Volcanic Hazard in the Kolumbo Submarine Volcanic Zone NE of Santorini Island.

Nomikou P., Carey S., Papanikolaou D., Croff Bell K., Sakellariou D., Alexandri M., Bejelou K.

University of Athens, University of Rhode Island, H.C.M.R.
Fly into Santorini Volcano, Greece
The study area lies within the Cyclades back-arc region of the present Hellenic subduction zone where the seafloor of the eastern Mediterranean Sea is descending beneath the Aegean microplate. The Cycladic region and the Aegean Sea as a whole are known to be regions of north-south back-arc extension and thinning of continental crust.

Santorini island and Kolumbo submarine volcanoes are located at the centre of the modern Aegean volcanic arc, developed within the Hellenic arc and trench system.
Volcanic centers (Nomikou et al., Tectonophysics 2011-in press)
The island complex of Santorini includes the islands of Thera, Therassia, Nea Kammeni, Palea Kammeni and Aspronisi, arranged in a circular shape.

They all represent the remains of the collapsed volcanic shield and form a ring around a large submarine caldera that was formed around 1600 BC.
The transtensional Anhydros sedimentary basin is bordered and dissected by normal faults, forming a “flower type” structure that extends towards the northeast. The “Kameni-Kolumbo Line” is an active, 40km-long, strike-slip fault zone which runs through the volcanoes of Nea Kameni and Kolumbo and controls the spatial distribution of the volcanic cones along the axis of Anyhodos basin. Thus the rift zone facilitates magma ascent through the continental crust.

Thick green line separates the Kolumbo eruption pumice products of 1650 AD from previous volcanic products.

Transverse profile across the Anyhodos basin showing the graben structure and the ascending magmatic products.
Recent Seismicity (2002-2004)

Results of a seismic tomography study in the Santorini/Kolumbo region. The identified low velocity zone is described to the Kolumbo magma chamber.

Magma with significant partial crustal melting components is ascending towards Santorini Volcano filling the magmatic chamber.

The magmatic chamber beneath Kolumbo submarine volcano is about 5km wide and 5km high. Magma and hydrothermal fluids rise towards the volcanic cone fracturing the surrounding rocks and causing multiplets.


Bohnhoff et al. (2006), Tectonophysics.

Dimitriadis et al., 2010, Journal of Volcanology and Geothermal Research.
Earthquakes on Santorini between 30 Aug and 28 Nov, 2012
(source: Department of Geophysics, Aristoteles University of Thessaloniki)
The line of craters lies within a rift in a basinal area which is rather flat and featureless with approximately 450 m maximum depth.
The distribution of the slope magnitudes illustrates the homogeneous areas of smooth or intense relief as well as the zones along which there is an abrupt change of slope. The zones of abrupt slope change correspond to **active tectonic structures** (like along the marginal fault zones) or **steep volcanic slopes** (within the Kolumbo crater and around the external flanks of the minor volcanic cones towards the NE).
The Nautilus Live website shares live video and intercom audio from the ship 24 hours a day, 7 days a week. To help viewers understand what they’re seeing and feel like part of the expedition team, the live feeds are supported by a steady stream of status updates, blog posts, photo galleries, and video highlights.
«Nautilus Live» Theatre of Mystic Aquarium & Institute for Exploration
Remotely Operated Vehicles

Hercules

Argus
Lobate and indulating outcrops consisting of pyroclastic material cemented by biological activity on the slopes of VC 10.

Cone 10 is an ellipsoidal structure with its major axis trending NW-SE. There is no crater at the summit of this cone and its slopes are steep with the exception of the southwest part where the topography is more gentle.
Very steep face along the extension of the northern valley into the summit area of \textbf{VC 6}.

Cone 6 is located almost 4km northeast of Kolumbo. It is also characterized by the absence of a crater and has a circular, dome-like symmetric shape. The base lies at a depth of 300m. Slopes are very steep on each side of this structure.
Top of ledge is at water depth 190m, very steep with uneven topography at **VC12**

**Cone 12** is dome-like cone with no apparent crater. Towards the summit, this step-like morphology is observed, constituting the majority of the seafloor. Steps are linear to curvilinear with an E-W trend.
An outcrop with numerous broken pieces between the two hills of VC7

VC7 has a circular, symmetrical shape with steep slopes on either side

Linear steps in E-W direction

A face of an exposed outcrop covered with black precipitation
VC 14 is circular, dome-shaped and rises to a depth of 340 meters.
Linear to curvilinear depressions filled with black sediments, oriented downslope in the summit area of VC14.

Circular depressions in the summit area. Each depression is less 0.5 meter in diameter and several tens of cm in depth.

This sediment was sampled and found to consist of precipitated manganese oxide that was growing on a variety of sedimentary particles.
Scanning electron microscope images of manganese oxide precipitates (light colored spherical shape) growing on lithic grains, (a, b), adjacent to volcaniclastic sediment with abundant glass shards (c), and on the surface of a rhyolitic micropumice.

Energy dispersive wavelength spectra of black precipitates from the summit showing the dominant elements Mn, O, Ca, and Mg.

The abundance of manganese precipitates associated with fractures in outcrops and along downslope channels, clearly indicates that low temperature hydrothermal venting is very active on cones 7 and 14.
Submarine volcanic activity northeast of Santorini appears to have been strongly controlled by active faulting within Anydros Basin.

- The distribution of the volcanic cones is aligned along two principal trends.
- Cones in the more northerly trend are generally larger, whereas cones in the more easterly trend are smaller and more uniform in size.
- The majority of the cones are dome-shaped and lack a recognizable summit crater.
- The highest frequency of seismic activity currently exists beneath Kolumbo volcano, but frequent seismic activity also continues northeast of Kolumbo located more in line with the easterly trend of the northeast cones, probably generating low temperature hydrothermal venting and manganese precipitation on cones 7 and 14.
1650 AD ERUPTION
1. Exploled above sea level, accompanied by earthquakes
2. Multiple explosive eruptions resulted in ash fallout up to Turkey and the production of tsunamis that adversely affected Santorini
3. Several people (70) were killed by gases

Fouqué (1879)

The principal hazard types likely associated with Koloumbo eruption are:

i) volcanogenic earthquakes,
ii) ash fallout
iii) tsunami,
iv) toxic gases.

The resident population of Santorini is at high risk from the hazards associated with a future eruption.
The caldera rim lies at about 150 m depth forming a submarine circular cliff of 350 m. The crater walls display a scalloped morphology that is visible by undulating contour lines. The topographic difference is apparently created by the collapse of a relevant volcanic cone.
Kolumbo crater walls

The upper crater walls are composed of over 150m of interbedded pumice lapilli and pumice block breccia beds produced during the eruption of 1650 AD.
Outcrops of lava with polygonal shape due to abrupt crystallization. Probably proceeding the 1650 A.D. Eruption. Numerous bacteria flow into the water column.
Lava dyke trending NE-SW, with angular shape covered partially with bacteria
White bacterial streams

Low temperature vents (<100° C)

High temperature vents (>100° C)

Distribution of hydrothermal vents on the crater floor of Kolumbo volcano

Sigurdsson et al., 2006, EOS
The entire crater floor of Kolumbo is covered by a reddish-orange bacterial mat a few centimeters in thickness. In addition, the water column in the crater below 250 meters in depth is extremely turbid with abundant bacterial filaments and other suspended particles.

Sigurdsson et al., 2006, EOS - Nomikou et al., 2011, Journal of Global and Planetary Change
H.V. are constructed of massive sulfides and sulfates, covered with bacteria.
Side view of Chewbacca area multibeam. Poet’s Candle is the large structure between blue and green.

Visual survey in the Poet’s Candle area showing the vents and white bacterial mat. Twenty-seven hundred individual stereo pairs were used to create the final image.

High frequency multibeam
Frequencies > 500 kHz
“Poet’s Candle”
Few Niskin water samples were collected at different depths close to the vents (first PH measurements showing ~5) during Nautilus cruise (September 2011).
The mineral deposits in the crater of Koloumbo Volcano are totally enriched in Au, Ag and Zn.

Principal Minerals phases
Analyzed by Electron Microprobe:

1. Pyrite  FeS
2. Sphalerite  (Zn,Fe)S
3. Galena  PbS
4. Barite  BaSO₄
5. Anhydrite  CaSO₄
6. Veenite  Pb(Sb,As)₂S₅
7. Anglesite  PbSO₄
8. Zinkenite  Pb₉Sb₂₂S₄₂

General structure of chimneys are highly porous polymetallic sulfide-sulfates with sulfates most euhedral in morphology and sulfides frambooidal. The SEM images show some typical structure.
Our results suggest that hazards associated with the northeast cones of Kolumbo are relatively low based on:
1) lack of fresh outcrops of volcanic products,
2) dominant effusive dome-building style based on typical morphology,
3) very small volume of individual erupted products, and
4) relatively deep water depths at potential summit vents (majority >200 m).

Apart from Kolumbo it appears that the cones aligned along the more easterly trend are perhaps undergoing more active volcanological/tectonic processes based on the distribution of seismicity and occurrence of hydrothermal venting.

However, Kolumbo remains the most significant source of future volcanic hazards within this zone northeast of Santorini and warrants a program of integrated monitoring (such as changes in the temperature, gas flux, and distribution of hydrothermal vents on the crater floor).
One of the miracles of what we, the nature observers, may be faced with.....

THANK YOU

“Painted” by
Mother Nature