Klontza-Jaklová, Věra

Introduction

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1. INTRODUCTION

1.1 The Santorini archipelago

1.1.1 Geographic and geological overview

The group of islands and islets around Santorini (Fig. 1), circa 120km North of Heraklion, belongs to the Cyclades and comprises a main island and four adjacent smaller uninhabited islets, together with three further islets of volcanic origin, which lie southwest of and at some distance from the main group. The largest main island, also called the ring island, has an area of 76.2km². The main island and some of the islets once connected to it were formed on a base of sedimentary limestone (also containing metamorphed limestone, such as phylite, and volcanic rocks) and were created circa 120k years ago, when the sediments were deformed and lifted up by the Alpine orogeny. (McBirney 2009, 68; McCoy 2017). Today the main body of the island consists of volcanic materials which were piled high by numerous eruptions. Circa 12 Plinian eruptions, during the last 120k years, have been recognized within the volcanic strata (McCoy 2009, 76, Fig. 3).

The highest point of the island is Agios Profitis[2], which is 565 m above sea level (Fig. 2). Other peaks include Megalo Vouno[3] (330 m asl), Mesa Vouno (369 m asl, Fig. 3), Mikros Profitis Elias[4] (314 m asl) and Kokkino Vouno[5] (283 m asl). These (except Agios Proftis and Megalo Vouno) are volcanic cones and were created by deposits of lava and ash.

Based on the latest census in 2011 the island had 15,550 inhabitants.

The islet of Therasia, which, until the Bronze Age eruption, might be connected with the main island, was abandoned after the eruption and earthquake of 1956.

The small islet of Aspronisi[6] was formed from the white pumice of the Bronze Age eruption and its highest point is 60 m above sea level. (Fig. 1, 4, 5).

These three islets lie around a central basin, known as the caldera, which is up to 400 m deep and 84km² in area. The caldera is shaped by four depressions.

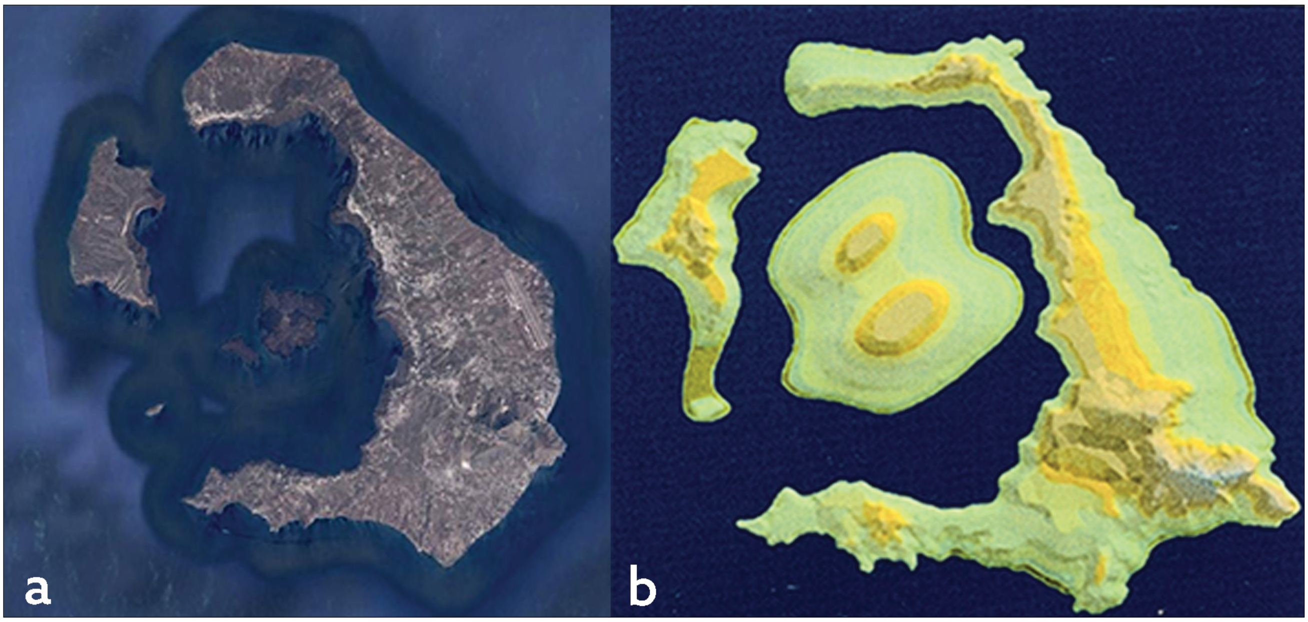

Fig. 1 / Santorini: a) contemporary shape of the island, b) reconstructed island's shape before the Minoan eruption. (Illustration by author after McCoy 2009; 2017.)

Fig. 2 / Agios Profitis. (Photo by author)

Fig. 3 / Mesa Vouno. (Photo by author)

Fig. 4 / Aspronisi. (Photo by author)

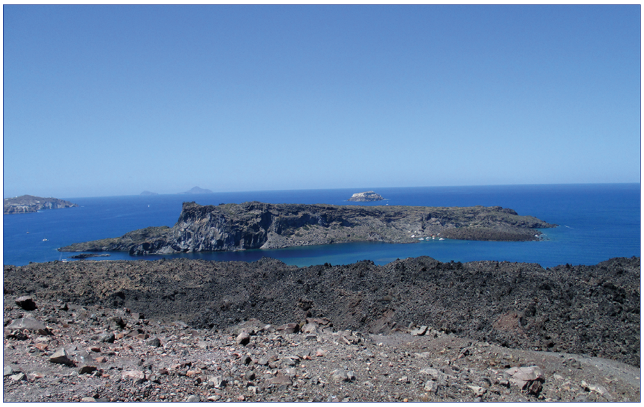

Fig. 5 / View from Nea Kameni to Palea Kameni and Aspronisi. (Photo by author)

Fig. 6 / Cliff of Palea Kameni. (Photo by author)

In the centre of the caldera is Palea Kameni[7] (Fig. 5, 6), an active volcano, which arose after the Bronze Age eruption. Part of this islet sank in the late Middle Ages. The Church of Saint Nicolas (Fig. 7) was built there, atop layers of lava flows, the latest volcanic layer of the region.

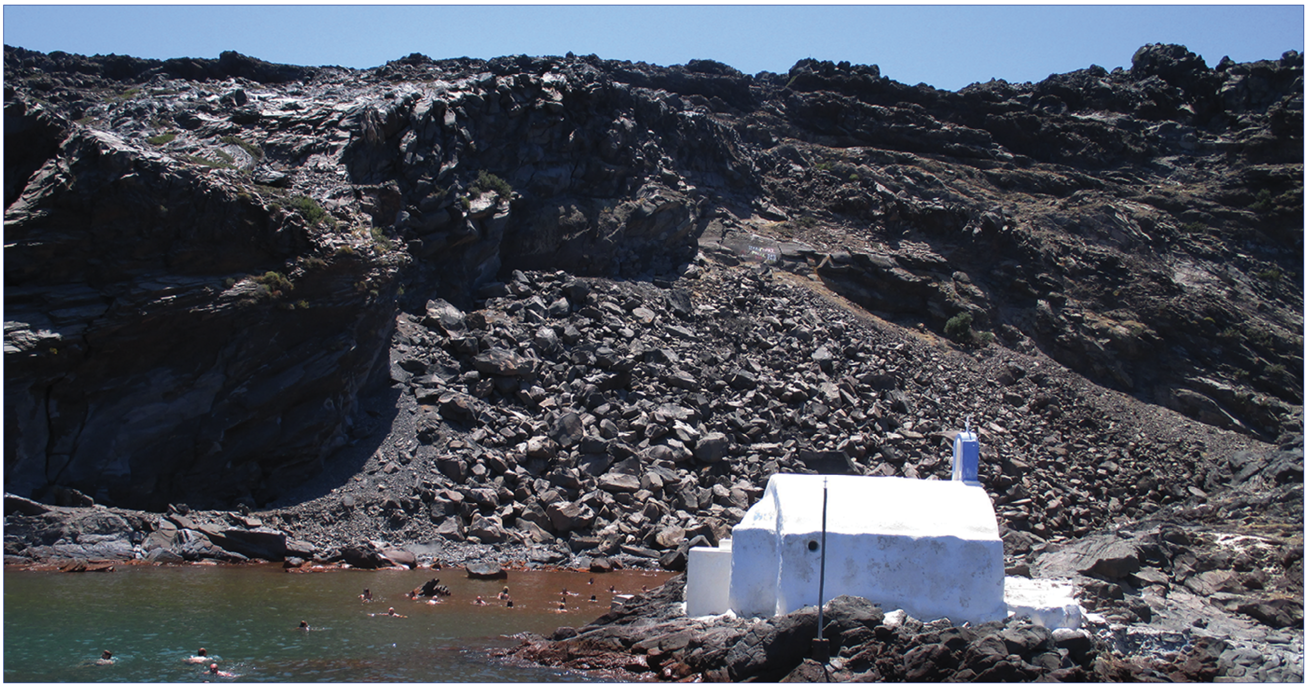

Fig. 7 / Church of St. Nicolas on Palea Kameni. (Photo by author)

Fig. 8 / Nea Kameni. (Photo by author)

The latest formation, adjacent to Palea Kameni and also volcanically active, was created in its contemporary shape by the eruption in 1707 and is called Nea Kameni[8] (Fig. 8). At the summit (124 m above sea level) is the Georgios crater (Fig. 9).

There is an underwater volcano, called Colombo, situated approximately 7–8 km North-East of the main island. Its highest point is 18 m below sea level and it was last active 1649–1650.

Three other islands of volcanic origin, Christiani, Askania and Eschati, are included in the Santorini

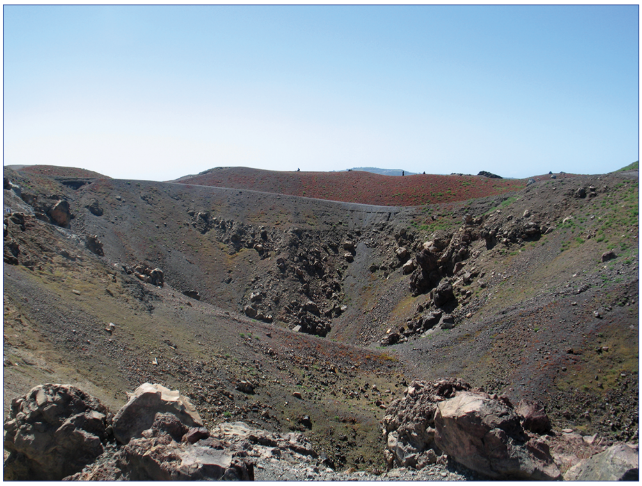

Fig. 9 / Georgios Crater on Nea Kameni. (Photo by author)

group and lie some dozens of kilometers southwest of Palea Kameni.

The entire Santorini archipelago is situated within the Aegean volcanic arc. (Friedrich 2000, 8–29, 2009, 34–49). Santorini itself is a volcano whose volcanism is set in a complex tectonic regime resulting from the collision of two major tectonic plates. As Africa moves northward it converges on the Eurasian continent and plunges at a rate of 5 to 6 cm per year beneath its southern margin. (McBirney 2009, 67) Interaction of three tectonic plates makes Santorini one of the most seismically active zones on Earth. (McCoy 2009, 76; Fig. 10)

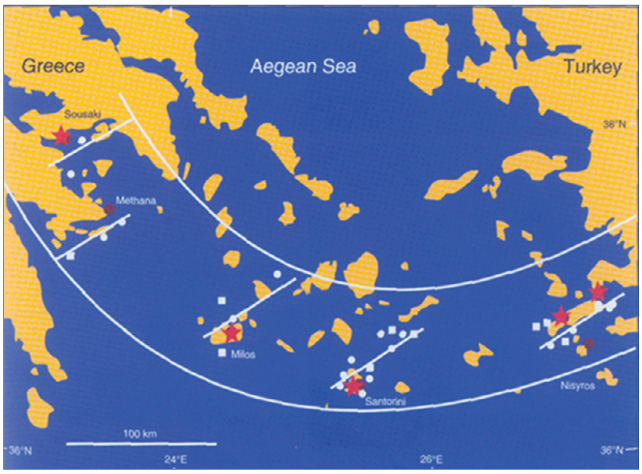

Fig. 10 / Aegean volcanic bow. (After Friedrich 2000, fig. 2.5)

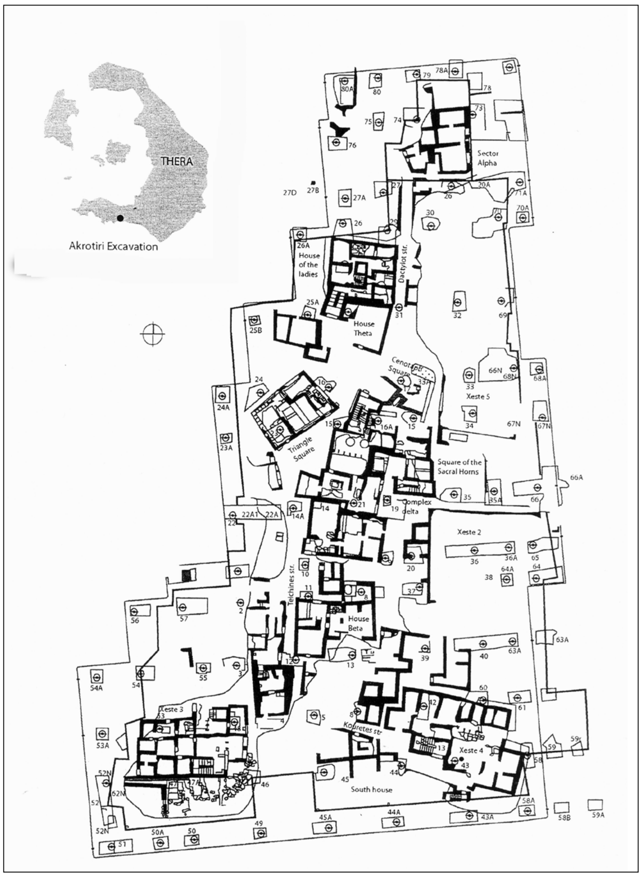

Fig. 11 / Plan of the excavated part of Akrotiri. (After Friedrich and Sigalas 2009, Fig. 9)

1.1.2 Brief history

The archaeology of Santorini has not been widely explored, due to the massive tephra layer sealing the pre-Late Bronze Age habitation, and even today there are not many known and excavated archaeological sites. The island has been inhabited at least since the Early Cycladic period (Friedrich 2009, 173). At the end of Cycladic period it became part of the Minoan cultural sphere and it has been generally accepted that the site of Akrotiri (Fig. 11; 12) was one of the main emporia of the Minoans. After the total catastrophe in LM IA/B the island seems to have been without permanent habitation until the Geometric period. A few Knossian Linear B texts dated to LM IIIA refer to the Qa-ra-si-ja people, who are hypothetically connected with the inhabitants of Thera.

Herodotus mentioned (Hist. IV, 147) that the Phoenicians founded a site on the island but there is no archaeological evidence for it, as far as I know. The first post-eruption inhabitants built their graves during the 9th century BC on the south slopes of Mesa Vouno. They didn't favour the coast and their main settlement was established on the spectacular mountain top of Mesa Vouno (Fig. 13). It is a marble block on the south coast of the main island, 369 m high, close to the highest island's point of Profitis Ellias. Mesa Vouno offers a perfect view covering all the south and east coast of the ring island. The establishment of this city is traditionally connected with the Dorians but probably should be related to the period of intensive connections between the so-called Orient and the Aegean islands, and later the Greek mainland. Geometric pottery of the 9th century BC (Fig. 14) was found mainly in cemeteries around the city. So called public enclosures, connected with the formation of a ruling class and dated to the 7th century B.C., were documented on the slope of Mount Profitis Elias. (Wallace 2010, 301). According to Herodotus (Hist. IV, 149–156), after a drought lasting for seven years, the city of Thera sent out colonists who founded a number of cities in northern Africa, including Cyrene, with Cretans and Rhodians. (Boardman 1990, p. 153–9)

The earliest surviving architecture of the city was dated to the 6th century BC. In that period Thera shows use of Doric dialect and the island claimed the status of a Spartan colony. In the 5th century BC, Spartan political features also appeared in Thera and can be understood as a result of a political alliance of Sparta with the South-West. During the Peloponnesian wars Thera was Sparta's ally against Athens. (Wallace 2010, 373) During the Hellenistic period, the island was a major naval

Fig. 12 / The site of Akrotiri today. (Photo by author)

Fig. 13 / Ancient Thera. (Photo by author)

base of Ptolemaic Egypt. The majority of architectural remains of ancient Thera originate in this period.

Later on, Thera was ruled by Romans and Byzantines. Thera is particularly mentioned in 727, during the reign of Leon III (the Isaurian) when its volcano was active again.

During the Crusades, Thera was captured by Franks[9], renamed Santorini, after Saint Irene, who is reputed to be buried on Therasia, and became part of the Duchy of Naxos.

Santorini was conquered by the Turks in 1579, became independent of Ottoman rule in 1821 during the Greek War of Independence and was later, in 1830, united with Greece, under the terms of the Treaty of London. (Doumas 1996, 67–84; Friedrich 2000, 13–17; Fig. 15)

1.2 Reconstruction of the Santorini Bronze Age eruption

The Bronze Age eruption of the Santorini volcano was probably the strongest volcanic eruption in the last 10,000 years. It impacted not only the geology and geography of the region but the climate of the entire northern hemisphere in both the short and long term. Effectively it changed the course of human history and did so well beyond its immediate neighbourhood. Reconstruction of this event is extremely difficult. Not only was it not reliably described by any ancient sources but eruptions of similar intensity are extremely rare and each eruption is unique. The reconstruction of the main phases, described below, was modelled to accord with the visible stratigraphy of the eruption products and the sequences exhibited by analogous eruptions documented and described in historical periods.

Fig. 14 / Funeral amphorae from the Iron Age cemetery on Mesa Vounos slopes. (Archaeological museum at Fira, photo by author)

The eruptions of Tambora (1815) and Krakatoa (1883) represent the main parallels and reference for the Santorini Bronze Age eruption (Friedrich 2000, 67–68; McCoy 2009, 87–88).

0. – warning phase (the precursor eruption)[10]

Initially quakes of low intensity, and possibly steam rising from the volcano, probably warned the inhabitants of the island that the situation was not normal. Floyd McCoy assumes that the island's *"residents did not know they lived on a volcano, much less one with an extraordinary geologic history of mega-eruptions, because there had been no active volcanism in the southern Aegean region (except for small phreatic eruptions on Nisyros) for hundreds, perhaps thousands, of years before the Bronze Age. Travellers to the west would have been familiar with erupting volcanos in Sicily and mainland Italy but application of that observation to the Aegean as a contemporary hazard rather than as a subject for mythology remains questionable"* (McCoy 2009, 78–79).

On the other hand the mythological memory can keep quite accurate information about such events, even for thousands of years (Barber and Barber 2004, 1–15) and, albeit the habitants didn't have any direct experience, they could still have known what a volcanic eruption is.

Physical indicators of impending eruptions are well known today and they are used for predicting eruptions. Although the inhabitants of the island didn't know what these phenomena preceded, the moment arrived when they evidently ceased to await events passively and realized that evacuation was essential. This means that this phase may have lasted days, weeks, or even a month[11] and could have represented the consequences of active magma intrusion within the volcanic edifice; tremors[12] of high intensity, causing some damage, and clouds of ash and steam ascending from the volcano (McCoy 2009, 78–79). Their increasing intensity convinced them that evacuation would be necessary. There was still time to organize the evacuation, clear evidence for which was found at Akrotiri, the only site so far subjected to extensive excavation. Smaller mobile items, which would normally be found in situ within a destruction layer, had been largely removed from this settlement, where only a few examples remained. Piled up furniture, and larger and heavy vessels (sometimes still containing raw materials) were found placed along the walls and between doors jambs under the lintel. This disposition suggests that the inhabitants had some experience with earthquakes. The people had abandoned the place, for another, as yet unknown, destination.

Stronger earthquakes must have followed and caused damage to buildings. Probably there were waves of tremors but these were clearly separated by quiet periods, when groups of people returned, started to remove rubble and collapsed debris and began making repairs, for which evidence has also been unearthed at Akrotiri. This indicates that the inhabitants, at least those of Akrotiri, had not, at this stage, abandoned the island but had sheltered somewhere nearby, making the return for repair work possible. These efforts to restore the settlement were not completed since the eruption continued with greatly increased intensity. This may well have happened almost without warning, when the volcano appeared to be calming down, judging by the incomplete repairs and hastily discarded tools found within Akrotiri. Despite the obvious rapidity of their final departure, the people themselves managed to abandon the city and no bodies have been found. (Doumas 1990, 48–50; McCoy 2009, 80; Friedrich and Sigalas 2009, 92)

I. and II. – phreatic and phreatomagmatic explosion
The eruption started with a huge, high volcanic plume and it is impossible to tell precisely how long this phase lasted; months, weeks or minutes. At first the column of material rose from the crater to great heights but the pressure of concentrated magma rising through the volcanic vent was so high that the walls of the vent disintegrated. The caldera was so enlarged that it completely changed the mode of the eruption. (Friedrich and Sigalas 2009, 97) The tephra started to flow under high pressure into the sea. This reaction was extremely rapid and its speed and intensity were supported by the very high temperatures of the tephra. Melted materials and large boulders freed from the broken vent and caldera slopes were catapulted in to the air. Some of them fell like bombs onto the settlement at Akrotiri along with the first layer of tephra. Pumice later sealed not only this settlement but a large part of the island as well. (Friedrich 2000, 71)

Simultaneously, fragments of volcanic ejecta 'peppered' the island; in Akrotiri some frescoes (e.g. the Fisherman in room 5 of the West House) look as though they have been hit by hundreds of bullets, mainly in their upper parts (Friedrich and Sigalas 2009, 92, Fig. 8).

However, this must have happened quite soon after the first major tremors because there are no sediments between the last traces of human activity and the layers created during this phase. It can be inferred that the boulders (and with them the first dose of tephra) fell onto houses which had been cleared out, ready for repair. We should assume days, no more (Doumas 1990, 48–50).

III. – so called Plinian phase
The tephra of this phase is easily recognizable: it contains dark fragments (Fig. 16; Friedrich and Sigalas 2009, 99). Layers of this phase's pumice are, on some parts of the island, as much as 11m high. In this phase, which represents the most intense of the eruption, at least 1.4 km^3 of melted material was catapulted into the atmosphere. The column of ash was up to 38 km high and even the stratosphere was impacted (more in chapter 2.1.2). The amount of material calculated to have been produced by the volcano is a broad

Fig. 15 / Carl Rottmann: Santorini in 1845. (After Rott et al. 2007) approximation, based on the mass of tephra sediments. (Friedrich 2000, 71–73; Friedrich and Sigalas 2009, 92) The eruption spread a huge fan of tephra (pumice and ash) over the eastern part of Mediterranean (from Santorini to the Black Sea, Near East, Egypt and South Aegean). The experience of similar eruptions in historical periods indicates that this phase could have lasted for a few hours. (Friedrich 2000, 71–73; Friedrich and Heinemeier 2009, 57) Many of the Akrotiri houses, or at least their ruins, were found still standing, solely because the rooms were completely filled by the pumice from this phase (Doumas 1990; 48–50, McCoy 2009, 81). In this phase the tephra and pumice covered the tree(s) whose branches were found in 2003 and 2007 and used for radiocarbon dating and dendrochronology. (Friedrich and Sigalas 2009, 97). The processes and reactions described above were continuing and repeating. Remnants of the volcanic chimney fell in pieces and magma again mixed with sea water and re-initiated a phreatomagmatic reaction. Pressures within the magmatic chamber and vent must still have been very high because the volcanic vent's fragments were launched in all directions with speeds of around 200 km per hour. This process was accompanied by clouds of ash, dust and smoke. This time the amount of pumice is calculated as 2 km^3. Part of the material fell back into caldera and the crater walls were re-built. A column of material, forced out from its narrow neck, once more touched the stratosphere, 38 km from the Earth's surface. This new chimney then, in turn, collapsed and its fragments were thrown into the air for one last time. (Friedrich 2000, 73–74)

IV. – concluding phase (debris and mud fows)

In this phase the volcano was still producing highly characteristic tephra: black shiny grains of pyroclastic material were spread within massive layers of darker coloured pumice. Although a column of smoke and ash was still ascending from the crater, it was slowing down and becoming lower and lower. The atmosphere around was full of dust and hot gases spreading not only from the crater but also from the waters of the caldera, which would have looked like a caldron full of boiling milk. A large area around the island was covered in pumice, which not only blanketed the island but also floated on the sea surface. This pumice was still very warm. There was darkness over a large region of Eastern Mediterranean. It was in this phase that the magma chamber (Fig. 17) was finally emptied. Although the body of the fallen material covering the island was huge, only a part of material concentrated in the magma chamber before the eruption was catapulted out and the majority wound up in the caldera. (Friedrich 2000, 74–77)

V. – secondary processes

All active reactions having concluded, large amounts of the dust and ash which had fallen on the body of the island shifted into the sea. This has been documented mainly in the south and south east of the island. (Doumas 1990, 48–50). It remains open to question whether the tsunami was born in this phase or, more probably, earlier, during the process which provoked the dilapidation of the caldera, or by entry of pyroclastic flows into the sea, as indicated by parallels from modern eruptions.

Fig. 16 / Tephra of the Plinian phase. (Photo by author)

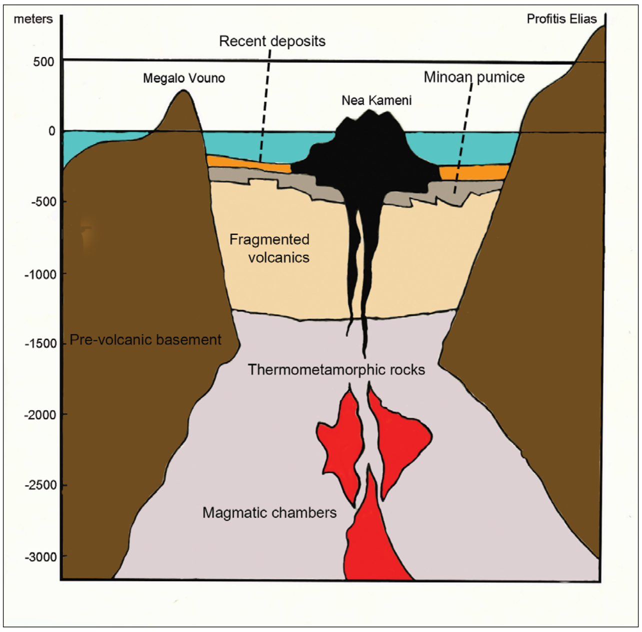

Fig. 17 / Section of Santorini volcano. (Illustration by author after Friedrich 2000)

(Pareschi et al. 2006; McCoy 2009, 82; Novikova 2011, 665). Sets of tsunami waves could have been produced as a result of any or all of these effects. (Pareschi et al. 2006; McCoy 2009, 86–87; Fig. 18), e. g. sea floor displacement caused the I. e. December 26 2004 Great Indian Ocean Tsunami (Yeh et al. 2005).

The Santorini tsunami clearly had huge energy, like the tsunami after the Krakatoa eruption, which ran twice around the Earth, and, when it crashed onto the Sumatran coast, killed about 36,000 inhabitants of the island, who were trying to reach higher land. That eruption was very loud and was audible on Madagascar, Sri Lanka, London and in Australia. The shockwave was even felt in Potsdam. The cloud of ash had a diameter of 30 miles and ash from this eruption was detected 3,300 miles away. The cloud of material in the atmosphere reduced sunlight so much that it induced ecological catastrophe over a broad region. (Fig. 19) The worldwide climate became colder during the years which followed and this was accompanied by extreme climatic phenomena. Yet the Krakatoa eruption was ten times smaller than Thera (Barber 1987, 221; Friedrich 2000, 69; Grove and Rackham 2003, 140, Table 8.1; McCoy 2009, 86–87, 89).

It can be concluded that very similar effects appeared during and after the Santorini eruption, which would not have produced one single tsunami but numerous sets (Pareschi et al. 2006).[13]

The Santorini tsunami, which most affected the south Aegean (Pareschi et al. 2006, Figure 2, 3), hit the north coast of Crete. Sediments composed of pumice (which not come with the tsunami but was washed in later – F. McCoy, *pers. comm.* unication), pebbles, shells and architectural fragments, have been identified in Amnissos (the port serving Knossos). When the major wave hits the coast it would have been from a few meters to 28m in height (Novikova et al. 2011, 665) and its speed could have reached the speed of sound. (McCoy and Heiken 2000, 59–64). It may have been as high as 50m near Thera (Pareschi et al. 2006). On Amnissos, Malia and Gournia there exists evidence, such as the removal of large blocks from their original positions, that these sites were hit by such a wave. (Driessen and MacDonald 1997, 89–90).

The Santorini volcano produced about 100 km^3 of magma[14] (Fischer 2009, 262). In the main phases magma was ejected from the vent into the atmosphere at a speed of about 3–10km per second (McCoy 2009, 82), the volume of ejecta was approximately 60 km^3 (Sigurdsson et al. 2006, 338) and the tephra accumulation rate is estimated to have been of the order of 3cm of material per per minute (McCoy 2009, 82). Phases 0, I. – IV. could have kept going for some hours or up to 4 days. The entire process (phases 0 – VI) lasted at most for a few months.

The main phases started in late spring/early summer according to the additional evidence from excavation in Akrotiri (McCoy and Heiken 2000, 48–49; MacGillivray 2009, 158–159).

In Crete the ash and tsunami deposits have been found on many sites and evidence for the post-eruption activities has also been documented. The worst of the tsunami damage was in central Crete and the Mirabello gulf: Waves in Mallia could have been circa 3m high but in Mochlos and Gournia they could easily have reached a height of 40 m. Tsunami were to blame for the dislocation of some ashlar blocks in the Villa of the Lillies at Amnissos (Marinatos 1939) and large pithoi were swept against walls at Zakros (Driessen and Macdonald 1997, 89–90). In the Dodecanese and

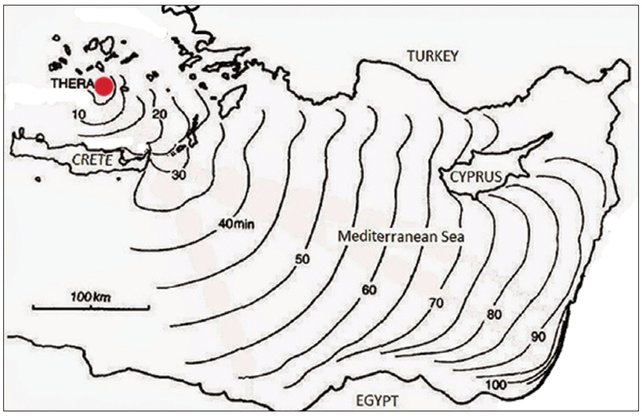

Fig. 18 / Reconstructed tsunami time-distance curves. (After Yokoyama 1978).

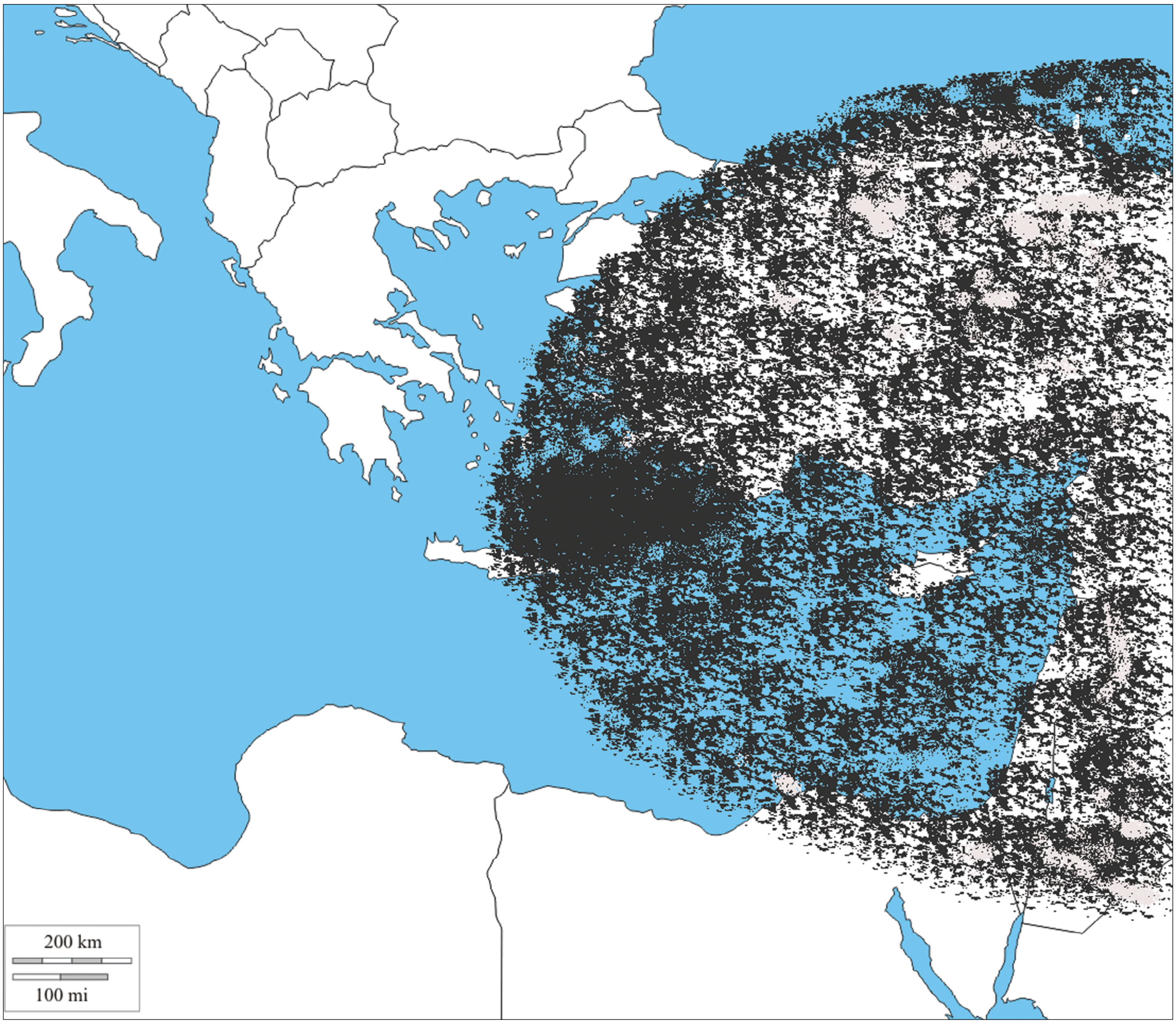

Fig. 19 / Santorini tephra dispersal pattern. (Illustration by author)

Anatolia the layers of ash are as much as 1m thick (Driessen and Macdonald 1997, 92). Among the more recently documented sites is Mochlos, where deposits of tephra, created at the time of the eruption and shortly after it, were found. Buildings there were destroyed by earthquakes associated with the eruption, or possibly by the ash fall itself, but there were also new LM IB buildings erected in the settlement immediately after the eruption. The excavators pointed out that these new houses display many architectural features that are typical of the houses of Thera, which are not to be found in the neighbouring LM I settlements e. g. at Gournia or Pseira, and expressed a hypothesis that they may have been built by refugees coming from Thera itself (Soles 2009, 108–114). An LM IA house on Pseira, another tsunami victim, was also rebuilt and Theran ash was worked into the agricultural soil making it even more fruitful (Betancourt 2009). Another very clearly recognizable ash layer was found in Papadiokampos where the ash layer sits immediately on top of Minoan cultural remains (Brogan and Sofianou 2009). Other tsunami deposits were studied in Priniatikos Pyrgos where the site was abandoned after the Santorini event (Molloy et al. 2014) and at Palaikastro (MacGillivray et al. 2009; Höflmayer 2012). Yet another ash deposit has recently been discovered on the island of Telos (Irene Nikolakopoulou, *pers. communication*).

This catastrophe must have impacted on all neighbouring regions: in the Aegean, Crete, the west coast of Asia Minor and other regions closer to or farther from Santorini. If the impact was not direct, the secondary effects would surely have been felt. The dramatic events on Santorini must have been visible from Crete, maybe even the Delta, from where the eruption would have been also heard, felt and smelt. It would have been announced by brilliant glows towards the northwest, particularly at night, daytime darkness, sounds like cannons firing and tsunamis, climate changes and, for a few seasons, spectacular sunsets. Over and above the physical effects, such an event could not fail to affect both individual and collective psychology (Driessen and MacDonald 1997, 94; McCoy 2009, 89–90).

1.3 Synopsis of the history of research

Based on results of early excavations and classical comparative archaeological typological and stratigraphical chronology, the date the Santorini volcano erupted in the Late Bronze Age was originally established as 1450 BC and this date was not really challenged until the 1970s. According to the stratigraphy of Cretan settlements, the eruption occurred at, and probably defined, the transition from the LM IA to the LMIB period, or LHI to LHII. This is the period following the horizon of the Mycenaean shaft graves, whose dating is a very important issue for central European archaeology. Many analogies and influences from the Mycenaean world are documented across Europe and artifacts (e.g. bronze nails, amber beads), imported from Northern parts of the continent were also found in the shaft graves (Harding 1984, 213–5). It was the first time when Europe, as a whole, was in active contact with regions which had already passed into the state stage, ergo producing literary documents or even elaborate calendars. At least such was the deduction of the first European archaeologists trying to determine absolute dates for the European Early Bronze Age (BA and BB phases of Reinecke's scale). The available Egyptian chronology was accepted as an almost perfect scale and the connections between the Aegean and Egypt observable on imports/exports were treated as adequate evidence for absolute dating. (Tab. 1)

The first calibrated radiocarbon dates, obtained not only from Santorini itself but also from Crete and the mainland, were not in agreement with historical chronology and suggested a date earlier than 1530 BC for the event. Discussion about who is wrong, archaeologists or physicists, started immediately. Initially, the radiocarbon method was mostly dismissed as not being secure for this period. However, the first calibrated radiocarbon dates were followed by dates obtained by dendrochronology and glaciology. Both shifted the event even further back, closer to the mid 17th century BC, and showed that there really was a serious need for detailed revision of Aegean Late Bronze Age dating. Dating of the Santorini eruption began to be one of the most discussed issues of Aegean prehistory and, in the 1980s and 1990s, there were intensive and systematic efforts to cast light on the problem.

One could wonder why, given that the Santorini catastrophe is one of the most discussed and studied issues in Mediterranean prehistory and the many scientific methods used to help establish its precise date, undisputed results and arguments generally or at least widely accepted have still not been presented. In the beginning, at least up to the 1990s, the majority preferred the 'low' (later) historical dates. Currently the 'high' (earlier) dates of the mid 17th century BC are generally privileged, except within Egyptology, where the arguments in favour of the accuracy of their historical chronological scales continue to hold sway. Contemporary monographs of Aegean prehistory sometimes present both dates as possibly correct (Shelmerdine 2008, 4–5), others present only the high chronology (Manning 2010, 23, Table 2.2.), while others instead prefer the low approach (Dickinson 1994, 19, Fig. 1.3). The only matter on which the majority agrees is that there is not a clear agreement for absolute dating of the early phases of the Aegean Late Bronze Age.

The Santorini event (probably the most dramatic and catastrophic event of the last 10 000 years in the Eastern Mediterranean, and, possibly, the Northern hemisphere (Manning 1999, 7)) was crucial for thousands of people then living in the region. Today it presents a test for science; on how to deal with complex questions and with inconsistent data, how to apply the theory of error and how to test results produced by the humanities and natural sciences where experiments or reconstructions are not possible.

I am sure that nobody will doubt the importance of the absolute time setting of the event. Causal and contextual questions taken out of their chronological frame make little sense. But why in particular is the absolute date of the so-called Santorini catastrophe so important? What would it mean to have fixed this date? Firstly, the Santorini eruption occurred in a period which is very important for the absolute chronology of Northern European regions because, as mentioned above, just shortly before it, at the horizon of the Mycenaean shaft graves, European prehistory had its first "meeting" with history (e.g. Vandkilde et al. 1996). Furthermore, this was the period when Cretans (Minoans) passed into the stage of creating a centralized state and it is probable that the Santorini catastrophe was the key event which stopped or disrupted this process (Klontza-Jaklová and Klontzas, *in print*). Determination of the absolute date is vital to help synchronize local chronologies with historical scales in the Eastern Mediterranean.

To find the reason for the error is also important for natural science and could be a precedent for other dating issues. Attribution of 'blame' – to science or the humanities – is pointless. Both are part of the one story. Solving the question is not a competition but the creation of new knowledge.

The goal I have set for this volume is not only to present a detailed overview of the contemporary state of investigation from the point of view of Aegean prehistory, Egyptology and physical science but also to pick up and underline the areas where solutions and errors may lie hidden.

E. Cline, in his book about Bronze Age collapse (2014, 139), suggested (albeit using a quote from Sherlock Holmes[15]) working with average data and M. Wiener (2009b, 288) with the most probable theory. But such approaches cannot be deemed wholly scientific. Science is not 'Gallup' and these are not election polls. Evidence is necessary. Average values document only our 'average opinion' or an average probability and not historical reality.

The problems with the Aegean Late Bronze Age absolute chronology demonstrate clearly that, in some cases, science and the humanities simply must work together. Each must be ready to present arguments to the other and to accept that it is possible those arguments may be wrong.

The island of Santorini was, from an archaeological perspective, 'discovered' between the years 1859–1869, during the exploitation of pumice used in construction of the Suez Canal (Manning 1999, xxvii), and as a result of the opportunity presented by the relatively minor eruption of its volcano in January 1866 (Fouqué (trans) 1998). Ferdinand André Fouqué, a French geologist, visited the island at the time and as a result of his research he dated the Bronze Age eruption within the interval between 2000 and 1500 BC. Given the methodology, data and instruments he had, this was an excellent conclusion (Manning 1999, 12).

The importance of the Minoan site buried under a massive (at some points over 10m high) layer of tephra was beyond dispute but the technical options available at the time precluded large scale excavations. Only smaller test trenches and pits were placed within the Akrotiri *intravillane*. The dramatic course of Greek history up to the 1970s made it impossible to develop a large scale archaeological project in Santorini. Systematic excavation eventually started in 1967 on the cape of Akrotiri where erosion had created easier access to archaeological contexts close to the coast. The first director of the Akrotiri excavation was Professor Spyridon Marinatos, of the Athenian University.

The Santorini eruption has been cited as the reason for the destruction of Minoan administrative centers during the LM IB period. The first to connect the eruption with those destructions, in which he saw the total collapse of Minoan civilisation, was J. Schoo (1937–1938). His theory was largely ignored by his contemporaries and it was S. Marinatos who became known as the author of this theory, which he published in Antiquity (1939). Schoo's original contribution was finally acknowledged when mentioned by Jan Driessen and Colin Macdonald (1997).

More recent archaeological evidence means that this theory of the collapse of Minoan civilisation due to the Santorini eruption is no longer current and the LMIB destructions cannot be related directly to the event (summary in Driessen and Macdonald 1997). In defence of both its proponents it must be said that, at the time, the chronology of the Late Minoan period was not known in as much detail as it now is and that the synchronism of some particular destruction horizons was unclear. It was also automatically assumed that the destructions at Knossos and other administrative centers would have been contemporary and would have resulted from the same causes. S. Marinatos not only excavated at Akrotiri but also at the site of the Knossian harbour in contemporary Amnissos on North Crete, which was totally destroyed by tsunami invoked by the Santorini eruption. Marinatos thought that the destructions of other Minoan sites documented in LM IB and the destruction of the harbour in contemporary Amnissos were of same date and all were related to this particular eruption. Albeit the concrete results of his research cannot be accepted any more, we cannot deny that S. Marinatos was one of the first to lay the foundations of modern comparative archeology and in essence we are still using his methodology (Doumas 2009, 263–264), which has not, thus far, been criticized or doubted. S. Marinatos studied imports from Egypt on Crete and Minoan and Mycenaean imports in Egypt and combined these data with the absolute chronological scale reconstructed for Egypt, based mainly on later literary sources. At least in one aspect he was clearly correct. It was he who correctly established the relative chronology of the Santorini volcanic eruption when he placed it between LM IA and LM IB. He also synchronized the event with the Eighteenth Dynasty in Egypt. This deduction is nowadays much discussed (i.e. Manning et al. 2002, 742). Within the framework defined by this methodology, he dated the Santorini catastrophe to around 1500 BC (Marinatos 1939). It is notable that Arne Furumark dated the equivalent ceramic phases of Mycenaean pottery to the same period (Furumark 1941a, b; 1950, summary in Manning 1999, 13–16), which provided something of a cross-check and meant that his date was not viewed as problematic and was broadly accepted.

It is self-evident that this is a key date for the European Bronze Age and one wonders why no effort was made to review the arguments for almost half a century. Until the 1980s the interval of 1500–1450 BC was generally adopted (e.g CAH II, 1, 558, or, in the Czech bibliography of ancient history: Pečírka et al.1989, 348, or European prehistory: Gimbuntas 1956; Pleiner (ed.) 1978; Buchvaldek, Sláma (eds.). 1982; Buchvaldek (ed.) 1985; Furmánek et al. 1991; Podborský (ed.) 1993).

Overviews of European and Aegean prehistory published in the 1990s had already begun to mention that the dating of the Santorini event was not so certain and that there was some disagreement on the subject between archaeologists and scientists (i.e. Dickinson 1994, 17–20; Furmánek et al. 1991; Podborský (ed.) 1993).

It was at the end of the 1970s and beginning of the 1980s that the data derived from stratified snow layers preserved in regions with permanent ice cover, particularly in Greenland, were presented. The method is called ice-core dating, but the first results surprised almost everybody. Anomalies had been found in the conductivity of ice layers which could have been caused by acid compounds, probably volcanic products spread by the Santorini eruption into the stratosphere and atmosphere. However the dates for these anomalies came out around 1390 ± 50 BC.

At the same time an attempt to apply thermoluminiscence dating provided dates in the interval of 3600 ± 200 bp, a range too large to be useful.

The majority of archaeologists assumed that the radiocarbon method was, for some reason, insufficiently accurate for the period concerned and merely reverted to the 'low' conventional dating. (Hood, S. 1978, 688; Manning 1999, 19–21)

In the 1970s some archaeologists had started to argue that the eruption could not have happened during the Eighteenth Dynasty in Egypt but during the Second Intermediate Period. They supported their conclusions by reference to particular archaeological comparisons and noted the silence of literary sources (Pomerance 1978, 797–804).

A publication by two dendrochronologists, Valmore C. La Marche and Kathrine K. Hirschboeck, in 1984 could be described as a breakthrough. They stated their empirical findings that any large scale volcanic activity releases substantial amounts of SO_2 and SO_3 into the atmosphere. These compounds are formed during the decay of sulphuric acid (H_2SO_4), which volcanos produce, and, when spread in high concentrations through the atmosphere and stratosphere, they create aerosols limiting the penetration of solar radiation to the Earth's surface. On examination of data for contemporary eruptions and those from the recent past, they have documented that volcanic eruptions can cause a decrease in average annual temperatures of about 0.4–0.7°C in the following years. This fact is then mirrored in the thickness of the new tree rings in the wood of long-lived species. Both scientists concluded that the date of the Santorini volcanic eruption fell between 1628 and 1626 BC (LaMarche and Hirschboeck 1984; Pyle 1990, 68). V. LaMarche had already proposed this date in the 1970s and published this conclusion in National Geographic (Matthews 1976), but Aegean prehistorians had completely ignored it. It was Peter Warren (1984) who brought these data to the attention of Aegean prehistorians and started a serious debate on them. His opinion, which was very important at that time, was that radiocarbon, dendrochronological and glaciological 'high' dates could no longer be ignored but must be reviewed and compared with historical and archaeological data. He further expressed the opinion that the data were impossible to explain away and that it was not scientific procedure on the part of archaeologists to blame the methodology of physical science for the discrepancy and simply to push the results to one side just because they were not coherent with previously created models. This gave the appearance that they were prepared to assert that the techniques of physical science are less accurate than those of the humanities in solving physical problems. He called for intensive and organized efforts to solve the problem. Warren's article can be described today as a classic; it presents a real threshold of long term debate, which still continues along the lines he predicted. (Warren 1984)

The next important point was the year 1987 when the Danish glaciologists revised their previous results, derived from the Greenland ice-core, and presented a series of the corrected data, which this time placed the relevant date to 1644 ± 20 BC (Hammer et al. 1987). More archaeologists became ready to consider the 'high' dating of the event. For example Gerald Cadogan, who, until some years previously, had been convinced that the absolute chronology of Aegean prehistory was stable and no radical change could be expected (1978), had to concede that a date of 1500 BC was no longer acceptable and that the date for the Santorini catastrophe should be sought before 1520 BC at least (Cadogan 1987). Martin J. Aitken (1988), on consideration of radiocarbon dates, reached the same conclusions: that the archaeologists and scientists should look for the correct date somewhere between 1670–1520 BC. Around the same time the Irish dendrochronological team published 1627 BC as the most probable date according to their analyses (Baillie and Munro 1988). Philip Betancourt (1990) for the second time contributed to the debate and it was he who first tried to compare the archaeological data (the particular archaeological finds and contexts) with historical absolute chronology and with chronology obtained by scientific methods. His conclusion was that the most probable date for the Santorini eruption seems to be the period around 1610 BC[16].

Even earlier, in 1980, a volume on Minoan pottery in second millennium Egypt was published by Barry J. Kemp and Robert S. Merrillees, who studied the Cretan and Mycenaean imports in Egypt and, without including the radiocarbon or dendrochronological dates in their assumptions, concluded that the Late Minoan period should have ended between 1600–1570 rather than starting in that period, as asserted by the then conventional dating. This finding provided some 'independent' support for the scientific dates.

Towards the end of the 1980s Sturt W. Manning added a comparative study of East Mediterranean chronology (1988). He didn't dispute the scientific results and supported that dating approach – he retains this position today (i. e. Manning et al. 2014). ,

Publications of the 1980s formed part of a major debate, which not only concerned the dating of the Santorini eruption and the chronological systems of the entire East Mediterranean, including Egypt, but also the security of the scientific and archaeological dates. It became obvious that the time had come to collect all the participants round the table in order to review the state of the argument. A conference, attended by many of the major players, was duly held in Göteborg in 1987 (Åström (ed.) 1987; 1987; 1989) and this really moved the debate forward. The 1500 BC date for the Santorini catastrophe was deemed incorrect, or, at best, minimally probable. Since this conference the question has at least been informally shortened to "high or low" (Fig. 20). More importantly perhaps, the participants set up an ongoing strategy to pull together further evidence to help fix the Santorini eruption date with greater accuracy, within the interval from 1648 to 1580 BC.

The debate at the Göteborg conference became so animated and epic that two years later yet another scientific panel was organized to revisit the topic (Hardy and Renfrew (eds.) 1990), during which the state of current knowledge was summarised, the disagreements were set out and questions meriting further research were defined.

At the end of the 1980s, at the Canaan site of Tel Kabri, Wolfgang-Dieter Niemeier (1990) recovered some destruction debris of Middle Bronze Age II date. This debris yielded an absolute date around 1600 BC. The debris came from the destruction of a habitation complex and covered the remains of painted floors, whose decoration parallels the style of Aegean frescoes of Late Minoan I period. Niemeier has therefore concluded that Cretan LMI and Near Eastern MBII are contemporary and placed both phases in the 17th century BC. He also tried to synchronize both chronological systems (Aegean and Near-Eastern) with the Egyptian chronological system and expressed his conclusion that the destruction of the palace in Tel Kabri happened before the Eighteenth Dynasty in Egypt.

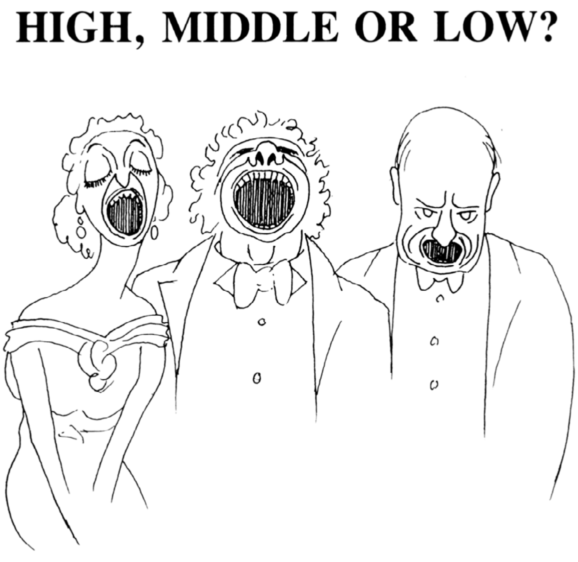

Fig. 20 / "High or low" – the conference logo.

At the same time the glaciologists returned to the debate with information that they had found documenting two sulphur compound anomalies in the ice sediments which probably mirror two different volcanic eruptions in the second half of the 17th C BC, dated around 1627 and 1645 BC. (Bietak 2000, 30).

Debate continued and escalated during the following decade with the main battlefield moving to the pages of the journal Archaeometry. There, the frequently dramatic clashes between individuals brought about the creation of robust datasets. At the start of the 3rd millennium James Muhly (2003, 17–23), possibly having been moved to exasperation by the combative positions being taken, expressed the not unreasonable opinion that the archaeologists and scientists could not continue as opposed teams but must cooperate.

The majority of academics, across the disciplines of science, archaeology and history began to prefer the 17th century BC as the most probable period for the catastrophe.

However, since the very start of discussion about the absolute date of the horizons carrying the signature of the Santorini volcanic eruption, there have been authors who ignored the debate and simply avoided the question of absolute chronology in their analyses and syntheses (e.g. Schachermayer 1976a, b, Duhoux 2003).

Another key point, closing and summarizing one stage of the debate, was the publication of a detailed study "A Test of Time. The Volcano Thera and the chronology and history of the Aegean and East Mediterranean in the mid second millennium" written by S. Manning (1999). He clearly and consistently supports a 'high' chronology, placing the Santorini catastrophe in the second half of the 17th century BC.

At the end of the millennium M. Bietak established an interregional and international project "The Synchronization of Civilization in the Eastern Mediterranean in the 2nd Millennium B.C. (SCIEM 2000, http://www.oeaw.ac.at/sciem2000/index.html) with the intention to create a broad database of all relevant data. The SCIEM project was dedicated to the establishment of clear links across the Aegean and Eastern Mediterranean at this time. A number of publications have been produced within the framework of this project. This large scale project was sorted into 19 chapters covering the main topics (establishing the Project in

Bietak (ed.) 2001).[17] Detailed results of the project are discussed in the appropriate chapters.

Another milestone was the finding of olive branches in the Fira quarry on the edge of the Santorini caldera in 2003 and 2007. The branches, burned during the early phases of the Bronze Age eruption, had remained in situ in tephra (Friedrich and Heinemeir 2009; Friedrich et al. 2009; Heinemeier et al. 2009). Their dating provided the motivation to organize a further conference dedicated to the discussion of 'Low or High' chronology (Warburton et al. (eds.) 2009). It was clearly agreed that there is a significant gap between classical archaeological comparative dates and the dates obtained by radiocarbon methods and that neither discipline can define a reason for the discrepancy (Warburton 2009, 295). At the beginning of the 21st century the arguments for a low chronology of the event were resurrected and dates around 1530 BC again became part of the debate (i.e. Wiener 2009a, b; MacGillivray 2009; Warren 2009).

Among the latest organized efforts to help settle the issues, is the Aegean and Near Eastern Dendrochronology Project directed by Prof. S. Manning at Cornell's 'Malcolm and Carolyn Wiener Laboratory for Aegean and Near Eastern Dendrochronology'. Their *"key long-range goal is to build long multi-millennial scale tree-ring chronologies in the Aegean and Near East that will extend from the present to the early Holocene to cover, broadly speaking, the last 10,000 years of human and environmental history. Our raison d'être is to provide a dating method for the study of history and prehistory in the Aegean that is accurate to the year. This kind of precision has, up to now, been lacking in ancient studies of this area. Indeed, few archaeological problems stimulate as much rancor as chronology, especially that of the Eastern Mediterranean. The work of the Aegean and Near Eastern Dendrochronology Project aims to help to bring some kind of rational and neutral order to Aegean and Near Eastern chronology from the Neolithic to the present."* (http://dendro.cornell.edu/projects/aegean.php)

There were also ERC projects at Oxford university "Radiocarbon-based Chronology for Dynastic Egypt" (Shortland and Bronk Ramsey 2013).

Other small projects are in progress e.g. a project, wherein the author is involved, examining the problem of volcanic, so called "old" CO_2 contained in plants in volcanic regions (Fernandes et al., *in print*) (Fig.21).

But the debate continues. No agreement seems to be on the horizon. The discrepancies between historical-archaeological and scientific dates have still not been bridged and the complexity of the problems appears actually to have increased.

Fig. 21 / Plants (Curry plant, Helichrysum Italicum) sampled on Nea Kameni. (Photo by author)