

Santorini and Nisyros: similarities and differences between the two calderas of the modern Aegean Volcanic Arc

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The Aegean Volcanic Arc, extending along the islands of Poros, Methana, Milos, Santorini, Yali, Kos and Nisyros (Fig. 1), is the result of northeastward-directed subduction of the Eastern Mediterranean lithosphere below the active Hellenic margin of the European plate (Papanikolaou, 1986) (Fig. 2). Santorini and Nisyros are the most recent active volcanoes in the Aegean Volcanic Arc, located at the centre and the eastern edge of the arc, respectively. Although Nisyros displays a spectacular geometry of volcanic scenery, it is the least-known and least accessible of all Mediterranean volcanoes in contrast to Santorini, which is world-famous both for its volcanic structure and its impact on human civilization.

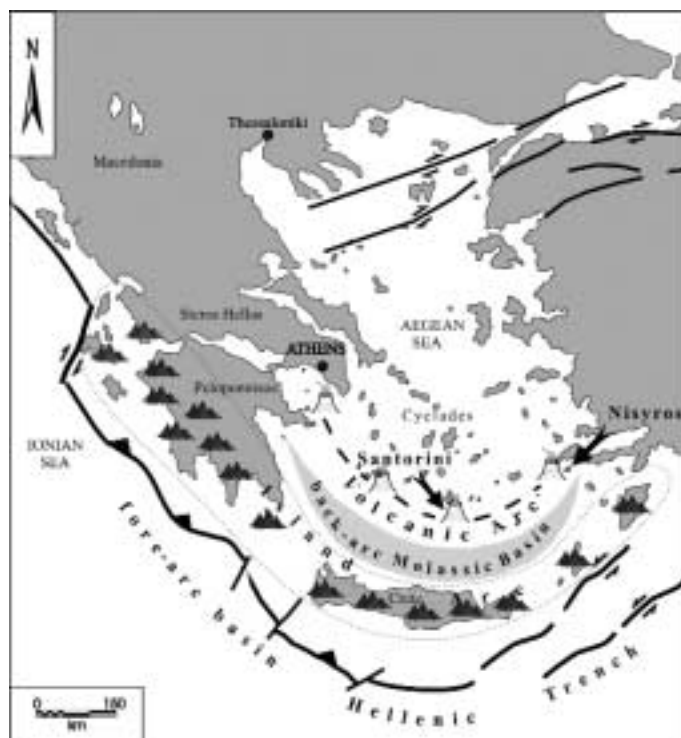


Fig.1. Simplified map of the present day geodynamic structure of the Hellenic Arc.

Nisyros

Volcanic activity is known in the area of Kos-Nisyros since Late Miocene-Pliocene times. One of the largest eruptions in the Eastern Mediterranean, manifested by the outcrops of the “Kos ignimbrite”, occurred 165,000 years ago (Keller *et al.*, 1990), producing more than 100 km³ of ashes, pumice and pyroclastics flows, devastating an area of about 3000 km². The center of this catastrophic eruption is not known with accuracy but it is probably located in the submarine area of Yali islet, north of Nisyros.

The island of Nisyros is composed exclusively of Quaternary volcanic rocks with alternating lava flows, pyroclastic layers and lava domes, ranging in age from 200 to 25 ky. Alpine basement rocks are detected at depth (-1,800 m) from geothermal drillings. It forms a truncated cone with a base diameter of 8 km with a caldera of 4 Km diameter. The evolution of this volcano is divided in five major stages (Martelli, 1917; Desio, 1931; Davis, 1967; Di Paola, 1974; Papanikolaou *et al.*, 1991): 1) An underwater volcano, which erupting basaltic and andesitic pillow-lavas, built up the lower volcanic rocks visible on the northern coast near Mandraki; 2) A 500-700 m high stratovolcano grew, on top of these partly submarine lavas, for a period of more than 100,000 years; 3) After many eruptive phases of gas and steam explosions, two major rhyodacitic plinian eruptions deposited huge volumes of pyroclastic flows and pumice covering the whole island; 4) Subsequently a major collapse of the volcano followed, leaving a large caldera behind it and 5) The western part of the caldera depression was filled up, during pre-historical times, by a series of rhyodacitic domes, the highest of which, Profitis Ilias, rises about 698 m above sea-level.

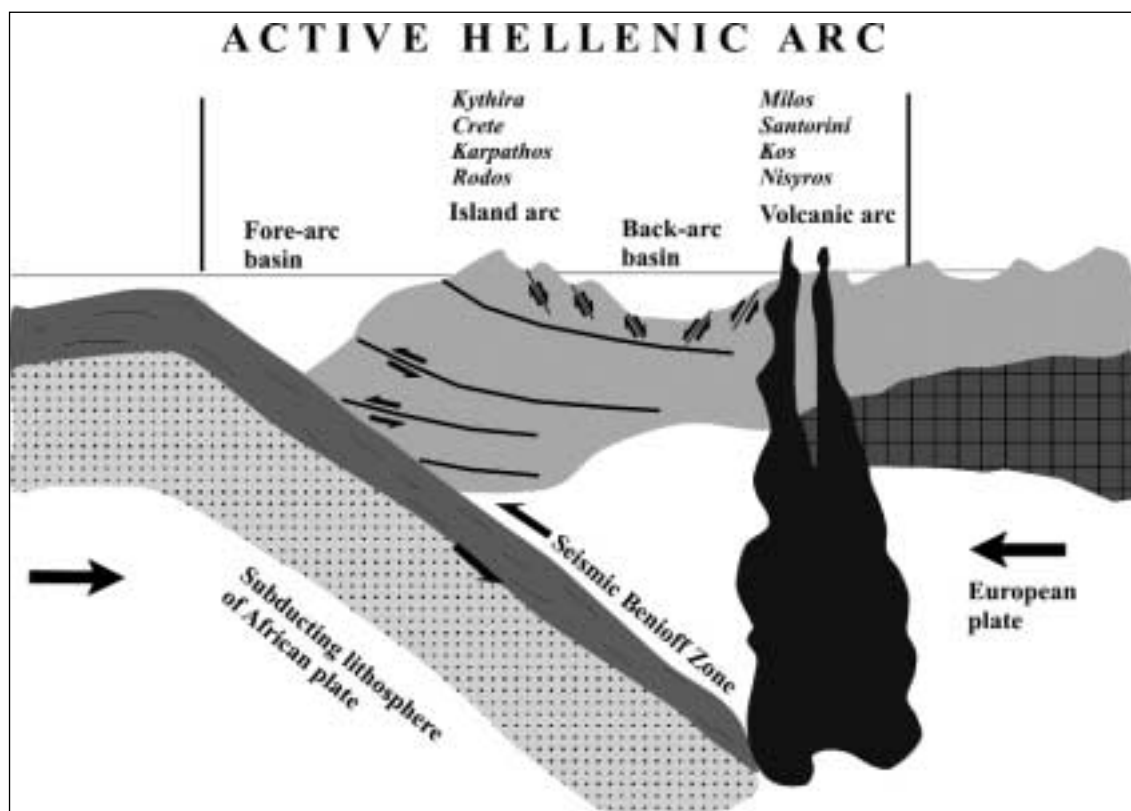


Fig. 2. Schematic profile showing the subduction of the East Mediterranean lithosphere.

No volcanic activity is known to have occurred on the island after the formation of the domes for at least 25,000 years; the only historical explosions mentioned are related with the formation of several craters inside the caldera, such as Alexandros, Polyvotis, Stephanos, Phlegethon and Achelous, which are still emitting fumaroles. Violent earthquakes, gas detonations, steam blasts and mudflows accompanied the most recent hydrothermal eruptions in 1871-1873 and 1887 (Marini *et al.*, 1993). No casualties were reported during this volcanic activity, although some people were slightly injured and minor damages were caused in the houses.

The fact that there are no reports of volcanic activity in the area by the classical authors suggests, but does not of course prove, that the main eruptions on Nisyros were over by the time the classical Greek texts were written. Archaeological evidence shows that the main cone and caldera were formed before 1200 BC. The ruined “Pelasgian” fortress of Mycenaean type, 1 km south of Mandraki, was built on the pyroclastics that erupted in the great plinian eruptions (Scarth 1983). Astrom (1978) reports that Neolithic artifacts which have been found within the Nisyros caldera, would push back its formation to, at least, a Neolithic age.

Recently, in the submarine area around Nisyros, new individual submarine volcanic centres have been discovered with swath multibeam mapping and seismic tomographic profiling (Nomikou and Papanikolaou, 2000), most of them emerging locally as small volcanic islets around Nisyros. The new submarine volcanoes revealed exhibit a different geometry and evolutionary stage. The lack of sediments overlying the volcanic domes indicates their very young age, ranging between Upper Pleistocene and Holocene. The compilation of topography and swath bathymetry enhances the visual presentation of the whole volcanic field as in Fig. 3, where the crater of Nisyros volcano is very clearly expressed by the circular depression in the middle of the island.

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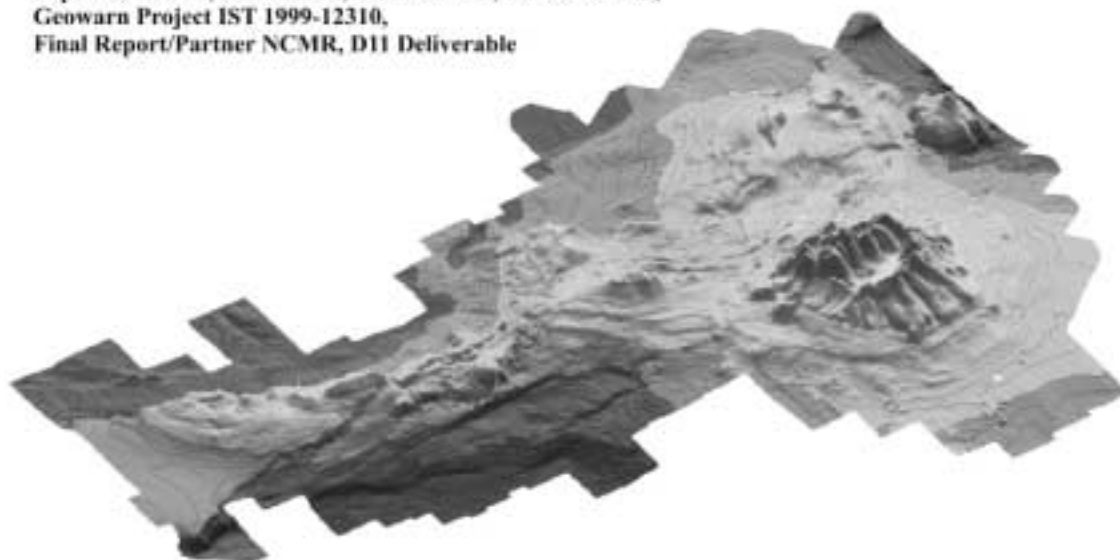


Fig 3. 3-D perspective diagram of Nisyros volcanic field viewed from south.

Santorini

Santorini which was a small non-volcanic island, was developed on a basement formed of late Mesozoic-early Cenozoic schists and marbles exposed in Profitis Ilias Mt (Druitt *et al.*, 1989). Volcanism in the area of Santorini, started 2 million years ago with the extrusion of dacite vents on the Akrotiri Peninsula and continued producing different kinds of lavas and pyroclastics (Friedrich, 2000). However, the most characteristic type of activity over the last 200,000 years has been the cyclic construction of shield volcanoes interrupted by large explosive and destructive events like the Minoan eruption, one of the biggest eruptions in human history. Witness of this activity is the ring-shaped sea-flooded caldera, 8x10 km in size and 250-400 m in depth, enclosed by Thera, the Therasia islands and Aspronisi islet. Palea and Nea Kameni were later formed within the caldera by several eruptions during historic and recent times.

Excavations beneath the Minoan ash- layer, started since 1969 by Prof. Marinatos, brought to light an important cycladic town with well-preserved wall paintings, ceramics and other finds. The archeological findings near Akrotiri clearly demonstrate that during the Late Bronze Age the island was vibrant with life and movement, enjoying a prosperous civilization similar to that of Minoan Crete. It was a richly developed and probably oligarchic maritime community whose

flourishing economy was provided by intensive trade, shipping and probably vine, like at present (Doulas, 1983). At that time, Thera was a ring-shaped island, a central shield volcano with hot springs and a cauldron caldera with an opening southwestwards, between Aspronisi and the cape of Akrotiri peninsula. The spectacular discovery induced continuing speculations that the volcanic destruction of Santorini forged the legend of the sunken Atlantis, a prosperous continent or island that sunk and disappeared into the sea (see Luce, 1969), as told many times since Plato.

The Minoan eruption on Thera was a major Plinian caldera-forming event that happened around 1640 B.C. (Hammer *et al.*, 1987) and continued over months or years. It is divided into four distinct phases: 1) Plinian phase, 2) phreatomagmatic base-surge 3) ash-flow phase and 4) non-welded ignimbrite (Bond and Sparks, 1976; Pichler and Friedrich, 1980; Druitt and Francaviglia, 1992). It erupted 30-40 km³ rhyodacite magma and the height of the plinian eruption column is estimated up to 36-39 km (Pyle, 1990). The dispersed Minoan tephra is found throughout the Eastern Mediterranean and might have led to global climatic impacts. The eruption was followed by collapse of the magma chamber up to 800 metres down, and enlarged the existing caldera causing massive sea level fluctuations. These giant waves devastated all surrounding Cycladic islands and most of the south Aegean coasts, and destroyed the towns of Mallia, Phaistos and Kato Zakro in south Crete. The Minoan eruption is estimated to have been five times more powerful than the one of Krakatoa, producing a high eruption cloud and generating tsunamis of 60-100 m high. So it is quite possible to believe that the city of Knossos, located just 90 km away in northern Crete, could have been destroyed by this event, covered by thick volcanic ash layers.

No human body has been found killed by the eruption. Apparently local populations had been warned by earthquakes and water explosions, which were considered omens sent by infuriated gods. The exodus was apparently not hasty, as neither valuable objects nor furniture were left behind. There were no close eyewitnesses of the eruption that could survive and give a direct report, but grass found on the roofs of buildings, which were destroyed later, indicates that at least one rainy season went by, between evacuation and the actual volcano eruption (Dietrich, 2000).

The volcano of Santorini activated again during historic times, building the dark-colored lava shields of Nea and Palea Kameni inside the caldera. Compared with the Minoan, these eruptions were very small and they did not cause any death. The ancient writer Strabo is the first to mention volcanic eruptions inside the caldera; he described the rising of a new small island, probably a precursor of Palea Kameni during the year 197 B.C. Thereafter, at least eight eruptive phases followed in the years 46/47 A.D., 726, 1570-1573, 1707-1711, 1866-1870, 1925-1928 (Fig. 4), 1938-1941 and 1950, the most recent eruption. At present, only fumarolic activity is visible at Kameni islets which are visited daily by hundreds of tourists during the summer season.



Fig. 4. Dafni Eruption (Nea Kameni), 23 October 1925.

It is noteworthy that besides the famous Minoan eruption of Santorini, the most destructive recent volcanic eruption occurred on Columbo on 27 September 1650 with extrusion of ash, pumice fall and toxic gasses that caused more than 50 fatalities and the generation of a strong tsunami. Today, its appearance is a circular caldera, 2 km in diameter, created apparently by the collapse of a relevant volcanic cone. The rim of the caldera with an almost indented perimeter stands at about 150 m depth, while its flat bottom which does not exceed 1 km in diameter, lies at a depth of 504 m (Fig. 5).

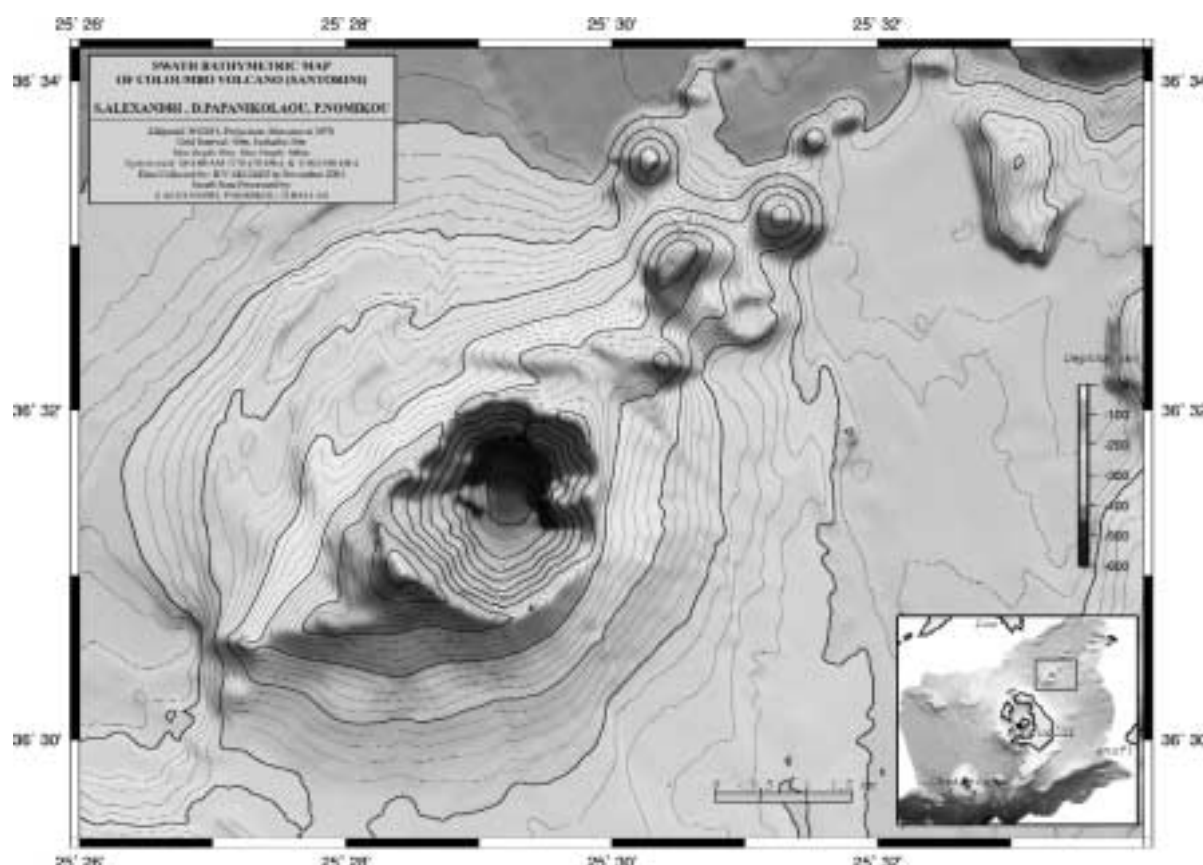


Fig. 5. A swath bathymetric map of Coloumbo submarine volcano, NE of Santorini.

Comparative remarks

Nisyros and Santorini are the most active volcanoes in the Aegean Volcanic Arc, displaying a different stage of caldera structure. In Nisyros, after the major collapse of the existing stratovolcano, the resulted caldera was never drowned by the sea (base of caldera at + 80m). In contrast, in Santorini, during the Minoan eruption, the crater collapsed down to 800m, the caldera was violently broken, cut into several parts and flooded by seawater in the center (base of caldera at - 400m).

The alpine basement in Santorini is exposed on Profitis Ilias Mt, at an altitude of 550 m, whereas in Nisyros there is no evidence of it on land although it has been detected in 1,800m below sea level by drillings in the central part of the caldera.

The post-caldera evolution in Nisyros comprises massive dacitic-rhyodacitic domes with the highest, Profitis Ilias, rising about 698 m above sea-level. On the contrary, in Santorini the dark-colored lava shields of Nea and Palea Kameni islands have been built inside the caldera, about 100 m above sea level. In Nisyros the top of the post-caldera domes are 300 m higher than the caldera rim, whereas in Santorini they are 200 m lower.

In Thera, the rich and unique civilization which was flourishing before the great Minoan eruption, violently vanished, covered under huge masses of pumice, and the island was abandoned for many decades. Quite the opposite occurred in Nisyros, where according to archaeological evidence, there was no volcanic disruption of the local civilization, since the neolithics.

During the Holocene volcanic activity is very low on Nisyros but very intense on Santorini.

The fatalities from the volcanic activity are in general very small in both islands; the most destructive event was the Columbo eruption in 1650. It is remarkable that both islands have suffered much more, with casualties and collapse of houses, by earthquakes not related to the volcanic activity (1931 in Nisyros, 1956 in Santorini).