 19–21].

A typical result from computer simulation of a plinian eruption of Vesuvius showing the temperature distribution of erupted material on and above the surface of the volcano is shown in Fig. 4. The collapse of volcanic column produces ground-hugging pyroclastic flows that tend to move along the valleys and change the direction of propagation from horizontal to vertical by producing secondary columns. This behavior of pyroclastic flows suggests that only a certain region close to the crater (exclusion nucleus) will be subjected to the maximum impact from the eruption and that further out from the crater (in the resilience belt) this impact will be significantly reduced.

The knowledge of potential spatio-temporal displacements, velocities, and accelerations caused by earthquakes and deformations from magma accumulation in the volcanoes of the Neapolitan area is currently insufficient for designing resilient and sustainable built environments. Currently, the potential earthquake hazard can best be determined by employing the neo-deterministic seismic hazard assessment methodology of Panza [22] and co-workers, because it allows for building seismic hazard scenarios based on the materials and structures of the Earth's crust.

Having established possible volcanic and seismic loads on different types of residential, commercial, and industrial structures and infrastructures at different times during the eruptions and at different locations around each volcano it is now possible to employ the dynamic structural analysis methods to determine the vulnerability, or safety and serviceability, of current and future structures in the exclusion nuclei, resilience belts, and sustainability areas [23]. This procedure allows for the establishment of specific *construction codes* or standards for use in the built environments of the Neapolitan area.

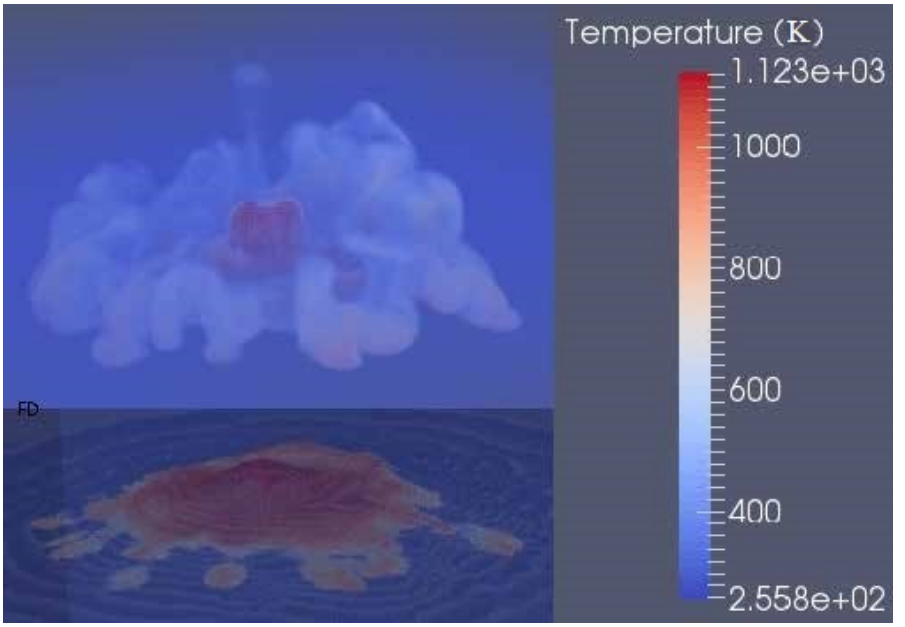

Figure 4. Three dimensional simulation of a plinian volcanic column of Vesuvius that produces pyroclastic flows. Shown in the illustration is the temperature distribution above the surface of the volcano (top image on the left) and on the surface of the volcano (bottom image). This result was produced with Global Volcanic Simulator that simulates volcanic column based on magma accumulation in magma chamber, magma ascent along the conduit, and current topography of the volcano [20].

The last two objectives of the pentalogue are no less significant, since without an informed public, responsible authorities, open-minded professionals, and organizations that value building the prevention culture more than promoting the current emergency culture there will be no clear paths toward resilience and sustainability for Neapolitans. Education must start in the schools and propagate through the students and their parents, and through the general public with effective risk information campaigns where the mass media provide the correct and critical information. But today we are far from achieving this objective, since neither the school students nor the public or the mass media are properly educated on the values of building resilient and sustainable societies [24].

4. Conclusions

VESUVIUS–CAMPIFLEGREI PENTALOGUE is an advanced interdisciplinary and transdisciplinary resilience and sustainability framework for the Neapolitan area and is an elaboration of the VESUVIUS 2000 framework proposed in 1995. The five key objectives of pentalogue aim at producing temporary and local

shelters for populations of danger areas during the volcanic crises, developing advanced engineering and urban planning solutions for producing resilient and sustainable environments around the volcanoes, developing effective risk information and educational campaign for the public, and establishing effective collaborations between professionals, organizations, institutions, and stakeholders for securing territorial interventions. The progress toward the achievement of pentalogue objectives is however hindered by the unreliable and institutionalized Vesuvius and Campi Flegrei evacuation plans and incommensurable habits of mind of many professionals and public officials.

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