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Analysis of historical and present earthquakes at Vesuvius for seismic hazard evaluation

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Introduction

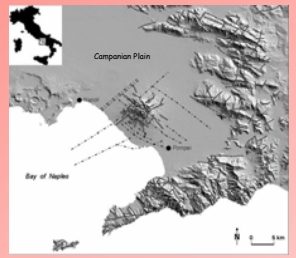
At Vesuvius about 600,000 people live on the volcano and the risk associated to a large eruption is very high, but its complete evaluation includes also the potential damage due to earthquakes accompanying eruptions. Moreover low-moderate energy earthquakes are also observed in volcanic active areas during quiescent periods. Generally such events are shallow and produce high intensities in the epicentral area. Today at Vesuvius 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 Vesuvius, data are required on the location, source mechanism and damage levels of historical earthquakes, in addition to understanding how Vesuvius works. A damage map of the maximum earthquake recorded is proposed.

Topographic map of Vesuvius and Gulf of Neaples (realized by Rizzi-Zannoni on 1794)

Geological and structural setting

Mt. Vesuvius rises in a graben structure. While eruptive activity in this area dates back about 400 ka, the edifice of Vesuvius formed only in the last 25 ka (*14*). The recent crater was built inside an older stratovolcano, Monte Somma, and since 1944 has been quiescent.

Main tectonic structures of the Mt.Vesuvius and the Campanian Plain (*18*). Continuous line: Topographic lineaments and faults by DTM analysis. Dashed lines and points: faults and fractures of the shallow basement from geophysical surveys (*1,2,9,15*).

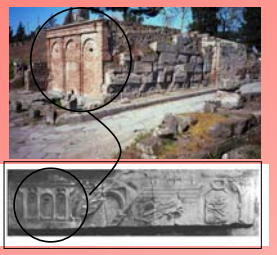


Only its later history, which begins with the eruption of 79 AD, has been reconstructed from the direct descriptions of eruptive events. After the subplinian eruption of 472 a significant eruptive events took place on 1631 with a subplinian eruption. From 1631 to 1944 the volcano produced eighteen eruptive periods of small and medium-sized eruptions (*14*).

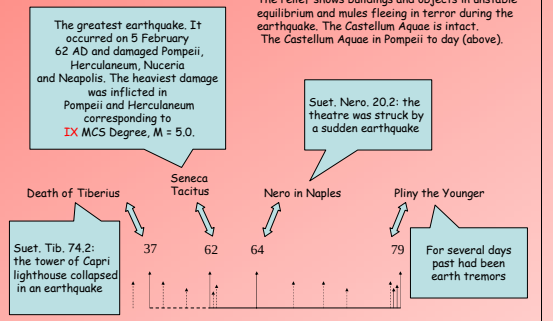
Seismic tomography suggests the presence beneath Vesuvius of a melting zone with the top at a depth of about 8 km, and a high P-wave velocity body corresponding to the crater axis zone was defined above the carbonate basement at a depth of approximately 2 km (*17*). Moreover we interpreted the decay of intensity of earthquakes in the Vesuvian area with a transition brittle-ductile layers under the volcano at a depth of 8 km (*4*).

Historical earthquakes

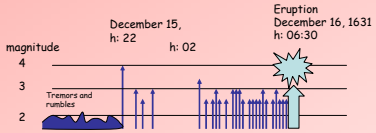
The oldest seismic event in the Vesuvian area was recorded by Classical fonts, buildings and represented on marble reliefs (*10,11,12*). In the last years of the Roman Empire, the sources describe a large eruption at Vesuvius in the 5th century well known to volcanologists, but for this period there are no data on seismicity. In Medieval times the available sources record no significant seismic activity in the Vesuvian area. By contrast, some large eruptions occurred.



Archaeological data: effects of AD 62 earthquake by relief of the Caecilius Jucundus House (below). The relief shows buildings and objects in unstable equilibrium and mules fleeing in terror during the earthquake. The Castellum Aquae is intact. The Castellum Aquae in Pompeii to day (above).



The largest eruption in modern times occurred in 1631: there is reliable documentary evidence for seismic activity during the night between 15 and 16 December from primary sources in State and Ecclesiastical Archives (*11*).

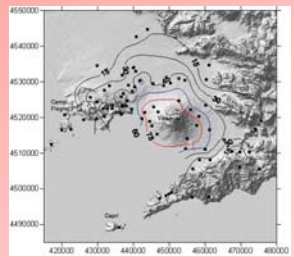


After this eruption up to recent times the earthquakes were generally of low-moderate energy and related to eruptive activity. The most dangerous occurred on 15 June 1794 during the lateral eruption which destroyed the town of Torre del Greco. The shocks caused damage to buildings in the Vesuvian area and shattered window panes in Naples. The Vesuvian area experienced moderate energy events from 1631 to 1944, last eruption.

The 1794 Vesuvius eruption. Town of Torre del Greco in the evening of 15 june 1794

Recent seismicity

Since 1944, seismicity at Vesuvius has been marked by few hundred events per year concentrated in the summit caldera. The most significant event recorded before the development of the surveillance seismic network at Vesuvius in 1970, is that of 11 May 1964 (V MCS degree), in the crater floor.
Several periods of greater activity were recorded in 1989, 1990, and more recently, in 1995 and 1996. The strongest occurred on 25 April 1996 (ML=3.4, h=2 km) and was clearly felt all over the Vesuvian region, including Naples and some zones in the Phlegraean Fields and on the island of Capri. In the early months of 1999 seismicity increased slightly. During August 1999 a seismic sequence began and culminated in the most energetic event on 9 October (*6,7*). Epicenter: crater area; ML=3.6; h= 3-4 Km.

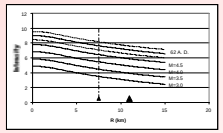


A macroseismic study of the 9 October 1999 event was carried out from an analysis of questionnaires sent out to all secondary schools in each municipality of the Vesuvian and Neapolitan area and surrounding towns (*4*). The area of maximum value (75%) covers the whole Vesuvian area. The felt index weaken strongly in NE and SE directions; toward Naples a slighter decrease is observed.

Felt index of the 9 October seismic event (percentage response to question *Did you feel the earthquake?*) (*4*). Using the whole data set we have estimated epicentral intensity (Io: 6-6.4), attenuation coefficient (Blake's formula), absorption factor, equivalent macroseismic magnitude (M = 3.6-4.1), the quality factor (Q=60-90), and related these to instrumental records.

Intensity-Magnitude and attenuation laws

The data on the 9 October 1999 earthquake can be used to assess the energy of historical earthquakes in order to determine the level of seismicity and relate it to the volcano's seismogenetic structures and/or to explosive activity. Using the intensity versus distance relation for the 3–5 Magnitude range, we estimated the magnitude of earthquakes preceding the eruptions of AD 79 and 1631. The earthquakes from 1631 to 1944 do not appear to have exceeded the value of M=4.5. The greatest pre-eruptive event, however, was rated at M=4.0, a value that corresponds to those recorded in recent times.

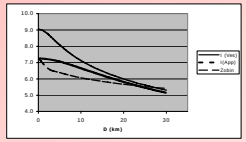


M=5.0:…like largest recorded 62 A.D earthquake
M=4.5:…can cause slight damage in Naples
M=4.0:…like October 9, 1999 earthquake
M=3.5: for earthquake felt throughout the Bay of Naples
M=3.0: for earthquake felt at the foot of volcano only

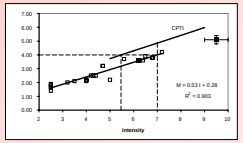
Expected earthquake intensity for magnitude 3-5 as a function of epicentral distance. The little triangle represents the mean distance of the towns at the foot of the Vesuvius from the crater axis; large triangle the distance of Naples.

Seismic hazard

An integrated analysis of both historical and current seismicity as well as the geological conditions of Vesuvius and the surrounding areas, evidence that the seismogenetic structures may fall within a crater axis and at the boundaries of the volcanic complex. In order to provide an estimation of expected effects it is necessary to consider that vesuvian earthquakes are as much as one to two epicentral intensity degrees greater than equivalent magnitude events occurring in the near seismogenetic Apennines Chain.



Intensity for M=5 earthquake as a function of epicentral distance. Ves: Vesuvius; App: Apennines; Zob: Zobin (2001), focal depth h=3 km. As may be observed the Zob relation (*16*) as that for tectonic areas (5,*8*) do not fit the data in the epicentral region at Vesuvius

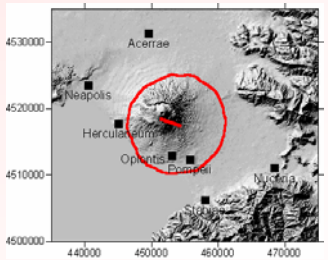


Magnitude versus epicentral intensity for Neapolitan volcanic area (Phlegraean Fields and Vesuvius) earthquakes and CPTI (*4,5*) relation obtained for tectonic italian areas

Damage map expected for maximum earthquake recorded

To sum up:
- The earthquakes from 1631 to 1944 do not appear to cross the threshold of M=4.5
- The seismic crisis preceding the 1631 eruption is characterized by energetic activity similar to that of 1999, temporally limited to hours preceding the eruption
- The years preceding the eruption of 79, on the contrary, were characterized by sensible seismic precursors, and probably, ground deformation too. The maximum earthquake occurred on Feb. 5, 62 AD (M=5)

Maximum recorded earthquake of Vesuvius area (like 62 AD): synthetic I = IX isoseism and surface projection of the causative fault utilizing the summation method proposed by Midorikawa (1993)(*13*). Focal mechanism was ipotized as October 9, 1999 event.



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