ANATOMY *of an* ERUPTION

How a Terrifying Series of Explosions Reshaped the Minoan Island of Thera.

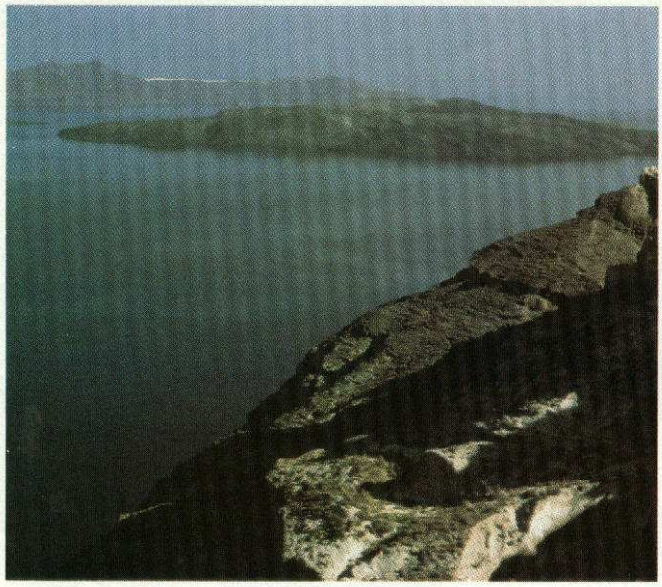
by Floyd W. McCoy and Grant Heiken

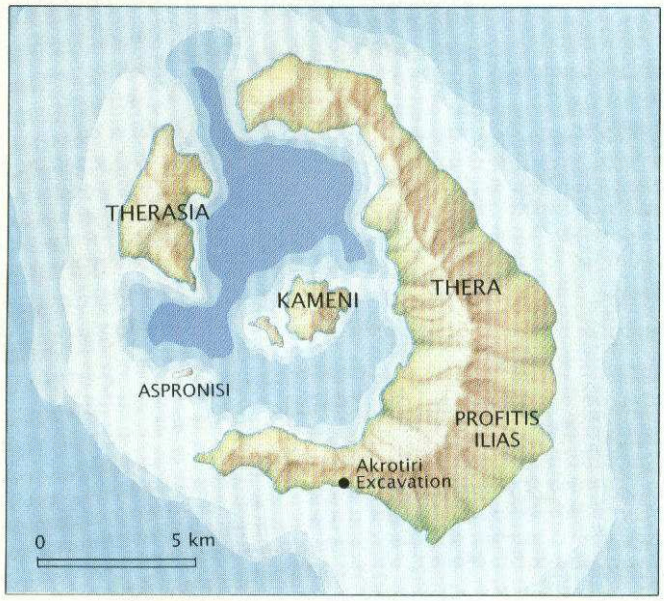
MINOAN CRETE was the pride of the Aegean world at the opening of the Late Bronze Age (seventeenth through mid-fifteenth century B.C.). From key administrative centers like Knossos and Mallia on the north coast and Phaistos with the nearby harbor town of Kommos in the south, Minoan influence and trade extended in all directions—to Egypt, the Levant, and Cyprus to the south and east, but especially to the north and the Aegean islands. Excavations at Ayia Irini, on the island of Keos off the coast of Attica, and at Phylakopi on Melos have revealed settlements with close ties to Minoan culture. The emerging Mycenaean society on the Greek mainland was also strongly influenced by Crete. Kastri on the island of Kythera and Triandha on Rhodes may well have been Minoan colonies. Akrotiri on the volcanic island of Thera, or Santorini, in the southern Aegean was another flourishing Minoan town.

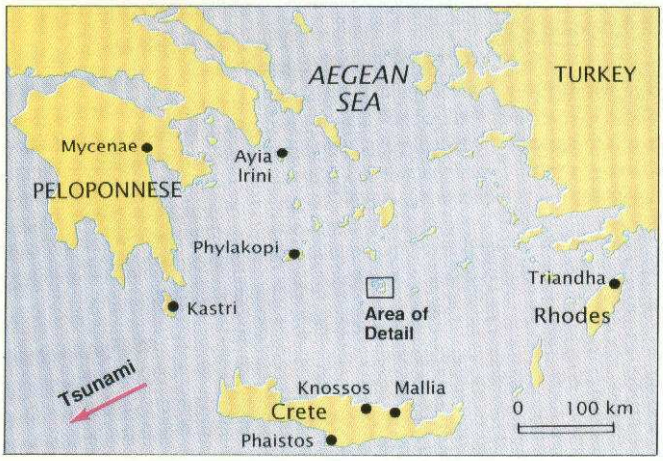
Akrotiri, however, was foredoomed. Like Pompeii

The cliff face at right records phases of the eruption that buried Minoan Thera: pumice of the first phase accumulated here to the height of a man; sweeping beds characterize second phase deposits; darker gray third phase deposits are above.

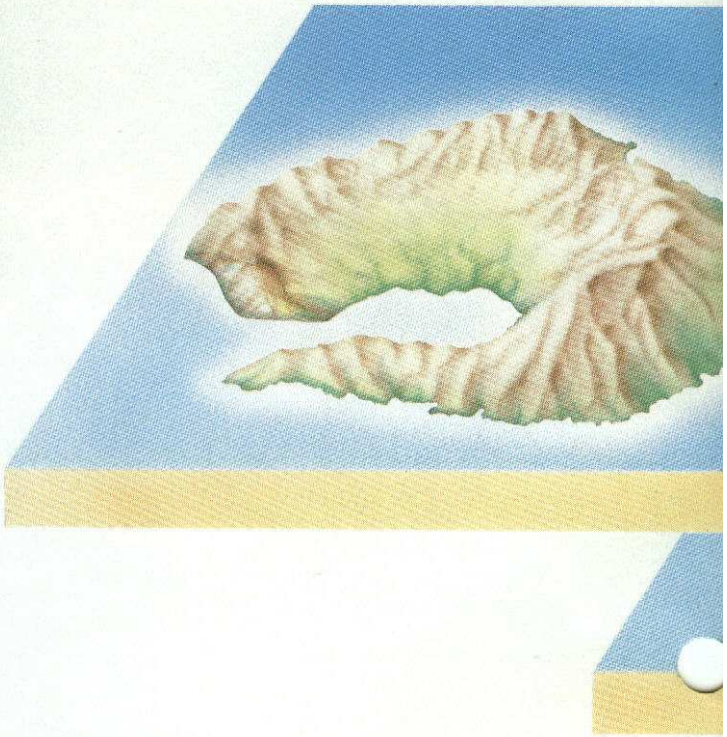
courtesy Floyd W. McCoy







Located on a geologic hot spot, modern Thera and neighboring Aspronisi and Therasia, created during the Late Bronze Age eruption, surround the Kameni Islands, the product of more recent volcanic activity (at top, the Kameni Islands as seen from Thera). While the eruption reshaped Thera, its effects on Minoan civilization remain a matter of debate.

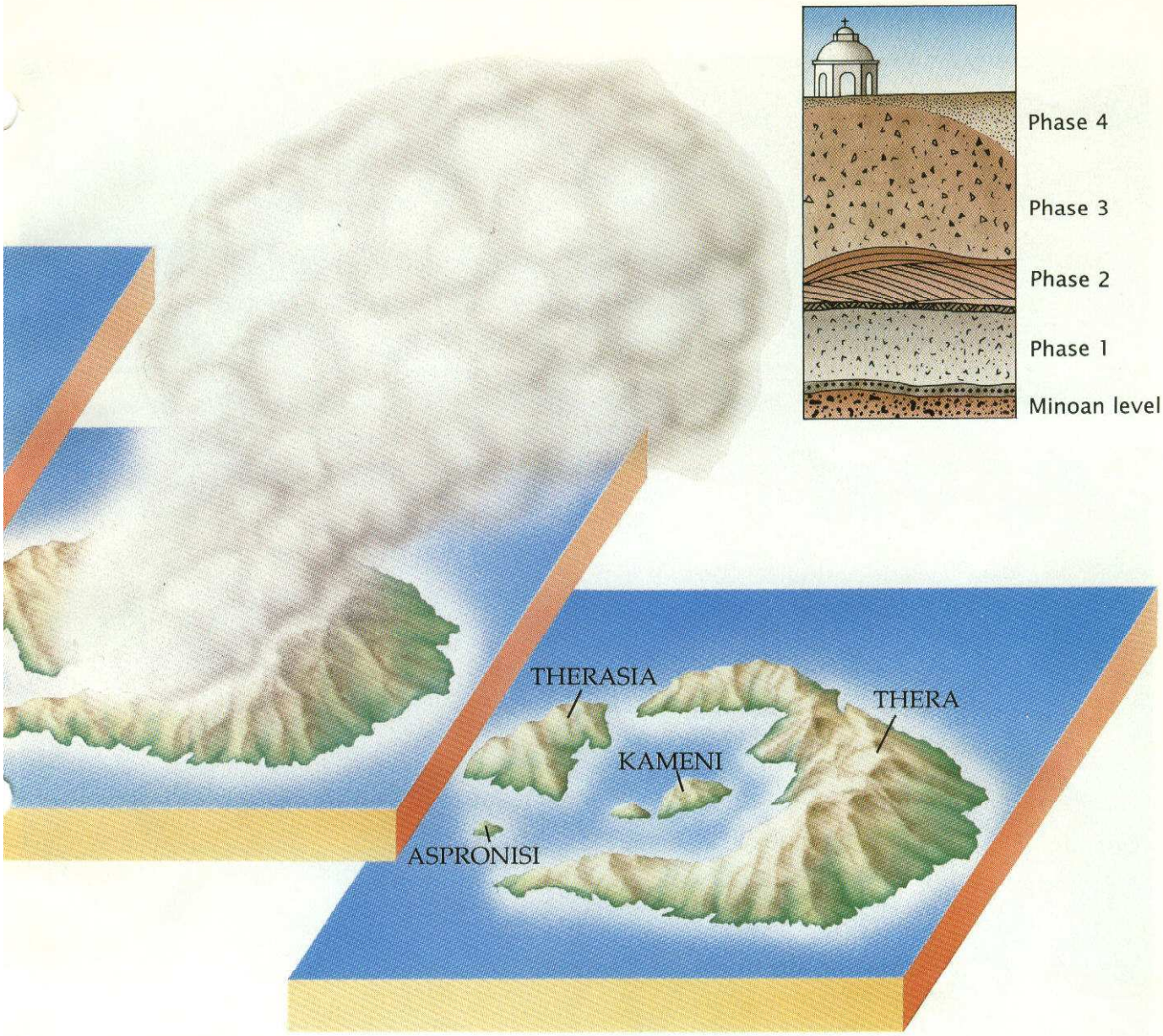


Four major phases of the eruption, top, have been distinguished by geologists. Before the eruption a broad low plain, or perhaps an island, occupied the northern portion of the modern bay, left. The collapse of this area and the land linking Aspronisi, Therasia, and Thera produced the geography seen today, right. The volcano remains active, as attested by the Kameni Islands.

some 1,700 years later, it would be destroyed by a massive volcanic eruption. The magnitude of that eruption, likened to the devastating explosion of Krakatoa off western Java in 1883, has been the subject of intense scrutiny by both archaeologists and geologists. Akrotiri, of course, was never reoccupied, and some scholars have speculated that its destruction spawned the legend of the lost continent of Atlantis. Romantic visionaries have even tried to link the eruption to ancient events such as the parting of the Red Sea during the Exodus and with the Ten Plagues in Egypt.

What was the effect of the eruption on Minoan civilization? Some have suggested that it created a major catastrophe for Minoan Crete—earthquakes and tidal waves destroying sites, ash burying and killing crops.

courtesy Floyd W. M

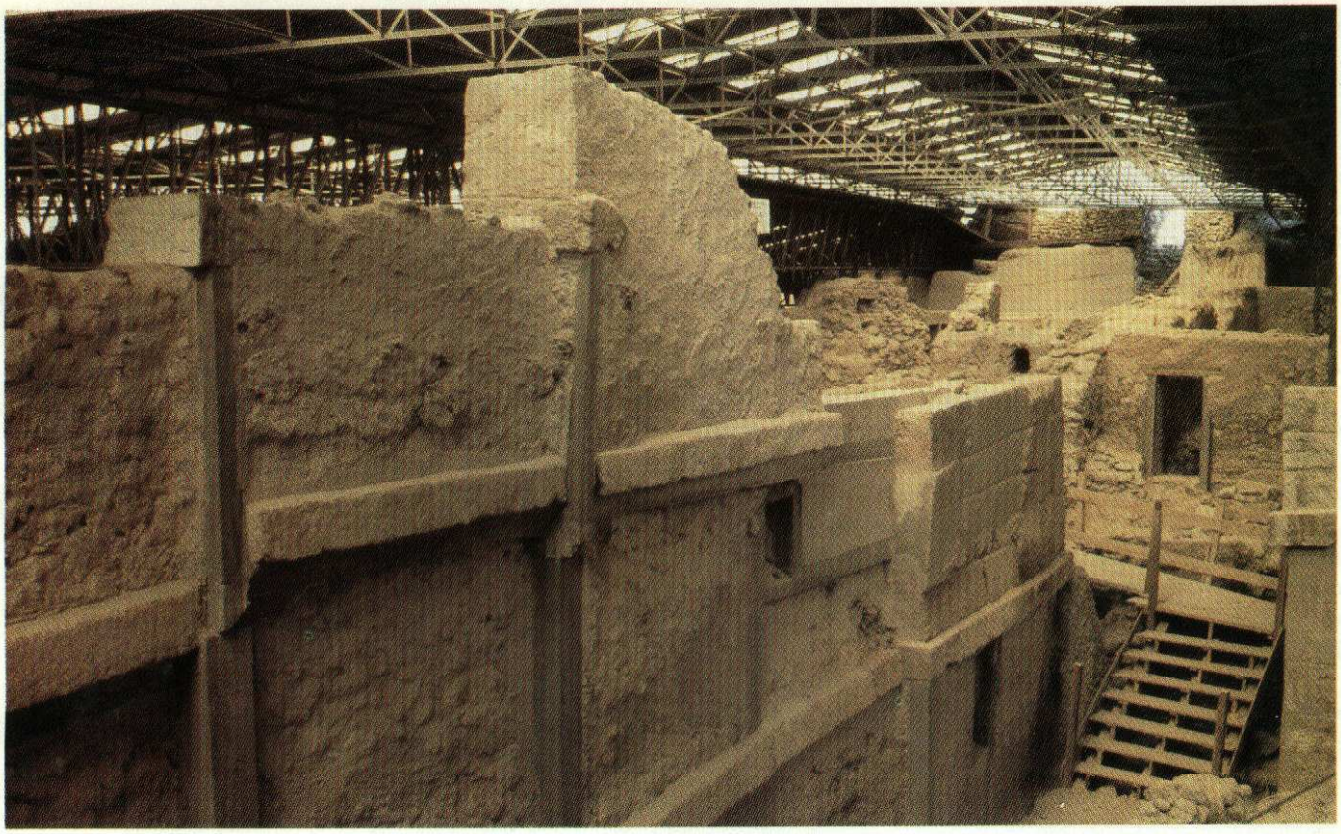


Other scholars believe the blast had little effect outside Akrotiri, a view to which we now subscribe, particularly concerning the effects of the ash fall—research continues on the effects produced by earthquakes, tsunamis, and climate perturbations, all of which could have been significant. What we can now reconstruct with some certainty are the events of the final days of Thera, the island's geography in Minoan times, and the aftermath of that cataclysmic eruption.

In the fall of 1628 B.C., what might have been another bright day on Thera was darkened by falling ash. The rain of cold gritty particles followed months of unusual and unaccountable phenomena: low-intensity earthquakes, larger tremors, landslides, and variations in the flow of hot springs. Now the ash was ankle-deep on the south coast at Akrotiri. It was time to go; the island's inhabitants were leaving, taking with them anything of value they could carry.

One of the largest volcanic eruptions in recorded history had started. A mile or more beneath Thera, viscous magma was rising to the surface, following conduits of older eruptions. Although a new phenomenon to the Minoans, volcanic activity had been the dominant theme in the geologic history of the island for more than 100,000 years. At least seven major eruptions are known to have taken place, the last some 16,000 years before, each leaving distinctive deposits of ash and lava—the multicolored stratigraphy so spectacularly displayed in the island's seaside cliffs.

Hours after the departure of the Minoans, the earth's



Gracefully painted antelopes are among the many frescoes recovered during the excavations at Akrotiri. After its inhabitants fled, the pumice fall of the first major eruption phase buried the Minoan town, above, and preserved it.

crust gave way beneath Thera. The consequent release of pressure freed dissolved gasses in the magma, much like uncorked champagne. The molten rock frothed, magma rose explosively. When the magma hit seawater, it became even more explosive. A major eruption was in progress, and the Minoan island was being reshaped just as it had been so often in the past.

Far beneath the Aegean, the geologic plates bearing the continents of Africa and Europe collide, creating volatile conditions on the surface. The northern edge of the African plate, overriden by the European plate, is forced downward until, at a depth of 50 to 75 miles, the rock melts. This molten rock then rises to collect in the shallow subsurface and later erupts at the surface; Thera sits on top of just such a geologic hot spot. How often and with what frequency these eruptions occur remains unknown. The events of the Late Bronze Age described above, however, are typical of the activity immediately preceding such an eruption.

Minoan artifacts beneath ash levels on the adjacent islet of Therasia, discovered during pumice quarrying for construction of the Suez canal in the mid-nineteenth century, first attracted the attention of a local physician. This discovery led to the first detailed examination of Thera's stratigraphy by a French geologist, Ferdinand André Fouqué, in 1879. Today, geologists have identified the ash from Thera throughout the Aegean and Mediterranean seas, on many of the surrounding islands, in lakes in Turkey, and as far away as the Nile Delta. Archaeologists have identified the ash at sites on Thera, Crete, and Rhodes. The regional extent of this ash is dramatic documentation of the enormous impact the volcanic event had on the Late Bronze Age world.

We have restudied Thera, and the adjacent islets of Therasia and Aspronisi, applying new knowledge from studies of large, caldera-forming eruptions elsewhere in the world. This has led to a better understanding of the Late Bronze Age event sequence and an interpretation of what the island looked like before the eruption.

In common with many other large explosive eruptions, the event on Thera progressed in four major stages, preceded by a minor precursor eruption. In the course of this precursor activity, ash was dispersed to the south over a small area of Thera leaving four distinct thin layers, each about a half inch thick. This suggests that four small eruptions of fine gray ash occurred, probably prompting the Minoans to leave. These steam-rich plumes of ash probably rose only a few hundred yards for a few hours each, a spectacular sight to any Minoans remaining in the vicinity.

An enormous plume charged with pumice and ash, rising perhaps 17 miles, well into the stratosphere, marked the first major phase of the eruption. It must have begun shortly after the precursor activity stopped, because there is no indication that wind or rain had time to erode the uppermost surface of the precursor ash layers. The gigantic plume deposited four-inch diameter chunks of pumice (frothy volcanic glass that can float on water) in layers up to six yards thick on Thera and Therasia. Variations in the intensity of this explosive activity

produced faint layering in the deepening deposit.

Vast rafts of pumice produced during this stage of the eruption apparently drifted throughout the Aegean and eastern Mediterranean to accumulate on the beaches of Melos, Cyprus, Turkey, Israel, and Egypt. The finer-sized ash was dispersed to the south and east by stratospheric winds to blanket a wide area: about two inches fell on eastern Crete, as much as 12 inches were deposited on Kos, up to three feet accumulated on Rhodes, and it settled in the seawater leaving a submarine layer as much as a yard thick in the Aegean and inches thick in the eastern Mediterranean.

All in all, it was a gritty mess for Minoans living downwind of Thera, such as those on Crete. But it was a mess that was largely an inconvenience, not unlike the results of the Mount St. Helens eruption in 1981. At Akrotiri on Thera, it was a different matter. The buildings and walls of the town were buried under pumice and ash from the first phase. This was more an entombment than leveling, and structural damage was largely limited to collapsed roofs and walls.

Then a dramatic change in the character of the eruption took place, signaling the start of the second phase as seawater poured into the vent, reacting violently with the rising magma. The result was steam blasts that produced towering plumes so densely laden with volcanic debris that they periodically collapsed, sending repeated flows of ash, pumice, and steam surging away at high speed from the vent at ground level. While the pumice fell during the first phase in horizontal layers, like snow draped over the countryside, the second stage phreatomagmatic surges, as they are termed, left a different signature: sweeping dunelike and rippled beds. The transition between the first and second stages of the main eruption was abrupt, and this is reflected in the sharp boundary between the deposits with no indication of erosion.

These flows were particularly destructive, and their violent nature is particularly evident at Akrotiri. None of the town's structures is preserved in the surge deposits—portions of buildings and walls not buried in the pumice-fall deposits of the first phase were leveled by the violent surges of the second phase. More than just a frightening spectacle, anyone on the island or within several miles of the shore would have been killed instantly by these surges, which can flow over water for short distances.

Transition into the third eruptive phase was gradual. The border between the deposits from the second and third phases is often indistinct, noticeable only by the disappearance of dunelike beds. The deposits left by the third phase are the thickest of the succession, up to 56 yards deep, a heterogeneous mixture of ash, pumice, and large rock fragments.

How this massive third phase level was deposited is still a mystery. Layers beneath many of the large lithic blocks indicate that the material was thrown through the air, forming pits upon impact. But the types of rock represented by the blocks are the same as those found in lava flows that occur on present-day Therasia and in the northern part of Thera, and there is evidence for localized volcanic mud flows. Whatever the means of deposition, geophysical evidence indicates the material was deposited at much lower temperatures than during the first and second phases.

The fourth and last eruptive phase consisted of ground-hugging, hot, gaseous clouds containing ash and small lithic pieces that chilled and thickened at the shoreline—forming the present-day coastal plains along most of Thera, especially near the airport and Akrotiri, and along northern and western Therasia. The phase left thin deposits (about a yard thick) near the caldera, but considerably deeper (up to 40 yards) along coastal areas. Locally, eroded surfaces between the third and fourth phase deposits indicate brief rainstorms probably concurrent with eruptive activity.

This was the end of the eruption, a sequence of events that may have lasted for a few days or weeks. To Therans who attempted to return, the sight must have been astounding—the island's shape and topography were changed, steaming white-gray ash and pumice mantled the landscape, and the sea was covered with rafts of floating pumice.

Now that we have a thorough understanding of the eruption sequence, we can attempt to re-create the geography of the pre-eruption island. The bulls-eye pattern of pumice deposits from the first phase of the eruption pinpoints a vent just north of the modern-day Kameni Islands. Since pumice is produced when there is no water reacting with the erupting magma, we know that this vent was located on dry land.

Surges characteristic of the second phase, however, occur when there is explosive interaction with water at the vent, in quantities that implicate seawater. Because the surges flowed away from the source, we can trace that source by following the dunelike structures and rip-

pled surfaces in the deposits. This study suggests that the center of the second phase of the eruption was south of the phase one position; we therefore assume the vent moved south to a new position that was within the sea.

The quantities of lithic fragments from lava flows in the northern portion of the island, and the thickness of the phase three deposit, suggest a large volume of erupted debris, expelled by the collapse that formed the modern-day caldera north of the Kameni Islands. Phase four was the final degassing of the magma, carrying with it whatever solid ash and lithic fragments were left in the vent.

Like today, Thera had a central bay surrounded by steep slopes and cliffs of spectacular beauty. During the Late Bronze Age, however, an extensive land mass existed in what is now the northern sector of the bay. We are not certain whether this was a broad low plain or a large island. Before the eruption, the central bay was open to the sea through the channel that exists today between Akrotiri peninsula and Aspronisi Island. The other two channels in today's topography (between Aspronisi and Therasia and between Therasia and Thera) were created by collapse during the volcanic activity, most likely in the third phase. The collapse of the channel between Aspronisi and Therasia islands produced the major tsunami (seismic sea-wave), which traveled out toward the southwest passing between Crete and the Greek mainland. For this we have deep-sea evidence of redeposited muds stirred by the passage of the tsunami, and suggests minimal tsunami effects toward the eastern Mediterranean region.

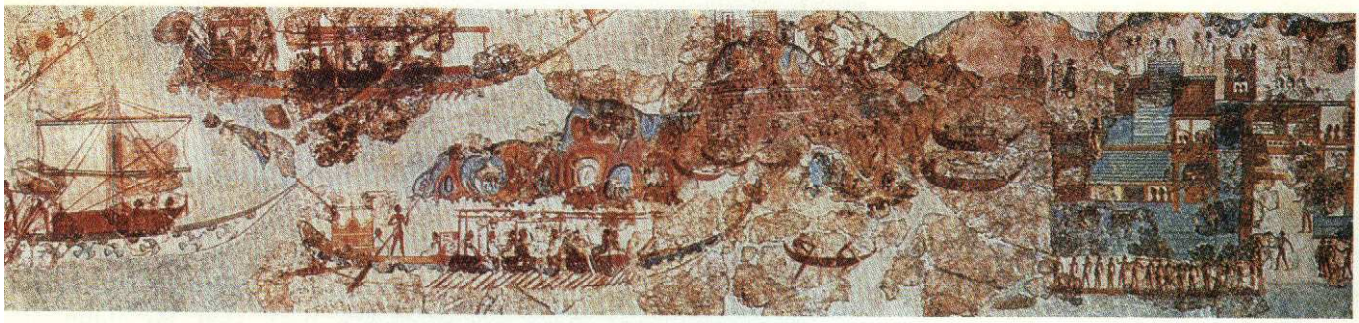
Thera never had a lofty, central, conical peak that collapsed to form the bay we see today. At least two overlapping calderas—an older one to the south, and the Late Bronze Age caldera to the north (they are topographically distinct below sea level)—form today's huge depression that is flooded by the sea. Small eruptions of lava from Roman times up until 1950 have formed the Kameni Islands, which lie along the common boundary of the two calderas.

Corroborating field evidence for our interpretation comes from numerous patches of Late Bronze Age volcanic debris mantling slopes that face inward toward the present-day depression—remnants of pre-Late Bronze Age eruption caldera walls that formed steep slopes during Minoan times.

What shaped this earlier caldera, which could have served the Minoans as a harbor? Exposed in the cliffs of Thera, well below the Late Bronze Age eruptive deposits, are two distinct white bands of ash and pumice produced by large explosive eruptions about 100,000 years ago, both as big as the Late Bronze Age eruption. Collapse associated with these older eruptions probably formed the southern caldera. Preservation of the caldera and its surrounding steep slopes for 100,000 years is not surprising, considering the slow rates of erosion and slope modification processes in the Mediterranean climate.

Much discussion has been concerned with the effects of the ash on Crete. By extrapolating from the deep-sea record, we feel that about two inches of ash were deposited on the central-eastern part of the island, certainly not enough to cause damage to crops or buildings, and quickly eroded or mixed into soils.

It would be nice to have some supporting evidence for our interpretation of the pre-eruptive geography of Thera, perhaps a snapshot left by the Minoans. We suggest that this may exist in the famous marine fresco of the ship procession found in the excavation at Akrotiri (West House, room 5, south wall). Perhaps the town and countryside depicted on the island at the left edge of the fresco is the southern part of the bay with either a stream running off surrounding highlands or a waterway around the town; in the background are high ridges and hills much like today (Profitis Ilias) that mark the older caldera wall; Akrotiri peninsula could be on the right depicted much as it looks today in terms of topography and color. Clearly there is much conjecture here, but the Minoans were depicting a landscape that existed prior to the eruption.



A fresco from Akrotiri may preserve a "snapshot" of Minoan Thera before the island was devastated by the Late Bronze Age eruption of ca. 1628 B.C.

How often do these huge eruptions occur? This is a major subject of volcanological research and no answer can be given. On Thera the timing varies between perhaps only a few thousand years to 16,000 years, the span between the last pre-Late Bronze Age explosive event that produced a caldera and the Minoan eruption. When will the next occur? It's hard to say, but when it does it will be just as dramatic as the eruption witnessed by the Minoans. We leave for others the problem of what became of the Therans, forced to flee their island home and seek refuge on Crete, other Aegean islands, or the mainland. ■