Géoarchéologie des îles de Méditerranée

Geoarchaeology of the Mediterranean Islands

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CNRS ÉDITIONS

Sommaire

Holocene sea level changes and palaeogeographic reconstruction of the Ayia Irini prehistoric settlement (Keos Island, Cyclades archipelago, Greece)

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Abstract

The history of the Ayia Irini promontory is closely linked to seismic activity and the successive changes in Relative Sea Level from the Late Neolithic to the Hellenistic period. After an occupation period of approximately 500 years, it was suddenly abandoned in 2000 BC, when the RSL rose from -5.0 ± 0.10 m to -3.60 ± 0.30 m. Following an undetermined interval, the promontory was resettled and the town grew in size and prosperity. The first landward fortification was constructed in the early 19th century BC and destroyed in the early 18th century BC. A larger fortification followed in the 16th century BC, which was reconstructed after the 16th century BC earthquakes probably related to the eruption of the Thera volcano. The coastal part of the Great Fortification was founded on an extended artificial rock fill that surrounds the promontory, thus expanding the area of the town to the seashore. In the mid-15th century BC a major earthquake caused widespread destruction, signalling the end of the settlement. The settlement was re-established and then completely abandoned following a severe earthquake in the mid-14th century BC. In the mid-2nd century BC, the RSL rose to -2.35 ± 0.15 m, a stand that probably lasted until *ca.* 1200 AD. A new sea level of -1.40 ± 0.10 m was maintained throughout the Venetian occupation period of Cyclades and after ca. 1570 the RSL rose to -0.85 ± 0.15 m. During the last 400 years, the RSL rose to its current position, completely submerging the coastal rock fill and the overlying fortifications.

Introduction

In a pre-eminently maritime civilization such as in the Aegean, which developed within a dynamic geotectonic setting, earthquake activity and sea level fluctuations are the key factors affecting coastal human activity throughout its history. The strategic position and coastal morphology were the main selection criteria for the establishment of a town-harbour in the prehistoric period. Earthquakes and their attendant macroseismic phenomena not only destroy anthropogenic constructions but sometimes also change the relationship between land and sea. Dynamic changes in sea level alter the natural features of the coast or may immerse the coastal harbour installations, thereby eliminating the comparative advantage provided by the location. The island of Keos is located on the western side of the Northern Cyclades (Figure 1A). The Cyclades Plateau is a marginal platform with water depths less than 250 m, and there are numerous outcropping islands between the relatively shallower northern Aegean and the deeper Cretan Sea. The Plateau area constitutes part of the Attic-Cycladic complex consisting of metamorphic and igneous rocks (Hejl and Riedl, 2002). It is considered to be an "aseismically deformed area", because seismic activity is limited to minor localized earthquakes of magnitude M < 2 on the Richter scale (McKenzie, 1972; Morelli *et al*., 1975; Papanikolaou *et al*., 1981; Papazachos, 1990). The island of Keos has an area of 121 km^2 and a total shoreline length of 86 km (Figure 1B). The island's morphology is characterized by a contrasted topographic relief, a complex drainage system, and steep coasts interrupted by small coves. The geological formations of the island are part of the "Northern Cyclades" geotectonic unit (Papanikolaou, 1986) and include Triassic – Jurassic limestone and a metamorphic complex of marble, gneiss, and schist (Davi, 1982).

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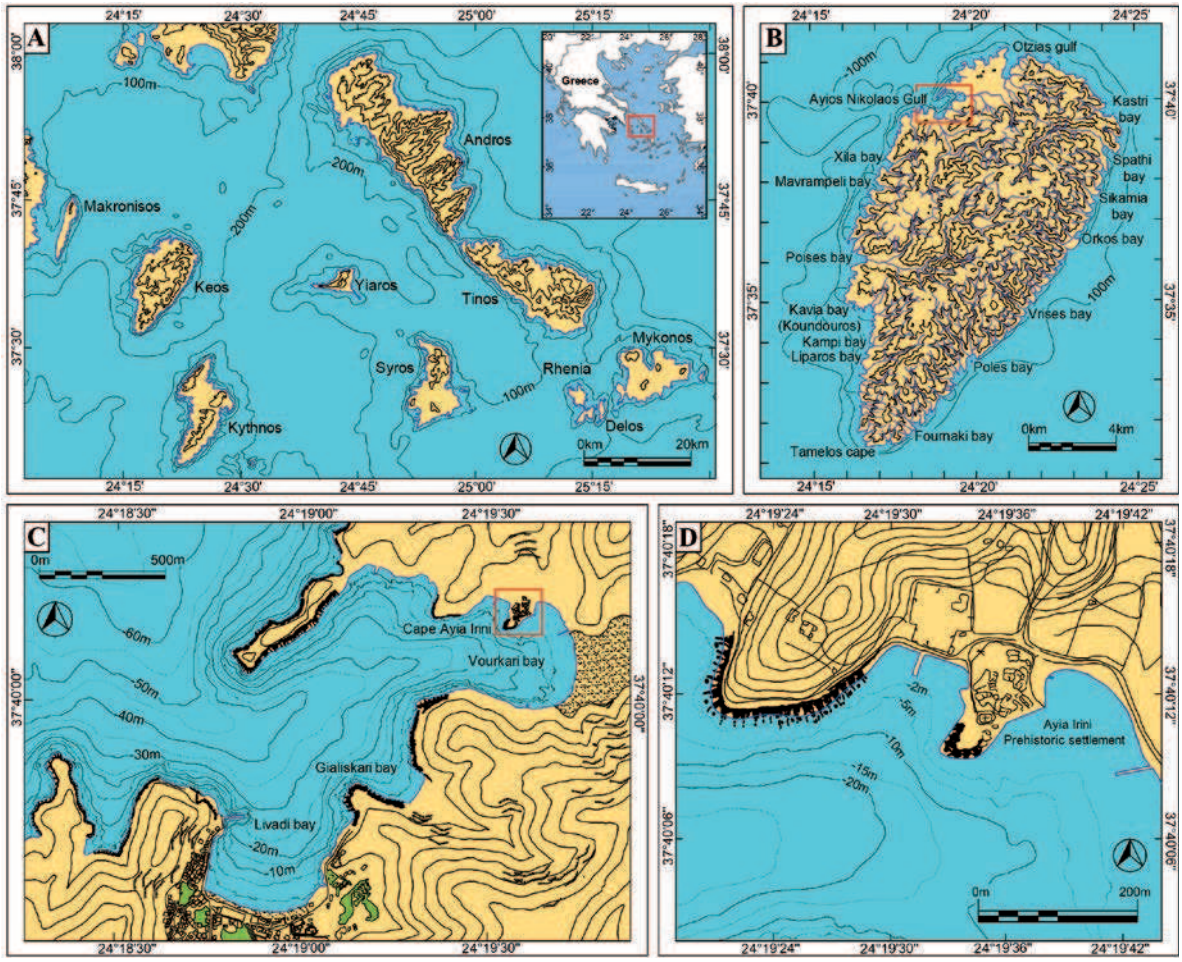

Figure 1: Location maps. Figure 1A: the Northern Cyclades; Figure 1B: Keos island; Figure 1C: the Gulf of Ayios Nikolaos; Figure 1D: the north coast of the Vourkari bay.

The small promontory, on which the prehistoric settlement of Ayia Irini is sited, is situated on the eastern tip of the northern coast of the Gulf of Ayios Nikolaos, which is a sheltered natural harbour (Figures 1C and 1D). The promontory is located at the end of a rock ridge which decreases in elevation to the southwest. It enters the sea in a length of 150 m and does not exceed 5 m in elevation. It is bounded by two small valleys to the east and west, which form a low alluvial terrain, slightly inclined towards the sea (Figures 1D and 3). During the Bronze Age, Ayia Irini was a small, densely-populated harbour-side settlement, on the strategically-located island of Keos, positioned between the powerful forces of the Mycenaeans based in Thorikos and Minoan Crete (Weisman, 2008). A spring on the northwestern side of the promontory provided fresh water for the inhabitants of the town, which had a maximum population of 780 to 1,250 (Weisman, 2008). The town had a well-planned road network, drainage system, and strong fortifications. The first fortification was built at the beginning of the 19th century BC, with a gateway controlled by a horseshoe-shaped tower and it seems only to have protected the northern landward part of the settlement. The Great Fortification was built in the 16th century BC, following the destruction of the earlier phase (Schofield, 1998). The new wall was more compact and stronger than the earlier fortification and had a number of towers and bastions along its perimeter. It was extended to the north, enclosing an area about three times greater than that of its predecessor (Figure 2A; Caskey, 1971; Schofield, 1998; Weisman, 2008). To build the coastal section of the Great Fortification, an extended rock fill surrounding the promontory was constructed, which was 220 m long and 30 m wide. Both the eastern and western limbs of the landward part of the wall end in two towers that were constructed on the fill; today, their ruins lie partially below sea level. Relics of the Great Fortification wall were detected on the southern central section of the fill. The lower course of the wall has a length of 32 m, at the depth of -2.0 m to -2.30 m, at a distance of 4.0 m from the edge of the rock fill upper surface (Figures 2A, 3A, 3B and 3C).

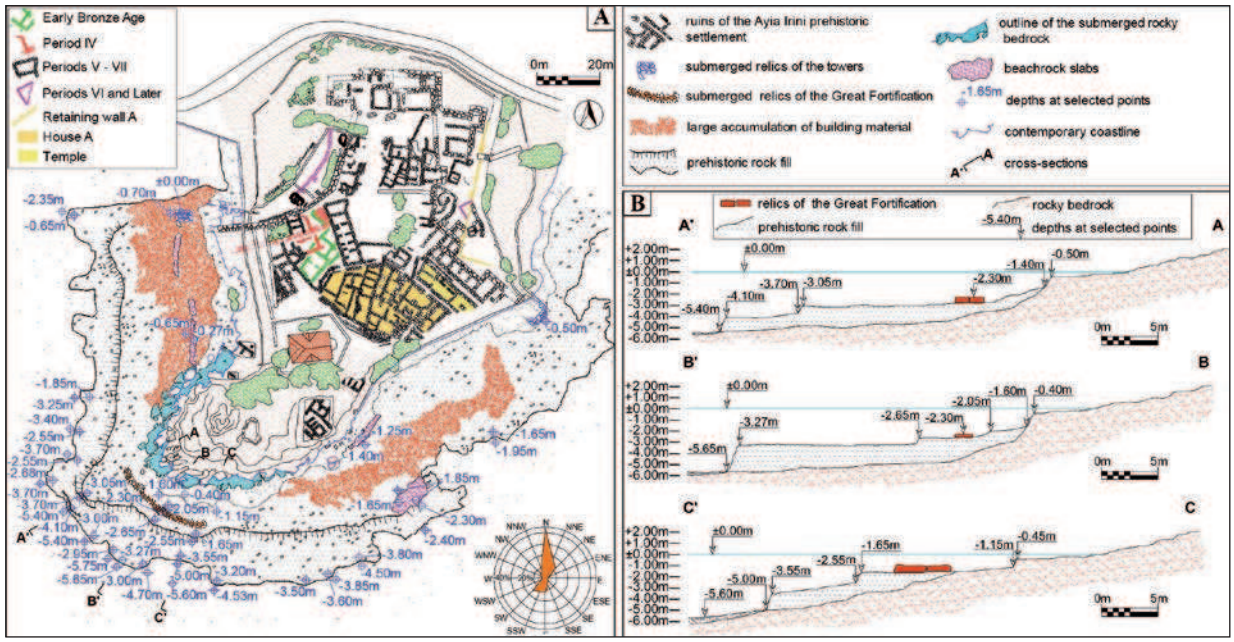

Figure 2: Figure 2A: Plan of Ayia Irini promontory and the surrounding submerged rock fill with a wind rose diagram for the location; Figure 2B: Cross sections of the southern section of the rock fill.

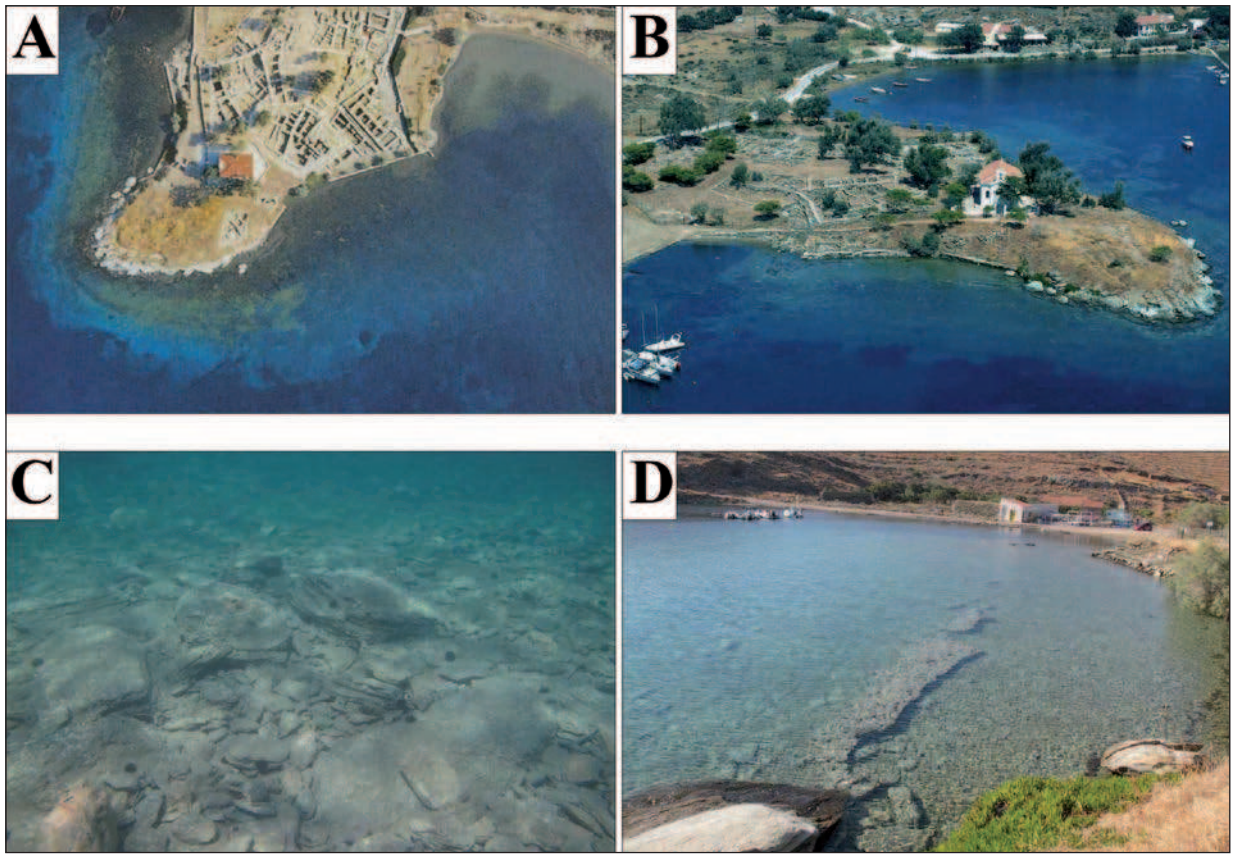

Figure 3: Figure 3A: Aerial photo of the headland of Ayia Irini (photographic archive of Miriam Caskey, photo W. and E. Myers); Figure 3B: the headland of Ayia Irini; Figure 3C: the lower course of the Great Fortification wall on the upper surface of the southern side of the rock fill; Figure 3D: the younger beachrock phase at -0.65 m on the western side of the rock fill.

This paper presents new data and interpretations relating to relative sea level change during the last 4,000 years along the shoreline of the Northern Cyclades, where recent relative sea level changes have not yet been adequately established (Gaki-Papanastassiou *et al*., 2005; Baika, 2008; Kapsimalis *et al*., 2009; Poulos *et al*., 2009; Stocchi *et al*., 2010). For this purpose, coastal landforms related to past sea levels and coastal archaeological installations and markers, together with historical data, provide a valuable source of information from which the relative movements of land and sea can be estimated. The paper also presents a case study of geoarchaeological research which aims to reconstruct the history of coastal changes with respect to urbanization in the prehistoric period.

Archaeological and historical context

The site has a long history, the earliest occupation activity is dated to the end of the Neolithic or to the very beginning of the Early Bronze Age (*ca*. 3000 BC, Period I of Ayia Irini; Figure 2A; Caskey, 1962, 1964, 1966, 1971 and 1981; Caskey, 1998). No trace of buildings has been found and only small deposits of pottery represent this period. Neolithic settlements dated to the end of the 4th century BC (~ 3300-3000 BC) were revealed on the Kephala headland and the nearby imposing hill named Paoura, on the northern coast, 1.5 km north of Ayia Irini. The earliest confirmed settlement on the promontory is assigned to the Early Bronze Age, about the middle of the third millennium BC (*ca*. 2500 BC, Period II of Ayia Irini). It is represented on the eastern side of the site by the clustered rooms of permanent buildings with successive floor deposits containing pottery, dated to the Early Bronze Age III period (*ca*. 2200 BC). The relatively few pottery finds suggest a direct relationship with Anatolian and southern Greek mainland models. The settlement was peacefully abandoned at the end of the Early Bronze Age (*ca*. 2000 BC, Period III of Ayia Irini).

After an undetermined lapse of time, which may have included the first phase of the Middle Bronze Age, the site was reoccupied (*ca*. 1900-1700 BC, Period IV of Ayia Irini). The first fortification wall, the gateway and the horseshoe-shaped tower were built across the peninsula. The new buildings were aligned differently from those of the Early Bronze Age. A Temple was built and grave plots were established. Objects were imported from the mainland, Crete and Cyclades. By the end of the Middle Bronze Age (*ca*. 1700-1600 BC, Period V of Ayia Irini) the town had grown significantly in size and prosperity. The first fortification no longer sufficed and it was replaced by the Great Fortification wall, which enclosed a larger area. In the Late Middle Bronze Age (*ca*. 1600-1500 BC, Period VI of Ayia Irini) impressive buildings were constructed (building of House A), and additions to the walls and alterations to the Temple were made, within which were placed the first of the many large terracotta statues of women. The Minoan influence was strong since this was the time of the Thalassocracy.

The late Bronze Age saw the greatest flourishing of the settlement (*ca*. 1500-1450 BC, Period VII of Ayia Irini). An enclosed Spring Chamber continued to be used for the water supply. Adjacent to the outer face of the circuit wall, near the main gateway, where a heroic tomb and tumulus and a small, elegant structure with a flagstone floor and frescoed walls. The Temple at this stage reached its greatest splendour, now holding more than fifty tall terracotta Figures of women and a plethora of offerings. However, in the mid-15th century BC most of the buildings of the town were destroyed by a great earthquake. The settlement was re-established in Late Helladic III (1400-1300 BC, Period VIII of Ayia Irini). The dwellings were rebuilt but not on a grand scale, mainly around 1400 BC. In pottery terms, the commercial orientation is predominantly mainland. Only a few examples of Minoan pottery have been found there, suggesting that the Cretans may have interrupted their contact with Keos, whereas abundant Mycenaean vessels indicate a Mycenaean presence on the promontory. Subsequently, another earthquake may have occurred between 1380 BC and 1330 BC, causing the direct supply of spring water to be cut off and most of the houses, if not all, to be abandoned. Stratified evidence of the post-earthquake periods has only been found in the Temple. The building was rebuilt several times and at least three phases of successive levels indicate interruptions by damage, followed by restoration, and which continued to be used until the end of the Bronze Age. The area of the Temple was still venerated in Protogeometric times and continued as a sacred place at least from the 6th century BC until late Hellenistic times. During the Roman period there may have been minor harbour installations on the promontory.

Material and methods

The relationship of geomorphological markers of sea level change to the functional elevation of ancient coastal structures, combined with historical data which highlight significant changes in human activity

in the coastal environment, enabled us to define and date five distinct sea level stands in the area of the Northern Cyclades. The coast of Keos, Andros, Delos, and Mykonos was studied in detail and the primary data on the shores of Rhenia and Mykonos published by Desruelles *et al*. (2009) were re-evaluated. We also assessed the published data from the excavation of the ancient harbour of Vryokastro in Mandraki bay, on the west coast of Kythnos Island (1990 - 2014 Kythnos Excavation Project, Annual Excavation Reports 2005 - 2011).

On the gneiss and schist coast of the Northern Cyclades, where other coastal landforms such as tidal notches -typical of carbonate rocks- are absent, beachrocks are the main geomorphological indicators of these changes. The intertidal cementation of beachrocks in the Cyclades has been documented by Desruelles *et al*. (2009), and for the wider Aegean area has been established by Dermitzakis and Theodoropoulos (1975), Neumeier (1998), Kampouroglou (1989), Erginal *et al*. (2008 and 2010), Psomiadis *et al*. (2014). Mourtzas *et al*. (2015) assembled a large amount of data from around the island of Crete in order to confirm the operative relationship between the seaward end of beachrocks with tidal notches that were formed at the same sea level stand in the late Holocene reduction in the rate of sea level rise. Beachrocks have been formed in a zone located between the mean low tide and the higher margin of the swash and backwash zone of the low-energy constructive waves. The depth of the base of the seaward end of the beachrock slab coincides with the mean low tide of the respective sea level in which it was cemented (Mourtzas, 2012; Mourtzas and Kolaiti, 2013; Mourtzas *et al*., 2014 and 2016; Kolaiti and Mourtzas, 2016).

Changes in sea level also affect the groundwater level in coastal aquifers and the change in the coastal water table has the same trend as that of sea level. The rise in sea level causes an increase of the groundwater level in regions where water is already close to the surface. Even small changes in the water table level can result in subsurface flooding, which affects the ancient infrastructure and water supply installations (Sivan *et al*., 2004; Mourtzas, 2010; Toker *et al*., 2012; Pagliarulo *et al*., 2013). The water supply Spring Chamber cut in the fractured permeable hard rocks of the promontory, with the spring discharge level at -3.85 m, is presently flooded with brackish water, below mean sea level. The current elevation of the various functional features of the buildings, such as foundations, floors, and stairways, which had surely been constructed above the then ground water level, gives a clear picture of the change in the coastal aquifer in parallel with the sea level from the Period VIII of Ayia Irini (1400-1300 BC) to the present. The current position of the submerged rock fill, which occupies the entire sea front of the promontory, and the various overlying constructions, is a sensitive indicator of the direction and magnitude of sea level change.

The palaeogeographic reconstruction of the submerged section of the promontory, and its ancient extension with the rock fill, was based on: i) accurate depth measurements of characteristic construction features of ancient submerged structures; ii) accurate depth measurements of beachrocks; iii) accurate measurements of the level of brackish groundwater, which is in hydraulic communication with the sea, in the flooded Spring Chamber and the flooded building foundations, floors, and walls in the eastern sector of the promontory; iv) definition and dating of past sea levels by correlating geomorphologic and hydraulic data with archaeological evidence; and v) correlation between past sea levels and the functional elevation of ancient constructions. All elevation measurements were done by mechanical methods at times of calm sea conditions and were related to the sea level position at that particular moment. The measurements are therefore reduced to mean sea level by applying tidal corrections at the surveyed site, using the data of the nearby available tide gauge of Syros hydrographic station.

Recent Holocene sea level history in the Northern Cyclades

The Recent Holocene history of sea level change in the Northern Cyclades begins with the sea level at -5.0 ± 0.10 m lower than at present. Little evidence of this earlier sea level is available and is limited to the deepest beachrock phase found in the bays of Poles (SE Keos), Kavia (Koundouros, SW Keos), and Mesa Steno, at the southernmost edge of Andros island. The dating of this level is associated with a time interval between the end of the Neolithic or the very beginning of the Early Bronze Age and the end of the Early Bronze Age, from 3300 BC to 2000 BC (5300-4000 yr BP). The traces of early habitation in the bays of Mikres and Megales Poles (SE Keos) found at the depth of -4.12 m to -3.10 m between the oldest and the next younger beachrock phases (Mourtzas and Kolaiti, 1998; Mourtzas, 2010), and the sudden abandonment of the Early Bronze Age settlement of Ayia Irini about 2000 BC (Caskey, 1971 and 1981), were most likely related to this earliest sea level stand and its abrupt change to the following stand.

The next youngest sea level, detected throughout the area of the Northern Cyclades, is at the depth of -3.60 ± 0.30 m. Widespread beachrock formations are located in SE and SW Keos (Poles, Kavia, Ligia

bays) and in the insular group of Mykonos (Kalafati, Ayios Ioannis), Rhenia (Kormou Ammos, Steni and Lazaret) and Delos (Dalongeville *et al*., 2007; Desruelles *et al*., 2009; Mourtzas, 2012). The dating of this sea level, between the end of the Early Bronze Age, at about 2000 BC, and the mid-2nd century BC, is made indirectly by comparison with the functional elevation of the following: the prehistoric settlement of Ayia Irini (2000-1300 BC; Caskey, 1971 and 1981; Weisman, 2008), the harbour installation in the Otzias bay (4th century BC) on the north coast of Keos, the functional level of the extensive harbour installations of ancient Karthaia on SE Keos (from the 8th century BC to the end of prosperity at *ca*. 180 BC; Mourtzas and Kolaiti, 1998; Simantoni-Bournia *et al*., 2009; Mourtzas, 2010), the coastal fortification of classical Palaeopolis (5th to 3th century BC; Mourtzas, 2007) on the west coast of Andros, and the submerged classical archaeological layers at -3.65 m to -3.85 m in the ancient harbour of Vryokastro in Mandraki bay, on the west coast of Kythnos (1990 - 2014 Kythnos Excavation Project).

A sea level of -2.25 ± 0.35 m was established by the beachrock formations that developed at this depth on the NE, SE, and SW coast of Keos (in the Gulf of Ayios Nikolaos, the bays of Orkos and Poles, and the coves south of Koundouros), on the SE coast of Andros (in the Gulfs of Korthi and Exo Steno), on the NW coast of Delos, the SW coast of Mykonos (Ayios Ioannis bay) and the E coast of Rhenia (Lazaret; Desruelles *et al*., 2009; Mourtzas, 2012). This sea level stand has been dated in Delos after the end of the Hellenistic period (Mourtzas, 2012), but it seems to have been prolonged after AD 39 in Andros, according to testimony that the harbour of Palaeopolis was in use at that time (Petrocheilos, 2012) – thus from 2030 to 1960 yr BP. The dating was achieved by correlation with the functional elevation of the Hellenistic – Roman shipshed on the south coast of Poises bay (W Keos), the submerged Roman structure in the Gulf of Exo Steno at the southernmost edge of Andros, the Roman harbour of ancient Palaeopolis (W Andros; Mourtzas, 2007), the Hellenistic coastal defence constructions at the sea front of ancient Delos (Mourtzas, 2012), and the submerged (at -2.45 m) Roman harbour installations in Mandraki bay (W Kythnos; Kythnos Excavation Project 1990 - 2014). However, this sea level stand may have been prolonged until the Early Venetian occupation period of Cyclades, about 1200.

The next sea level stand at -1.40 ± 0.10 m is dated to the Venetian occupation period of Cyclades (1207-1566 AD, 793- 434 yr BP). The beachrocks and the tidal notches in the Poles bay and along the entire length of the coast of Keos (Spathi, Ayia Irini, Orkos, Kavia, Ligia, Kampi bays), Andros (Vlychadia, Ayios Petros, Anerousa, Palaeopolis, Gyalia, Kremmydes, Mesa Steno bays), Mykonos (Kalafati, Ayios Ioannis bays), Delos (Fourni coast), and Rhenia (Kormou Ammos and Steni coast; Desruelles *et al*., 2009), all at about the same depth with minor deviations, clearly indicate this younger level. The dating was achieved by comparison with the functional levels of a sea defence wall and a shipshed of the Venetian period on the coast of Nimporio in Chora Andros.

Finally, the sea level at -0.85 ± 0.15 m was determined on the basis of the depths of the most recent beachrock phase on the coast of Keos, Andros, and Delos (Mourtzas, 2012), but it has so far not been possible to assign a date to it. The formation of the seaward end of the beachrock and its submergence should be ascribed to the last 400 years.

On the basis of a comparison of the local sea level stands resulting from the interpretation of the geomorphological and archaeological indicators and historical evidence from the islands of Keos, Andros, and Kythnos, and the insular group of Mykonos, Rhenia, and Delos, five distinct sea level stands for the area of the Northern Cyclades were defined (Figure 4). The relative sea level change prediction curve for the Northern Cyclades during the Late Holocene is shown in Figure 5.

Sea level change indicators

The indicators of sea level change in the area of Ayia Irini are divided into geomorphological indicators, which are the three submerged beachrock phases around the promontory; and archaeological indicators, which in turn are distinguished as coastal markers, which today are submerged below sea level, and landward markers which today are flooded because of the increase in the groundwater level in parallel with the sea level rise.

Geomorphological markers

The three distinct beachrock phases at the SE and W side of the promontory have been formed by the cementation of the coarse material of the ancient fill, also incorporating many potsherds (Figures 2A and 3). The deepest beachrock slab, 11 m × 6 m in size, has been formed at the SE side of the promontory. The depths of the top and base at its seaward end are 1.80 m and 2.30 m, respectively. The intermediate beachrock phase is represented by an elongated slab, 14 m × 2 m, on the SE coast of the promontory. The top and the base of the seaward end of the slab are at -1.25 m and -1.40 m, respectively. On the west coast of the promontory, the shallower phase of the beachrock appears as an elongated slab of total length 35 m, width up to 2 m and thickness 0.40 m.

The depths of the top and base of its seaward end are 0.27 m and 0.65 m, respectively. The depths of the seaward ends of the three beachrock phases on the coast of the Ayia Irini promontory coincide with the respective depths of the three younger sea level stands which have been defined for the entire area of the Northern Cyclades (Figures 4 and 5).

Archaeological markers

The submerged rock fill occupies the entire sea front of the promontory. It is 220 m in length and up to 30 m in width (Figures 2A and 3). It seems that it was constructed to gain space for the construction of the seaward section of the Great Fortification. The rock fill is about 2.80 m high and is made up of stones, 0.20 m - 0.40 m in average size. The upper surface of the seaward south edge of the rock fill is at -2.65 m to -3.0 m, while the sea floor at the foot of the fill is at -5.0 m to -5.75 m. The lower course of the fortification wall, in the southern central section of the rock fill and within 4 m from its seaward end, consists of blocks 1.50 m × 1.0 m in size. The upper surface of the fill at the foot of the fortification wall is at -2.65 m, and the upper surface of the blocks at -2.30 m. On the rock fill, between the depths 3.70 m and 4.10 m, an erosion marine platform 6.50-m-wide has been formed. A second erosion marine platform is formed between -3.55 m to -2.65 m and -2.55 m to

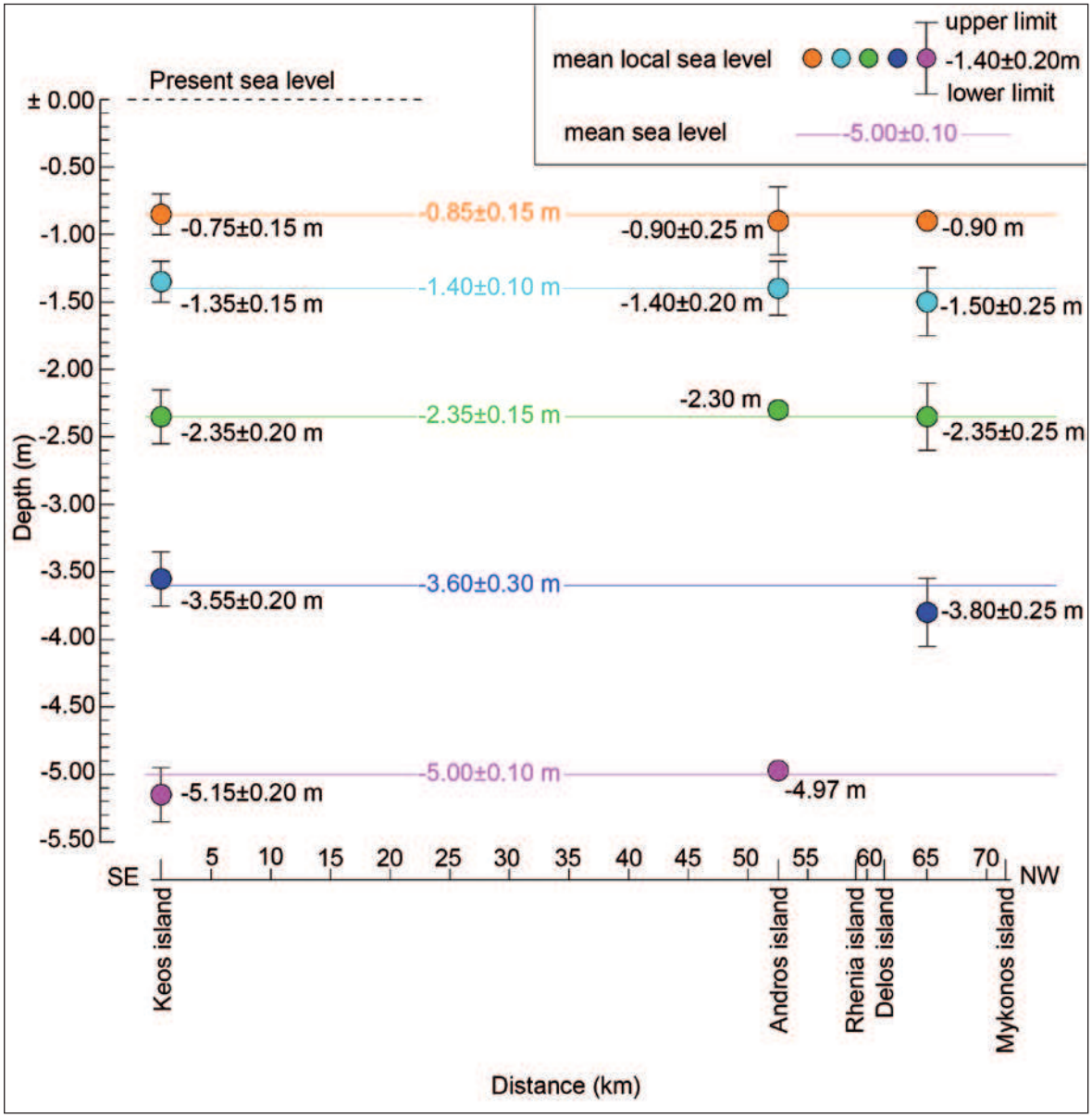

Figure 4: Correlation of the mean local sea level stands.

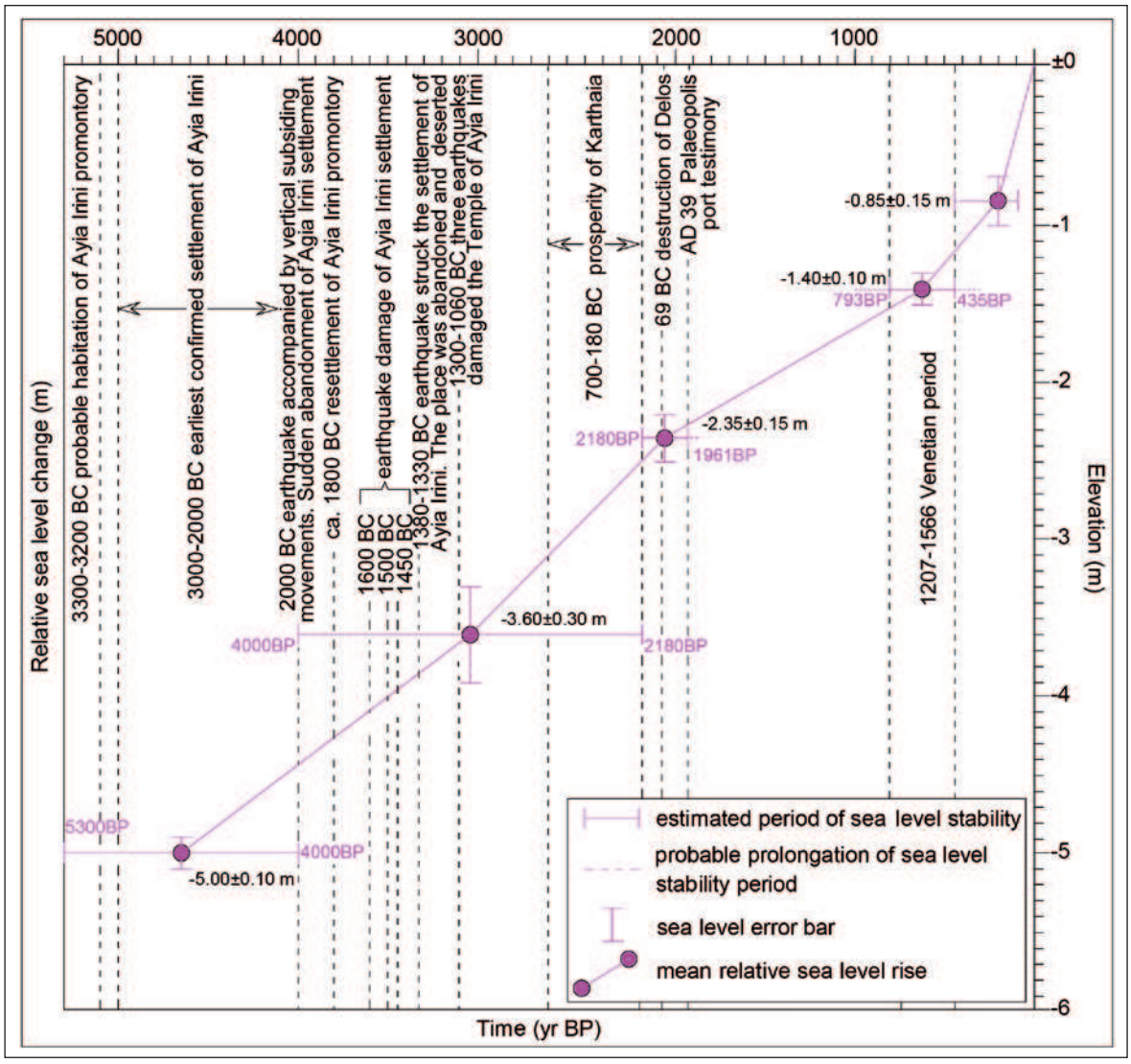

Figure 5: Relative sea level for the Northern Cyclades.

-2.30 m, and a third between -2.0 m and -1.60 m to -1.15 m. However, the shallower marine platform is formed at the depth -0.40 m to -0.50 m (Figures 2A and 2B).

The rise of the brackish groundwater table, which is in hydraulic communication with the sea, flooded the relics of the buildings and the water supply installations of the eastern and western side of the prehistoric settlement, respectively. The foundations and parts of the superstructure had been constructed at various elevations below the current sea level (Figures 3, 6 and 7). Tomb 58 is located on the eastern edge of the settlement, near the foot of the retaining wall A. The cover slabs were encountered just below the modern sea level and the side walls reach bedrock at about -1.20 m to -1.40 m (Figure 2A; Caskey, 1971). Soundings performed on the eastern side of the long, straight retaining wall A, showed that its base is at approximately -0.50 m, and below that level there are older walls, one of which reached bedrock at -2.53 m (Figure 2A; Caskey, 1971). Archaeological investigation revealed that Wall A had been fitted around another early retaining wall, made of huge blocks. This very heavy structure of cyclopean masonry runs south-eastwards and its base is at approximately -0.85 m to -1.50 m (Figure 2A; Caskey, 1971). Caskey (1971) states that the bulk of the excavations of the Temple were carried out below water level with constant pumping. In the south corner of Room 6, the bottom of the southwest wall of the building, named Wall A, was at -1.55 m, and the bottom of the partition wall between Rooms 5 and 6, named B, at -1.65 m (Figure 6). The earliest destruction is marked by fallen stones in a layer at -1.20 m. Above

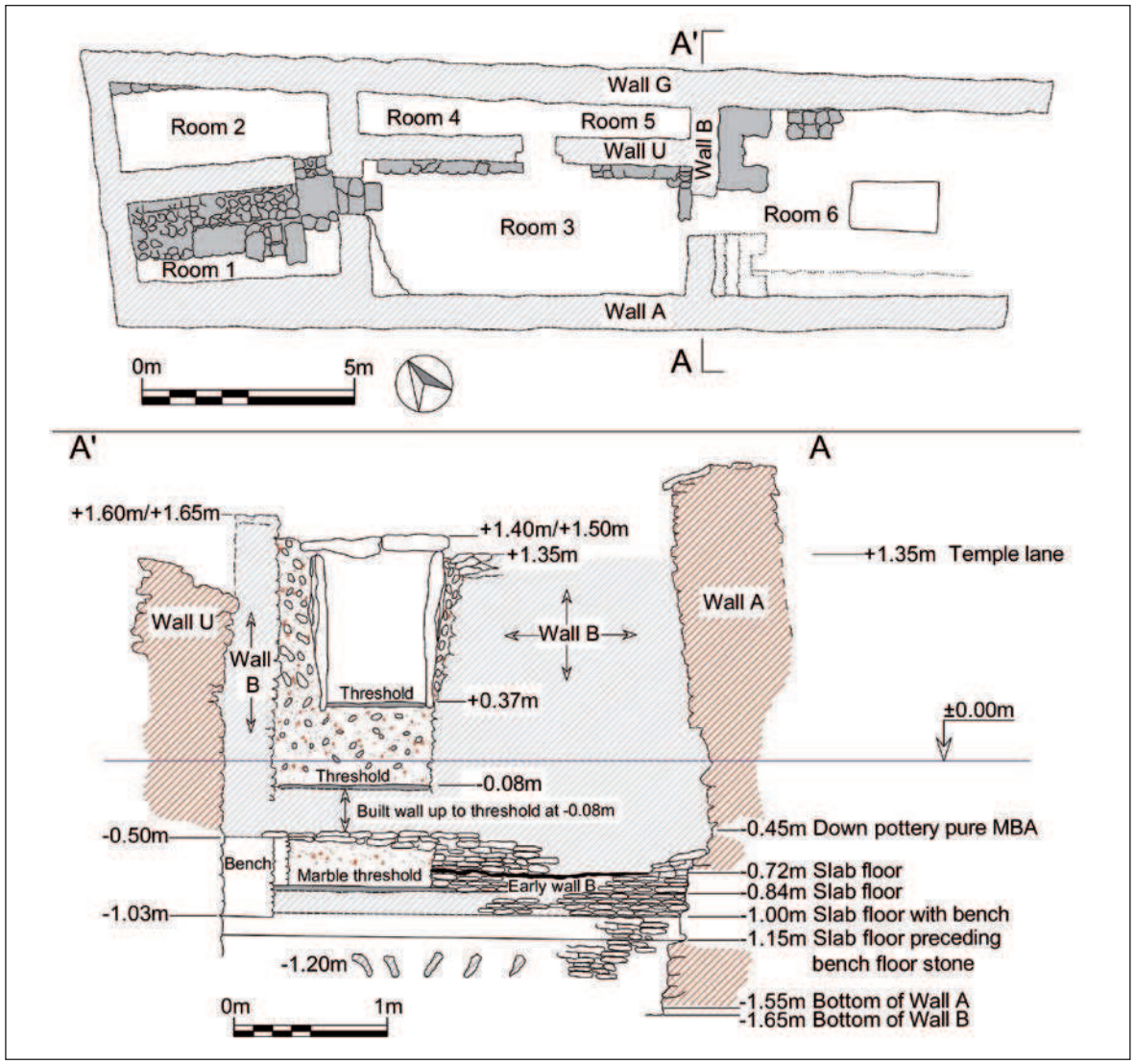

Figure 6: Plan and cross section of the Middle Bronze Age Temple (from Caskey, 1998).

this, a floor with flagstones was found at -1.03 m and with it evidence of a doorway to Room 3, namely a white marble step or threshold slab at -0.84 m that had to be built up as the floorlevels rose. Also, the bench beside the partition wall between Rooms 3 and 5, called Wall U, was covered. All of this activity took place during the Middle Bronze Age. In Room 3, Caskey (1971) discovered that the inner face of Wall A extended to below -1.90 m, where the flow of water made further excavation impractical. Fallen stones in the room indicated a time of destruction such as is evidenced in Room 6. He also observed a stepped bench against the NE wall of the building, named Wall G, with a floor-level about -1.10 m. Traces of burnt material, suggesting fireplaces rather than a conflagration, were found on this floor in the middle of the room, which may indicate continuing religious practices. In Room 3 the pottery found up to -0.60 m was Middle Helladic (Figures 3 and 6; Caskey, 1971 and 1981; Caskey, 1998).

The earlier water supply spring is located in the western sector of the settlement, just to the east of the early fortification tower. It is a deep irregular cavity in the bedrock and a subsequent building of the Early Bronze Age had been constructed over it. Although it is now below sea level and filled with salt water, it probably once received a flow of fresh water (Figure 2A; Caskey, 1981). The Spring Chamber for the water supply of the settlement (Caskey, 1971) is located in the western sector of the settlement outside the Great Fortification wall (Figures 2A, 3 and 7). Thirteen stone steps descend from the outer face of the wall to an underground chamber. The chamber is irregular in plan and its sides were constructed of very

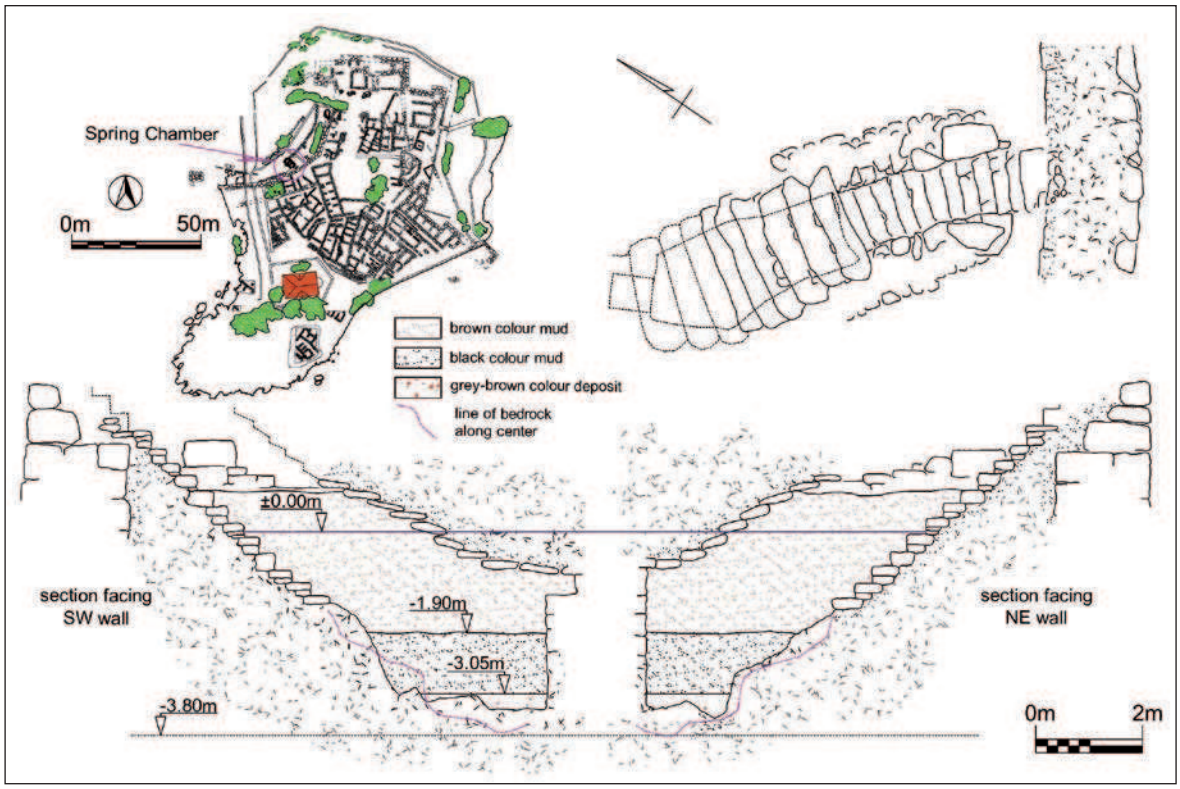

Figure 7: Location, plan, and cross-sections of the Spring Champer (modified after Caskey, 1971).

long slabs, overlapping in series. The lowest step rests on bedrock, which therefrom slopes steeply and irregularly downward, and at the bottom there are natural hollows and fissures. The Chamber is now filled with salt water up to sea level. According to archaeological observations (Caskey, 1971), it was found filled with accumulated mud which varied in colour at different depths. To the depth of about 1.90 m, the filling was brown with fragments of jars, near the top of the filling, dated at the first half of the 4th century B; and small pots and sherds of LH IIIA2 style (1350-1300 BC) in the lower part. From -1.90 m to -3.05 m the accumulations were black, and below this to the bottom of the deepest hollow at -3.78 m there was a lighter grey-brown deposit with sand, gravel, and stone fragments. In the lower black and grey-brown deposits there were sherds of LM IB/LH II (1500-1450 BC) wares, jugs, and cups (Figure 7).

Archaeoseismology of the site

Archaeological data enable us to identify several phases of occupation - abandonment of the settlement, and construction, destruction, reconstruction and repair of the buildings, which together with dated macroseismic effects, such as collapsed walls, cracks, displaced blocks, piles of fallen stones, and debris, allowed us to define the past earthquakes that affected Ayia Irini. The sudden abandonment of the settlement in the Early Bronze Age, Period III of Agia Irini (2200-2000 BC) could be attributed to an earthquake that was accompanied by vertical subsiding movements. As a result, the sea level rose by 1.30 m, flooding a considerable coastal section of the promontory and forcing the inhabitants to flee the site. Approximately one century later, in the Early Bronze Age, Period VI of Ayia Irini (1600-1500 BC), a sequence of strong earthquakes that preceded and followed the eruption of the Thera volcano *ca*. 1600 BC, caused damage to the Great Fortification wall, House A, and other structures. The fortification wall at first had a roughly uniform thickness of about 2.0 m. After the collapse, it was reconstructed with a new front further out, but without removing the fallen debris at the foot of the old wall or sinking the new foundations deeper. Therefore, another collapse left a new group of blocks scattered at a higher level near the modern ground surface (Caskey, 1971 and 1981).

In the Late Bronze Age, in the Mid-Period VII of Ayia Irini (1500 BC), a probable earthquake caused damage to House A, and many cellar rooms were abandoned, as evidenced by repairs and additions to the buildings. Another earthquake in the Late Period VII of Ayia Irini (1450 BC) destroyed House A and marked the end of this phase of the settlement. The

towers of the fortification wall were seriously damaged, as evidenced by cracks, displaced blocks, and heaps of fallen stones along the north side. However, the extent of the destruction caused by the LM IB/LH II (1450 BC) earthquake is unclear, although it destroyed many buildings. Parts of the walls either survived or were repaired soon afterwards, since most of the fallen stones lay in a layer containing imported Mycenaean wares of LH IIIA style (1400-1300 BC; Caskey, 1971 and 1981). In Late Bronze Age III, Period VIII of Ayia Irini (1400-1100 BC), an earthquake probably struck the settlement between 1380 BC and 1330 BC. The direct supply of spring water was cut off and most of the houses were abandoned (Caskey, 1981). After the desertion of the settlement, an earthquake, which probably occurred at about 1300 BC, damaged the Temple, which then fell into disuse, as evidenced by the relatively small amount of pottery of the LH IIIB period (1300-1190 BC; Caskey, 1981). Caskey (1981) has also recognized at least two later phases of the Temple represented by successive levels that indicate interruptions by damage, probably caused by subsequent earthquakes between 1200 BC and 1060 BC.

Comparison and dating of geomorphological and archaeological indicators

The functional elevation of the prehistoric rock fill is defined between the depths of 4.10 m and 3.70 m. Within this depth an erosion marine platform has been formed on the rock fill, which corresponds to the sea level stand of -3.60 ± 0.30 m. This stand has been established in the area of the Northern Cyclades and is dated to between 4000 yr BP and 2180 yr BP. At the depth of 3.78 m to 3.80 m was found the discharge level in the Spring Chamber, which supplied the prehistoric settlement with water. At the same depth was probably the discharge level of the older spring that was located some 10 m to the NW. The depth of the foundations, floors, and superstructures at the eastern end of the settlement below the present sea level also reflects the magnitude of sea level change. The deepest foundation of the retaining wall at the east end of the settlement was located at a depth greater than 2.50 m, while foundations, floors, and parts of the superstructure of all of the Bronze Age phases of the Temple are below the modern sea level, up to the depth of 1.60 m.

The second erosion marine platform formed on the rock fill between -3.55 m to -2.65 m and -2.55 m to -2.30 m corresponds to the next youngest sea level stand of -2.35 ± 0.15 m, which in the area of the Northern Cyclades has been dated to between 2180 yr BP and 793 yr BP. This sea level stand also coincides with the depth of 2.30 m of the seaward end of the deepest beachrock slab situated on the east coast of the promontory.

The depth of the intermediate beachrock phase between 1.25 m and 1.40 m, and of the third erosion marine platform formed on the rock fill between 2.0 m and 1.60 m to 1.15 m, is consistent with the sea level stand of -1.40 ± 0.10 m that has been dated to between 793 yr and about 435 yr BP. The shallower erosion marine platform is formed at -0.40 m to -0.50 m. On the west coast of the promontory, at a depth of 0.65 m is also located the younger beachrock phase. This depth corresponds to the younger sea level of the Northern Cyclades at -0.85 ± 0.15 m which changed in the last 400 years.

Palaeogeographic reconstruction

The palaeogeographic reconstruction of the promontory and the prehistoric settlement of Agia Irini was based on the evaluation of the geomorphological, archaeological, and historical markers of sea level and its changes in the study area, and their integration with the established and dated Upper Holocene sea level stands in the wider area of the Northern Cyclades.

From the end of the Neolithic (3300 BC) to the end of the Early Bronze Age (2000 BC)

During the period between the end of the Neolithic and the end of the Early Bronze Age the sea level was at -5.0 ± 0.10 m lower than at present. The shore of the Gulf of Ayios Nikolaos was wider by 15 m to 35 m along the steep rocky north and south coast, and up to 140 m in the shallow sandy coasts of Vourkari (140 m), Gialiskari (120 m), and Livadi (100 m) bays (Figures 1D, 8A and 8B). The promontory of Ayia Irini was a coastal hill, wider by approximately 35 m than today, maintaining a narrow sandy coast at its southern extent, and surrounded from the east and west by the lowland end of two small valleys (Figure 8B). During the same period, on the headland of Kephala, on the north coast of Keos, flourished a Neolithic settlement with stone-built houses on the southern sheltered side of the promontory; a cemetery above the narrow sandy shore of the bay; the significant production of goods and handicrafts; and communication with the nearby mainland and the Aegean islands. The settlement was suddenly abandoned for some unknown reason 100 - 150 years later and most likely was transferred to the location of Paoura, about 2.0 km to the east, beyond the Gulf of Otzias, on an imposing rock outcrop rock protected from pirates (Coleman, 1977). Although no

trace of buildings has been found on the coastal ridge of Ayia Irini, Neolithic people occupied the site on a temporary basis, perhaps stopping on their voyages in a sheltered location, where fresh water was available (Caskey, 1981).

For a long time there is no evidence of human presence until the occupation of the ridge and the establishment of the first settlement of Ayia Irini in the Early Bronze Age. It seems to have grown dynamically, and evidence of this period is abundant. Lower courses of walls, well preserved, have been found in several areas that mark the clustered rooms of permanent buildings, which with time were modified, rebuilt, and expanded. New inhabitants were added peacefully and the settlement prospered. Except for the southern Greek mainland, transactions reached Anatolia (Caskey, 1971 and 1981). However, the site was suddenly abandoned without violence. The abrupt or short-term change in the sea level forced the inhabitants to flee the location. The sea level rose by 1.40 m, from -5.0 ± 0.15 m to -3.60 ± 0.30 m, and a significant part of the headland, of about 30 m length, was submerged below sea level (Figure 8C).

From the end of the Early Bronze Age (2000 cal. BC) to the mid-2nd century BC

At the beginning of the Middle Bronze Age (2000 BC) the sea level was at -3.60 ± 0.30 m. The sea transgressed the land, turning the rocky ridge of Ayia Irini into a headland and the lowland alluvial terrain that surrounds it from east and west into shallow bays (Figure 8C). After one or two centuries from the sudden abandonment of the site, at about 1900-1800 BC, the promontory was resettled. The landward side of the settlement was fortified. The earlier system of fortifications, in the western edge of the settlement, is equipped with a curving tower beside a gateway. Streets inside the town converged upon the gate, from the threshold of which ran a path sloping downwards towards the area of the spring. Several phases of habitation are represented by house walls and other structures, which succeeded one another while the early fortifications were in use. A Temple was built, and grave plots were established along the eastern and western flanks of the town. The town had grown in size and prosperity (Caskey, 1971 and 1981). The first circuit of fortifications no longer sufficed and therefore towards the end of the Middle Bronze Age (1600 BC) new fortifications were built – greater structure that surrounded the settlement, which also protected it from the sea. However, space is extremely limited and the buildings extend to the coastline; moreover, the rocky terrain is steep enough to enable the coastal part of the fortification wall to be constructed on it without specific technical interventions. They therefore constructed the coastal rock fill that surrounds the promontory (Figure 9A). It had a width reaching 30 m, a thickness of 2.50 m, and was formed by the accumulation of some 10,000 m^3 of stones. Relics of the wall are located at the south end of the rock fill, within 4 m of its seaward end. During this period the sea level was 0.30 m to 0.70 m lower than the top of the rock fill, and the base of the wall was 1.50 m to 2.0 m higher than the then sea level. The landward north side of the Great Fortification wall, constructed in several phases, had a general E-W orientation between the two rectangular towers. Subsequently it was extended to the south in both the eastern and western limbs in SE and SW directions, respectively; and terminated in two towers which today are partially submerged. The settlement was approached by land from the east, while the main gateway is at the eastern side of the wall (Figure 9A). This period of prosperity continued without interruption into the Late Bronze Age (1600 BC-1450 BC).

Ayia Irini is still an important harbour – station in the Aegean. At the beginning of this period, Ayia

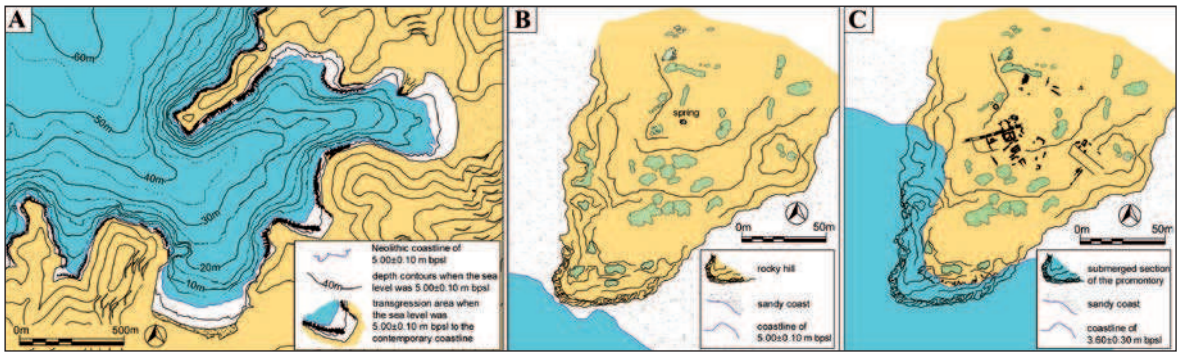

Figure 8: Figure A: Palaeogeographic reconstruction of the Gulf of Ayios Nikolaos; Figure 8B: Palaeogeographic reconstruction of the promontory of Ayia Irini when the sea level was -5.00 ± 0.10 m lower than at present, between 5300 yr BP and 4000 yr BP and Figure 8C: when the sea level changed from -5.00 ± 0.10 m to -3.60 ± 0.30 m, at about 4000 yr BP.

Irini suffered serious damage from the earthquakes that preceded and followed the eruption of the Thera volcano (*ca.* 1600 BC). The fortification was repaired and reinforced, and a large building project was implemented. Most of the major buildings were constructed during this period. House A, a two-storey building with many rooms and cellars, is almost surely the largest and probably the most important single establishment in the town of the Late Bronze Age. The city had a well-designed street layout, paved roads, and a sewerage system. In the Mid-Period VII of Ayia Irini (*ca.* 1500 BC) a probable earthquake caused damage to House A, and to many cellar rooms which were then abandoned, as evidenced by repairs and additions to the buildings. A heroic tomb and tumulus and an elegant little structure beside the outer face of the circuit wall, near the main gateway, indicate that safety measures were declining towards the end of this period (1500-1450 BC). It seems that attacks by enemies were no longer to be feared. The Minoan Thalassocracy must have imposed peace in the Aegean (Caskey, 1971 and 1981).

Subsequently, however, there was a major disaster. The town and the fortification wall were razed to the ground by the 1450 BC earthquake. Pre-earthquakes warned the inhabitants of the impending catastrophe, causing them to flee. A few returned to rebuild amongst the ruins. This was the period of Mycenaean domination that was terminated by a severe earthquake between 1380 BC and 1330 BC. The settlement was abandoned and the site was deserted. The Temple stood alone on the promontory, still serving as a sacred place, and was restored several times until the Hellenistic period (Caskey, 1971 and 1981). The sea level continued to remain constant at -3.60 ± 0.30 m during the 7th - 6th century BC when the four city-states of Keos Island were established: Ioulis, in the inland of Keos, and the other three town – harbours, Koressos on the NW coast and Karthaia and Poieessa on the SE and SW coast. The great Karthaia in the Poles bay, with a sandy shore about 40 m wider than today, was equipped with a breakwater 160 m long and 30-35 m wide. It started from the shoreline, proceeded in a SE direction, and terminated 10 m before a small island in the middle of the bay, thus creating a channel. The breakwater was constructed by filling the intervening spaces of the bedrock occurrences with boulders and slabs. The presence of potsherds and tiles, and the base of a large bronze vessel stuck to the surface of the breakwater, is clear evidence of human activity in antiquity. With a sea level stand at -3.60 ± 0.30 m, the ancient breakwater protruded from the then sea level by 0.20 m to 1.50 m, and the depth of the channel between the end of the breakwater and the islet was about 2.0 m (Mourtzas and Kolaiti, 1998; Mourtzas, 2010). In the bay of Otzias, few kilometers east of the settlement of Ayia Irini, there is a dock which is submerged at the present day. It is dated to between 600 BC and 200 BC (Spondylis, 1998) and consists of a superstructure 2.30 m high which was carefully constructed with elaborate schist slabs on a rock fill

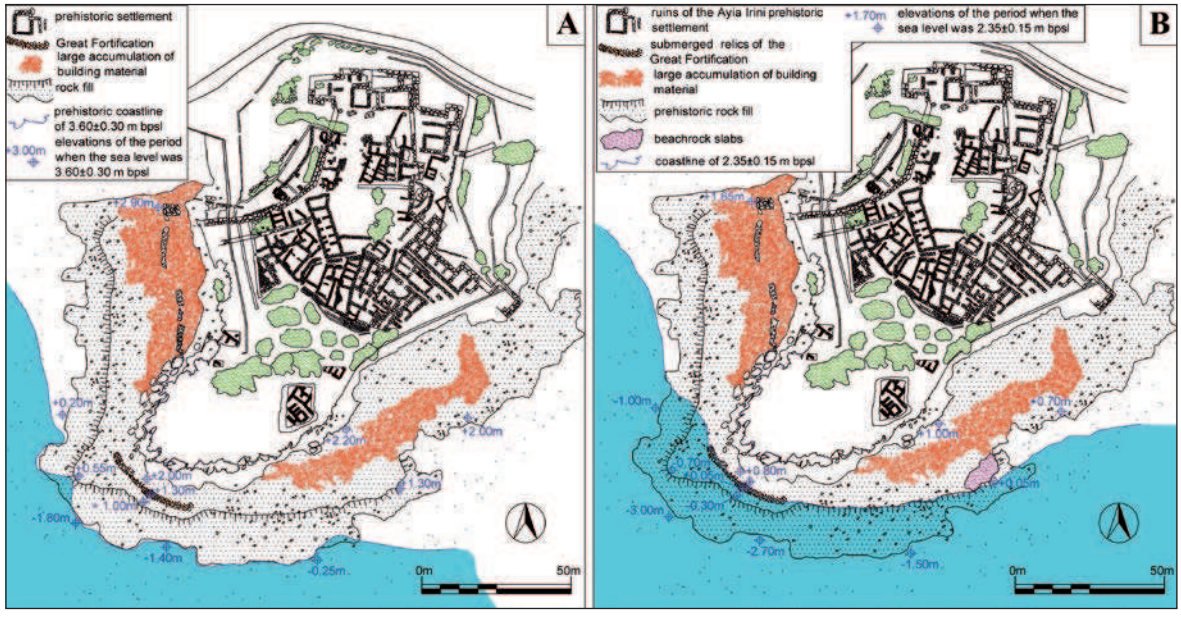

Figure 9: Palaeogeographic reconstruction of the promontory of Ayia Irini. Figure 9A: when the sea level was -3.60 ± 0.30 m lower than at present, between 4000 yr BP and 2180 yr BP; Figure 9B: When the sea level was -2.35 ± 0.15 m lower than at present, between 2180 yr BP and 1960 yr BP, and may have been prolonged to 793 yr BP.

0.70 m high resting on the sea floor. The depth of the base of the superstructure, which coincides with the top of the rock fill, is at -3.70 m. This is exactly the depth that defines the functional level, since in antiquity they never built below water level. The sea level seems to have remained constant until the end of the period of prosperity of Karthaia and the other cities of the island. From the mid-2nd to mid-1st century BC, Keos and Karthaia are notably absent from any written historical reference (Simantoni-Bournia *et al.*, 2009). At about the end of the Hellenistic period the sea level rose by 1.25 m in the area of the Northern Cyclades (Figure 9B; Mourtzas, 2012).

The mid-2nd to certainly the mid-1th century AD (39 AD), or probably to the beginning of the Venetian occupation period (2180-1960 or 793 (?) yr BP)

The sea level was now at -2.35 ± 0.15 m and the southern part of the rock fill and the ruins of the fortification wall on it were flooded (Figure 9b). What still remained of the imposing coastal fortification wall after at least four strong earthquakes and the passing of a millennium was/is the lower course of the wall masonry and building stones scattered around. The upper surface of the rock fill was/is now at -0.30 m to -0.70 m, while the ruins of the wall just protrude above the then sea level. However, the greater part of the rock fill to the east and west of the promontory still remains above the then sea level by 0.70 m to 1.70 (Figure 9B). The ruins of the abandoned settlement of Ayia Irini are probably covered with soil that accumulated over time. Since the new sea level remained stable, the earliest beachrock phase was formed in the intertidal zone of the SE coast. The rise of the groundwater level, together with the change in sea level, caused the salinization of the spring and the flooding of its Chamber. The marine transgression also caused major changes to the morphology of the Gulf of Ayios Nikolaos; for example, the coasts of Vourkari, Gialiskari and Livadi bays retreated inland by 50 m to 70 m. However, the impact of the change was more significant on the SE coast than the effects caused to a settlement which was already deserted. The coast of Karthaia retreated by 15 m to 20 m and the large breakwater of the harbour was submerged by 0.80 m to 2.50 m (Mourtzas and Kolaiti, 1998; Mourtzas, 2010). At this new sea level stand seems to have been constructed the rock cut slipway on the north side of the Poieessa bay, where the ancient acropolis is located (Blackman *et al.*, 2014).

The Venetian occupation period of the Cyclades (1207-1566 AD, 793-435 yr BP)

The change in sea level by 1.0 m produced a new stand of approximately -1.40 ± 0.10 m. This occurred during an unspecified period of time between the mid-1st century BC, when the previous sea level (-2.35 ± 0.15 m) made functional the artificial harbour of ancient Palaeopolis in Andros (Mourtzas, 2007;

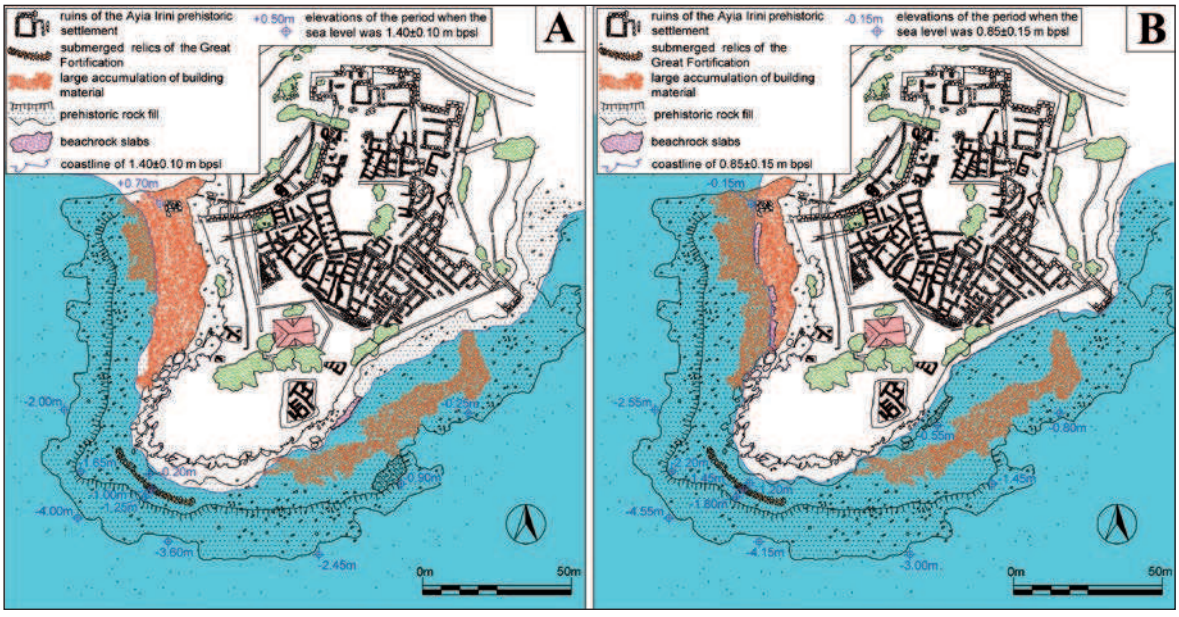

Figure 10: Palaeogeographic reconstruction of the promontory of Ayia Irini.
Figure 10A: when the sea level was -1.40 ± 0.10 m lower than at present, between 793 yr BP and 435 yr BP;
Figure 10B: when the sea level was -0.85 ± 0.15 m lower than at present, from 435 yr BP to the present day.

Petrocheilos, 2012), and the Venetian period to which are assigned the coastal constructions in Nimporio (Chora Andros) that were built at this new sea level stand. In Ayia Irini almost the entire rock fill on the south and east side of the promontory, and a considerable part of the west side, lies below the sea level. The surface of the fill on the southern front is submerged at -1.80 m and the relics of the fortifications built on it are at -1.0 m. On the east coast the surface of the fill is submerged together with an older beachrock phase at -0.50 m to about -1.0 m (Figure 10A). The water level in the Spring Chamber rose by one additional meter, while the buildings at the eastern end of the settlement, such as Tomb 58, the earlier and part of the later phase of the retaining wall A, and the foundations and the lower course of the masonry of the Temple, were found below the water table. However, the towers at the end of the western and eastern limb of the landward fortifications still remain above the then sea level. On the west coast of the island, in the bay of Poieessa, a large section of the inclined rock-cut floor of the slipway, whose functional level was at -2.55 m, was submerged below sea level. After the end of the Venetian occupation period the sea level changed by 0.55 m and stabilized at -0.85 ± 0.15 m, further immersing the rock fill and the ruins of the overlying fortifications (Figure 10B).

The last 400 years

During the last 400 years, the relative sea level rose by 0.85 ± 0.15 m. As a consequence, the ancient rock fill was submerged to its present depth, with its top being up to -3.0 m, and the remains of the overlying fortifications up to -1.0 m. The rectangular towers at the end of the western and eastern limbs of the landward fortifications were submerged at -0.70 m to -1.0 m (Figure 2A). The groundwater level increased in parallel, inundating the Spring Chamber, and flooding the ruins of the eastern side of the settlement. The small Christian church of Ayia Irini was built in 1912 in the site of an older church, thus continuing the 4,000 years of religious history of the site. From 1960 to 1976, under the direction of J. Caskey, the University of Cincinnati excavated the ancient settlement, highlighting its great past.

Conclusions

Previous archaeological investigations of the prehistoric settlement of Ayia Irini have disregarded a considerable part of the prehistoric settlement and a remarkable engineering project of the Bronze Age, which today are submerged below sea level. This paper has attempted to determine the position of the shoreline during the various periods of sea level stability, the timing of the abrupt changes, and the extent of the marine transgression. During the interval of human presence on the promontory, the people of the Early Bronze Age experienced an abrupt change in sea level 4,000 years ago, which seems to have forced them to abandon the coastal site, after 500 years of occupancy. When the promontory was resettled, there followed a long period of sea level stability of about 600 years, and only the leveling of the city between 3380 BP and 3300 BP caused the permanent abandonment of the area. The fill part of the coast of an already-deserted settlement was gradually submerged by the three changes in sea level that followed. A future systematic underwater survey will almost certainly clarify the construction phases of the ancient rock fill and the overlying fortification walls, thereby documenting an important part of the history of the settlement, which currently is missing.

Acknowledgments

The study of sea level changes in the entire Northern Cyclades began three decades ago, with the archaeological survey of Ancient Karthaia, under the direction of Lina Mendoni, Archaeologist, PhD. It was continued within the research project "Neotectonic deformations of the Aegean islands during the Upper Holocene and their impact on archaeological sites and monuments" under the direction of Paul Marinos, Professor NTUA, funded by the General Secretary of Research and Technology of the Ministry of Industry and was licensed by the XXI Ephorate of Prehistoric and Classical Antiquities of the Cyclades. There then followed an archaeological investigation of the ancient Palaeopolis in Andros under the direction of Lydia Palaiokrassa, Professor NKUA. The underwater survey of the ancient harbour of Palaeopolis was licensed by the Ephorate of Underwater Antiquities of the Ministry of Culture. The palaeogeographic research of the Ayia Irini promontory, carried out in parallel with the archaeogeological study of Ancient Karthaia and the survey of the coast of Keos, was strongly encouraged by Miriam Caskey, Archaeologist ASCSA. The preliminary results were presented at the International Symposium "Keos-Kythnos: History and Archaeology", 22-25 June 1994. We thank them all.

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