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THE QUATERNARY PHLEGREAN FIELDS VOLCANIC COMPLEX

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Map of the Gulf of Pozzuoli, with a part of the Phlegrean Fields, drawn by Pietro and Francesco La Vega in 1778, printed by Perrier in 1780 (Carte du Golfe de Pouzzoles: avec une partie des champs phlégréens).

A CLASSIC AREA FOR THE STUDY OF VOLCANIC ACTIVITIES AND VOLCANIC HAZARD ASSESSMENT SINCE THE 18TH CENTURY.

The site had a major role in the European debates that created the modern science of geology in the 18th and 19th centuries. Naturalists were attracted to the area to record evidence directly in the field regarding both active and extinct volcanoes and their products preserved in the landscape. The Phlegraean Fields is one of the very few volcanoes in the world considered capable of producing a colossal eruption of level VEI 8 (Orsi *et al.,* 2004), which had already occurred during its volcanological history with the emplacement of the Campanian Ignimbrite that supposedly caused the near disappearance of Neanderthals (39ka).

SITE 002

GEOLOGICAL PERIOD	Upper Pleistocene – Holocene
LOCATION	Campania, Naples. Italy. 40° 49' 37" N 014° 08' 20" E
MAIN GEOLOGICAL INTEREST	History of Geosciences Volcanology

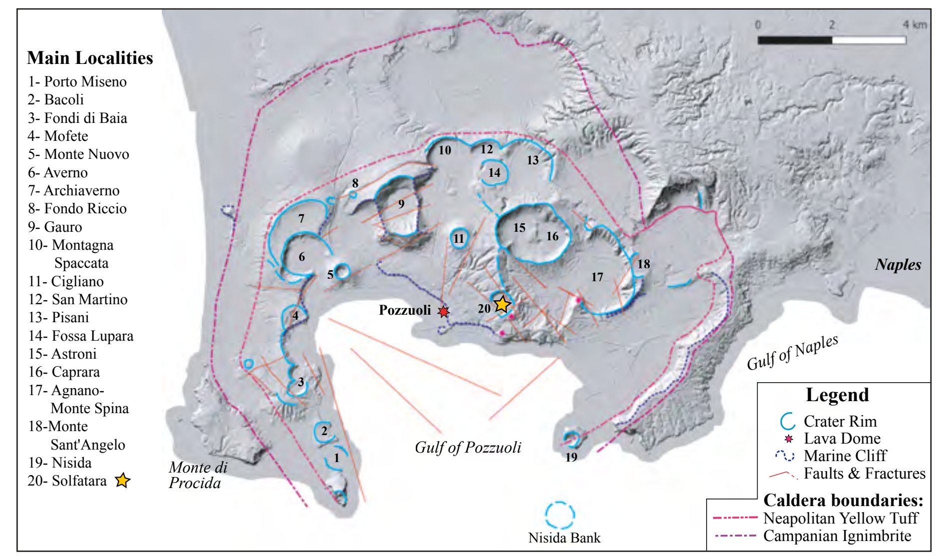
Diffuse hydrothermal fumaroles discharge at Solfatara crater. The yellow-orange colours are deposits of Sulfur. (Photo courtesy of Roberto Bonomo).

Geological Description

The Phlegrean Fields volcanic complex is a 13 km wide nested volcanic caldera complex located west of Naples, near Vesuvius, famous for the iconic Temple of Serapis, with evidence of vertical ground movements since the Roman period. The volcanic complex started its activity c.80 ka BP. That activity ranged from phreatomagmatic-magmatic explosions to effusive eruptions. The present volcanic structure results from major collapses related to the Campanian Ignimbrite (39 ka) and the Neapolitan Yellow Tuff (15 ka) emplacement. During the last 12 ka volcanism has been concentrated within the former area forming tuff cones and rings, minor scoria cones, and lava domes. Intense ground deformation generated by uplift and subsidence phenomena indicates the presence of an active volcanic system associated with hydrothermal fluid inflation-deflation processes. In the famous locations of Solfatara and Pozzuoli this activity is particularly evident. The Solfatara crater is characterized by high temperature hydrothermal fluid discharge, boiling pools, and diffuse CO_2 emissions. In recent decades Pozzuoli has undergone several episodes of bradyseism, raising the coastline by c.4.5m. Today, the area is highly monitored as a rapid release of magmatic gases or new magma intrusion could trigger a significant eruption at anytime (Sbrana *et al.,* 2021; Orsi *et al.,* 2022).

Scientific research and tradition

The site is one of the most intensively studied volcanic area in the world, ranging from the observations by Ray (17th century), to Spallanzani and Lyell in the 18th and 19th centuries (Dean, 1998). A focal point in this research, based on fieldwork, was the work of William Hamilton (1776-79).



Phlegrean Fields DTM map showing the main volcanological and structural features (modified after Isaia et al., 2019 and Di Vito et al., 1999). The principal localities are listed. The red and yellow stars indicate Pozzuoli town and Solfatara crater, respectively.

CRETACEOUS TO PALEOGENE STRATIGRAPHIC SECTION OF BOTTACCIONE GORGE, GUBBIO

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Upper part of the Bottaccione Gorge section, showing the Campanian and Maastrichtian part of the section. A medieval aqueduct is also seen. (Photo by Birger Schmitz).

ONE OF THE MOST COMPLETE CRETACEOUS TO PALEOGENE PELAGIC LIMESTONE SECTIONS KNOWN, AND WHERE THE K-PG IRIDIUM ANOMALY WAS FIRST FOUND.

The section is a global reference succession for bio-and magnetostratigraphy across the Cretaceous and Paleogene, including the K-Pg boundary. Here pelagic limestones were first dated with foraminifera in thin section, long-section magnetic polarity-reversal stratigraphy was first established, and the K-Pg iridium anomaly was first detected. Reconstructions have also been made of Earth's orbital cycles and variations in flux of extraterrestrial matter from different regions of the solar system. Every year the section is visited by hundreds of geologists. Many students learn here the basics of reading Earth's history from its stratigraphic record.

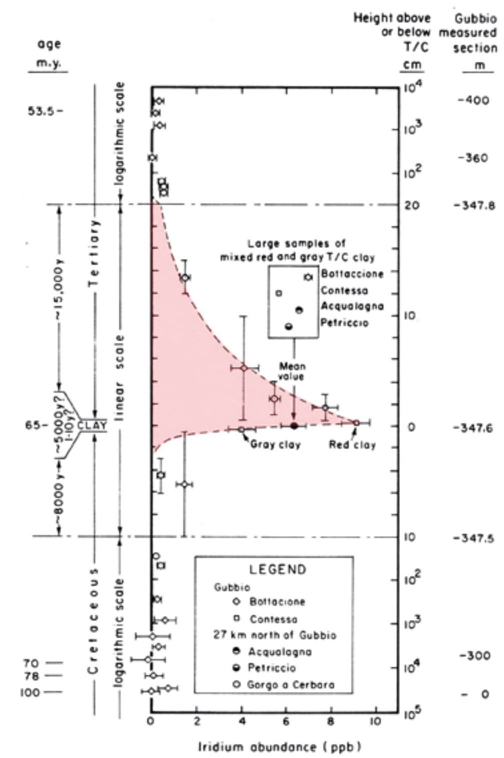
SITE 020

GEOLOGICAL PERIOD	Cretaceous - Paleogene
LOCATION	Umbria, Italy. 43° 21' 55" N 012° 34' 57" E
MAIN GEOLOGICAL INTEREST	Stratigraphy and sedimentology History of geosciences

Cretaceous-Paleogene boundary interval at the Bottaccione section. (Photo: Marco Menichetti).

Geological Description

The Bottaccione Gorge at Gubbio was the first major outcrop of pelagic limestone ever studied. Here the identification of planktonic foraminifera in thin section was first applied to hard rocks from which isolated foraminifera could not be extracted (Renz, 1936; Luterbacher and Premoli Silva, 1962). Anomalous levels of iridium were first reported from the K-Pg boundary at this and nearby localities (Alvarez *et al.*, 1980). Iridium is present in meteorites but essentially absent in Earth's sediments, which led to the theory that a large comet or asteroid impacted the Earth, triggering the K-Pg mass extinction. This theory was later confirmed by the discovery of the 150-km diameter Chicxulub structure in the subsurface of the Yucatán Peninsula of Mexico, the largest impact crater known from the last billion years of Earth history. Magnetic polarity reversal stratigraphy of limestones was first done in the Bottaccione Gorge, with the foraminiferal biostratigraphy making possible the dating of the magnetic polarity stripes on the ocean floor, and in turn the dating of the opening of the Atlantic Ocean by sea-floor spreading (Lowrie and Alvarez, 1981). Lately, a high-resolution cyclostratigraphic framework has been established at the section. For a review see e.g., Galeotti *et al.* (2015).



The iridium profile across the Cretaceous-Paleogene boundary from samples collected in several Scaglia Rossa sections throughout the Umbria-Marche basin, as reproduced from fig. 5 in Alvarez et al. (1980). Note the linear scale (in cm) in the 15 cm interval bracketing the boundary interval (from Montanari and Coccioni, 2019).

Scientific research and tradition

The section has been the subject of scientific research since the pioneering work of Renz in 1936. During the '60s and '70s, the analysis of the section contributed to an integration of bio- and magnetostratigraphy. The section is visited by hundreds of geologists from all over the world every year.

VAJONT LANDSLIDE

ITALY

The extensive scarp and the huge body of the Vajont landslide detached from Mt. Toc. (Drone photo courtesy Monica Ghirotti).

ONE OF THE MOST EMBLEMATIC AND BEST RESEARCHED LARGE LANDSLIDES WORLDWIDE KNOWN FOR ITS PECULIAR DYNAMICS AND CATASTROPHIC EFFECT.

The Vajont is one of the best researched landslide localities globally, and it has received regular attention from the scientific community during the last 60 years. It has a unique scientific importance, as the complex geology and mechanism of the landslide have been debated since the occurrence of the event, which was a turning point in the scientific knowledge of landslides. The wide scar and the enormous landslide body are still visible in their entire extent, and they indelibly mark the landscape of the valley. The site is easily accessible to visitors, who can also visit a memorial museum in Longarone, the first village to be destroyed. The Vajont can be considered an excellent example of a site of landslide geomorphology (Morino *et al.,* 2022).

SITE 095

GEOLOGICAL PERIOD	Quaternary / Holocene
LOCATION	Vajont valley (Eastern Italian Alps). Friuli Venezia Giulia, Italy. 46° 15' 30'' N 012° 20' 31'' E
MAIN GEOLOGICAL INTEREST	Geomorphology and active geological processes Engineering Geology

Panoramic view of the Vajont valley and of the residual lake located upstream of the landslide. (Photo: Mauro Soldati).

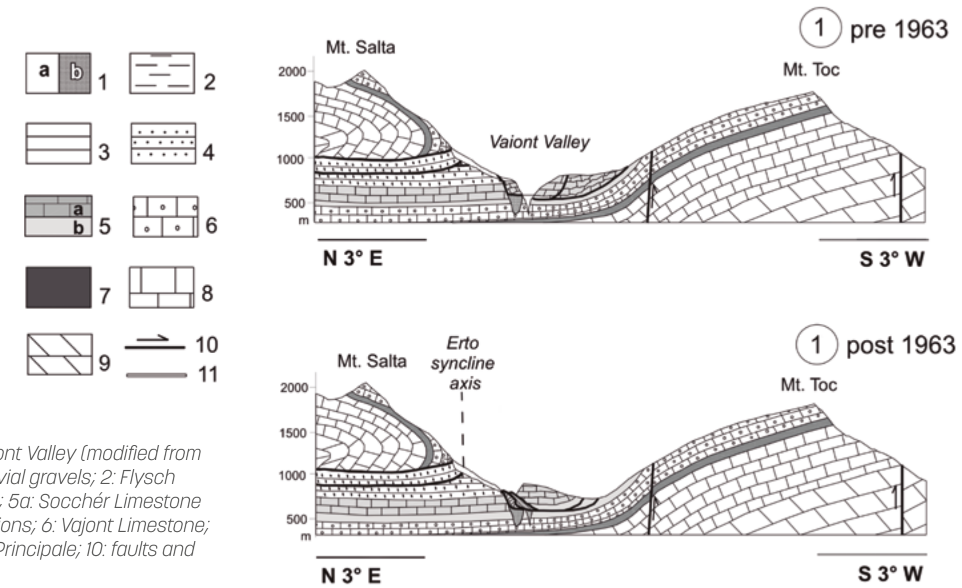
Geological Description

The Vajont landslide is a vast compound rock slide of approximately 270 million m³ of rock and debris detached from Mount Toc in 1963. It collapsed into a reservoir created by a 262 m high double curved arch dam built across the Vajont valley (Ghirotti, 2012). The movement mainly involved jointed limestone and marl of Jurassic and Cretaceous age, and it occurred along a M-shaped failure surface, which corresponds to a paleo-sliding surface (Semenza and Ghirotti, 2010). The impressive landslide body filled the reservoir in a few tens of seconds, causing the overflow of the dam and a 50 million m³ displacement wave that destroyed seven villages in the Piave River Valley, killing almost 2000 people.

The dynamics of the initial stages of movement and of the final collapse are complex and still under debate (Selli *et al.,* 1964; Hendron and Patton, 1985; Paronuzzi and Bolla, 2012), but the groundwater variations related to the reservoir water filling operation are considered as the most important triggering factors.

Scientific research and tradition

The Vajont is one of the best-studied landslides in the world. The site is visited and studied by many scientists, and hundreds of articles have been published. A dedicated museum and many scientific and educational projects have been promoted in order to preserve the memory of the deadliest landslide event in Europe in recorded history.



Pre-1963 and post-1963 geological sections of the Vajont Valley (modified from Ghirotti, 2012). Legend: 1a: Quaternary; 1b: stratified alluvial gravels; 2: Flysch Formation; 3: Marls of Erto; 4: Scaglia Rossa Formation; 5a: Socchér Limestone Formation; 5b: Ammonitico Rosso and Fonzaso formations; 6: Vajont Limestone; 7: Igne Formation; 8: Soverzene Formation; 9: Dolomia Principale; 10: faults and overthrusts; 11: failure surface of the 1963 landslide.