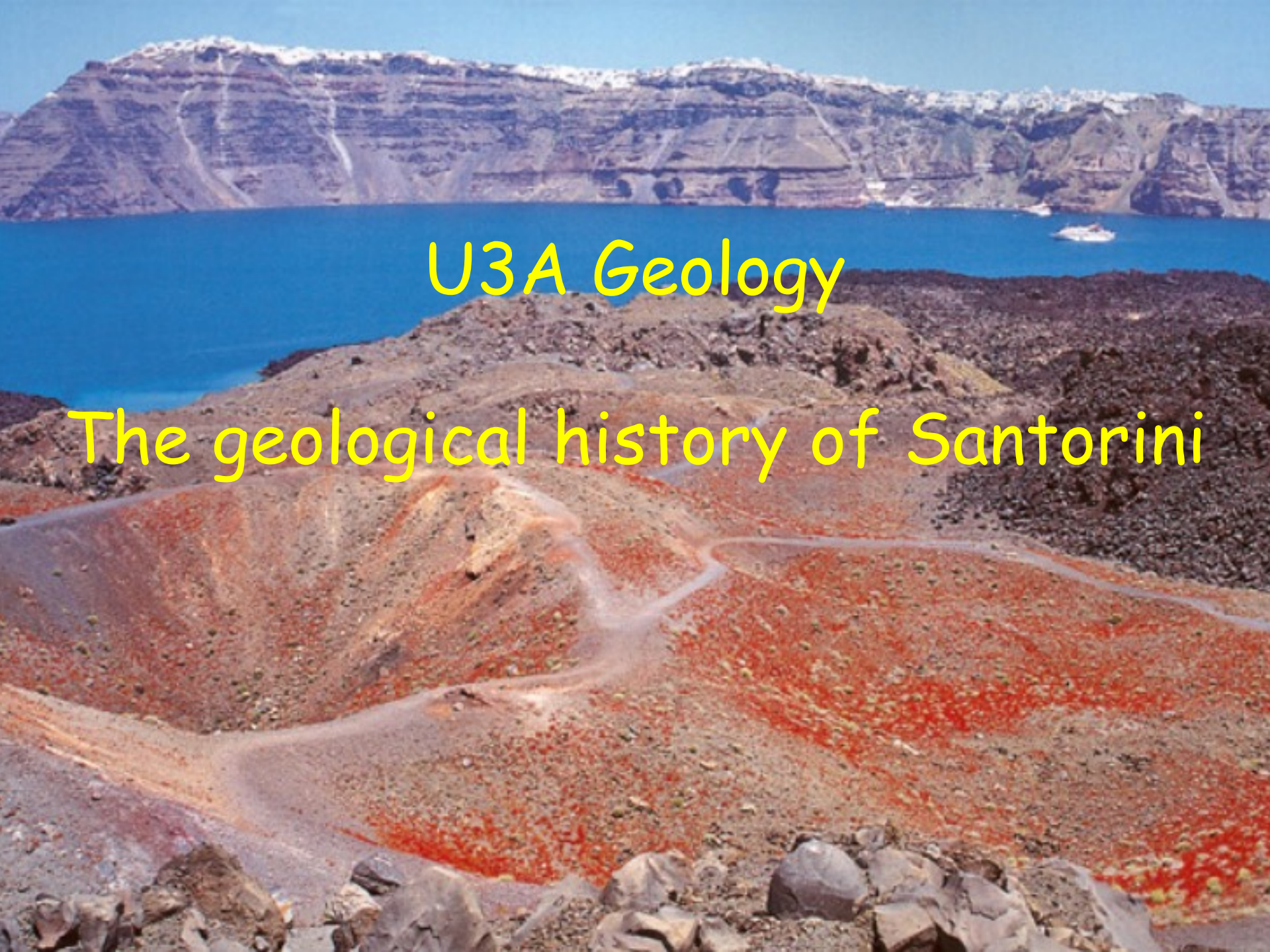


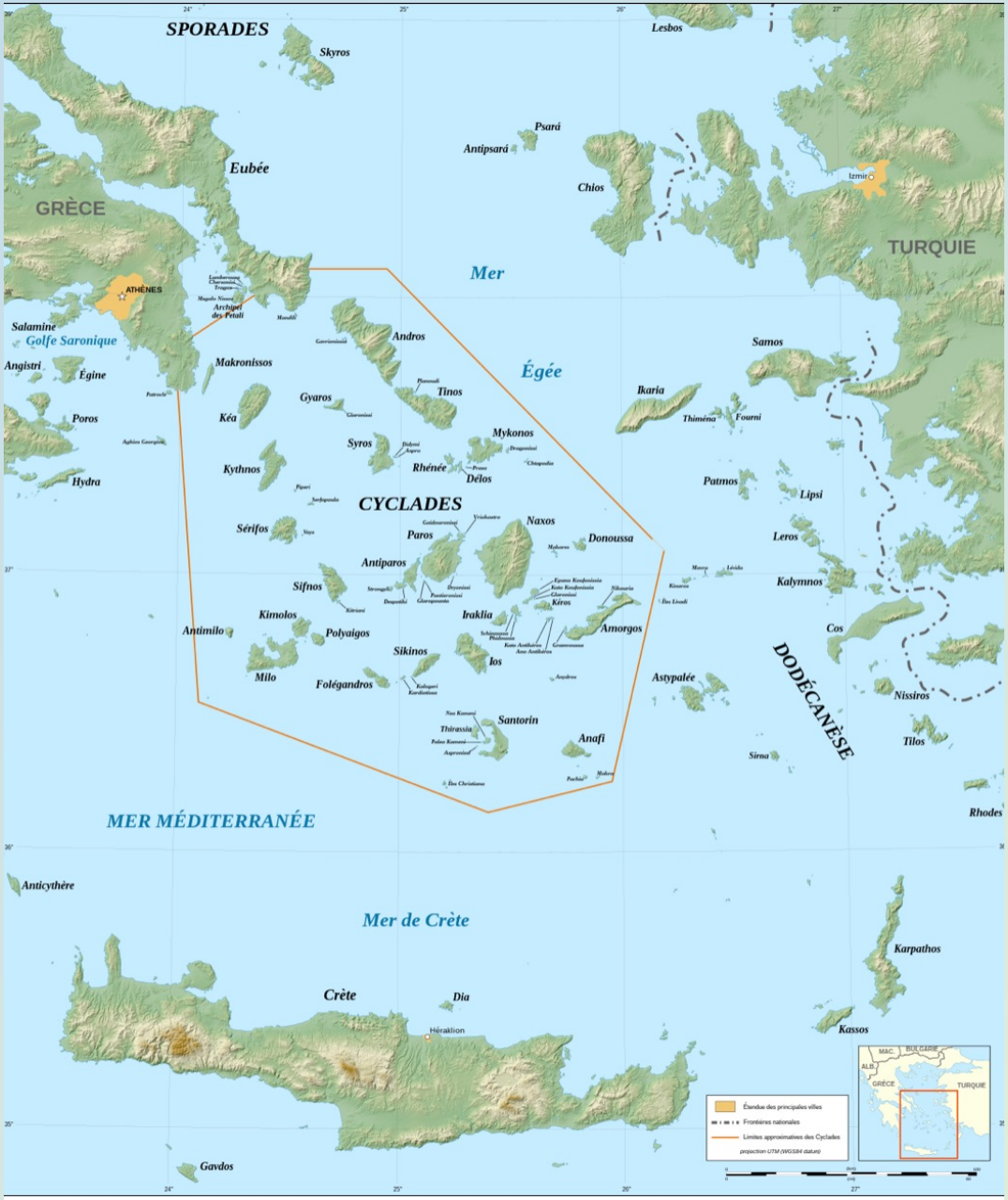
U3A Geology

The geological history of Santorini

Introduction

- Santorini is a small group of islands in the South Aegean Sea about 200km SE of Greek mainland
- the southernmost member of the Cyclade group of islands
- it is the most active volcano in the South Aegean volcanic arc
- remnant of a caldera that formed ~3,650 years ago during the Minoan eruption
- Minoan eruption → one of the largest eruptions in human history
  → led to decline, eventual demise of Minoan civilisation

Cyclades


SPORADES
Skyros
Lesbos
Psará
Antipsará
Eubée
Chios
Izmir
GRÈCE
TURQUIE
Mer
ATHÈNES
Archipel des Petali
Salamine
Golfe Saronique
Andros
Samos
Angistri
Égine
Makronissos
Égée
Tinos
Ikaria
Gyaros
Thiména
Fourni
Poros
Kéa
Mykonos
Syros
Kythnos
Rhénée
Délos
Patmos
Hydra
CYCLADES
Lipsi
Sérifos
Naxos
Donoussa
Paros
Leros
Antiparos
Kalymnos
Sifnos
Kéros
Kimolos
Iraklia
Cos
Antimilo
Polyaigos
Amorgos
Sikinos
Ios
DODÉCANÈSE
Milo
Folégandros
Astypalée
Nissiros
Santorin
Thirassia
Anafi
Tilos
Sirna
MER MÉDITERRANÉE
Rhodes
Anticythère
Mer de Crète
Karpathos
Crète
Dia
Héraklion
Kassos
Gavdos
Étendue des principales villes
Frontières nationales
Limites approximatives des Cyclades
projection UTM (WGS84 datum)

South Aegean volcanic arc

- Santorini lies along the South Aegean volcanic arc a chain of volcanic centres in the South Aegean Sea
- the arc is ~500km long extending from mainland Greece to the Bodrum Peninsula Turkey
- arc characterised by sub-aerial and submarine volcanism
- arc formed by the African tectonic plate subducting northwards beneath the Aegean Sea tectonic plate at ~35mm/year
- the arc comprises a number of dormant and historically active volcanoes including Sousaki, Regina, Methana, Milos, Santorini, Kolumbo, Kos, Nisyros, Yali and Akyariar

South Aegean volcanic arc

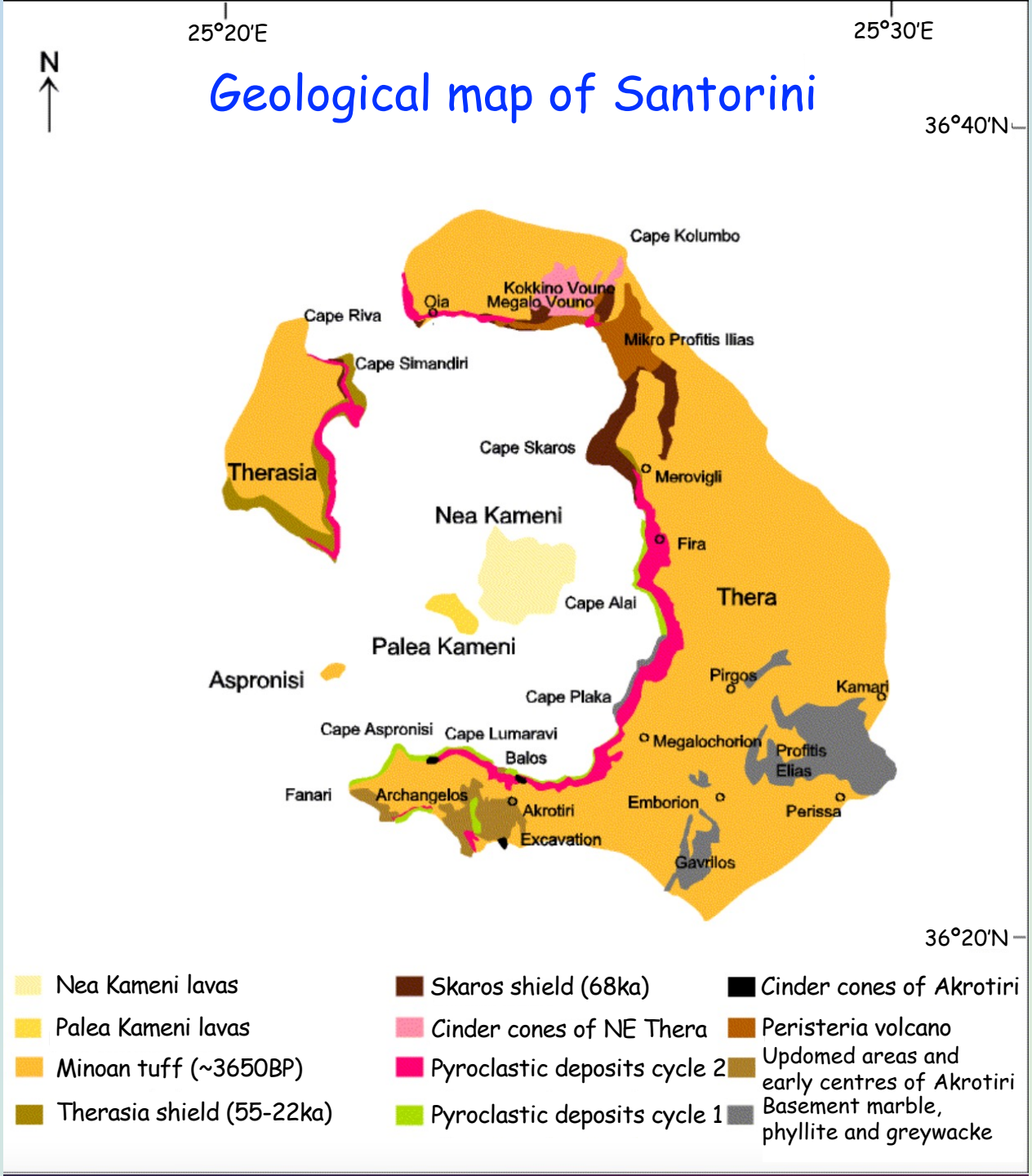
South Aegean volcanic arc


Paradise Beach
Ammoudi Beach
Oia
N
Vourvoulos
Imerovigli
Therasia
Thirasia
Firostefani
Fira
Karterados
Monolithos
Nea Kameni
Messaria
Palea Kameni
Thera
Santorini
Aspronisi
Cyclades Islands, Greece
Kamari
Megalochori
Ancient Thira
0
5 km
Emporio
Perissa
Akrotiri
White Beach
Red Beach
Vlichada

Local geology

- Mikri Profitis Ilias is a non-volcanic ridge in eastern Thera
- the non-volcanic rocks on Thera consist of marble and phyllites, Triassic to Tertiary in age
- pre-Minoan basalt lava flows and cinder cones occur at Akrotiri, Peristeria with rhyodacite flows at Skaros (westThera coast)
- pre-Minoan pyroclastics are exposed along rim of caldera
- Minoan tuffs and pyroclastics cover most of Santorini
- Kameni rhyodacite lavas, blocky flows, ballistic ejecta are relatively young volcanic features

Geological map of Santorini



Marble outcrop Kamari

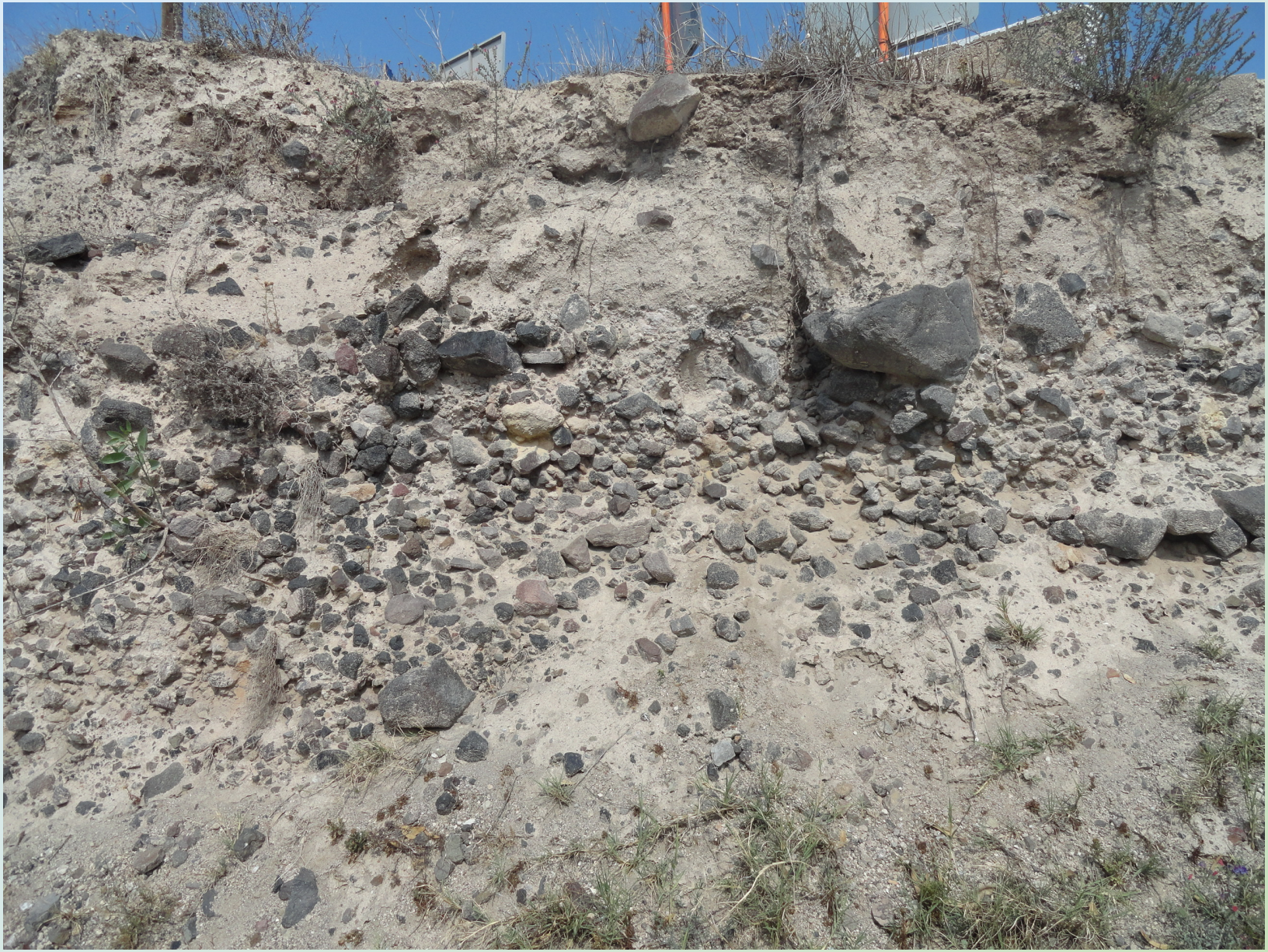
Red Beach outcrop Akrotiri

Pumiceous Minoan tuff with included rock fragments

Blocky pumiceous Minoan tuff

Blocky Minoan tuff with lapilli layer

Pyroclastic flow with large rock fragments - Akrotiri



Rhyodacite flow overlying thick layers of pyroclastics

Rhyodacite flow interbedded with pyroclastics

Layered pyroclastic and lava flows edge of caldera

Therasia shield

- Rhyodacite Lava flows and pyroclastic layers below Minoan tuff formed 55-22ka
- underlying the shield rocks are ancient pyroclastic deposits
- overlying shield rocks are white Minoan tuff deposits

Santorini geomorphology

- Island of Thera (Santorini) crescent shaped furthest east of island group
- island's west edge formed by a steep, rocky caldera wall
- west coast plunges into a caldera body of water ~80km^2
- cliffs surrounding caldera range in height 150-300m → consist of horizontal, parallel bands of red and black rock and lava (repeated pre-Minoan eruptions)
- landscape on eastern side of Thera very much different → limestone massifs, highest mountain Mt Profitis Ilias

Caldera wall - Fira

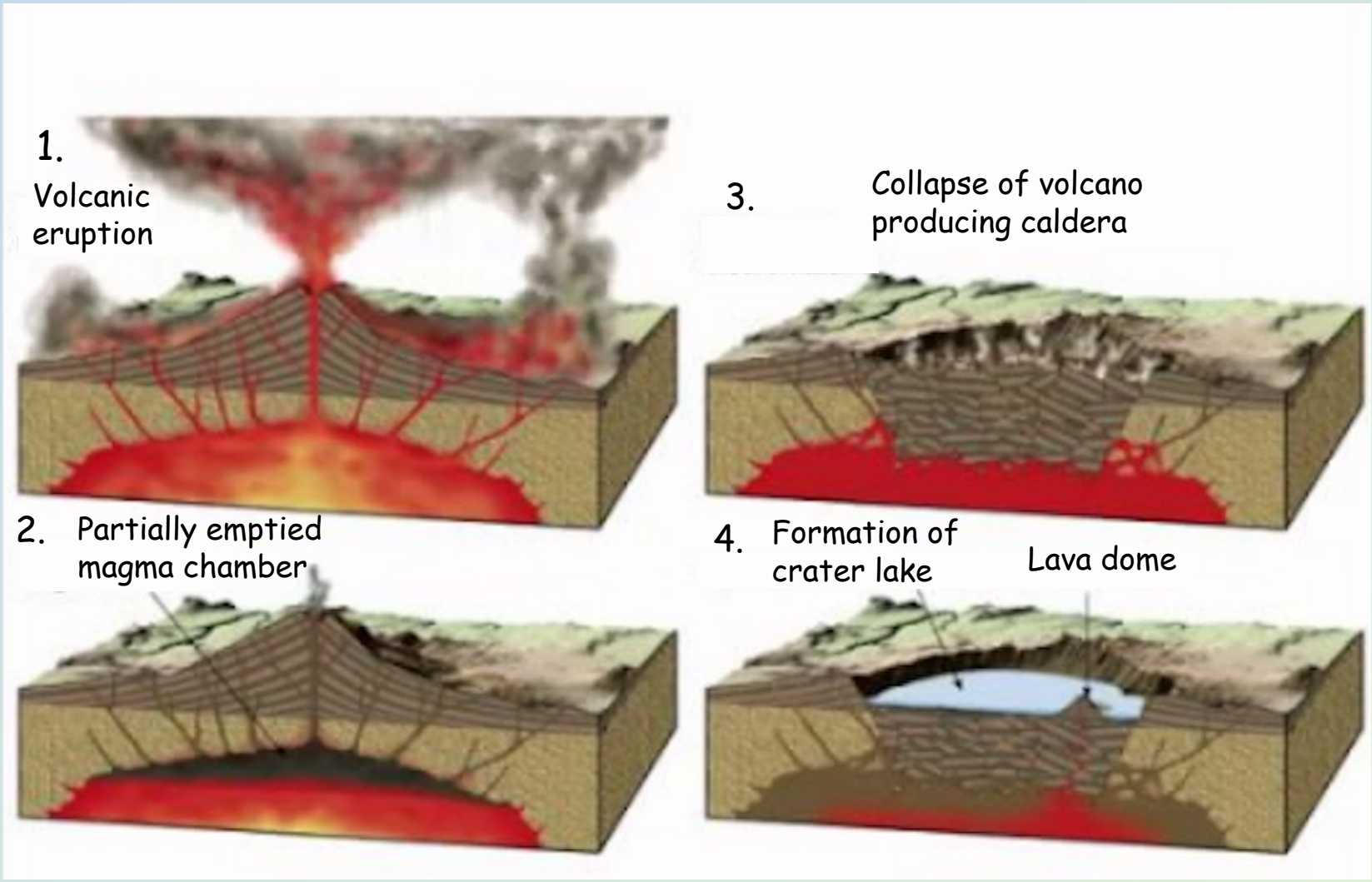
Caldera wall - Fira

Mt Profitis Ilias

Caldera formation

- Caldera begins to form when a chamber of gas-rich magma begins to move upwards towards the surface directly below a volcano
- magma's high concentration of dissolved gases increases pressure inside chamber until it exceeds confining pressure of overlying rock
- when roof of chamber ruptures → magma bursts out in most violent explosion known → caldera eruption
- eruptions empty magma chamber in matter of days or weeks
- roof of chamber collapses into cavity leaving a giant depression → caldera

Caldera formation



Large calderas

- The largest, most violent and catastrophic eruptions
- extremely violent, gas-rich rhyolite magmas
- produced by collapse over a large magma chamber
- may be tens of kilometers across
- products are pumice and ash moving as very fast ash flows
- resulting rocks are ignimbrites – welded tuffs

Lake Taupo – North Island NZ

Crater Lake and Wizard Island - Oregon

Ancient Geological history (1)

- Santorini archipelago began ~2Ma during the Pleistocene period
- the Aegean sea did not exist at that time
- entire area of what is now sea was a a single landmass called *Aegis*
- during this period, Aegis began sinking → some parts covered by water other parts exposed above sea level
- this is how the Cyclades were formed

Ancient Geological history (2)

- Also ~2Ma the first craters started to form SW of Mt Profitis Ilias
- over time, the craters broke through to form what is now Akrotiri
- later craters formed in the north of the existing island
- volcanic craters began to fuse together to form a single island called Strongyle (round one)
- scientists have concluded that Strongyle was a volcanic cone, height ~1000m above sea level, diameter 14-15km

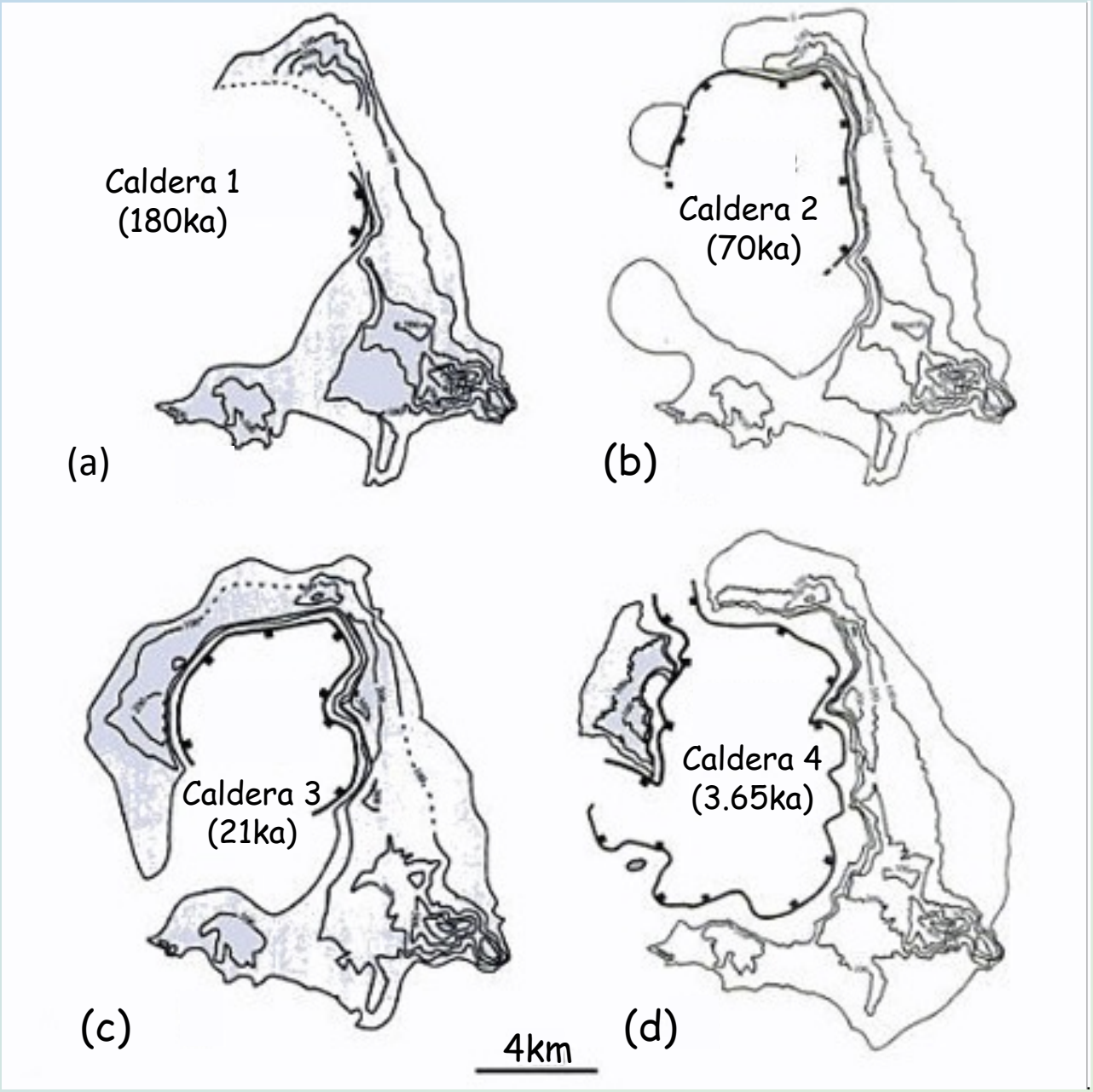
Pre-Minoan Geological history

- Santorini did not begin as a volcano, its basement rocks consist of Mesozoic and Cenozoic marble and phyllite
- geologists think that ~200,000 years ago, Thera began to release immeasurable quantities of magma in a chamber below Mt Thera
- explosive phenomena of the release occurred over the next 200,000 years forming deepening calderas
- present day caldera is composed of overlapping shield volcanoes cut by at least 4 overlapping calderas
- the current caldera formed ~3650 years BP during the Minoan eruption

Pre-Minoan Geological history

- Geological evidence shows that the Thera volcano erupted at least 4 times over several thousand years before Minoan eruption
- in repeated process, the volcano would erupt violently, then collapse into circular caldera filled with sea water with small islands circling the caldera
- caldera would slowly fill with magma, building new volcano that erupted then collapsed in ongoing cyclical process
- prior to Minoan eruption, walls of caldera formed nearly continuous ring with the entrance between Thera and Aspronisi

Santorini caldera evolution



Minoan eruption

- Earthquakes were always a common occurrence in the region
- it is thought that a catastrophic earthquake triggered the eruption partly destroying buildings
- magnitude of eruption difficult to estimate → majority of products deposited in the sea
- estimated volume expelled during eruption → 28-41km^3
- eruption comparable to eruptions of Mt Tambora (1815), Mt Samalas (1257) and Taupo (230CE)

Volcanology

- Eruption was of ultra-Plinian type resulting in estimated high 30-35km high eruption columns
- magma underlying the volcano came into contact with shallow marine embayment → phreatomagmatic blasts
- thriving city of Akrotiri on southern Thera → buried under thick pile of ash like Pompeii
- ash layers in cores drilled into the seabed and from lakes in Turkey show heaviest falls were in the east and northeast
- heavier ash deposits in the east attributed to westerly winds → consistent with summer climate

Minoan eruption sequence

- On Santorini a 60m thick white tephra layer overlies the soil, the layer has distinct bands indicating various stages of eruption
- four major stages and one minor precursory stage are identified
- thinness of first ash layer with no notable erosion suggests volcano gave local population a few months warning
- since no human remains have been found at Akrotiri, preliminary volcanic activity caused island's population to leave before major eruptions
- eruption caused formation of conical volcanic island that grew steadily → rose above sea level

Minoan eruption sequence (2)

- Intense magmatic activity of first major phase deposited up to 7m of pumice and ash with minor lithic component
- second and third phases involved pyroclastic surges and lava fountaining. Possible generation of tsunamis (?)
- fourth and final phase marked by various activity → lithic-rich base surge deposits, lava flows, lahar floods and ignimbrite formation ash deposits
- final phase characterised by completion of caldera collapse, megatsunamis

Minoan tuff Mavromatis pumice quarry Thera

Result of Minoan eruption

- Material ejected from magma chamber created large void → central part of Strongyle was sucked down into vacuum
- 80km^2 of surface area disappeared into a caldera of ~800m depth
- sea inundated what was once dry land → formed large lagoon
- for days on end, darkness turned day into night
- volcanic gases in atmosphere → global temperature drop of 3°C for up to 3 years
- volcanic ash that spread forward must have covered a wide area

Effect on Minoan civilisation

- After initial eruption most residents appear to have abandoned the island in panic
- evidence for a few residents remaining → who fled before main eruption (scavengers)
- archaeological evidence revealed few objects (no jewellery) and no animals (except one pig) or human remains → unlike Pompeii
- huge chunks of basalt thrown from crater with such force → damaged buildings
- the whole island was buried under a thick layer of tuff in many places >30m thick, up to 60m thick

Archaeological excavation Akrotiri

Summary of Minoan eruption

- Probably the largest eruption in human history
- in matter of hours or days → volcano discharged several km^3 of gas-charged magma → entered sea as pyroclastic material
- tephra, aerosols and rock debris blanketed the town of Akrotiri and in a matter of hours the whole east Mediterranean region
- ensuing tsunami (at least 9m high) travelled as far as the northern coast of Crete ~110km away
- eruption led to decline of Minoan civilization, dominant civilization in the Mediterranean at the time

Post-Minoan eruption volcanic history

- Between ~1627BCE and 1950, the volcano on Santorini was active on 14 occasions with varying degrees of intensity
- the first volcanic island to form after the Minoan eruption was in 197BCE and led to the formation of the island, Palea Kameni in the centre of the caldera
- in 1573 fresh sections of dry ground appeared, forming the small island of Mikri Kameni

Kameni islands

- The Kameni Islands are a sub-aerial expression of a $4km^3$ lava shield, height 470m above the sea floor
- historical eruptions of Palea Kameni and Nea Kameni shaped the morphology of the present day volcano inside the flooded caldera
- magmatic vents on both islands lie within NE-SW volcanotectonic line → Kameni line → controls magma ascent in region
- Kameni islands have been defined by 9 sub-aerial eruptions
- every eruptive event formed lava flows, lava domes, blocky lava, ash plume, ballistic ejecta and undersea pillow lavas

Kameni islands

Eruptive events, Kameni Islands

197BCE

46-47CE

726CE

1570-73

1707-11

1866-1870

1925-28

1939-41

1950

Volcanic island Palea Kameni

Palea Kameni

- First of Kameni islands to form after Minoan eruption
- began to form 197BCE . Break up occurred 1457-8

Volcanic island Nea Kameni

- Larger of the two volcanic islands within the caldera
- height of summit 127m above sea level
- hot springs present in sea adjacent to Nea Kameni

Rhyodacite outcrop – Nea Kameni

Hot springs in sea – Nea Kameni

Palea Kameni: the eruption of 46-47CE

- Towards the end of 46CE the volcano became active again
- large volumes of magma spouted out of the sea 2km SW of Thera, enlarging Palea Kameni
- at the time, the circumference of Palea Kameni was 5,500m
- Palea Kameni gradually acquired its shape through fragmentation, by great cracks and partial collapse of shoreline

Palea Kameni: the eruption of 726CE

- Over the next 7 centuries the volcano was dormant
- it erupted violently again in 726AD
- numerous explosive events spewed pumice and volcanic ash several km into the air sending it drifting across the Aegean sea into Asia Minor
- viscous magma that later filled the crater appears now as a black tongue of lava with scoriaceous surface on NE shores of Palea Kameni

The 1570-73 eruption

From 1570 until about 1573 a new small island formed in the sea approximately 4km NE of Palea Kameni, it was given the name Mikri Kameni

The appearance of Nea Kameni 1707-11

- A large eruption in 1707 created two small islands that joined Mikri Kameni → formed Nea Kameni
- eruptions of 1707-11 inside the caldera were of interest → one of rare occasions when a volcano was observed emerging from sea
- 3 days after a large earthquake in May 1711, a white island arose W of Mikri Kameni
- island was composed of pumice and black lava → reached diameter of 500-600m and height of 70-80m
- two weeks later fire appeared and a black island emerged in the N

The eruption of 1866-70

- Eruption of 1866-70 caused the smaller island of Mikri Kameni to join the larger Nea Kameni
- the eruption produced columns of smoke visible from Crete and resulted in destruction of 50 summer houses and 2 small chapels
- the eruption occurred over several stages → tripling the size of Nea Kameni
- in February 1866 the volcanic cone of Georgios was created as a small island near Nea Kameni
- after a few days it connected to Nea Kameni along with small islands that finally submerged → today 1m below sea level

The eruption of 1866-70 (2)

- Black island was so large that it united with white island
- by the time volcanic activity ceased in September 1711, Thera and Mikri Kameni had sunk by a metre or more
- new-shaped island → Nea Kameni measured 900m long in the S, 1650m in the W, 1440m in the E, reached height of 106m

20th century eruptions

- The volcano became active in summer 1925 and continued until 1928
- a small island emerged between Mikri Kameni and Nea Kameni → joined to form present Nea Kameni
- Nea Kameni obtained its present shape during the 1939-41 eruption
- the last eruption of Nea Kameni occurred in 1950 and fumarolic activity takes place in some present craters
- small changes occurred through water erosion in the 1950 eruption

Kameni islands volcanism
(Holness et al 2005)