Archaeological indicators of relative sea-level changes in the Attico-Cycladic massif: preliminary results

BAIKA, K.[1]

ABSTRACT

Recent underwater archaeological investigations and marine geological surveys in Attica and the Cycladic islands provide solid archaeological markers for the estimation of the RSL fluctuation since prehistory. The area under study, the Attico-Cycladic massif with small tidal range, relative geo-tectonic stability and with ample archaeological remains that bear witness to past sea levels, provides an excellent laboratory for examining various contributions to local relative sea level changes. As a result, the study of the field data demonstrate a severe RSL change of ca. 4.00-6.00m or more around 4000 BC, ca. -3.00 - 3.5m since Late Bronze Age/Mycenaean period (1550-1100 BC) and ca -2.50-2.80m (±0.30) since Classical/Hellenistic period (500-30 BC). The combined data can be used to correlate predictive sea-level curves, refine glacio-hydro-isostatic modelling approaches, and give insights for the prediction of future sea-level trends. Moreover, the results can advance the landscape reconstruction of Attica and the Cyclades in Classical antiquity and help inform current and developing environmental policy and cultural management decisions on coastal and submerged archaeological sites in the Central Aegean.

Keywords: Aegean, Attica, Cyclades, sea-level change, underwater archaeology, submerged archaeological sites

1. INTRODUCTION

The combined forces of sea-level rise, sedimentation/siltation, progadation of coastlines, coastal erosion, tectonics and anthropogenic impact have resulted in a transformed coastal landscape, that underwent significant modifications since prehistory. Archaeological markers of this constant transformation include submerged and/or eroded settlements, inundated or uplifted sites, silted or submerged harbours, and other structures. Moreover, geomorphological evidence that can be read in the field can be put in historical context with the help of precise and well-dated archaeological indicators. New archaeological data from submerged sites are elucidating the coastal paleogeography of the Central Cyclades and the Aegean, offering direct archaeological markers of RSL changes since antiquity.

The reconstruction of the palaeogeography of ancient coastlines has been recently promoted by ambitious interdisciplinary projects all over the Mediterranean (Marriner-Morhange 2007; Marriner 2009; Keay et al. 2006; Nieto et al. 2005; Brückner et al. 2009; Deviliers et al. 2007) and in the northern Europe (Flemming 1998; Bailey and Flemming 2008). In Greece and the Aegean, several studied have focused mainly on the Peloponnese, South Aegean and Crete, the Ionian islands, Euboea and Aegean Turkey (Negris 1904; Hafemann 1960; Flemming et al. 1973; Blackman 1973; Van Andel and Shackleton 1982; Flemming- Webb 1986, with bibliography; Lambeck 1996; Kelletat 2005; Vött 2007; Brückner et al. 2009). The evidence lead to different interpretations and sea-level curves. Yet, precise data for the Central Cyclades region was dispersed or lacking, due to the limited underwater research and geophysical prospection undertaken. Recently investigated harbour and coastal archaeological sites in the Aegean and more specifically in the Attico-Cycladic region, have provided new direct archaeological evidence of RSL changes. Therefore, the aim of this paper is to reconsider all available and new field observations in order to

[1] *Dept. of History, Archaeology and Cultural Resources Management, University of the Peloponnese, kbaika@gmail.com*

create a preliminary updated database of RSL geoarchaeological indicators for the Attico-Cycladic zone in the Late Holocene. More precisely, the objective is to a) assemble all available field data and reassess their quality as RSL markers in order to proceed to a regional synthesis b) present well-dated and precise archaeological information that could be used to correct sea-level predictions and refine modelling estimations, study patters on neo-tectonism and promote the study of past and future predictions of sea-level trends, e) explore directions for future underwater geoarchaeological research in the area, and f) inform current policies in managing the coastal environment of the Aegean Sea for protecting submerged or silted archaeological sites.

2. ARCHAEOLOGICAL FIELD OBSERVATIONS AND PREDICTIVE MODELS

The study of sea-level fluctuations in the Mediterranean is based on the assessment of archaeological and geomorphological data and combined interpreting methodologies, essentially mathematical modelling. Different sea-level curves have been produced in regional and/or global scale by high-resolution numerical models developed in recent years in an attempt to estimate glacio-hydro-isostatic changes (Lambeck-Purcell 2005; Stocchi-Spada 2009; Peltier 2004). While mathematical modelling approaches can be valuable tools to use in areas where no data is available, well-dated archaeological field observations with a precise relation to ancient sea-level can provide precise constraints on predictive sea-level curves. On the other hand, the correct assessment of field data is also difficult. Field data (archaeological and geological) are usually scattered or of approximate value, while, on the other hand, rarely do we have a continuous tectonic record for a single site. Thus, cooperation between modelling approaches and field work data is essential (Pirazzoli 2005).

As a result, recent studies have attempted to verify the degree of the accuracy of produced curves confronted with observational data in the Mediterranean French coast, the Italian peninsula and the Adriatic, Israel and Aegean Turkey in order to refine the modelling parameters (Lambeck et al. 2004a, 2004b; Antonioli et al. 2007, 2009; Scicchitano 2008; Lambeck and Bard 2000; Sivan et al. 2001, 2004). Moreover, numerical models have also been used in order to separate glacio-hydro-isostatic changes and separate them from tectonic contributions (Lambeck 1995). Any significant discrepancies between predictions and observations are thought to reflect mainly tectonic contributions. In consequence, field data have been used in order to abstract vertical tectonic movements (Antonioli et al. 2007; Lambeck et al. 2004a) or discuss discrepancies and consistencies (Pirazzoli 2005).

3. PREVIOUS STUDIES IN THE AEGEAN

For the Aegean Sea, the pioneers who produced estimations on sea-level fluctuations based on archaeological evidence were Ph. Negris (1904), D. Hafemann (1960), N.C. Flemming, D.J. Blackman (1973, 2005b) and P. Pirazzoli. Negris (1904) concluded from a survey of submerged ruins in Eastern Mediterranean, mostly in the Aegean, that the sea had risen 2.5-3m in the last 2000 years and 3.5m in the last 2500 years. Hafemann studied coastal sites with particular emphasis on the Eastern Mediterranean, where 37 sites were examined, 21 in the Aegean. For the Aegean, he concluded an eustatic rise of sea level from 2.5-2.8m over the last 2500 BP, i.e. since the Classical period, and a rise from 1.7-2.2 since 2000 BP (Hafeman 1960: 195).

However, there is a controversy among the scientific community as to whether the observed RSL changes in the Mediterranean should be explained mainly by glacio-hydro-isostasy and/or by local neo-tectonism. Flemming after investigating 202 ancient harbour site in eastern Mediterranean (excluding the Cycladic plateau) and 175 independent estimates, he estimated an overall eustatic component of <0.5m over the last 2000-3000 years and produced a curve of relative stability (±0.30 up to 2.0ka) for the Mediterranean. According to him and his colleagues, observed coastal submergence or emergence is due to neo-tectonic activity (Flemming 1969;

Flemming and Webb 1986).Lambeck (1995) sought to separate the eustatic, isostatic contribution from tectonic factors of RSL. He suggested that the observed submergence on the coast of Greece and western Anatolia could be largely explained by isostatic processes, rather than severe tectonic process as Flemming proposed (1978) (Lambeck 1995: 1042). In his work in the Aegean, where he tested his hydro-isostatic model due to availability of field data, he advocated that at 18000 BP the sea level was 110-130m lower, at 10.000 BP was -44-60m, and at 6000 BP the sea-level was 2-8m below present-day level and for 2000 BP at -1.00-1.75m (Lambeck 1996: fig. 4). The efficiency of his modelling approach was questioned by Pirazzoli, who concluded to a nearly stable global eustasy over the last 6000 years, while according to him and his colleagues, the relative sea-level changes in the Eastern Mediterranean must be attributed mainly to local tectonism (Thommeret et al. 1981; Pirazzoli et al. 1982; Pirazzoli 1986, 2005).

4. THE ATTICO-CYCLADIC REGION

The Attico-Cycladic geotectonic region is a promising zone for the study of RSL fluctuations. Firstly, the plateau is characterised by relative absence of earthquakes and thus limited neotectonic activity. Moreover, areas close to the periphery of the region show minimum or no uplift during the last few thousand years (Papazachos 1990; Poulos et. al 2009). Being relative stable, the area under study can provide a significant parameter in calculating vertical movements. Secondly, the area is a small tidal-range environment (±0.25-0.30m), thus the observational evidence can often be related precisely to mean sea level (based on the study of tidal gauge databases in Syros and Piraeus, Andritsanos et al. 2000).Moreover, the study of RSL rates in this region could give insights for the prediction of past and future sea-level trends and shoreline migrations and help towards a comprehensive cultural management policy of the coastal and underwater cultural heritage. Indeed, the study of RSL fluctuations since antiquity has been used in an attempt to calculate future rates of sea level rise in different regions (Mörner 2005). Rates of historical sea-level changes throughout the centuries can give insights for the sound prediction of future sea-level trends and contribute to the debate on the impact of humans on climate change (Lambeck et al. 2004b). Data from regions of small tidal range, as the Attico-Cycladic massif, are particularly significant. For example, based on past and present field observation on this relative aseismic area, geologists concluded that the current rate of relative sea-level 'rise' is much slower than predicted (Poulos et al. 2009). More archaeological evidence is now available.Most important, the area of Central Cyclades and Attica was densely inhabited since prehistory and there is an abundant archaeological and geological record available (Table A, B). Yet it has not been studied in detail, as most systematic excavations in coastal sites and surveys on islands, lacked combined underwater research. Recently, several coastal archaeological sites have been surveyed underwater and provide concrete archaeological markers. Available data from older surveys offer approximate estimations as well, but not always based on direct underwater observations; other submerged/inudated/silted structures are only indicative of RSL change in a certain period, as we are unable to assess their quality as RSL indicators (i.e. if the structures have been measured from the foundation level, the upper original surface, or if the effects of liquefaction have been taken into account, etc.). Finally, several reported sites are today destroyed and the data cannot be verified, due to the sudden urbanisation of the Attic and the Cycladic coast that has lead to the rapid destruction of the coastal sites (e.x. Piraeus). Overall, the results demonstrate the need of more systematic interdisciplinary underwater research (archaeological and geological) in the Aegean coastal zone. In general, the database (Table A and B) include archaeological evidence from harbour and coastal installations that have been assessed for their quality as RSL markers (Flemming et al. 1973; Blackman 1973, 2008; Auriemma *et al.* 2009). In our study area these are primary water wells or submerged rock-cut quarries, that in the rare occasion that they can be precisely dated, they are first-quality archaeological markers, from where the minimum RSL change can be established with accuracy. Other markers include harbourworks (moles, quays, piers, shipsheds and slipways), fortifications, tombs, submerged settlements, urban quarters, industrial installations, temples and other structures. Dates are given approximately and roughly for the Neolithic period (5500-3000BC), Bronze Age (3000-1100BC), Geometric/Archaic period (1100-500BC), Classical (500-323 BC), Hellenistic (323-30BC), and the Roman period (30BC-324 AD).

5. ARCHAEOLOGICAL EVIDENCE OF RSL CHANGES

5.1 Attica

Numerous submerged archaeological remains have been observed from the beginning of the 20th century along the Attic coast by Greek and German scholars. They range from prehistoric settlements to Classical harbourworks, public and private buildings (Table A). For example, at Piraeus, a typical thriving Mediterranean harbour with centuries of history, the coastline has been in continuous transformation. Several structures lay underwater, but there is a controversy on the actual rate of 'submergence' in the ancient harbours. Direct archaeological evidence include a submerged rock-cut quarry at Zea harbour, extending at -0.98m, shipsheds at Zea harbour indicating a ca. -1.90m RSL change, while the excavator estimates a maximum 2.90m sea-level change since Classical antiquity (Lovèn 2007: 68, fig.8 p. 69; Lovèn, *forthcoming*, personal communication). Indeed, the proposed RSL change affects considerably the reconstruction of the naval bases and the actual length of the warships housed; yet, assessing dry and underwater lengths of shipsheds involve intriguing and complicated issues concerning ancient navies and military harbours thus the estimation of the RSL change is crucial (Blackman and Rankov et al. *forthcoming*; Baika 2003).

Along the Attica coast, submerged structures certify important RSL fluctuations, sedimentation processes and propagation and/or erosion of shorelines resulting in different coastal landscapes since prehistory. These include extensive prehistoric settlements (Mylonas 1959; Theocharis 1956; Pantelidou-Gofas 2000), public buildings, as the *agora* at Cape Sounion, even the *Iera odos* towards Eleusis (Koumoundouros sea) that lies partly inundated (Lohmann 1993); or, most striking, the abandonment of the temple of Artemis at Brauron (425 BC) one century after its construction, because of a severe positive RSL change and the subsequent sedimentation of the coastal plain (Papadimitriou *PAE*, 1948: 81-90; Psychoyos 1988: 103-104).

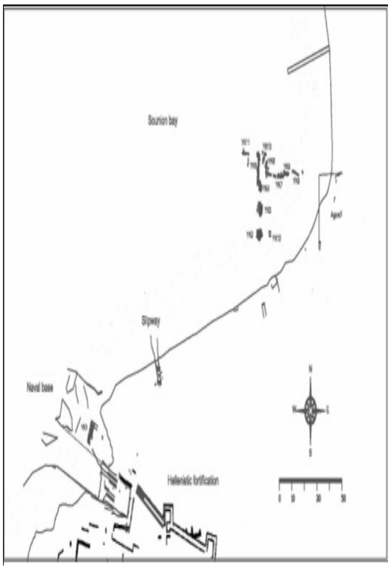

Figure 1: Cape Sounion. Submerged archaeological remains in the bay and at the naval base

Figure 2: Sounion Bay. Submerged wall YK2 from north (photo of the author).

Several submerged harbour structures and coastal installations on the eastern side of Attica are related to the metallurgical activities of the Lavreotiki region. The silver mine area was served by suitable and safe harbours as Thorikos, Fragkolimano, Gaidouromantra, Pountazeza, Passalimani, *akra Sounias*, from where raw metals and sub-products could be directly exported (Kakavogiannis 2005: 283-284). Impressive remains of the submerged settlement, that have been systematically recorded underwater, lie on the bay of Sounias *akra* and under the famous temple of Poseidon at Cape Sounion (Baika, *forthcoming;* Baika in Blackman-Rankov *et al., forthcoming*; 2007/8; 2003) (Fig. 1). An interdisciplinary underwater survey conducted in 2004 and 2006 revealed concrete, well-dated archaeological evidence of RSL change. In the bay, several remains of submerged walls were recorded parallel to the shoreline at a depth of ca. 2.35-2.65m (±0.30cm) (Fig. 2). The NE corner of the presumed *agora* of the city is today destroyed in the water (Fig. 1).

Finally, a rock-cut naval base with two shipsheds was investigated on the NE side of the promontory. On its extension into the sea, a rectangular ashlar masonry structure (YK1) was discovered underwater (Fig. 3), probably part of the Hellenistic circuit of the Cape. Clamps cast with lead on the upper surface of the blocks of the foundation course at a depth of -1.52m (±0.30) provide a concrete archaeological marker of a minimum RSL change since the Hellenistic period, while the foundation of the structure, if originally erected on dry land, indicates a relative sea-level change of at least -2.20 (±0.30m) (Baika, *forthcoming*).

Similar ‘submergence’ is recorded in all three bays of the Pountazeza peninsula. In the southern bay, Passa Limani (today Poseidonia) remains of two walls were observed at a depth of 2m (top surface?) (Tzalas, *forthcoming*). At Pountazeza (ancient Porthmos), a public building constructed with ashlar marble blocks was recorded at a depth of -1.85m (Salliora-Oikonomakou 2004: 68-69, fig. 51-52). Unidentified structures also lie in the southern bays of Thimari and Tourkolimano (Lohmann 1993: 15).

Figure 3: Naval base of Cape Sounion. Underwater structure YK1 (submerged tower?), from SE (photo of the author)

Finally, submerged beachrock strands have been studied at the southern part of Attica (Pavlopoulos 1997: 74-76, figs. 14-15) at different depths: of 1.80- 2.10m (±0.30m) at the bay of Tourkolimano, at Sounion, at the bays of Analipsi and Agios Nikolaos, as well as at the site of Aspro Lithari, where the thicker beachrock formation in the area was observed. At the same depth, a strand of ca. 500m eroded in parts was observed at Legrena, as well as at Thorikos, Passa-Limani (80m length), and Vromopigado. Beachrocks at depths of 2.80 to 3.40m (±0.30m) were studied at Tourkolimano, bay of Aghios Nikolaos (Frangkolimano), Poun – tazeza and Legrena bay. Finally a beachrock strand at a depth of 4.40-4.70m (±0.30m) was recorded at the south part of Tourkolimano bay. According to K. Pavlopoulos, the results indicated that the coastline retreated during the Higher Holocene, and we can monitor a ca. -3.00m RSL change since 500 BC (Pavlopoulos 1997: 181).

Beachrock formations were also observed at the western Attica shorelines, at Anavyssos, Lagonisi, Aghios Dimitrios, Kalamaki and elsewhere.

5.2 Cyclades

In central Cyclades, the archaeological evidence are copious. Yet, they need a more methodological approach involving systematic underwater research in order to be rightly assessed. Table B that reassembles most known direct and approximate archaeological data, is preliminary and, by all means, not exhaustive. Direct evidence include the partly submerged M/L Neolithic settlement at the islet of Saliagos, at Antiparos, the first systematic study undertaken in the Cyclades for RSL changes, that concluded to a RSL change of 6m or more at 4000 BC (Renfrew-Evans 1968: 5, 77; Morrison 1968). Based on evidence on and around Antiparos and neighboring islands, the excavators suggested a Neolithic level ca. -6.00 m below present sea level, a Mycenaean level at least ca. -3.00m and about the same for the Hellenistic period. These figures are consistent with the hypothesis of an eustatic rise of about 1m per millennium over the last 6000 years. Other Neolithic settlement in the Cyclades can only provide approximate evaluations, such as Kokkinobrachos in Naxos (Philaniotou 2006: p. 36, Fig. 2 with bibliography), Ftelia on the island of Mykonos (Sampson 2002, 14-15, fig. 2; Kambouroglou 2002), or Kephala, at northern Kea (Coleman 1977: 1 note 3).

For the Bronze Age period (3000-1100 BC), direct evidence is more abundant and include the partly submerged extended settlement at Grotta, Naxos. The underwater investigation undertaken, recorded remains at a depth up to -3.5m (Papathanasopoulos 1981; Lambrinoudakis 1979), while excavation trenches in the Mycenaean *acropolis* were literary performed in the water (Kondoleon *PAE* 1951: 222; Kondoleon *PAE* 1967: 112-113. Plate 91a, b; see also Dangoville and Renault-Miskovsky 1993).

On the east coast of Kea, at the Bronze Age settlement of the promontory of Aghia Irini, the lower level of a spring chamber of the 16^{th} c. BC was recovered at -3.78m, while the extremities of the fortification walls of the settlement are today well underwater (Caskey 1971: 365-367; Psychoyos 1988: 132-133). At Phylakopi at Melos, a water well of the same period (1550-1450BC) indicated a sea-level change of at least -3.00m to allow freshwater to fill the well (Renfrew 2007: 5, 64; Davidson-Tasker 1982: 82-94; Bintliff 1977: 528-538). Submergence of cist tombs were reported at Antiparos and a partly silted Mycenanean settlement at Delos.

Finally, according to a geomorphological survey, the Early Bronze Age coastline of Kavos Daskaleiou lies at depths between ca. -2.5-5.00m below modern sea-level (Bassiakos-Doumas 1998: 56-58, fig. 4)

With the exception of preliminary investigations at Saliagos and Grotta, none of the submerged Neolithic and Bronze Age archaeological sites have been thoroughly investigated underwater, a considerable handicap for the study of landscape geomorphological evolution of the prehistoric Cyclades. An exemplary case is the underwater survey of the Neolithic site (6500-3000BC) of Aghios Petros (Kyra Panagia) in the Sporades, where a detailed underwater exploration concluded that the relative sea-level change could be estimated to ca. -5.00m (Flemming 1983; Efstratiou 1985).

For the Classical (ca. 500-323 BC), Hellenistic (ca. 323-30 BC) and Roman period (ca. 30 BC – 324 AD), the evidence are more concrete. At the on-going underwater survey in the harbour of Kythnos, direct evidence of RSL change are documented by the *euthynteria* of a wall that was recorded at a depth of ca. -2.50m (Charalambidou *et al.*, *forthcoming*; Kourkoumelis, *personal communication*). Archaeological markers of relative sea-level change are reported from the Hellenistic city of Delos, while a submerged Roman quay at Rheinia was founded at -2.6m (foundation level) (Duchêne, Fraise 2001: 175; Dalongeville et al., 2007: 18-20, Fig. 2, 3; Desruelles et al., 2004; Desruelles et al., 2009). At Antiparos over 20 sites were investigated underwater, and among several are dated to the Classical and Helenistic era (Morrison 1968: 96-7, fig. 24 p. 95). At Paros submerged rock-cut structures in different bays around the island have been wrongly interpreted as harbour installations, docks for loading marble on ships or as rock-cut shipsheds (Photiou 1973). However, most of them are nothing more than rock-cut vine-trenches, similar to the ones studied at Antiparos (Renfrew-Evans 1968; Morrison 1968). Other submerged architectural elements have been discovered in the survey of the Paroikia bay at depths from -1.00m to -6.00m, while harbour moles, foundation structures and cist tombs were observed at depths of -1.00-2.50m. The RSL change is estimated to ca. -3.00m or more (since Classical antiquity?) (Papathanasso-poulos and Schilardi 1981; Photiou 1973). At the city of Aigina, substantial harbour remains indicate, according to P. Knoblauch (1972: 59-63, fig. 6), a RSL change of -3.55-4.05 (minimum -3.80m) for the earlier breakwater (1880 BC) assuming a 0.50m functional height, and a general ca. -1.75m RSL change for the 480 BC military harbour based mainly on assuring the functionality of the shipsheds complex (Knoblauch 1972: 79, 82-83, Fig. 17, 19, 21; Knoblauch 1969: 104ff, 115-116; cf. Negris 1904: 348-349). At Kea (ancient Keos), there are different RSL archaeological indicators and of different periods (Baika 2009; Baika 'Poiessa' in Blackman-Rankov et al., *forthcoming*; Baika 2007/8). A slipway at the eastern coast is more than half-submerged; its rock-cut surface was traced for at least *ca* 13.90 m (from 0.00) to a depth of -1.924 m (±0.30m) below present sea-level, while the western side of the rock-cutting of the slipway was traced underwater to a depth of -2.491 m (±0.30m). At Karthaia, one of the main harbours of the island, examination of submerged harbourworks, consisting of a mole 160 m long and 35 m wide, indicated a continuous positive relative sea level change since antiquity. Taking into account other submerged remains in the island, geologists assumed that sea level 2.500 years ago (in the Classical period) would have been 3.40 - 3.90m below the present level (probably a relative high estimation), and in a more recent phase -1.10 to -1.50m.

The estimation was based on the investigation of submerged beachrock coastlines along the shoreline of the bay, located at a depth of 0.90 to 1.10m (Mendoni and Mourtzas 1990: 390-6 and n. 26). Finally, a submerged waterfront quay *ca* 24 x 26m was revealed on the north coast of the island, in the bay of Otzias, probably the harbour of Ioulis. If we assume an operational height for the platform of 0.5 to 1m from the surface of the water (that corresponds approximately to the two upper courses), then we must calculate a RSL change of ca. -1.90 to 2.40m since Classical antiquity (Spondylis 1998: 700-703). Finally, remains of two robust breakwaters that protected and closed the ancient port of Palaiopolis of Andros have been investigated (Palaiokrassa-Kopitsa 2007: 104-108, figs. 187-194; Th. Theodoulou, *personal communication*).

The geologists estimated a -3.50m RSL change, but were based on the earlier hypothesis for Karthaia harbour basin. For the Roman period, underwater remains have been reported at Melos (at Phylakopi, Klima, Tria Pigadia, Emborio and possibly Aliki) by the work of the British School at Athens and summarised by Bintliff (1977: 528-538 with older bibliography, Fig. 1: location of underwater sites). Finally, submerged coastlines were reported at Kea and Mykonos, and were systematically studied in Delos, Rheinia and Mykonos (Desruelles et al. 2009; Kambouroglou 2002; Mendoni-Mourztas 1990). In conclusion, according to study of the beachrock bands, the oldest phase of relative stability was dated around 2000 BC, when the sea level was at -3.60 m (±0.50 m). A next phase was dated to the Classical/Hellenistic period, around 400 BC and corresponds to a relative sea level change of -2.50 m (±0.50 m). The mean value of this phase was obtained from information on the submerged archaeological remains on Hellenistic Delos and Rheinia. Finally, the most recent phase of relative stability is dated around 1000 AD and corresponds to a sea level at −1.00 m (±0.50 m) (Desruelles et al. 2009; Dalongeville et al. 2007).

6. CONCLUDING REMARKS

Therefore, we possess a preliminary concise database of precise and approximate archaeological indicators in Attica and the Cyclades. As many sites have not been investigated underwater, the catalogue is also indicated where future coastal research and underwater surveys must focus on, with a systematic interdisciplinary approach.

As a conclusion, the majority of the collected data denote that for the Neolithic period, the RSL change should range between -4 and -5.5/6.00m or more. For the Bronze Age/Mycenaean period, we can deduce a RSL change of more than ca. -3.00 to 3.50m. For the Classical/Hellenistic period (500-30 BC), when we possess most precise data, quality archaeological indicators from South Attica and the Cyclades indicate a RSL change of ca. - 2.50 to 2.80 (± 0.30m). For the Roman period, less abundant and indirect evidence point to a RSL around -1.50-2.50 (±0.30m). However, every site must be studied independently and small inconsistencies between sites must be considered. Our results are a bit lower than previous estimations of Ph. Negris (1904) and almost in accordance with Hafemann (1960). They are in approximate good agreement with some of the sea-level curves available for the Aegean (Vouvalides et al. 2005; Kambouroglou et al. 1988; Kambouroglou 1989; Poulos et al. 2009: fig. 4b; Brückner et al. 2009: fig. 3). For the Classical antiquity, our estimations are higher than the RSL change of -1.00-1.75m calculated by Lambeck (Lambeck 1996: fig. 4) and inconsistent for more than 1.00-1.5m from the Lambeck-Purcell model, according to which the sea-curve for Attica, South Euboea and Central Cyclades is at -1.00m at 2000BP (Lambeck and Purcell 2005: Fig. 14d). According to Lambeck and his team, this rate difference between the archaeological data and the model curve indicates influence of regional active vertical tectonics in the two past milleniums (Lambeck et al. 2004a; Lambeck and Purcell 2005; Antonioli et al. 2009).

However, as we already discussed, there is a general disagreement between geologists in interpreting the observational data. For example, in Delos, Mykonos and Rheneia the results obtained from the study of the beachrock strands were explained by Desruelles and his colleagues as tectonic subsidence during the last 6000 years, very slow positive eustasy, combined with rapid tectonic subsidence, probably associated with the so-called ‘Early Byzantine Tectonic Paroxysm’ (1530+_40 BP), as defined by Pirazzoli (Desruelles et al. 2009; Dalongeville et al. 2007; Pirazzoli, 1986). On the other hand, Poulos and his colleagues, focusing in the Attico-Cycladic massif, argued that the RSL change during historical times is due to eustatic factors and concluded that the sea level 3000BC was 4.50-5.00m below its present level and it continued to rise at a steady rate of approximately 0.9mm/a up to present, while tidal gauge analysis from Syros island (1974-1991) showed a positive sea-level trend of 0.86mm/a. Therefore, they alleged that between 500BC and 1BC the sea level was 1.50 to 2.5 m below its present level (Poulos et al. 2009, fig. 4a-b).

In conclusion, the archaeological indicators provide concrete information for the reconstruction of the geography of the coastal palaeoenvironment in Attica and the Cyclades, especially when combined with different methodologies, such as eustatic and isostatic sea level predictions, beachrock dating, tectonic movements, sedimentology, coastal dynamics, geoarchaeological sea level indicators, as well as anthropogenic impact.

Finally, the preliminary study of all available archaeological data demonstrated that a major part of the ancient Attica coast and of the Cycladic islands is today submerged. Numerous invaluable archaeological sites dating from the Palaeolithic to the Medieval period are lying in depths of few centimetres up to ca. -6m or more. Yet, under the pressure of urban construction projects and tourist development, the coastal landscape is transformed and the archaeological sites are subject to rapid destruction. Therefore, the recorded RSL change is an important factor to be assessed, when official permits are granted for modern harbourworks and other constructions associated with the exploitation of the coastline, where surviving evidence is destroyed at an alarming rate. The need to protect and study the coastal zone is today imminent. Interdisciplinary cooperation for the collection of multidisciplinary data (archaeological, marine and terrestrial geomorphological, geological, etc) is necessary and should be implemented as part of a comprehensive systematic policy for the cultural management and protection of the

Table A. Archaeological data in Attica

SITE	DATE	RSL CHANGE, DEPTH IN METERS	TYPE OF EVIDENCE	BIBLIOGRAPHY
Marathon plain, Nea Makri	Early/Late Neolithic 6500-3000BC	Covered with alluvium (under 3m of sand)	settlement	Psychoyos 1988: 98-100 Theocharis 1956: 3
Marathon plain, Kato Souli	Late Neolithic/Early Helladic 3000 BC	Covered with alluvium (2m below the present surface)	Settlement inundated by the swamp of Mega Helos (Her. VI 113; Paus. I, 32, 7)	Psychoyos 1988: 96-97 Mastrokostas, AAA VII, 1974, 1-7.
Marathon plain, Plassi	Late Neolithic 3000 BC	Covered with alluvium (under present sea-level)	Settlement (originally coastal)	Psychoyos 1988: 97-100, note 3 Mastrokostas AAA III, 1970, 18
Marathon	Early Helladic 3000BC	submerged	Remains of settlement 'literrary in the sea'	Theocharis 1956: 3
Marathon plain	1800BP	3.55m (±0.05)	C14 dating of borehole sedimentological samples	Baeteman 1985; cf. Pavlopoulos et al. 2006
Aghios Nikolaos Anavyssou	1900-1550 BC Middle Helladic	submerged	Coastal settlement	Eliot 1962: 104-105; Pritchett 1965: 135; Lohmann 1993: 14-16; Salliora-Oikonomakou 2004: 24, fig. 5, 6
Aghios Kosmas (Kolias akra)	1550-1050 BC Late Helladic (=Mycenaean)	At least -1.00 – 2.00m	Settlement on a reef and a headland	Mylonas 1959: 5, 7-8, 12-13, 56-58, Drawing 17; Papachatzis 1974: 131-133, fig. 56- 57; Psychoyos 1988: 107-111, p. 111, note 4.
Marathon plain, Nea Makri	1550-1050 BC Mycenaean	submerged	Remains of settlement	Psychoyos 1988: 164-165
Marathon plain, Plassi	1550-1050 BC Mycenaean	-2.5m under the fluvial alluvium	Remains of settlement	Psychoyos 1988: 95-96, 170
Sounion Bay	415-300 BC	-2.35-2.65m (±30cm)	Stone walls	Baika, forthcoming
Sounion Bay	500-30BC	-2.34m	Rectangular rock-cutting	Baika, forthcoming
Sounion Bay	500-30BC	submerged	NW corner of agora (?)	Baika, forthcoming, with bibliography
Cape Sounion, Naval base	415-300 BC	-1.52m (±0.30) (top) -2.21m (±0.30m) foundation level	Ashlar structure (tower?), (lead clamps on top surface)	Baika, forthcoming
Zea harbour west entrance)	500-300 BC	-0.98m (at least)-1.90(if manmade)	Rock-cut quarry	Lovèn 2007: 68, fig.8 p. 69
Zea harbour (east side), Area 1	500-300 BC	-1.90m estimation: max. -2.90m	Shipsheds	Lovèn, forthcoming; personal communication
Zea Harbour (east side of the entrance)	?	submerged	Rock-cut quarry	von Alten 1881: 13, fig. 9
Kantharos harbour	500-300BC	ca. -2.00m	harbourworks	Steinhauer 2003: 11, note 5
Kantharos Harbour (east coast)	500-30BC?	-2.00 to 3.00 ±0.50m	Rock-cut quarry	Negris 1904 : 349
Kantharos Harbour	500-400 BC	submerged	Tomb of Themistocles	Papachatzis 1992: 111-112, fig. 39, 40 (plan)
Mounychia	Classical? Roman?	submerged	Shipsheds	Negris 1904: 350; Von Alten, Karten p. 13-14
Piraeus, Krommydarou bay	Classical /Hellenistic? 500-30BC?	-2.00 to 3.00m	fortification	Negris 1904
Eetioneia	Classical period	Partly submerged	fortification	von Alten 1881: 13-14
Akti peninsula, (Akti Miaouli)	500-400 BC	Partly submerged	Tomb of Themistocles	Papachatzis 1992: 111-112, fig. 39, 40 (plan) with bibliography
Akti peninsula, near pharos	?	submerged	Rock-cut tombs	Negris 1904: 350
Phaleron bay	Classical/Hellenistic?	-3.00 to 3.50m	Mole and harbour structures	Negris 1904: 350-351
Phaleron bay	400 BC	- 1.80 to 2.00m	Long Walls?	Negris 1904: 351

SITE	DATE	RSL CHANGE,DEPTH IN METERS	TYPE OF EVIDENCE	BIBLIOGRAPHY
Kakia Skala	Late antiquity	submerged	building	Lohmann 1993
Daskaleio	?	submerged	mole	Petropoulakou-Pentazou 1973: 119 (X9-Y3), Nr 14
Koumoundouros sea	Archaic to Roman	submerged	Iera Odos remains	Lohmann 1993
Ramnous	Classical/Hellenistic (500-30 BC)	awash	Foundation of coastal tower	Petrakos 1999: 162
Pountazeza (ancient Porthmos)	Classical/ Hellenistic? Roman?	-1.85m	Public building with ashlar marble blocks	Salliora-Oikonomakou 2004: 68-69, fig. 51-52
Passalimani (SE Attica)	Classical/ Hellenistic? Roman?	-2.00m	Walls	Tzalas, forthcoming
Cape Zoster (mod. Vouliagmeni)	400-300 BC	Foundation of the sekos under sea-level	Temple of Apollo	Kourouniotis, AD 11, 1927: 21
Brauvron	425 BC	Foundation under sea-level	Temple of Artemis	Papadimitriou PAE, 1948: 81-90
Coasts of Attica	ca. 500BC	ca. -3.00m	Beackrock strands	Pavlopoulos 1997: 181

Table B. Archaeological data in the Cyclades

SITE	DATE	RSL CHANGE, DEPTH IN METERS	TYPE OF EVIDENCE	BIBLIOGRAPHY
Antiparos (Saliagos)	ca. 4000BC	-5.00 to 6.00m or more	settlement	Renfrew-Evans 1968: 5, 77; Morrison 1968
Mykonos (Ftelia)	Neolithic ca. 6500-3000BC	In a alluviated plain	settlement	Sampson 2002, 14-15, fig. 2
Kea (Kefala)	Final Neolithic ca. 4500-3000BC	Submerged (more than 1m), erosion	Settlement and cemetery	Coleman 1977: 1, note 3
Cyclades (Delos, Mykonos, Rheinia)	ca. 2000 BC	−3.6 m (±0.50 m).	Beachrock strands (dated by archaeological evidence)	Desruelles et al. 2009; Dalongeville et al. 2007
Antiparos (between islets Despotikon -Aghios Georghios)	Late Bronze II 1550-1100BC	-3.00	Cists tombs	Morrison 1968: 97
Keros (Kavos Daskaleiou)	Early Bronze Age 3000-2000BC	2.50 – 5.00m	settlement	Bassiakos-Doumas 1998: 56-58, fig. 4
Kea (Aghia Irini)	16c. BC	- 3.78m (lower level)	Spring chamber	Caskey 1971: 365-367, fig. 6, Pl. 78; Psychoyos 1988: 132-133.
Kea (Aghia Irini)	3000-1450BC	submerged	Western and eastern towers of fortification, urban quarters, temple	Caskey, Hesperia 1966: 365, fig. 1; Hesperia 1962: 277-278, Fig. 1, area D; Coleman, 1977, Keos 1: vii
Naxos, Grotta	1600-1100 BC Mycenaean	-2.00 – 3.00m	Settlement, Mycenaean acropolis	Kondoleon PAE 1951: 222; Kondoleon PAE 1967: 112-113. Plate 91a, b; see also Dango-ville and Renault-Miskovsky 1993: 31-32, fig. 20.
Naxos, Grotta	1600-1100 BC Mycenaean	-2.50-3.50 m	settlement	Papathanasopoulos 1981; Lambrinoudakis 1979
Naxos, Mikri Vigla, north of promontory	Middle Bronze Age 1900-1550BC	submerged	Unidentified remains	Morisson 1989: 142-144
Melos, Phylakopi	1600-1100 BC Mycenaean	At least -3.00m	Well shaft within the city	Davidson-Tasker 1982: 82-94; Renfrew 2007: 5, 64
Delos	1600-1100 BC Mycenaean	partly silted	settlement	Psychoyos 1988: 132; Gallet de Santerre 1958: 17-112, 313
Antiparos	1600-1100 BC Mycenaean	-3.00m	structures	Morrison 1968: 97
Aigina, bay north of Kolonna hill	ca. 1880 BC	- 3.55-4.05m (minimum -3.80m)	breakwater	Knoblauch 1972: 59-63, fig. 6

SITE	DATE	RSL CHANGE, DEPTH IN METERS	TYPE OF EVIDENCE	BIBLIOGRAPHY
Aigina (harbour)	480BC	-1.55m (minimum) ca. -1.75 m	Closed harbour Harbour fortifications Shipsheds	Knoblauch 1972: 79, 82-83, Figs. 17, 19, 21; Knoblauch 1969: 104ff, 115-116; cf. Negris 1904: 348-349
Aigina (harbour)	Roman?	>2.00 ±0.50m	Aqueduct	Negris 1904: 349
Kea (Karthaia)	ca. 500BC	-3.40-3.90m	Mole	Mendoni, Mourtzas 1985-6: 135-6; 1990: 390-6 and n. 26
Kea (Poiessa)	Classical/Hellenistic	-2.00-2.50m (±0.30m)	Rock-cut slipway	Baika 2009; Baika 'Poiessa' in Blackman-Rankov et al., forthcoming
Kea (Otzias)	400BC	-1.90-2.40m	quay	Spondylis 1998: 700-703
Andros (Palaiopolis)	Classical/Hellenistic	Partly submerged and silted Estimation: -3.5 m	Harbour basin and breakwaters	Mourtzas in Palaiokrassa-Kopitsa 2007: 104-108, figs. 187-194; Th. Theodoulou, personal communication
Kythnos harbour	Classical/Hellenistic	ca. -2.50m	Euthynteria of submerged wall in the harbour	Charalambidou et al., forthcoming; D. Kourkoumelis, personal communication
Delos, 'Flanc de la colline'	323-30 BC Hellenistic period	-1.33m	Hellenistic house floor	Duchêne-Fraise 2001: 175 Danlogeville et al. 2007: 23, fig.7
Delos	400 BC	ca. -2.50m (±0.50)	C14 dating of submerged beachrock bands	Desruelles et al. 2009
Rheinia	Roman period	-1.30m (top surface) -2.60m (foundation)	Quay with bollards	Negris 1904 Dalongeville et al. 2007: 18-20, fig. 3
Rheinia	400BC	Estimated: ca. -2.50m (±0.50)	Necropolis	Dalongeville et al. 2007
Rheinia	400BC	2.50m (±0.50)	Submerged Beachrock (dated by archaeological evidence)	Desruelles et al. 2009
Mykonos	400 BC	2.5m (±0.50)	Submerged Beachrock (dated by archaeological evidence)	Desruelles et al. 2009
Mykonos (Ftelia)	?	-2.20 m	Beackrock strands	Kambouroglou 2002
Mykonos (Ftelia)	?	-0.80m	Rock-cut quarrying	Kambouroglou 2002
Antiparos	Classical 500-323 BC	-3.00m	Quarry	Morrison 1968
Antiparos	323-30 BC Hellenistic	-3.00m	Vine-trenches	Morrison 1968: 96-7, fig. 24 p. 95
Paros, Oikonomos island	?	-1.60 to 2.00m	Rubblestone structures	Photiou 1973: 8-10, fig.5; Papathanassopoulos-Schiladi 1981: 143-144, fig. 13.
Paros, Oikomomos island	?	-1.00 to 2.00m	Cist graves	Papathanassopoulos-Schiladi 1981: 144, fig. 14; Schilardi, AAA 6, 1973: 263-264, fig.9; Schilardi, PAE 1975: 205.
Paros, Paroikia	?	-2.00 to 3.00m	Moles (top surviving surface)	Papathanassopoulos-Schiladi 1981: 137-8, figs. 2, 6.
Paros, Paroikia	?	-4.00 to 5.00m	Stone circle (foundation of a structure?)	Papathanassopoulos-Schiladi 1981: 138-139, fig. 7
Paros, Naoussa bay	?	-1.00 to 2.00m (top surviving surface)	Two moles	Papathanassopoulos-Schiladi 1981: 140-141, fig. 11.
Paros, Naousa bay	?	-1.00 to 2.50 (foundation level). Estimation: -3.00m or more	mole	Papathanassopoulos-Schiladi 1981: 141, fig. 8
Kea (Karthaia)	3rd c. BC	Under 3.5m of fluvial alluvium, under current sea-level	Doric temple (Aklepios or Demeter)	Baika 2009, with bibliography
Paros	Roman?	-0.50m	Stone structure	Papathanassopoulos-Schiladi 1981: 139.
Melos, Klima	Late Roman/Early Byzantine	-1.50-2.00m of recent alluvium	buildings	Bintliff 1977: 531
Melos, Klima	Early Byzantine	submerged	Two harbour moles and a	Bintliff 1977: 531

			building in-between	
Melos, Tria Pigadia (NE coast)	Late Roman	Engulfed under ca. 2.50m of fluvial alluvium	Settlement on the shore, stone walls	Bintliff 1977: 532
Cyclades (Delos, Mykonos, Rheinia)	ca. 1000 AD	−1.00 m (±0.50 m)	Beachrock strands (dated by archaeological evidence)	Desruelles et al. 2009; Dalongeville et al. 2007
Kea	Recent phase: Medieval period?	-0.90 to 1.10m	Beachrock strand	Mendoni and Mourtzas 1990: 390-6 and n. 26

Aegean coastal and underwater archaeological cultural heritage.

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