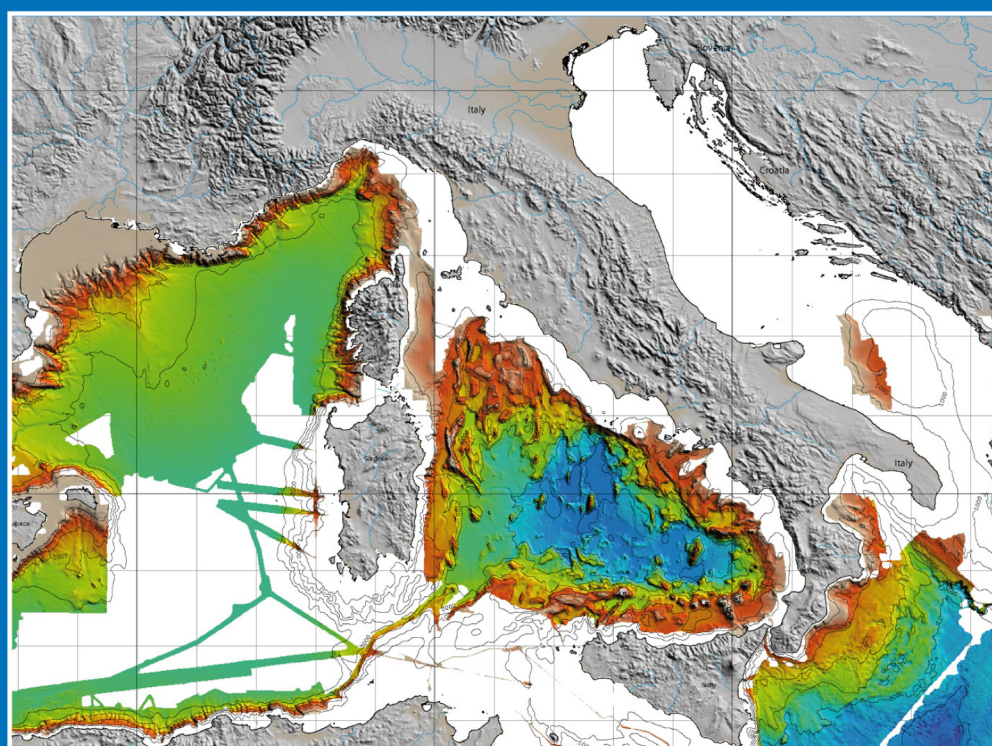


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Sea level changes, ground deformations, human settlements in the bay of Naples

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Key words: *Bay of Naples, Ground deformations, Human settlements, Sea level changes, Neapolitan volcanoes.*

Ground deformations (soil uplifts) in active volcanoes are considered precursors of eruptions according to the most tested models; therefore monitoring networks of ground deformations are installed on inhabited dangerous volcanoes. Direct measurements of such deformations are carried out since 1861 when Luigi Palmieri monitored the eruption at Mt. Vesuvius with levelings along the shoreline near the town of Torre del Greco. Relative sea level changes were measured at Serapeo in Pozzuoli in the middle of 19th century to record soil uplifts which are locally known as bradyseism. To enlarge the time series of data on these phenomena it is necessary to utilize historical and prehistorical informations on the location of shore-line of human settlements. It is common practice to spread to research on earthquakes, tsunamis, eruptions, by analyzing documentary fonts and relics left by ancient peoples. When the historical data are poor, to enlarge the time series of events for deeper knowledge of the natural history of investigated sites, the research is devoted to geological processes and particularly to the location of marine terraces in respect to present sea level.

As regards the regions of active volcanoes as the Neapolitan one three processes contribute to sea level changes as eustatism (LAMBECK *et alii*, 2004), regional tectonics and local intrusive and effusive phenomena. Therefore at the same time the relative sea level should be different at far-away places only few kilometres according to the volcanic activity. In fact eustatic and tectonic processes contribute to sea level changes with very lesser rates than volcanic activity.

The Neapolitan region for its geological history is an excellent laboratory for testing the validation of new paradigms for some natural phenomena. The geological structure of the Neapolitan area, located in Campania Plain, at the margin of Tyrrhenian Basin, is formed by the succession of effusive and explosive rocks as lavas and pyroclastic products erupted by polygenic and monogenic volcanoes. Moreover this area is characterized by shallow seismicity capable to produce high intensities in small epicentre areas.

The whole range of phenomena observed, in particular the present stress field, as is amply shown by seismicity, recent tectonics and chemism of magmas feeding active and recent volcanoes can be accounted for in relation to a local mantle upwelling, a lithosphere plate bending and subsequent collapse. The measure of tectonics contribution to relative sea level changes is obtained by the velocity of sedimentation of rocks forming Campanian Plain due to tensile processes during quaternary time (LUONGO *et alii*, 1991 a). This value is of about 1-2 mm/yr in accordance with the results observed in other areas characterized by active tectonics. It is 10^{-10^3} times less than that observed in active volcanoes (Fig.1,2).

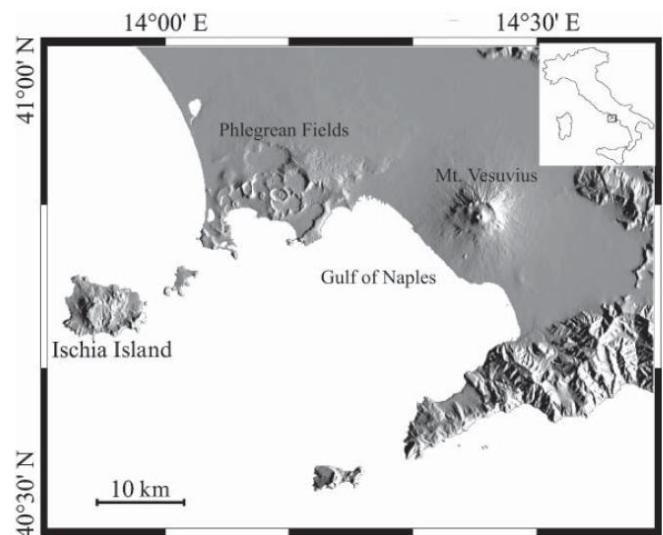


Fig.1 - Volcanoes of Neapolitan region (Vesuvius, Campi Flegrei, Ischia) located in the Campanian Plain, a like-graben structure at the continental margin of Italian Peninsula.

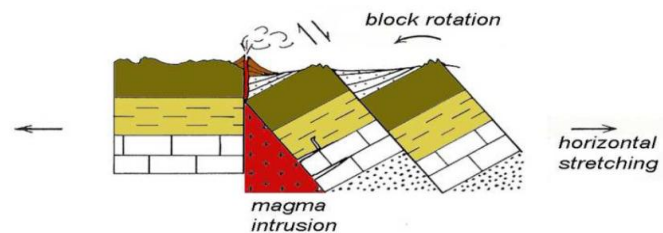


Fig.2 - Half Graben structure model for Campanian Plain. The lower block spaces are filled by magma intrusion and the upper block spaces by volcanic rocks.

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Eruptions and earthquakes occurred in the Neapolitan area, have produced myths, legends, historical documents, archaeological findings.

The name Campi Flegrei (Fields of fire) of the district including the town of Naples with its western suburbs suggests that manifestations of volcanism were evident in Ancient Times. This area was once a preferred location to the entrance to Hades. It is caldera complex, formed by collapse of the ground following two giant eruptions (Campanian Ignimbrite, 39 ka and Neapolitan Yellow Tuff, 15 ka). Part of the structure is submerged to form the Pozzuoli Bay; the landward floor is peak marked by tens of volcanic cones (D'ARGENIO *et alii*, 2004). Campi Flegrei attracted special attention during the nineteenth century, thanks to the Serapeo, ruined roman market in Pozzuoli, which had been submerged by slowly sinking and re-emerged from the sea, due to a rapid rising of the land before 1538 Mt. Nuovo eruption and the well known 1970-72 and 1982-84 crises (Bradyseism) (LYELL, 1872; BERRINO *et alii*, 1984; LUONGO *et alii*, 1991 b) (Fig.3,4).

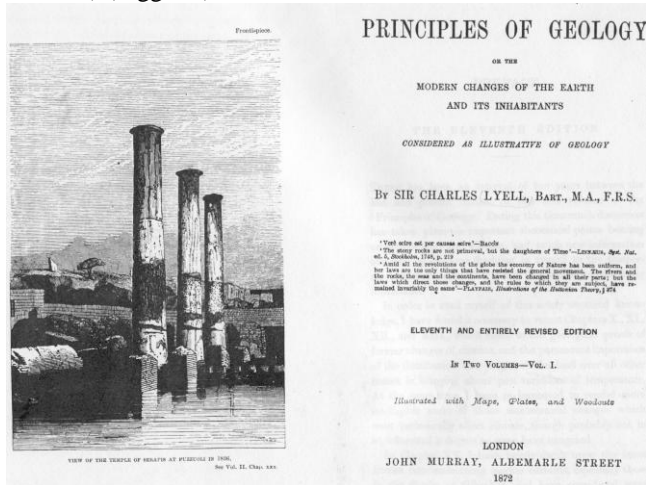


Fig.3 - View of Macellum (Temple of Serapis) in 1836. Frontispiece of "Principles of Geology" by Charles Lyell.

The investigation of submerged roman ruins at many places round the bay of Pozzuoli let us to reconstruct the ancient coast line which had fallen some meters but it was rising to the present level as recorded upon columns of the Macellum (Temple of Serapis) by the hollows of the lithodomi in historical times, and by geometrical levelings in recent times. In the environs of Pozzuoli the land within short distance of the coast terminates in a cliff of moderate elevation (30-40 m). It is interpreted as an ancient coast line and the inland marine terrace, called "La Starza", evidences a ground inflation which occurred 8-4 ka ago (OBRIZZO *et alii*, 1991). Evidences of the subsidence of the Phlegrean area derived also from the investigation on the ancient harbours of Puteoli, Avernus, Misenum, Nisida, located at short distance one another along the coast of the Bay of Pozzuoli. The largest and best known roman breakwater is that of Puteoli, called "The bridge of Caligola". This consist of tall piers which

must originally have been at a convenient height above the surface of water, while they were 1-2 m below it at the beginning of XX century (GÜNTER, 1903). Now the piers are concealed from view with the new breakwater of the harbour.

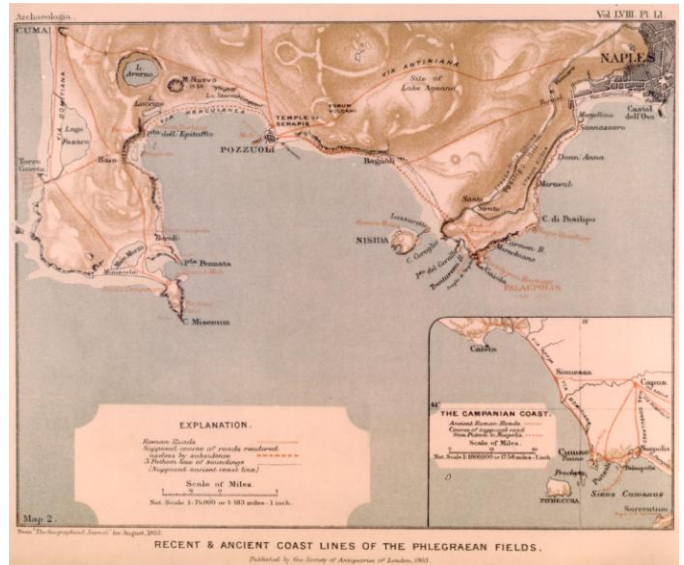


Fig.4 - Coast line of Campi Flegrei in Roman times. «The discovery that one submerged "rock" after another showed clear signs of artificial origin was so fascinating, opening as it did a new field for research, that we were led to add to our geographical investigation a survey of the sunken antiquities» (GÜNTER, 1903).

Vesuvius has acted like a powerful magnet from time immemorial, drawing people to settle on the fertile soils (Bronze Age), to wonder at the beauty of the landscape as tourists, or to undertake scientific investigations. Eruptive activity in Vesuvius area dates back about 400 ka according to the stratigraphic and radiometric data on volcanic products and paleosoils from the borehole drilled down to depth of 2200 m b.s.l. in the southern side of the volcano for geothermal exploration. The volcano edifice formed only in the last 25 ka when the volcano produced at list five large-scale plinian eruptions and smaller scale subplinian eruptions. Some archeological relics of the Bronze Age in the eastern part of the Campanian Plain are covered by fall products of the plinian eruption of 3800 yrs BP, known as Avellino eruption. Instead the eruption of 79 AD, is described in the letters of Pliny the Young; at present quantitative analysis models of the mechanism of this eruption utilize the detailed descriptions of Pliny. Before the 79 A.D. eruption Tacitus and Seneca wrote about the damage caused by the strong earthquake which struck the town of Pompeii and surroundings in A.D. 62 (CUBELLIS *et alii*, 2007). In light of recent archaeological and epigraphic evidences this earthquake with the subsequent low-moderate energy seismic swarms have been considered as precursors of the A.D. 79 eruption, responsible for the destruction of Pompeii and Herculaneum and of the displacement of the coast line offshore, of about 400 m, by the occurrence of dense pyroclastic currents which reached the sea.

Archaeological and geological surveys carried out onland and offshore between Herculaneum and Pompeii show that at present the coast line at the time of 79 AD eruption have sunk of about 4 m. As the eustatism contributes to this value only for an amount of about 1 m, the large part of the subsidence was caused by the long term tectonics of Campanian Plain and volcano dynamics with uplift before large eruptions and sinking afterwards.

The island of Ischia was the site of the earliest known Greek settlement in Italy. Strabo mentions that Greek colonies abandoned the island repeatedly in consequence of the violent of the eruptions, earthquakes and tsunamis that took place in Pythecusa since the 6th century BC. Pliny the Elder, in his *Naturalis Historia* writes that on the island of Ischia, the earth swallowed up a town and that after this catastrophe a lake was formed (Lago del Bagno?). This eruption was dated by the 6th-5th century BC pottery remains (BUCHNER, 1986). About historical seismicity more comprehensive accounts are available for Ischia island since 1228.

We have considered a possible relationship between volcanic activity in the island and large sea level changes during the late Quaternary. Eruptions may be triggered by loading and unloading the crust owing to change in sea mass. Seven phases of activity have been distinguished in the Island since 140 ka B.P. Two major activity phases (1 and 7 in fig.5) occurred between 140 and 123 ka and in the last 18 ka when there was a continuous sea level rise of about 130 m and 125 m, respectively. Instead at 55 ka B.P., when the catastrophic caldera forming Mount Epomeo Green Tuff (MEGT) eruption occurred, the sea level showed some oscillations up to 50 m (4 in Fig.5).

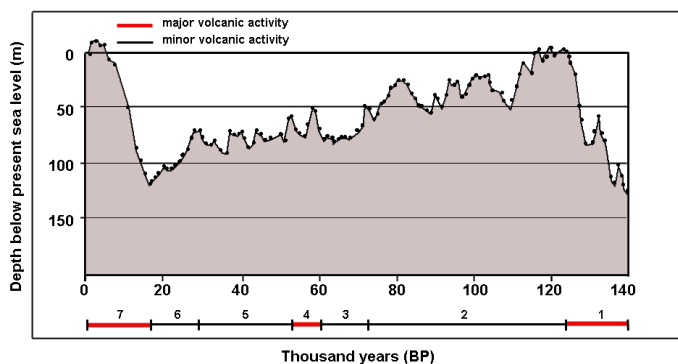


Fig.5 - Late Quaternary sea-level variations (after SHACKLETON, 1987, modified) and volcanic activity of Ischia Island since 140 ka B.P.

The caldera depression was filled – at first in sub-aerial and subsequently in submarine conditions – by the MEGT and pyroclastic deposits of the eruptions occurred in the island between 44 and 33 ka B.P. These deposits were involved in an uplift process starting between 33 000 and 28 000 years ago, forming the Mount Epomeo block. Total uplift, deduced from the present height of marine deposits and eustatic variations, is 710 m on the southern flank and 920–970 m on the northern flank, with an average uplift rate of 2.3 and 3 cm^{yr}⁻¹ respectively

(BARRA *et alii*, 1992; TIBALDI & VEZZOLI, 2004). Today Greek and Roman ruins may be observed along the island coast line, submerged under the sea. According to archaeologist the ruins have sunk by about 2 m. Geographers comparing 16th century and current maps of the island infer coastal subsidence of about 1 m (FRIEDLAENDER, 1938; CARLINO *et alii*, 2006).

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