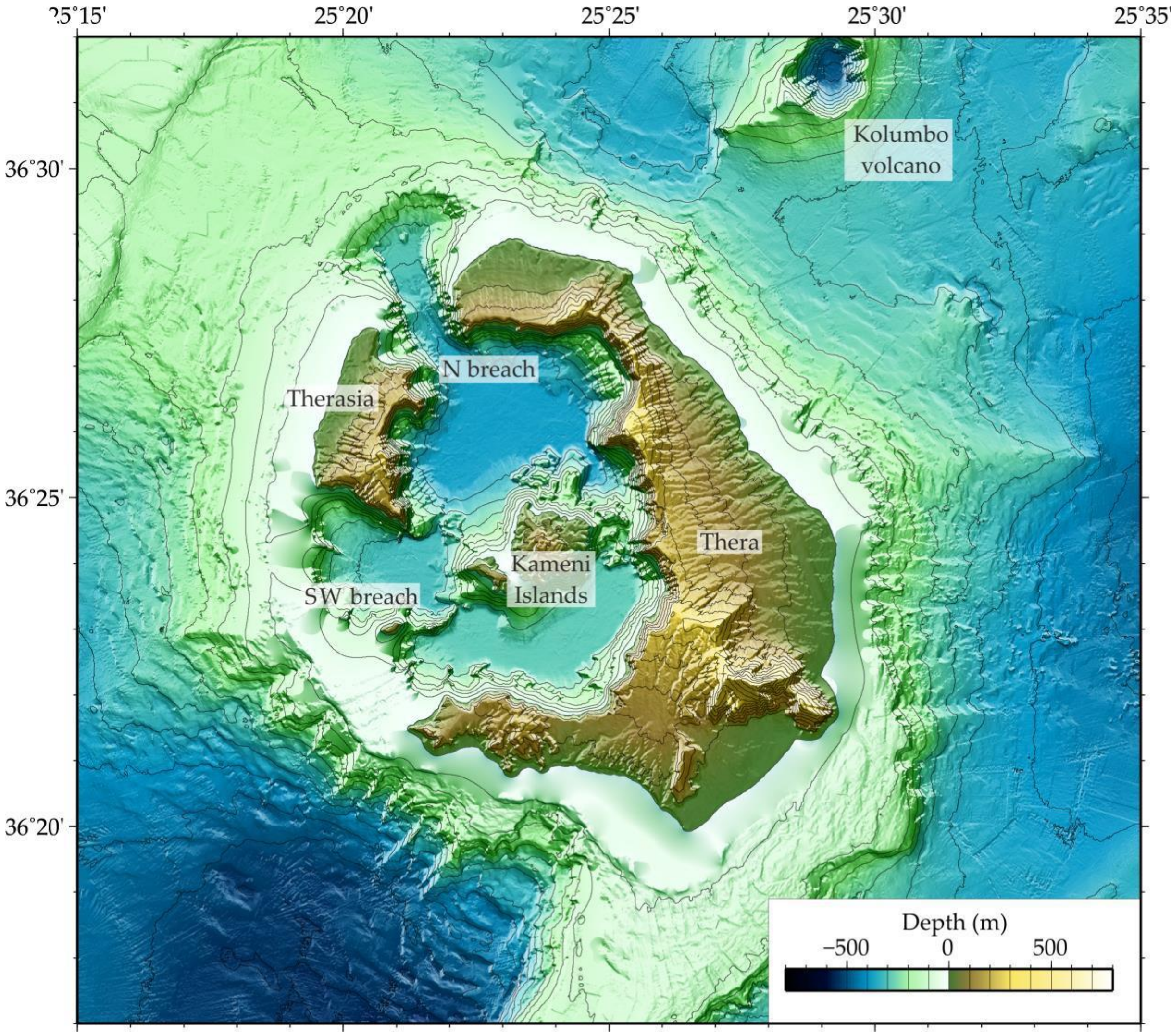
Staples Field Trip Seminar 2018 – Santorini Field Trip



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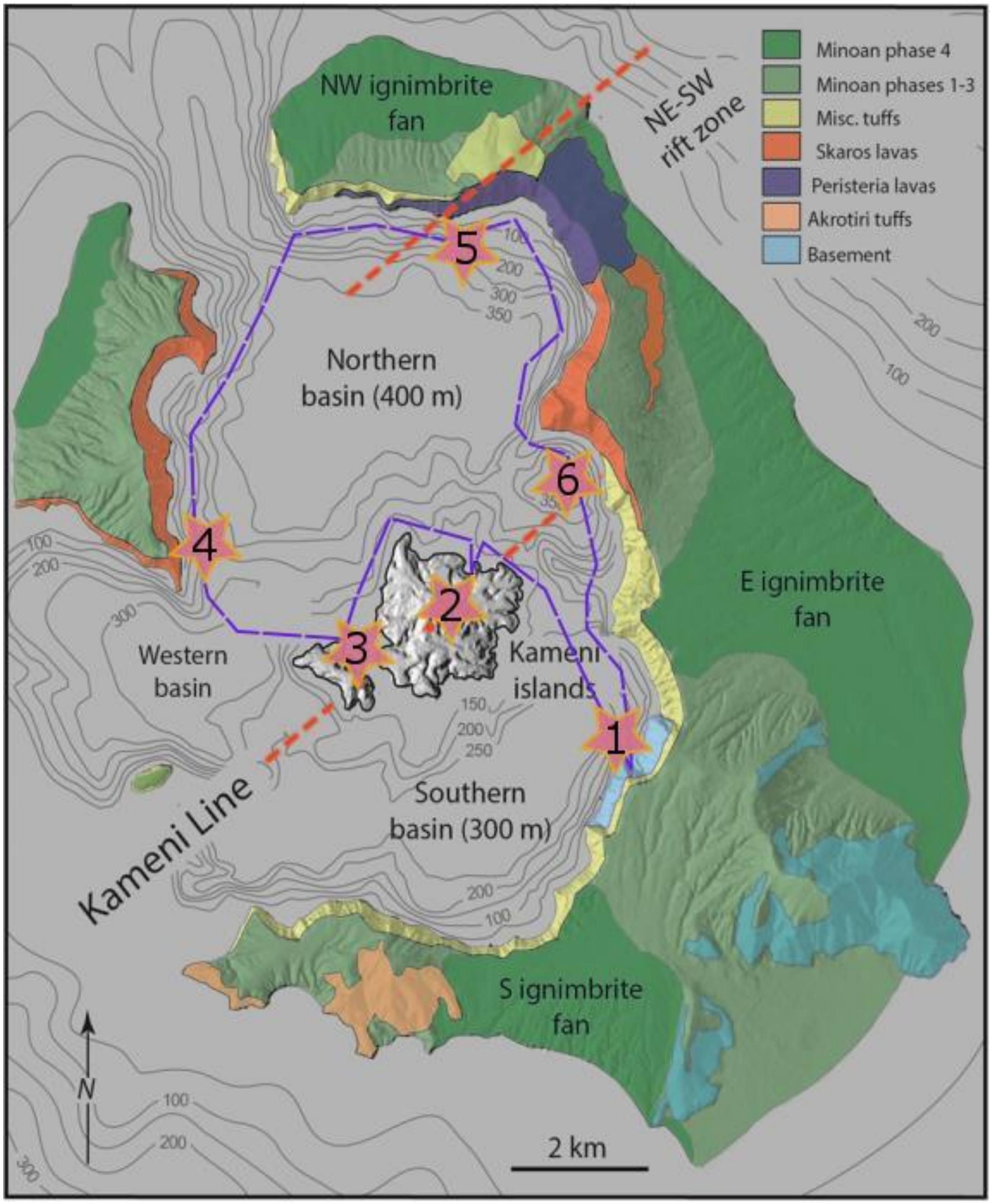
Field-Trip guide to Santorini Volcanic complex



Index map showing locations of field trip stops (stars)

1. Athinios Port (Basement lithologies-Eruptive Cycles-Caldera collapse events)
2&3. Nea Kameni & Palaea Kameni (Eruption History – Features)
4. Therasia Island (Skaros shield-Therasia dome complex-Cape Riva eruption)
5. Northern caldera Dyke swarm
6. Fira Harbor

1. Athinios Port

(Basement lithologies-Eruptive Cycles-Caldera collapse events)

Basement Lithologies

Athinios Port is located at the southern part of the caldera wall (inside the caldera ring) roughly between Fira (capital) and Akrotiri village (excavations). It is built on the basement metamorphic massif, which is part of the prevolcanic island that formed close to the nowadays center of Santorini Island, from late Mesozoic to early Tertiary during the Alpine folding Orogeny. The metamorphic lithologies represented by low-grade phyllites (metapelites and schists) were found along the caldera wall at Athinios port but also at Profitis Ilias and Mesa Vouno mountains.

The metamorphic pathway (P-T path) is characteristic of the metamorphic facies of the typical subduction and exhumation processes influenced by (1) an Eocene high pressure blueschist phase followed by (2) an Oligocene-Miocene greenschist to amphibolite facies overprint (Barrovian metamorphic event, a sequence of regional metamorphic mineral reactions that form typical mineral assemblages) which was associated with a granitic intrusion (mostly about 20 - 9 Ma). The latter, which is part of the Cycladic Granitic Province, is the source of various ore minerals and it is observed at this spot.

The fabric that dominates the metamorphic rocks is a differentiated crenulation cleavage (schistosity) that indicates later deformation and metamorphism. In addition, a N-S lineation in schists is observed in the field scale (Fig 1).

Fig. 1: Location of basement lithologies at the Athinios port. (Photo: A. Gudmundsson, 2014)

Eruptive cycles

The history of the Santorini volcanic field is composed by 6 distinct stages. In detail, two explosive cycles which volumetrically play the most significant role on the stratigraphy of the island, contain 12 major explosive eruptions (Thera pyroclastics) and at least 3 large lava shields. The first eruptive phase (360 -172 ka) is mainly distributed in the southern Thera cliffs while the second eruptive phase (172 – 3.6 ka) is totally defining Therasia and Aspronisi and parts of the Northern and central (Fira towards the south) caldera wall (Fig 2).

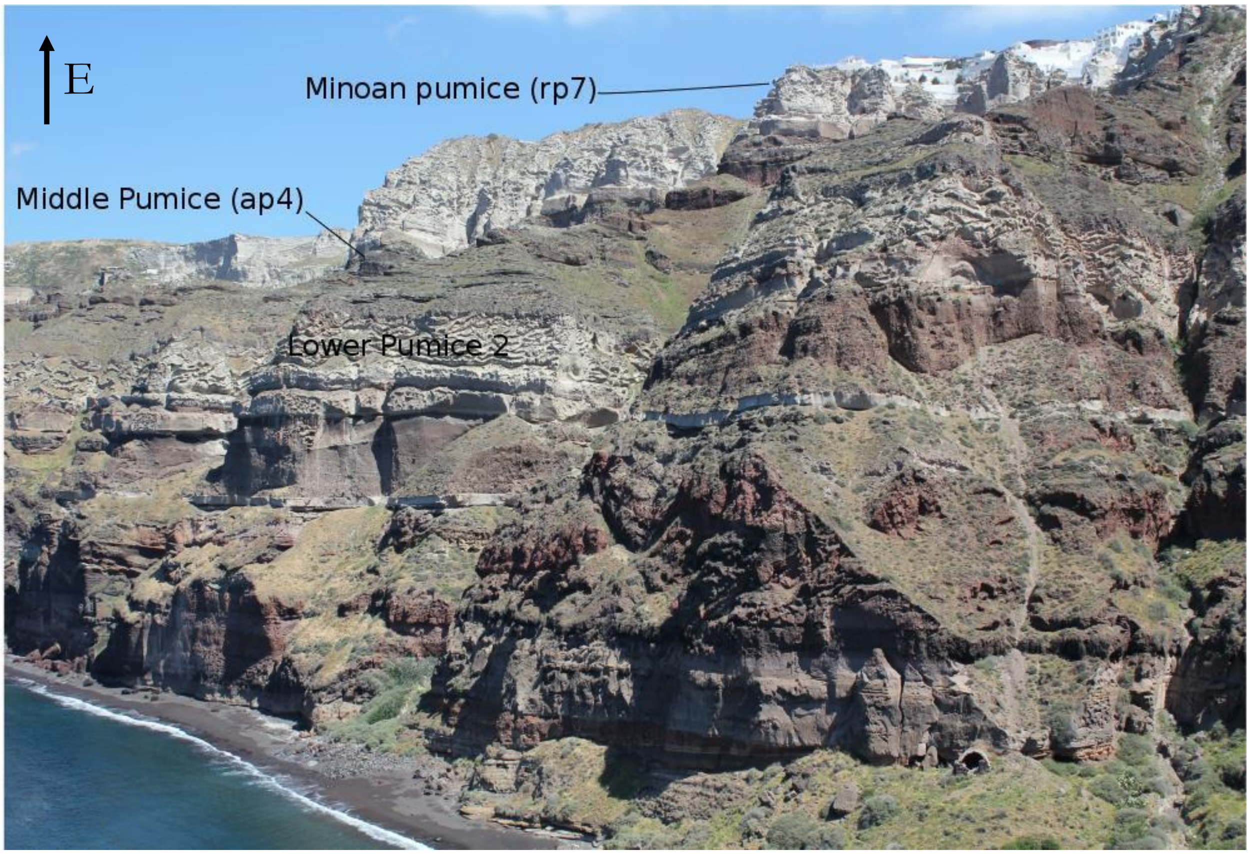


Fig. 2: Panorama at Athinios Port showing the pyroclastic successions of the 2 major eruptive cycles. (Photo: A. Gudmundsson, 2014). The caldera walls are ~400m tall while they continue below the sea level up to 390m deep.

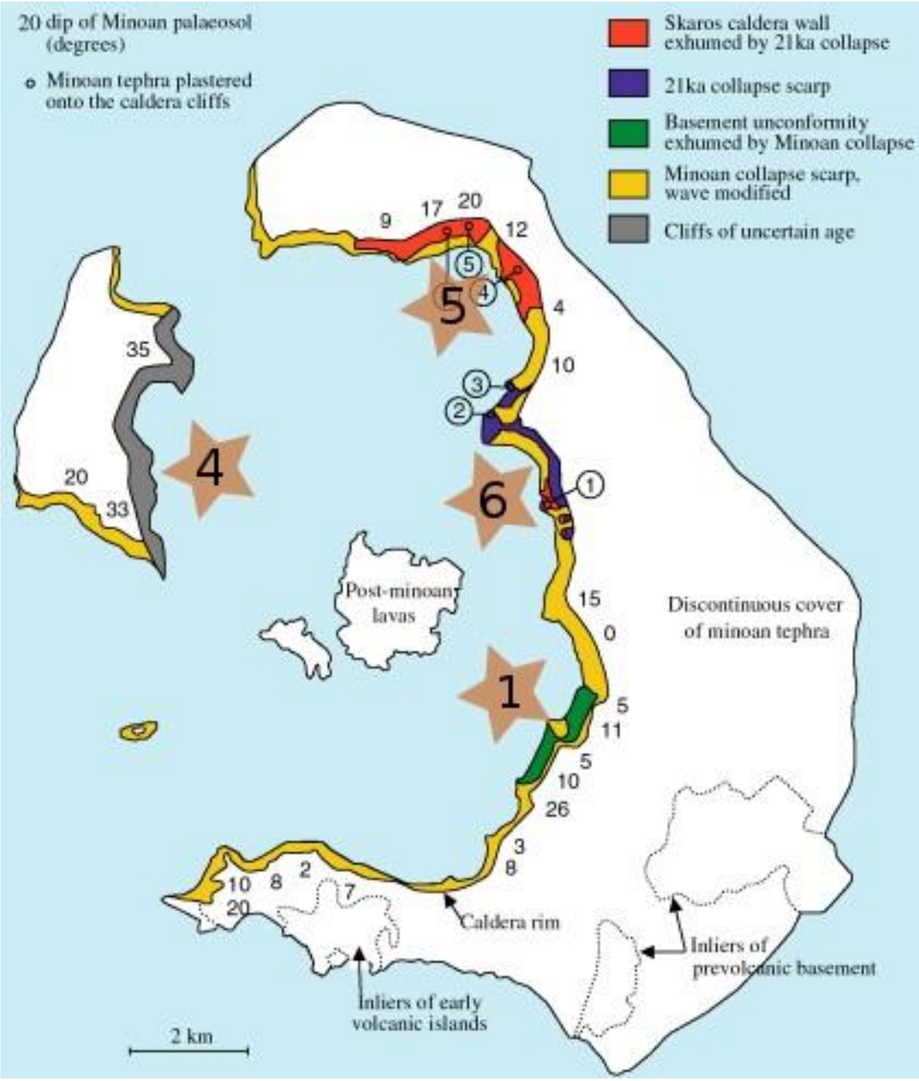
Caldera collapse events

<u>Mechanism:</u> Collapse caldera forms when the magma chamber cannot support the weight and associated stresses of the volcanic edifice above. Calderas never form, as far as we know, into a large empty cavity - because such cavities cannot form at many km depth. In contrary, they form as piston of rock subsides into a magma chamber while magma is, commonly, being squeezed out.

The volcanic evolution in Santorini is permeated by (at least) 4 caldera collapse events that took place during the 2 eruptive cycles since 172 ka. Each cycle began with mafic to intermediate volcanism and terminated by silicic extrusions accompanied by collapse events. The remnants of the latter are observed on the caldera cliffs defined usually by unconformities and underlying palaeosols layers (Fig 3).

Caldera 1 (172 ka): Is located south of Thera defined by a 150 m unconformity which is covered by pyroclastic deposits.

Caldera 2 (76 ka): Is located north of Thera and is formed by the Middle tuff eruption series and covered by the Skaros lavas (67 ka).



Caldera 3 (22 ka): Is located on the present-day caldera wall at northern Thera and in Fira harbor (Minoan pumice layer- 140 m elevation)

Caldera 4 (3.6 ka): Is located mainly north of the Kameni line. At Athinios port is defined by the collapse of Minoan eruption (tuffs) which exhumed the northwest cliff and shore of the pre-volcanic basement.

Fig. 3:Geomorphological map of the caldera wall modified after Druitt and Francaviglia, 1992 showing the generations of cliff surface. The stars indicate the field stops that would be visible to be observed.

2&3. Nea Kameni & Palaea Kameni

Eruption History

A possible third eruptive cycle of intracaldera volcanism initiated at 197 BC and formed the present-day islands of Palaea and Nea Kameni. The magmatic vents of both lie within a NE-SW volcanotectonic line which control the magma ascent of the region and was reactivated (seismic epicenters) during the last volcanic unrest (2011-2012). The evolution of the Kameni islands has been reported by 9 subaerial eruptions that discharged dacitic flows and formed domes, channels and levees, blocky lavas, ash plumes (Vulcanian eruptions) and ballistic ejecta. Bathymetric imagery data have revealed submarine flows (pillow lavas) defining the actual morphology (pillow lavas) and final volume of products to 4.85±0.7 km^3 instead of 4.3 ±0.7 km^3 (Fig 4 & 5).

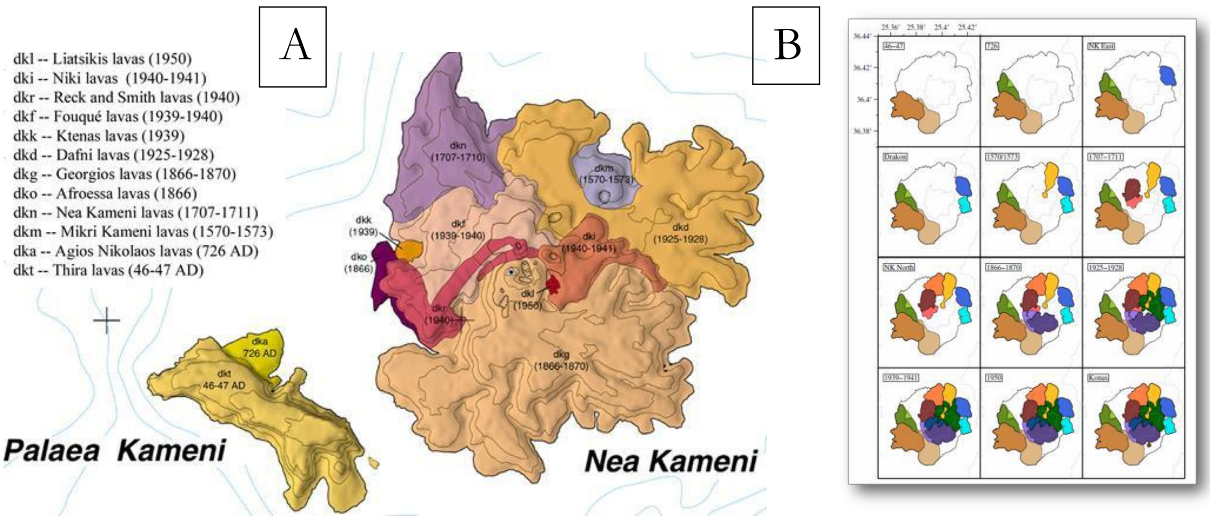


Fig 4: (A) Geological map of the Kameni islands (Druitt et al., 1999), (B) onshore and offshore extrusion events (Nomikou et al., 2014).

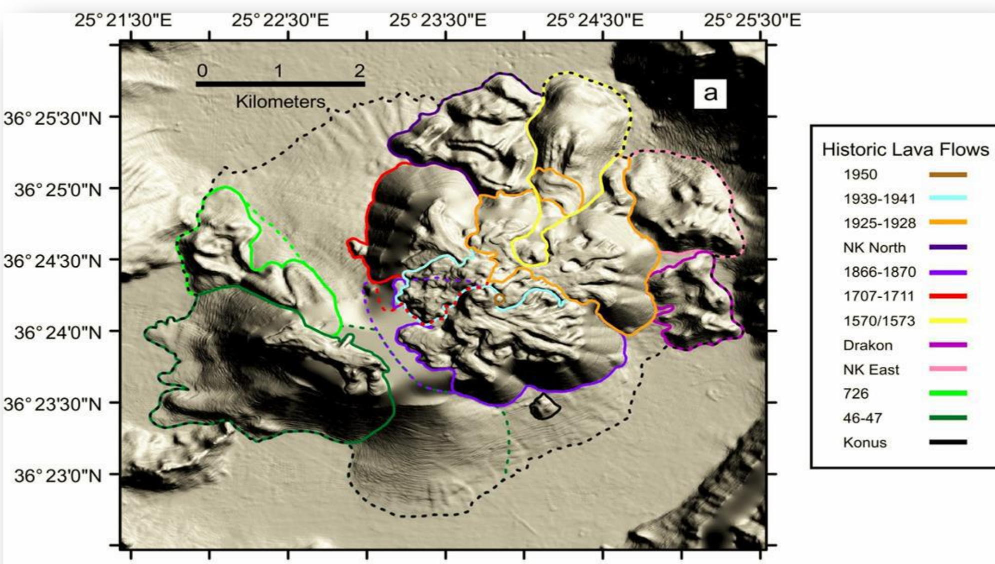


Fig.. 5: Bathymetric imagery of the Kameni, DRE volume is 4.85 km^3 (Nomikou et al., 2014).

Eruption	Details
197 BC	Formation of Iera pyroclastic cone
46-47 AD	Extrusive activity and formation of Palaea Kameni
726 AD	Explosive activity on the northern part of Palaea Kameni
1570-3	NE vent migration – Mikra Kameni formation
1707-11	Effusive/explosive eruptions formed the NW part of Nea Kameni
1866-70	Effusive activity dominated the southern part of Nea Kameni
1925-28	NW explosive activity that united Nea with Mikri Kameni (Dafni crater)
1939-41	Phreatic eruptions - flows, domes of Ktenas, Fouque, Smith-Reck, Niki
1950	Extrusion of Liatsikas lavas (Center of Nea Kameni)

Table 1: Eruption historic records by previous authors (Fyticas et al., 1990; Druitt et al., 1999).

Features

The hiking path to the top (and central) part of the Nea Kameni volcano is permeating the last 3 eruptive periods of the post-minoan eruption flows. In general, during the first volcanic eruption period (1925-1928) volcanics were practically extruded in two phases forming the Dafni lavas which merged the Mikri Kameni island with the Nea Kameni edifice. The middle period (1939-1940) is divided into six distinct phases-flows which respectively formed the Ktenas, Fouqué, Smith (2 phases), Reck and Niki lavas (the WW2 lavas). The final effusive activity of the volcano, which occurred in 1950, formed the Liatsikas lavas. Besides the unrest period of 2011-2012 the volcano is still dormant.

The main volcanic products of the 3 last eruption periods were dacite domes and flows which created classic surface morphologies normally associated with viscous felsic lavas e.g. rafted blocks and blocky lavas, flow folds and layering, coulee and levee. In addition, gas escape and oxidation signs as well as different populations of magmatic enclaves have been observed and reported (Fig 6-8).

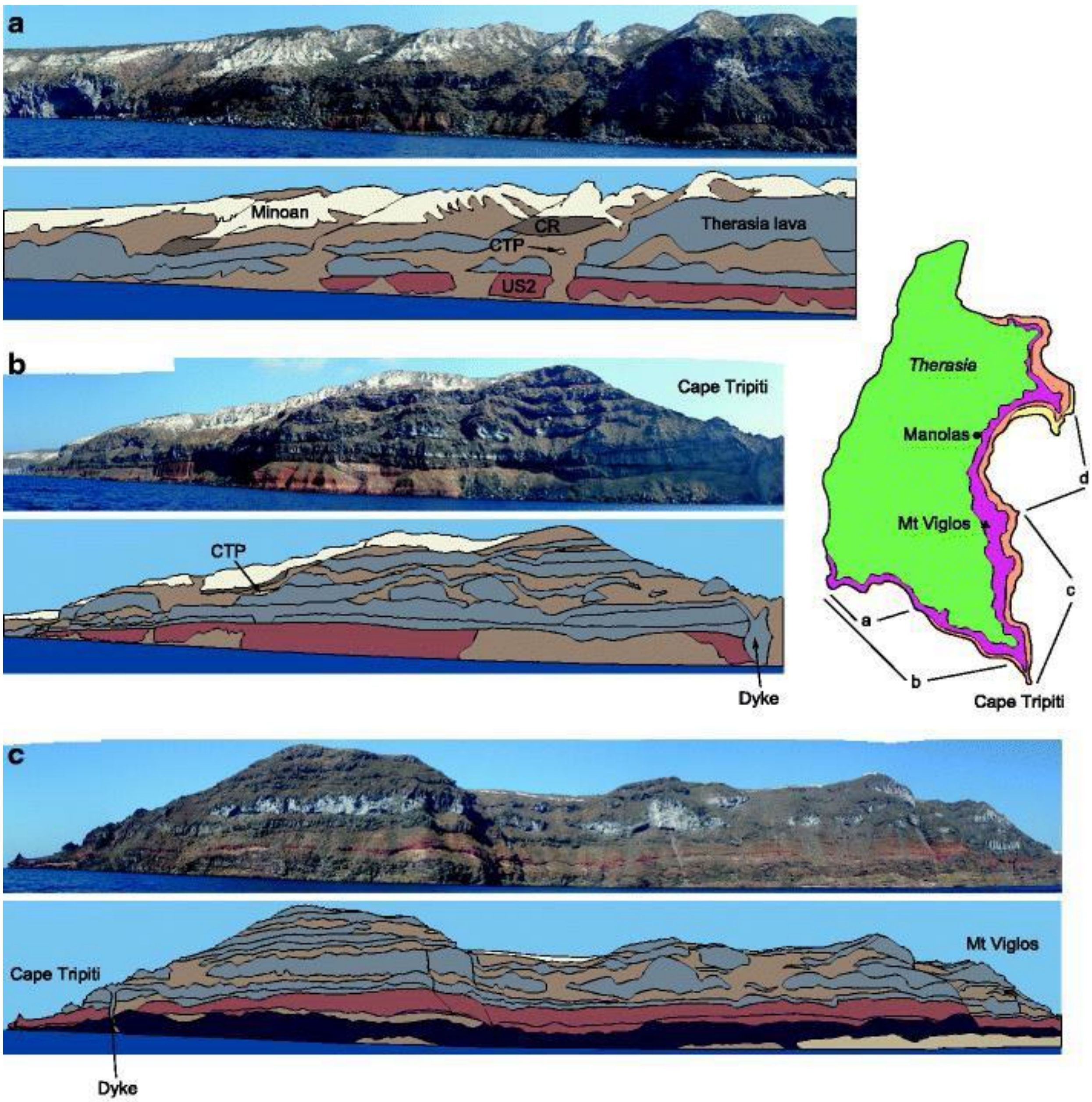
Fig. 6: Magmatic enclaves observed at Dafni Lava flows (Drymoni et al., 2014).

Fig. 7: Coulee flow of Niki blocky lavas (1940-1941). At the front we observe the Dafni crater (1925), (Drymoni et al., 2014).

Fig. 8: Layering and flow patterns (A), flow folds (B) observed at Liatsikas and Niki lava flows, (Drymoni et al., 2014).

4. Therasia Island (Skaros shield-Therasia dome complex-Cape Riva eruption)

Therasia dome complex is the western part of Santorini complex mainly influenced by the 70-21 ka volcanic activity. The stratigraphic sequence has been studied in detail by *Fabbro et al., 2013.*



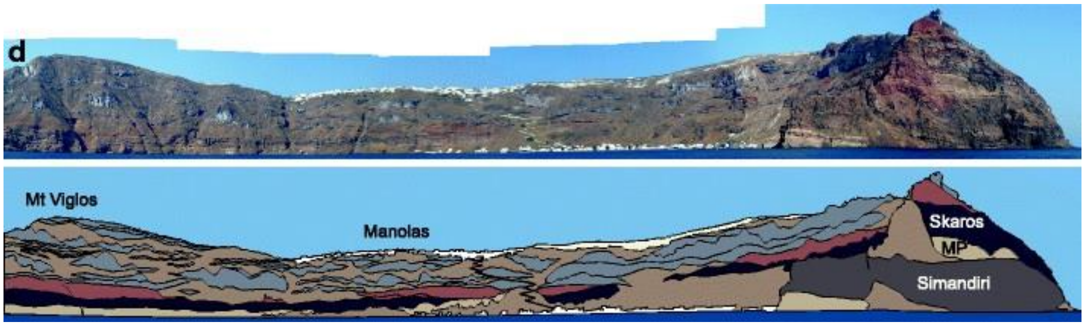


Fig. 9: Panoramic photos and sketches from the cliffs of Therasia (Fabbro et al., 2013).

Skaros shield

The Skaros shield atop the caldera that formed after the Middle Tuff eruptions (70-54 ka) and is observed in Therasia Island and extensively at Cape Tourlos. It is formed at the basement with silicic domes and coulees covered by well bedded mafic lavas. The same lavas are also found on the northern caldera wall.

Therasia dome complex

It is a succession of domes (dacitic) and flows (hybrid andesite) that dominates the cliffs of Therasia island and the top of the Fira cliff.

Cape Riva eruption

It occurred at 22 ka and began with a pumice fall deposit that preserved mostly on the Northern caldera wall. As a continuation, a welded ignimbrite was emplaced over the island followed by second one.

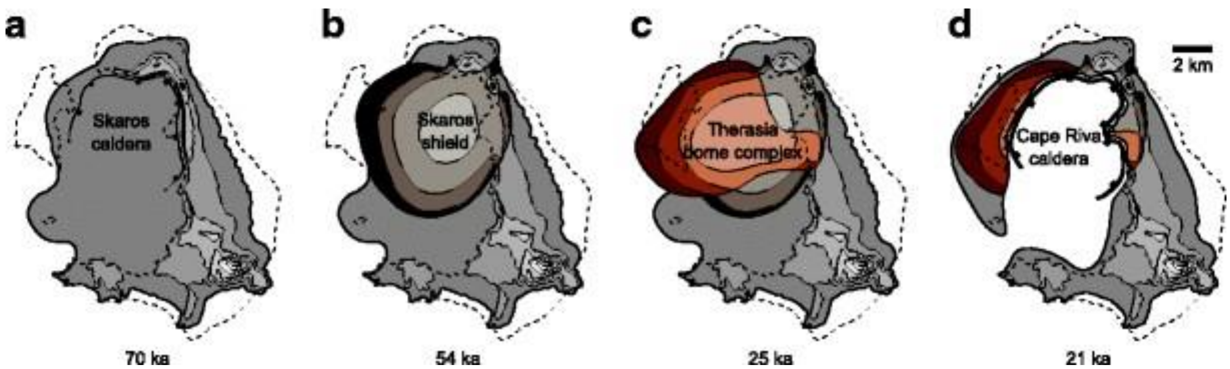


Fig. 10: Morphological evolution of Santorini between 70 and 21 ka, after Druitt et al., 1999.

5. Northern caldera Dyke swarm

Dyke or (dike) is a fluid driven (magma driven) extension fracture (mode I) that if it reaches the surface as a feeder (dyke) it feeds a volcanic eruption but if it became arrested on the way to the top, a volcanic eruption is suspended. A dyke-fracture is almost entirely forced to propagate by the overpressure of the magma.

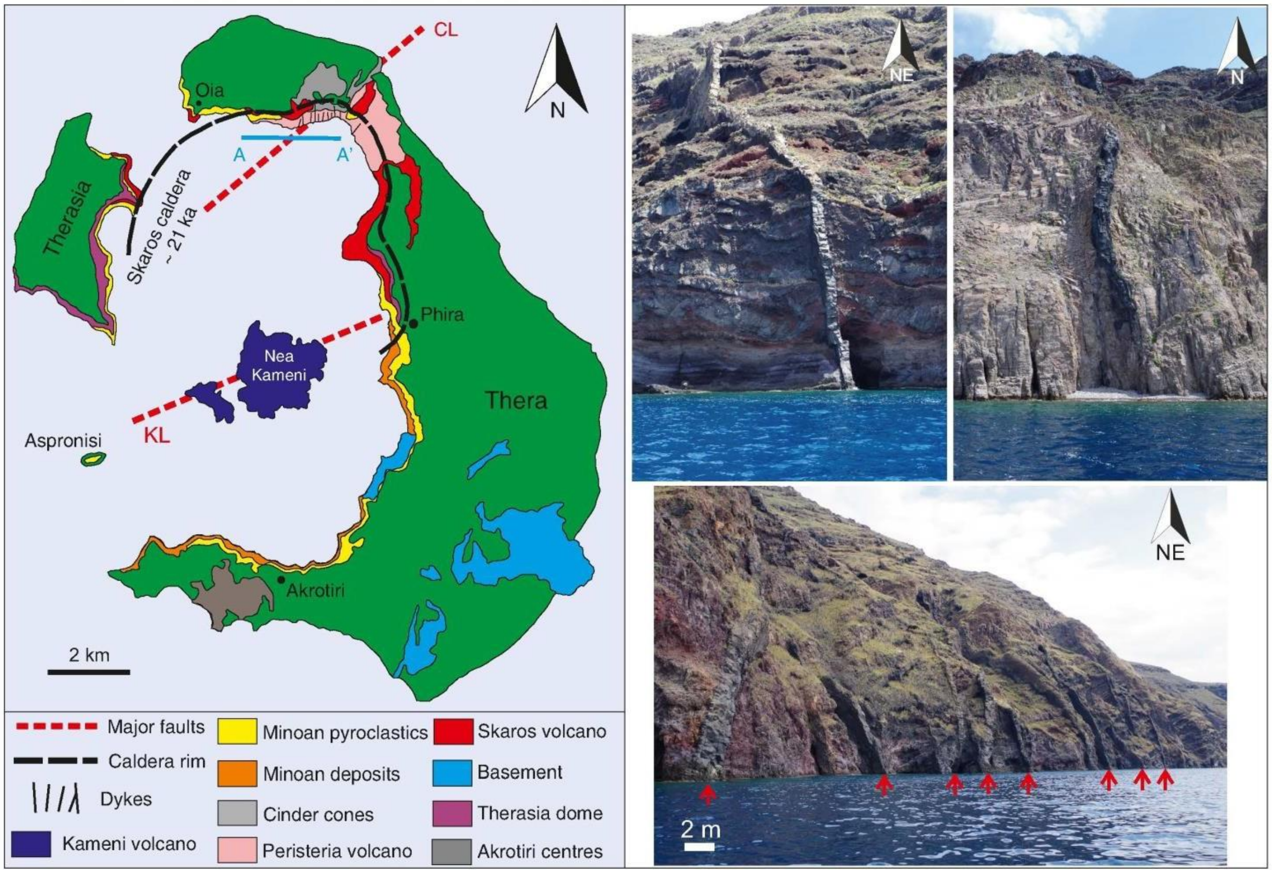


Fig. 11: Simplified geological map of Santorini, showing the two main tectonic elements: the Kameni and Kolumbo lines, the inferred Skaros caldera rim, and the location of dykes within the northern caldera wall (schematic). All the exposed dykes are located along the northern most extent of the Skaros caldera wall and the island of Therasia; some are marked in the figure with red arrows. Most dyke measurements were taken from a boat along the profile A – A'. The stratigraphy of the caldera is complex, being made up of many different types and ages of deposits. Many dykes within the wall are arrested, i.e. are non-feeders (Browning et al., 2015).

Recent studies have shown that the dyke swarm is emplaced in a highly heterogeneous host rock made up of many layers of contrasting mechanical properties; for example, stiff lava flows and comparatively compliant layers such as ash, volcanic tuffs and breccia. A total of 91 dykes has been recently mapped and structurally studied showing that the majority of the dykes have been arrested due to changes of the stress field during their emplacement and only a few of them probably fed (or not) a volcanic eruption.

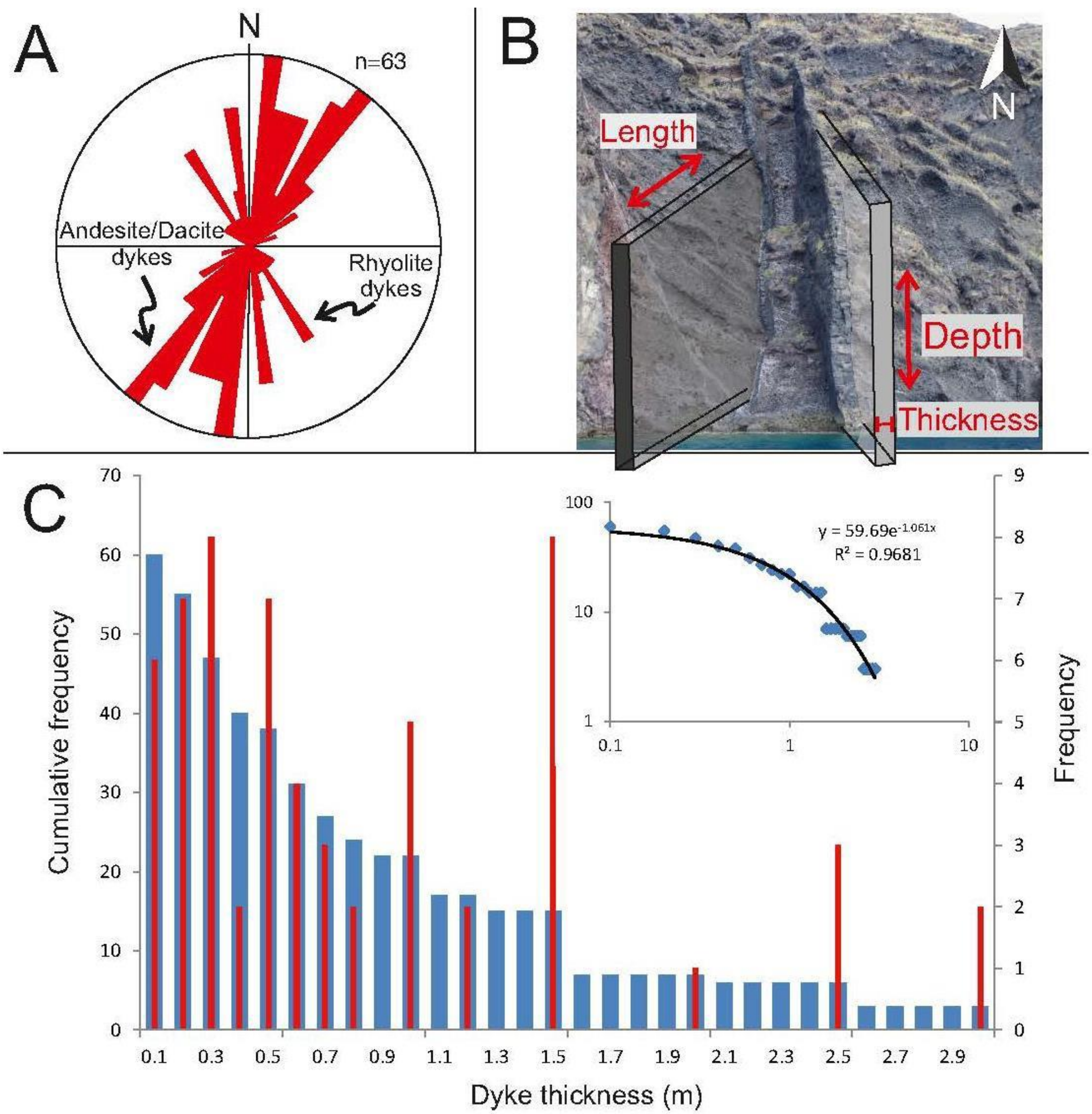
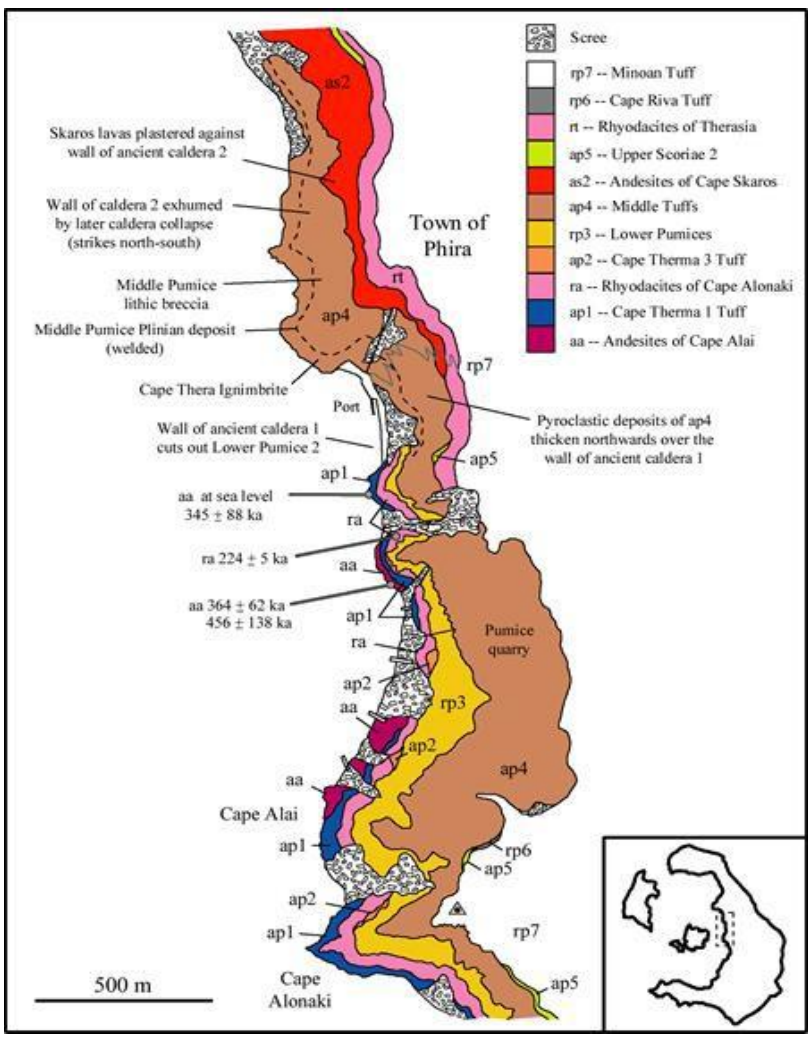


Fig. 12: A) Orientation and C) thickness of 63 dykes in B) the northern caldera wall of Santorini. Most dykes are less than 1.5 m thick and strike dominantly NE-SW, those dykes which strike NW-SE generally tend to be thicker and composed of rhyolitic magmas. The average thickness of dykes measured is 1 m, the minimum being 0.1 m and the maximum 5 m. For visualisation purposes the largest dyke shown is 3 m. C) Dyke thicknesses plotted as cumulative frequency distributions follow an exponential trend (blue bars). Individual dyke measurements plotted as a histogram with bin size 0.1 m are shown as red bars (Browning et al., 2015).

6. Fira Harbor

Fig. 13: Panoramic photo and stratigraphic interpretations of the Fira cliff (Simmons et al., 2017). According to the authors a Northward dipping unconformity is truncating the LP2 sequence, reflecting late-stage caldera collapse or post eruption slumping.



Key Observations

- Unconformity (truncates LP2 and underlying units)
- Caldera collapse during the LP2.
- Volcanotectonic line (Kameni line) permeates the harbor into distinct morphologies (seismic epicenters during the 2011-12 unrest lay along that line)
- Landslides-Hazards

Fig. 14: Geological map of Fira cliff (Druitt et al., 1999).

COVER: Combined topographic map of Santorini Volcano based on onshore and offshore data (Nomikou et al. 2016).

INDEX MAP: Geological map of Santorini modified after (Druitt et al., 1999) showing the locations of the field-trip (stops).

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