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Analysis oh historical and recent earthquakes at Campi Flegrei caldera for seisimc hazard evaluation

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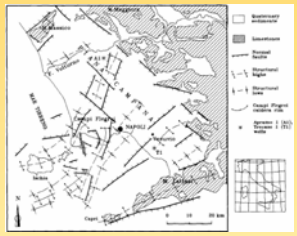
Introduction

At Campi Flegrei about 500,000 people live on caldera and the risk associated to an eruption is very high, but its complete evaluation includes also the potential damage due to earthquakes accompanying eruptions. Moreover low-moderate energy earthquakes are also observed in volcanic active areas during quiescent periods. Generally such events are shallow and produce high intensities in the epicentral area. Today at Campi Flegrei the high housing density and economic value exposed make the area of considerable importance for mitigating seismic risk. To evaluate the effects of the earthquakes at Campi Flegrei, data are required on the location, source mechanism and damage levels of earthquakes, in addition to understanding how dynamic processes occur. A damage map of the maximum earthquake expected is proposed.

Outline of structural setting and volcanic history



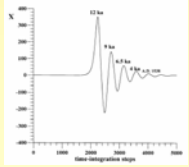
Main tectonic structures of the Campi Flegrei caldera and the Campanian Plain (16).

Campi Flegrei is a caldera complex in the graben structure of Campania Plain. The eruptive activity dates back about 300 ka, while the formation of on or more calderas occurred in the last 39 ka (*22, 15, 23, 21, 11*). The last eruption occurred on 1538 and produced Monte Nuovo. Since this data the caldera has been quiescent but unrest episodes on the area was recorded.

After the Campanian Ignimbrite (CI, about 39 ka) producing the caldera a new eruption occurred 18 ka and subsequently about 12 ka the Neapolitan Yellow Tuff (NYT) eruption produced a new collapse. Many smaller eruptions occurred on the floor of the caldera and La Starza uplift of 40 m above s. l. testifies the resurgence in the last 10 ka. The activity inside the caldera continue until 1538.

Sketch map of Campi Flegrei volcanic area enclosing the CI and NYT calderas (9).

The caldera structure was defined by geological and geophysical survey and different models were proposed on its evolution. Interaction between local and regional dynamics was proposed by Luongo et al. (*17, 18*), Cubellis et al. (*8*) that include low-density body intruded at a depth of about 3Km. This body may represent the top of a larger and deep magma body. The different eruptive phases might be related to deterministic chaotic magma flows well schematized by Lorenz equations (*9*). Different convective cells were hypothesized to operate at decreasing time and spatial scales to explain the volcanic history starting from the CI phases, through the NYT, up to Mt. Nuovo and the recent bradyseismic crisis.

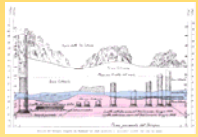


X solution of Lorenz equation relative to NYT scenario. The results are in agreemnet whit eruptive phases (9). h= 3.5 km (tickness) and L = 10 Km (widt) of convective cell

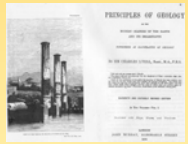
Historical dynamics and earthquakes

A series of upward and downward ground movements, sometimes of considerable proportions, are recorded in the caldera area since Roman Empire, but for this period there are no significant data on seismicity.
The history of major earthquakes at Campi Flegrei is probably complete starting from mid-15 century and more intense earthquakes can be evaluated in VII-VIII MCS degree.

Coast line of the Campi Flegrei and Campanian Plain from archeological ruins (Gunter, 1903).



C. Babbage (1847)



Charles Lyell (1872)

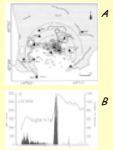
Vertical movements of the ground have been detected in the Seraopeo area in Pozzuoli since it was built (before the 1st century B.C.). Studies and analyses of lithodomes traces on the columns of Serapeo have been utilized to define see level variations in the phlegraean area during the last 2000 years.

Only the historical eruption in the caldera, of Mt.Nuovo (1538), has been reconstructed from the descriptions of eruptive event. There is reliable documentary evidence for seismic activity and ground deformations preceding the eruption from primary sources in State and ecclesiastical Archives, manuscript and historical literature.

A view of Mt.Nuovo on Campi Flegrei by air. On the right of photo Averno lake.

In the 2 years preceding the Monte Nuovo eruption there was a very intense seismic activity which increased in the last 2 days when about 20 earthquakes were felt by the population of the city of Naples too. Ground-shaking stopped at the start of the eruption, a few hours into the night of 28 September (*12*). It is difficult to separate cumulative effects of several events, however, the maximum intensity may be evaluated in VIII MCS degree.

After this eruption up to recent times the earthquakes were generally of low-moderate energy and related to the bradyseismic crises characterized by consistent ground deformations.



A). Earthquakes locations and contours of vertical ground deformations (1982-1984) (20). B). Temporal behaviour of vertical ground movements and seismicity (1970-1995) (3).

Recent seismicity

The recent seismicity at Campi Flegrei, monitored since 1970, occurred during bradyseismic crises on 1970-72 and 1982-84 marked by events concentrated in the central sector of the caldera at 1-4 km depth. The M_{max} recorded is 4.2 (*1, 2, 10, 13, 20, 24*). Minor seismic activity, which consisted of only a few felt earthquakes, occurred from 1970 to 1971. In the second crises intense earthquake swarms lasted from mid-1983 to 1984, again damaging many buildings in Pozzuoli. The most intense event recorded is that of 4 October 1983 (I = VII MCS degree).

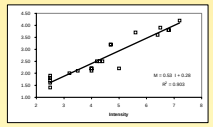
Following the event of 4 October 1983, questionnaires (consisting of 18 yes/no questions) were sent to all middle schools in the Campi Flegrei Caldera, Naples and surrounding towns within an area of about 60 km from Pozzuoli.
Maps of earthquake intensity were drawn up. The isoseisms show maximum values in Pozzuoli (VII MCS degree) while whole the caldera area records VI MCS degree. The intensity decrease in the external areas.
Using the whole macroseismic data set was estimated epicentral intensity (Io=7.2) and attenuation law of the intensity was obtained and compared with those obtained for other volcanic areas (*4, 7*).

October 4, 1983 earthquake. Intensity distribution and interpretation in terms of isoseisms (4)

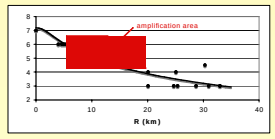
October 4, 1983 earthquake. Intensity distribution in Naples (4)

Intensity-Magnitude and attenuation laws

The 1982-1984 bradyseismic crisis was accompanied by a seismic activity characterized by a spatial and temporal cluster of earthquakes, swarms and single events, a large number of which felt by population. Thus an attempt was made to correlate the values of instrumental magnitude to macroseimic intensity and generalize the magnitude-intensity relation for Campi Flegrei caldera.



Magnitude versus Epicentral intensity for events that occurred in Campi Flegrei caldera during the period 1982-1984 (1.5≤M_D≤4.2; 2.3≤h(km)≤3.9)

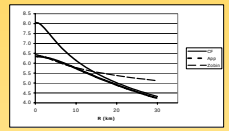


Expected intensity for M_D = 4.2 Campi Flegrei earthquake as a function of epicentral distance. Circles are the experimental data of the 4.10.1983 earthquake. The attenuation law was obtained by the 9.10.1999 vesuvian earthquake data (7) . Note the amplification effects up to about 20 km.

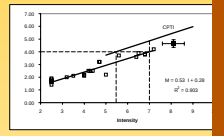
The attenuation law for Campi Flegrei caldera shows that the intensities versus epicentral distance for 4 October 1983 event are in agreement with the relation obtained at Vesuvius.
We can observe an amplification zone of the intensities respect to the attenuation law (red area in figure) up to 20 km from the caldera center. This effect can be explained by the arrival of totally reflected body waves from some discontinuity within the crust (*4*).

Seismic hazard

Using instrumental data in the period 1975-2000, Galluzzo et al (estimate the value of M_{max} equal to 4.35+/- 0.30, for a recurrenc period of 25 years. This value is in agreement also with macroseis magnitude evaluated for historical seismicity. Moreover an integr analysis of both historical and recent seismicity as well as the geological conditions and volcanic history of Campi Flegrei (where kind of cyclic processes may be hypothesized), evidence that the seismogenetic structures fall within the caldera area.
In order to providing an estimation of expected effects it is necessary to consider that Campi Flegrei earthquakes are as muc one to two epicentral intensity degrees greater than equivalent magnitude events occurring in the near seismogenetic Apennines (as obtained for Vesuvius (*6*).



Expected intensity for M_D=4.6 earthquake as a function of epicentral distance. CF: Campi Flegrei; App: Apennines; Zobin: Zobin (2001), focal depth h=3 km. As may be observed the Zobin relation (25) as that for tectonic areas (14) do not fit the data in the epicentral region at Campi Flegrei



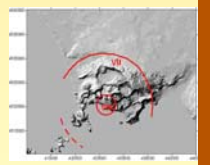
Magnitude versus epicentral intensity for Campi Flegrei earthquakes and CPTI rel (5, 14) obtained for tectonic Italian areas 8.1 intensity MCS degree is associated a event of M=4.6.

Damage map for maximum earthquake expected

To sum up:
- The earthquakes at Campi Flegrei during the recent crises not to cross the threshold of M_D=4.2
- The seismic crisis preceding the 1538 eruption is characterize energetic activity similar to that of 4 October 1983, temporally to days preceding the eruption
- The years preceding the eruption of 1538 were characterized seismic precursors and ground deformation too.

. The analysis of historical seismicity show that the maximum int of the earthquakes might be evaluated in VIII MCS degree.

Effects of maximum earthquake expected at Campi Flegrei (M_D= 4.6): synthetic I = VIII and VII isoseismals degree. The epicenter is the same of 4 October 1983 event. Magnitude-intensity relation, attenuation curve and amplification effects have been considered .



Expected MCS intensities for M_D= 4. earthquake (h=3Km)

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