Late Quaternary beach deposits and archaeological relicts on the coasts of Cyprus, and the possible implications of sea-level changes and tectonics on the early populations

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Abstract: Late Pleistocene beach deposits in 22 selected sites around Cyprus demonstrate the vertical changes in the Earth's crust in that island over the last 125 ka. The beach/shallow-marine deposits were observed on the abraded coastal cliffs at 3–22 m above the present sea-level. They overlie Pliocene marls, and some of them contain the Senegalese marine gastropods *Persististrombus latus*, *Bursa granularis* and *Conus ermineus* that no longer live in the Mediterranean. These are index fossils for the Marine Isotope Stage (MIS) 5e in the Mediterranean and, as such, suggest an uplift of up to 15.5 m over about the last 125 ka: that is a maximal rate of 0.12 mm a^{-1}. These findings are in accordance with Holocene beachrocks, abrasion platforms, wave notches and Roman/Byzantine fish tanks that retained their elevations, and thus enable the reconstruction of the coast encountered by the early colonizers. While the maximal uplift since the early Holocene has been minor and did not exceed 1.2–1.5 m, the sea-level changes have reached 40–50 m. The transition between the impermeable Pliocene marls and the porous Late Pleistocene deposits above them is the origin of freshwater springs and associated vegetation. The early colonizers seemed to recognize the potential of that essential permanent source of water and excavated wells, the earliest wells known so far. The locations of the Early Neolithic settlements (Mylouthkia and Akanthou) adjacent to visible water springs along the coastal cliffs may not be incidental. Not surprisingly, recent wells dug in the coastal Pleistocene deposits rely on the very same hydrological setting.

Supplementary material: Appendices 1–4, which include tables and diagrams showing the vertical changes (m) and rates of vertical changes (mm ka^{-1}), assuming that MIS5e isotope stage deposits are 122 ka old and are at elevation of 7.2 m asl, or 116 ka at 6.5 m, are available at http://www.geolsoc.org.uk/SUP18830.

Cyprus, one of the largest islands in the Mediterranean, is situated some 60 km from southern Turkey and 100 km from the nearest Levantine coast (Fig. 1). Open sea, about 1000 m deep, separated Cyprus from the surrounding mainland for several million years, long before humans appeared there in the Early Holocene (Broodbank 2006). The island played a major role in the evolution of the eastern Mediterranean Neolithic culture and the spread of agriculture (Peltenburg *et al.* 2000). The transition from hunting and gathering to a food-producing economy in the Near East resulted in a growing demand for land and water resources. The unexploited natural resources of land, water, fauna and flora of Cyprus attracted agro-pastoralists from the mainland, where the population grew and

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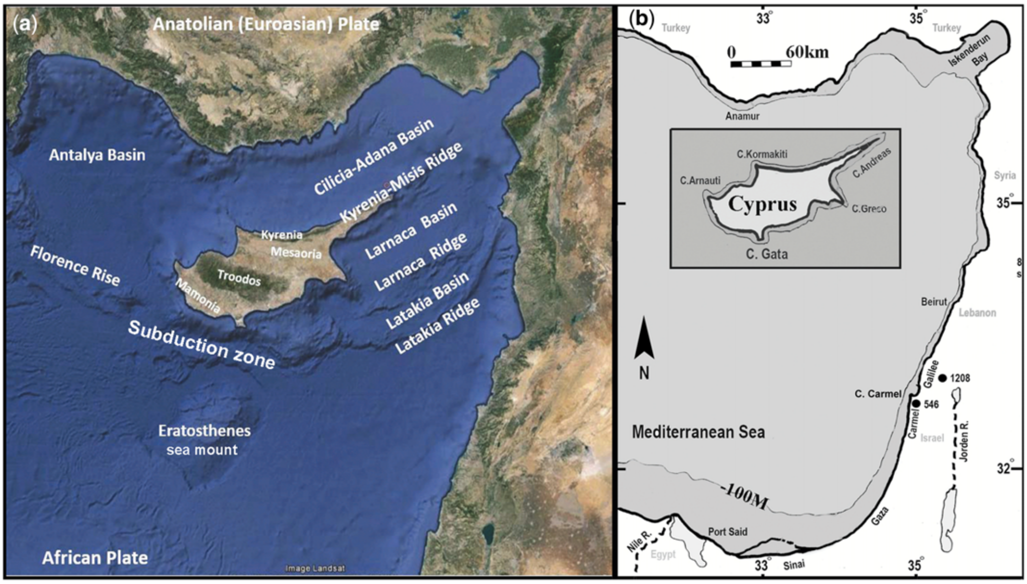

Fig. 1. Location map of the study area: (**a**) geographical setting of the eastern Mediterranean and the island of Cyprus; and (**b**) morphostructural and tectonic elements in the NE Mediterranean and Cyprus, modified after Google Earth.

the natural resources became short, especially near large settlements (Galili *et al.* 2002, 2004*a*, *b*; Bar-Yosef 2008). Yet, the mechanisms and exact timing of colonization in Cyprus and the origin of its population are not fully understood. Reconstructing the coastal landscape met by the first colonizers may help in understanding the effect of the landscape on the colonization process. Such an investigation requires defining the changes in coastal morphology, sea-level and tectonics around Cyprus during the Late Pleistocene and Holocene.

It is difficult to determine the vertical changes of the Earth's crust during the short time interval of the Holocene because of its low values (Ferranti *et al.* 2006). However, it is reasonable to assume that these changes are gradual and constant over time, and thus the average vertical rate of movements since the last interglacial can be extrapolated to the Holocene. This will enable us to determine how the vertical crust and sea-level changes modified the coast that the early populations of Cyprus encountered.

This paper presents a synthesis of the existing geological, sedimentological and archaeological evidence, along with an original field survey of 22 selected sites on the coasts around the island (Fig. 2). The fieldwork focused on identifying and sampling *in situ* Late Pleistocene and Holocene beach and shallow-marine deposits (abbreviated here as B/SM) and coastal archaeological features. These deposits are archives of climatic and environmental changes, and may provide invaluable information on past sea-levels, coastal changes and tectonics. In order to verify the nature of the coastal sections, we also studied the lowest exposed unit, which in most cases, was the Miocene–Pliocene marl. The data collected enabled us to resolve both the values of vertical movements of the Earth's crust and relative sea-level changes in the last 125 ka, as well as reconstructing the environment encountered by the early colonizers of the island.

Geological and geomorphological setting

Cyprus lies in the NE Mediterranean Sea, surrounded by the deep Cilicia–Adana Basin in the north, the Kyrenia–Misis Ridge, and Latakia Ridge and Basin in the east, the Cyprus Trench and Eratosthenes Seamount in the south, and the Florence Rise and Antalya Basin in the west (Harrison *et al.* 2004) (Fig. 1). The present configuration started in the Early Miocene with the migration of the subduction boundary between the subsiding African Plate and the overriding Anatolian (Eurasia) Plate towards the south of Cyprus (Kempler & Ben-Avraham 1987; Poole *et al.* 1990). During that collision, the island emerged and was pushed onto the overriding plate to its present position. This caused north–south compression in the Early Pliocene that was accommodated by thrusting in the Kyrenia Range and along the northern coast of Cyprus, from Cape Andreas in the NE to Cape

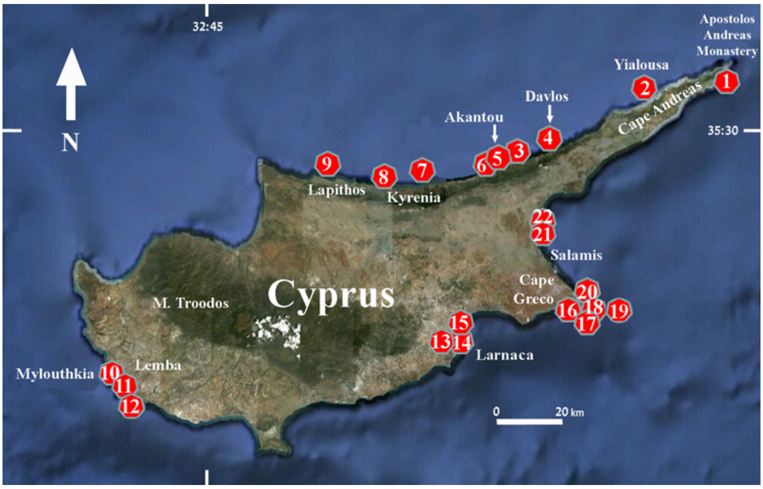

Fig. 2. The main localities studied along the coasts of Cyprus. The numbers denote the sites described in the section on 'Observations on the coastal sites around Cyprus', modified after Google Earth.

Kormakitis to the NW. Later, in the Quaternary, the deformation transferred into north-dipping strike-slip faults in the NE and NW, one of which was found to be still active in the Holocene (Harrison *et al.* 2004, p. 193).

Overall, the tectonic framework of the island is composed of several subparallel east–west-trending belts, namely the Kyrenia Range in the north, the Troodos and Mamonia ophiolite complexes in the south and the Mesaoria Plain in between (Figs 1 & 2).

The island hence represents a piece of oceanic crust, and the thickening of the lithosphere has resulted in uplift of several hundred metres since the Late Pliocene (*c.* 2.2 Ma) (e.g. Bear 1960; de Vaumas 1962; Poole & Robertson 1991; Kinnaird *et al.* 2011; Weber *et al.* 2011).

In the Late Miocene and Pliocene, marine marls and calcarenites were deposited in and around the island, in the areas that were submerged at the time. During the Pliocene, coarse clastic materials derived mainly from the Troodos Ophiolite Complex and the surrounding Miocene marls were deposited as fanglomerates on the slope of the mountain range that emerged at that time (Poole & Robertson 1991; Robertson *et al.* 1991). Clastic material that was found inside the hollow parts of Pliocene molluscan fossils also supports the idea that the Troodos was already exposed at that time (Moshkovitz 1968, 2012). The main uplift phase, however, took place during the Early–Middle Pleistocene, most probably due to the combined effect of the ophiolite emplacement and the collision with the Eratosthenes Seamount (Robertson *et al.* 1991).

The coasts of Cyprus are encircled by shallow-marine and terrestrial Pleistocene deposits, mainly sandstones, conglomerates, and beach and shallow-marine (B/SM) deposits about 10 m thick and several hundred metres wide, lying unconformably above the Miocene and Pliocene marls (Poole & Robertson 2000). Pleistocene terraces and B/SM deposits were found at the present sea level and up to 360 m above it (Poole & Robertson 2000; Poole *et al.* 1990). In low coastal areas such as the Akrotiri Peninsula, as well as in river channels, there are concentrations of reworked fluvial materials such as conglomerates and 'Havara' deposits (a local term referring to limestone deposited through the evaporation of calcium-rich groundwater) (Simmons 1999). In places, the Havara is capped by a thick calcrete (caliche) crust, locally called 'Kafkalla'. These marine and terrestrial deposits are the result of a series of marine transgressions and regressions induced by the glacial and interglacial cycles. This section is abraded by the sea, in many places forming coastal cliffs associated with the collapse of large blocks, as well as rock-cut platforms and wave notches at or close to the present shoreline.

Late Pleistocene beach deposits on the coasts of Cyprus

Previous studies in Cyprus suggested several different dates for the coastal beach deposits and the marine terraces at several sites. The first study was carried out by Gaudry (1862), who investigated marine deposits on the southern coasts of Cyprus, especially at Larnaca Salt Lake. On the basis of his palaeontological findings, mainly the presence of *Strombus coronatus*, he suggested that these sediments and many others along the southern coasts of Cyprus belong to the Pleistocene period. The previous names of this index fossil were *Strombus bubonius* and *Lentigo latus*, and, more recently, Kronenberg & Lee (2007) suggested the name *Persististrombus latus*. Since the term '*Strombus bubonius*' appears to be very common in the literature, including articles quoted in here, we abbreviate its name as '*Sb*' throughout this work.

Studies of the northern coastal areas supplied some more palaeontological information from the outcrop at Thavlou (Dhavlous). Some authors (Bellamy & Jukes Browne 1905; Henson *et al.* 1949) regarded the age of the sediments as Pliocene. Later, it was demonstrated on the basis of geomorphological grounds, and the presence of the tropical – Atlantic index fossils *Sb* and *Polinices lacteus* (=*Natica lacteal*) (Horowitz 1964; Moshkovitz 1964, 1966), that these sediments should be related to the Pleistocene – Tyrrhenian stage. These layers unconformably overlie more ancient marls of different ages. Henson *et al.* (1949) also established the term Kyrenia Formation for the few-metres-thick bioclastic limestone (carbonatic sandstone) on the northern coast. Later on, Moore (1960) correlated the Kyrenia Formation with the older Athalassa Formation. Pantazis (1967) dated the Tyrrhenian terraces of the Larnaca area and the Kyrenia terrace to the Middle Pleistocene or the Tyrrhenian 2 stage. Moshkovitz (1966) described the section of the Kyrenia Formation (which is uncomfortably deposited on top of Miocene marls of the Kythrea Formation) and dated it to the Tyrrhenian transgression. Saucier & Major (1963) studied the geology of the west Karpasia. Horowitz (1964), who described the geology of the East Karpasia Peninsula, reported well-preserved specimens of *Sb* and other fossil molluscs in the Kyrenia Formation, and dated this formation to the Middle Pleistocene. Ducloz (1968) dated the Kyrenia terrace deposits to Marine Isotope Stage (MIS) 5. Using the ^{14}C method, Vita-Finzy (1990, 1993) determined the ages of nine B/SM deposits on the western and SW coasts of the island, at elevations ranging from 4 to 30 m above the present sea-level (hence asl), to be of 30–44 ka. However, given that the sea level at that time was approximately 70–80 m below that at present, the ages obtained seem to reflect the limitations of the ^{14}C method rather than the true age of the studied deposits. Poole *et al.* (1990; Poole & Robertson 1991) used the uranium–thorium (U–Th) method for determining the ages of B/SM deposits on the south and west coasts of Cyprus, and dated them to MIS 5 (Terrace F4: 116–134 ± 10 ka) and 7 (Terrace F3: 185–204 ± 8 ka) and suggested that the southern coast has been uplifted by a maximum of 6 m since the last high sea stand. However, the elevation of their F4 terraces, which were associated with MIS 5, is at 3 m asl. Given that the MIS 5e reached an elevation of about 6.5 m asl, these F4 terraces may also suggest a 3 m subsidence. Moshkovitz (1966, 1968) noted that the present elevations of the Kyrenia deposits, which vary from 1 to 10 m asl, indicate that there has been no major tectonic change in this region since the Tyrrhenian.

Archaeological setting

The earliest *in situ* coastal sites in Cyprus were discovered in recent decades on the northern and the western coasts of the island and are of the Pre-Pottery Neolithic (PPN, 10 ka BP) times. The site of Akanthou (Tatlısu) (Şevketoğlu 2008), which was severely abraded by the transgressing sea, is one of the earliest known on the north coast of Cyprus (Figs 2 & 3), and seemed to have subsisted on agro-pastoral and marine resources. The other PPN site is Mylouthkia, located on the western coast, near Paphos (Peltenburg *et al.* 2000, 2001*a*, *b*) (Fig. 4). Rescue excavations there revealed several deep shafts, the most ancient water wells known so far in the world, filled with rich faunal and floral remains. Unfortunately, no dwellings or other surface structures or installations that might have indicated a permanent coastal settlement were found at the site. A later PPN coastal site was found at Cape Andreas Castros, on the eastern tip of the Karpasia Peninsula. The settlement subsisted mainly on marine resources and specialized in fishing (Ducos 1981; Le Brun 1981, 1987; Desse & Desse-Berset 1994). Pottery Neolithic (PN) coastal settlements were discovered near Paralimni, on the southern coast (Flourentzos 1997), in Ayios Epiktitos-Vrysi and Troulli (Dikaios & Stewart

Fig. 3. Akanthou (Tatlısu) Pre-Pottery Neolithic (PPN) settlement (Site 5), northern coast of Cyprus, note the severe erosion.

Fig. 4. Mylouthkia Pre-Pottery Neolithic (PPN) settlement, on the western coast of Cyprus (Site 10) general view.

1962), and in Agios Amvrosios and Agia Marina on the northern coast (Şevketoğlu 2000). Recently, several concentrations of worked flint artefacts were found on the coastal sandstone ridges near the Akamas Peninsula on the western side of the island, and near Agia Napa on the SE coast. These sites were claimed to be campsites of early hunter-gatherers who visited the island before the Neolithic colonization. The dating was determined on the basis of the flint artefact typology (Ammerman *et al.* 2008). However, as of today, neither *in situ* structures nor datable organic material were found at these sites. Mediterranean fishing villages along the Cyprus coasts of later prehistoric times were discussed in detail by Galili *et al.* (2002, 2004*a*, *b*). Archaeological features from historical periods include mainly rock-cut fish tanks, stone-built harbour installations, coastal structures and unconsolidated archaeological deposits.

Quaternary sea-level changes

Global sea-level fluctuations in the last 2 million years that were caused by glaciation cycles, led to global falls in sea-level to as low as 130 m below the present level (Fig. 5), as well as highstands during interglacial periods (Bard *et al.* 1996; Muhs 2002; Schellmann & Radtke 2004; Siddall *et al.* 2007). These cycles of regression and transgression must have significantly affected the coasts of Cyprus, as has already been shown in previous studies (Horowitz 1964; Moshkovitz 1966, 1968; Flemming 1978; Dreghorn 1981; Poole *et al.* 1990; Vita-Finzy 1990, 1993; Poole & Robertson 1991; Morhange *et al.* 2006). Away from Cyprus, studies in stable regions in the Mediterranean coasts (e.g. in western Sicily and southern Sardinia, Italy) indicated that the maximal sea level during the last interglacial reached approximately 6 ± 3 m asl (Lambeck *et al.* 2004; Ferranti *et al.* 2006; Siddall *et al.* 2007). In particular, in Italy, Ferranti *et al.* (2006) determined that the sea-level rise during MIS 5e reached a maximum of 6.5 m asl; Kopp *et al.* (2009) estimated a rise of 7.2 ± 1.3 m, an average obtained from 46 sites, and Stirling *et al.* (1998), Siddall *et al.* (2007) and Pedoja *et al.* (2011) calculated it to be 2–4 ± 1 m using results obtained from various sites worldwide. For comparison with the relevant studies on the southern coast of Cyprus (Poole *et al.* 1990; Poole & Robertson 1991), we also refer to 116 ka and elevations of 5 and 8 m asl for the last interglacial stage MIS 5e.

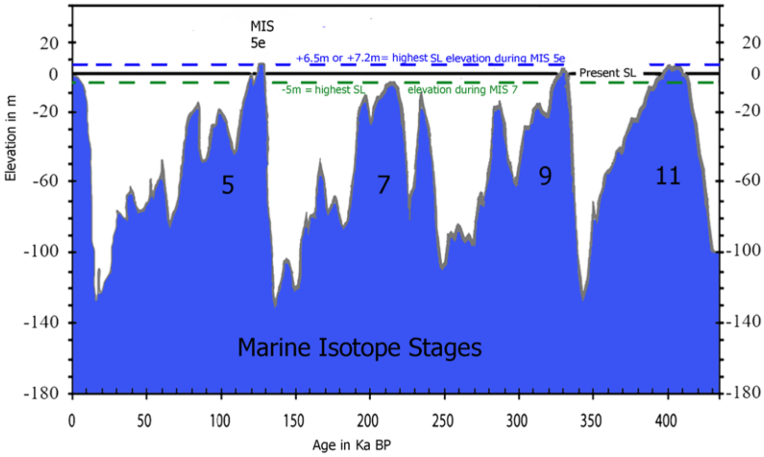

Fig. 5. Global sea-level changes and marine isotope stages in the last 450 ka and the maximum elevations of MIS 5 (dashed upper line) and MIS 7 (dashed lower line) (modified after Siddall *et al.* 2007).

Sea-level markers and indicators for vertical movements

There are some geological and archaeological markers that can record and preserve the location of the coast and the level of the sea at the time of their formation, and thus can be used as detectors. The advantages and limitations of the markers used in our study are described below.

Late Pleistocene beach and shallow-marine (B/SM) deposits. Consolidated B/SM deposits such as beachrocks and coastal conglomerates reflect sediments cemented by carbonate at the littoral zone (Hopley 1986). They are usually formed at high sea-level stands in the intertidal zone or near to it, where seawater and terrestrial groundwater mix (Russell 1959; Frankel 1968; Hopley 1986). Lambeck *et al.* (2004) estimated the range of uncertainty of the height of the sea level in regard to Mediterranean beachrocks to be of the order of 1 to −5 m. Since these sediments are associated with the edge of the former coastlines, they can also be used as palaeo-coastline and sea-level markers, and their relicts are often used as proxies in Quaternary sea-level and neotectonic studies. Aeolian sandstone deposits, however, do not provide accurate information regarding palaeo-coastlines and vertical movements. They are wind-driven sediments (sand dunes) that were originally deposited on land at different elevations and sometimes at a considerable distance from the coast. Beach conglomerates and fossil beach sands formed in the littoral zone are lithologically similar to beachrocks, but are less accurate as sea-level markers (Lambeck *et al.* 2004; Galili *et al.* 2007). Thus, it is possible to rely mainly on the MIS 5e beachrock deposits as indicators of crustal movements since its formation. The MIS 5e B/SM deposits along the Israeli coast were specifically focused on by Galili *et al.* (2007); and preliminary results of the current research of the MIS 5e B/SM deposits in Cyprus have already been presented on several occasions (Galili *et al.* 2011*a*, *b*). Nonetheless, very little is known about the possible impact of sea-level changes, tectonics and coastal modifications on the early human colonists of Cyprus.

Natural Holocene depositional, bioconstructional and erosional sea-level markers. Natural sea-level markers can be divided roughly into three categories – depositional (coastal alluvial fans, coastal marshes and river deltas), constructional (e.g. incrustations such as vermetides and algae) and erosional (abrasion platforms and marine notches) – owing to physical, chemical and biological effects (Kidson 1986; Pirazzoli 1986, p. 367; Morhange *et al.* 1996). Noteworthy erosional features are the marine notches on the rocky coasts. Three kinds of marine notches were classified by Pirazzoli (1986, pp. 362–365), according to their location along the coastal profile and exposure to waves: tidal notch, formed in sheltered rocky areas in the intertidal zone; infra-littoral notch, formed in the subtidal zone under exposed conditions and high surf; and surf notch, formed under exposed conditions in the supralittoral zone (supratidal zone). Abrasion platforms (shore platforms) are the product of marine erosion, which creates surf notches in exposed rocky coasts under long, stable sea-level conditions.

Overall, local Holocene sea-level studies of the Levantine coast suggest that the sea-level reached its present elevation about 4 ka ago (Galili *et al.* 2005, 2011*a*, *b*; Morhange *et al.* 2006). Since Cyprus is located in a microtidal region of the eastern Mediterranean ($\leq$0.5 m), such depositional and erosional features may provide valuable information about the vertical changes during the Holocene and historical times.

Archaeological features as sea-level markers. Archaeological features associated with the coastal and marine environment may provide invaluable information on palaeo sea-level and vertical changes, and thus were also considered in this work. This is usually carried out by dating, measuring their elevation relative to the present sea-level, defining their function and determining their potential use as sea-level markers (Flemming 1969; Blackman 1973; Galili *et al.* 1988, 2005; Galili & Sharvit 1998; Sivan *et al.* 2001, 2004; Lambeck *et al.* 2004; Antonioli *et al.* 2006; Auriemma & Solinas 2009; Anzidei *et al.* 2011; Evelpidou *et al.* 2012; Stanley & Bernasconi 2012). In addition to the original observations made on archaeological features during this study and presented in this work, we also reevaluated previous studies that dealt with such indicators along the coasts of Cyprus (e.g. Flemming 1974, 1978; Dreghorn 1981; Morhange *et al.* 2000). Ancient coastal man-made structures may be found today at an elevation that would not have enabled them to function for one or several of the following reasons (Fig. 6): (i) crustal vertical movements (Galili & Sharvit 1998) (Fig. 6a) resulting from local or regional tectonics and local structural changes, as well as isostatic adjustments; (ii) global eustatic sea-level rise or fall (Fig. 6b); (iii) the settling of these structures into unconsolidated sediments, compaction or liquefaction of the sediments (Fig. 6c); and (iv) erosion and collapse of structures (Fig. 6d). Sedimentation may lead to a horizontal shift of the coastline seawards, away from the installations and thus prevent proper functioning. However, this has no vertical impact and, therefore, it is not relevant in terms of relative vertical sea-level changes. Thus, interpretation of

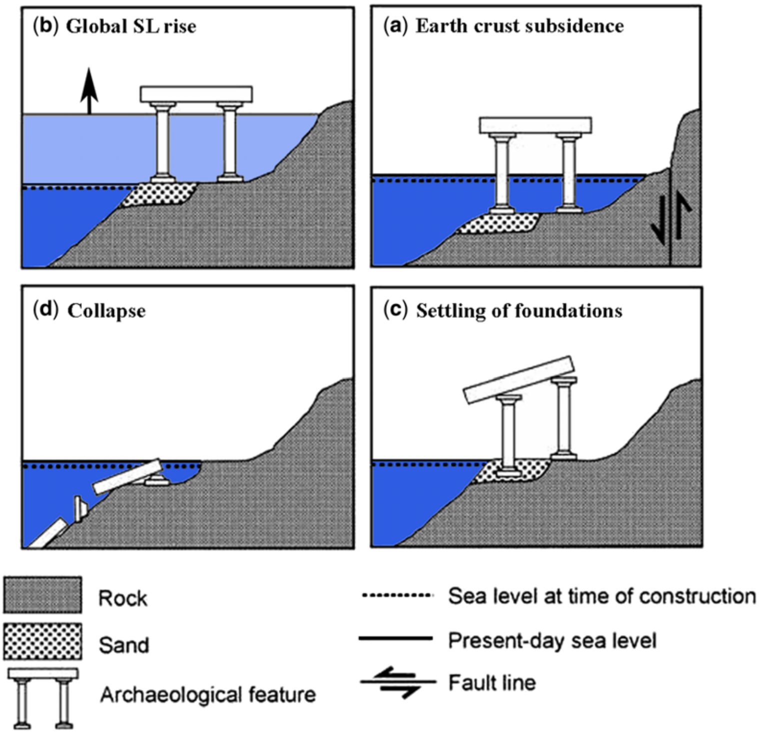

Fig. 6. Schematic drawing demonstrating possible reasons for vertical movement of man-made structures (after Galili & Sharvit 1998, fig. 1): (**a**) vertical crustal movements; (**b**) global sea-level rise; (**c**) settling of foundations; and (**d**) collapse.

palaeo sea-level that relies solely on archaeological features should be reviewed very cautiously. The archaeological features used as sea-level markers can be divided into the following categories (Blackman 1973; Flemming 1978; Flemming *et al.* 1978; Galili & Sharvit 1998):

- Features that need to be at sea-level or partially below sea-level in order to function properly. These include, for example, pools that are fed by seawater driven by gravity (wash tanks), slipways, harbour installations and salt-production installations. These types of structures may mark the uppermost and lowermost sea-level at the time of construction.
- Features that are normally located on dry land, including, for example, dwellings (Fig. 7a), quarries, roads, wells and freshwater pools. These structures usually provide the uppermost sea-level at the time of construction (Pirazzoli 1976, 1986; Galili & Sharvit 1998). However, under certain circumstances, they may also provide the lowermost possible sea-level.

Coastal freshwater wells, for example, should be on land but their bottom has to be slightly (*c.* 0.5 m) below the groundwater table. The water table of coastal groundwater aquifers is usually at sea-level elevation near the shoreline and its inland gradient depends on the local conditions. Thus, some coastal wells may provide both the upper and lower limits of the sea-level at the time of excavation (Fig. 7b) (Galili & Nir 1993; Nir 1997).

Coastal quarries usually provide the uppermost limit of sea-level. However, in coastal areas where the demand for building stones required thorough exploitation of the existing rock down to sea-level (e.g. the city of Akko in Israel), coastal quarries may provide the uppermost and the lowermost possible sea-level (Fig. 7c) (Galili & Sharvit 1998).

Wash pools/fish tanks that use seawater by natural gravity (Fig. 7c) provide useful indications about the uppermost and lowermost sea-level at the time of construction. It is assumed that the bottom of these pools must have been at a certain depth underwater to enable functioning, and that the feeding channels and sluice gates were not to be washed by the sea. Several studies have already interpreted past sea-level conditions on the basis of rock-cut coastal fish tanks (Dreghorn 1981; Auriemma & Solinas 2009; Evelpidou *et al.* 2012).

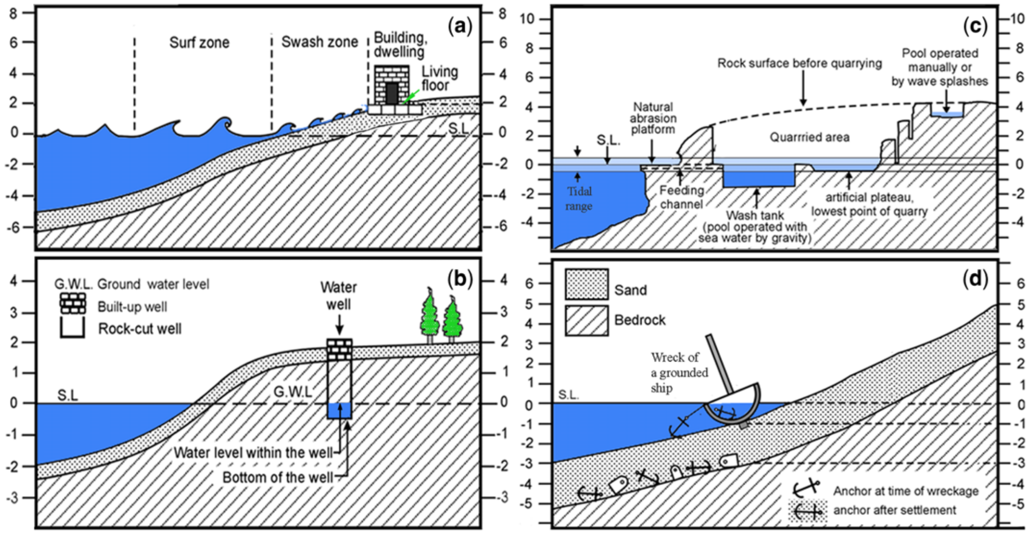

Fig. 7. Typical archaeological sea-level markers (after Galili & Sharvit 1998, fig. 2): (**a**) dwelling; (**b**) coastal water wells; (**c**) coastal quarries and fish tanks; and (**d**) wreck of a grounded ship.

The lower the fish-tank entrance is, the more seawater it gets, but then it is exposed to flushing: and, vice versa, the higher the entrance to the fish tank, the less seawater it gets, but it is safer. The fish tanks were most probably planned for the growing or keeping of certain marine species and were intended to function in specific seasons, under proper sea conditions. Unfortunately, it is not known in which seasons and under what tidal conditions specific fish tanks operated, and for how many hours a day they were fed by the sea during the spring tides. Unless these details are fully understood, and given the typical tidal range of approximately 30 cm in Cyprus, determining the relative uppermost and lowermost possible sea-level at the time the fish tanks were operated should be undertaken with caution, with an uncertainty of no less than about 30 cm.

Harbour installations such as breakwaters, moles, jetties, docks and quays were originally built partly underwater, and thus they are also good markers for uppermost and lowermost sea-level. Bio-structures and geomorphological markers identified on such man–made structures may further improve their precision as sea-level markers. It is generally agreed that walking and working surfaces in harbours were planned to be asl at all times. However, determining the sea-level using these features has some limitations: (a) it is not easy to determine whether the uppermost surface found today is the original one used in the past because some stones courses may have been removed either by natural agents or deliberately for reuse (Blackman 1973, p. 124); (b) it is possible that some harbour and coastal installations were not planned to function 365 days a year in all sea conditions – some of them might have been used seasonally under certain sea conditions, and were then flooded during high tides and wave storms; and (c) some constructions seemed to have been deliberately built underwater and there is historical evidence for such activities (Marsden cited in Blackman 1973, p. 138; Galili & Sharvit 1998, p. 158): for example, in the port of Akko, sandstone blocks several metres long were carefully laid at the foundation of the Tower of Flies at 5–7 m below sea-level (Raban 1985; Galili & Sharvit 1998, p. 158). Thus, the assumption that ashlar-built surfaces and structures that were originally constructed asl and were planned to be above the water all year is not always correct, and may be misleading in interpreting the associated past all year round.

Unconsolidated archaeological or natural deposits can move from their original location to somewhere nearby and thus cannot be used as sea-level markers without particular care. For example, a shell deposit found in Ashqelon, southern Israel at an elevation of 11 m asl was interpreted as evidence of uplifting (Neev *et al.* 1973, 1987) but was later proven to be a man-made archaeological feature (Ronen 1980).

Compaction and liquefaction of unconsolidated sediments may cause settling and subsidence of harbour installations. For example, sections of the Roman breakwater at Caesarea, central Israel, are currently submerged at a water depth of 5 m and were interpreted as evidence of seismogenic or tectonic subsidence (Neev *et al.* 1973, 1987; Raban

1985, 1991; Neev & Emery 1991; Mart & Perecman 1996; Reinhardt 1999). However, no tectonic fault was found there and the submergence was attributed to geotechnical settling of the breakwater into the unconsolidated sand, or even liquefaction (Galili 1986; Galili & Sharvit 1998).

Discriminating sea-level changes from local tectonic or isostatic changes can be achieved by comparing local sea-level curves with global curves (Galili *et al.* 1988; 2005). Overall, the use of installations cut into the rock rather than those built from stones enables the possible impact of erosion, settling and collapse to be eliminated.

Methodology

Aiming at the reconstruction of the shape of the coastal areas of Cyprus in prehistoric times, this study focused on correlating the position and height of the lithostratigraphic beach and shallow-marine deposits that are nowadays exposed along the Cyprus coasts (Fig. 2) in order to figure out the magnitude and rate of the vertical changes that occurred during the Late Pleistocene and the Holocene. Archaeological features, as well as natural erosional and depositional products (abrasion platforms, tidal notches and beachrocks), were also observed to determine the possible vertical changes during the Late Holocene. The fieldwork included detailed examination of the deposits in each of the 22 sites investigated and careful identification of the faunal assemblages. Exact locations were obtained by the GPS navigational system, and elevations were defined using topographical maps and an electronic elevation gauge, as well as by manual measurements of the lithological contacts using rolled tape and hand level, all dependent on the nature of the section and the local conditions. Estimated accuracy of the measured elevations of the depositional features is ±0.5 m.

Identifying the Late Pleistocene B/SM deposits

The observations on the 22 coastal sites (Tables 1 & 2) focused on investigating the sedimentological characteristics, identifying depositional facies and determining the elevations of the B/SM deposits. These include the examination of their sorting, lamination when present, grain size, cross-bedding and the faunal assemblage, especially the presence of molluscs and *Cladocora* corals, as these criteria may indicate the palaeo-environment of that section. The term 'beach and shallow-marine deposits' (B/SM deposits) used here refers specifically to deposits originating from shoreface, foreshore and backshore environments. Assuming that whole and fragmented shells and corals could reach up to about 1 m asl under normal conditions and rarely up to 2 m asl under moderate stormy conditions, the presence of such products in a deposit suggests that the shoreline at the time of deposition was at, or close to, its *in situ* elevation. The presence of poorly sorted gravel and coarse-grain-sized sand with whole and fragmented shells and corals indicates a high-energy environment at, or very close to, the palaeo-coastline at the time of deposition. The MIS 5e sea-level was the uppermost and most recent highstand over the last 500 ka or so, and, therefore, the inner edge or the highest deposition line of a deposit that contains such coarse, poorly sorted products, including shells and corals, may be interpreted as being close to the elevation of the MIS 5e coastline.

The matrix of beachrocks or other deposits associated with high sea-level stands is considered to consist of aragonite (Hopley 1986). However, a B/SM deposit may first be deposited *in situ* as loose remains for a while and then cemented only later under terrestrial conditions, after the sea has receded. Thus, the intergranular cement of a given deposit should not be considered a sole indicator of B/SM deposits. Mollusc species and assemblages were identified using the mollusc collections of the Tel-Aviv University and the Hebrew University of Jerusalem, and analysed in order to determine past coastal environments and to correlate the deposits from various sections along the coast. Microscopic study of the calcareous nannofossils found in the marly layers underlying the Late Pleistocene B/SM deposits mainly from the northern coastline in the Kyrenia area, was carried out at the Geological Survey of Israel and enabled the age of these rocks to be identified.

Dating the Late Pleistocene B/SM deposits

Absolute U–Th dating of the B/SM deposits from the Cyprus coasts is problematic (see further discussion later in the section on 'Age of the Late Pleistocene B/SM deposits'). Thus, we base our dating on conventional stratigraphic considerations, such as field relationships, typical/indicative sequences of the strata and, most importantly, the presence of the following index fossils: (i) the marine gastropod *Sb* (Gignoux 1913; Deperet 1918; Galili *et al.* 2007); (ii) *Bursa granularis*; and (iii) *Conus ermineus*. These species are of western equatorial African origin and no longer live in the Mediterranean (Table 2). The locations in the eastern Mediterranean where fossils of the indicative species of *Sb* are found are the Galilee and the Carmel coasts of Israel (Issar & Kafri 1969; Sivan *et al.* 1999; Galili *et al.* 2007), as well as on the coasts of Lebanon (Wetzel & Haller 1945–1948). Overall,

Table 1. *Summary description of the studied sites: For practical considerations, sections 11, 12, 16, 17, 18 and 19 were converged, and so were sections 17, 18 and sections 19, 20*

Site No. and name	Longitude Latitude	Present elevation of the B/SM deposit (m)	Inferred MIS 5e sea level (m asl*)	Vertical magnitude and rate of uplift since the MIS 5e stage referred to sea levels of 6.5 m since 116 ka or 7.2 m since 122 ka	Direction of the cliff face (CF) Pointing to the East (E.), West (W.), West-North West (W-NW), North-North West (N-NW), etc., and comments	Inner Edge Visible	Deposition Environments of the Late Pleistocene Deposits	No. of mollusc species living at a water depth of up to 5, 10, 20 m, total No. of mollusc species, index fossils in the deposit
1 Apostolos Andreas monastery, Karpasia	34°34′29″ 35°39″34″	7.5–12.5 ± 0.5 (7.5 m near the coast, 12.5 m inland)	≥12.5 ± 0.5	≥6 ± 1.58 m, ≥51.72 ± 13.64 mm ka^{-1} ≥5.3 ± 1.39 m, ≥43.44 ± 11.61 mm ka^{-1}	**CF: E.** The lower part of the sandstone complex above the marl consists of 6 m-thick finely sorted coarse sandstone containing no shells	+	Top–FS Bottom–SF	0, 0, 0, 2 (Horowitz 1964) reported of *Persististrombus latus* in the region.
2 Yialousa, Karpasia Bay	34°13′06″ 35°33′23″	8–13 ± 0.5	≥13 ± 0.5	≥6.5 ± 1.58 m, ≥56.03 ± 13.64 mm ka^{-1} ≥5.8 ± 1.39 m, ≥47.54 ± 11.65 mm ka^{-1}	**CF: W-NW.** Present-day beachrocks at sea level containing Greek/Roman sherds, *Cladocora*	+	Top–FS Bottom–SF	22, 4, 3, 83
3 Flamoudi	33°51′38″ 35°24′58″	19.5–23.5 ± 0.5	≥23.5 ± 0.5	≥17 ± 1.58 m, ≥146.55 ± 13.69 mm ka^{-1} ≥16 ± 1.39 m, ≥133.61 ± 13.17 mm ka^{-1}	**CF: N-NW.** The layer overlaying the B/SM deposit consists of several metre thick, finely sorted coarse carbonatic sandstone with no shells.	+	Top–BS Bottom–FS	0, 0, 0, 4.
4 Davlos	33°55′04.5″ 35°26′5.3″	17–20 ± 0.5	≥20 ± 0.5	≥13.5 ± 1.58 m, ≥116.38 ± 13.64 mm ka^{-1} ≥12.8 ± 1.39 m, ≥104 ± 12.53 mm ka^{-1}	**CF: NW.** Similar to sections in sites 3, 4 and 5, *Cladocora*	−	Top and bottom–FS	5, 3, 6, 25
5 Akanthou–archaeological site	33°44′54″ 35°24′17.8″	13–15.5 ± 0.5	≥15.5 ± 0.5	≥9 ± 1.58 m, ≥77.59 ± 13.65 mm ka^{-1} ≥8.3 ± 1.39 m, ≥68.03 ± 11.9 mm ka^{-1}	**CF: W-NW.** PPN Prehistoric material on top of the section. Travertine deposits and dense vegetation associated with freshwater spring at the upper terrace, 13 m asl, *Cladocora*	+	Top–FS Bottom–SF	12, 5, 6, 53
6 Agia Marina	33°40′12″ 35°21′51″	12–17 ± 0.5	≥17 ± 0.5	≥10.5 ± 1.58 m, ≥90.52 ± 13.65 mm ka^{-1} ≥9.8 ± 1.39 m, ≥80.33 ± 12.08 mm ka^{-1}	**CF: N.** PN Prehistoric site on top of the cliff near the springs, *Cladocora*	+	Top–FS Bottom–BS	8, 2, 4, 37 *Persististrombus latus*, *Bursa granularis*, *Conus ermineus*

7 Kyrenia memorial–east of the port castle	33°19′30.36″ 35°20′26″	6.5–8.7 ± 0.5 (6.5 m in the north, and 8.7 m south inland)	≥8.7 ± 0.5	≥2.2 ± 1.58 m, ≥18.97 ± 13.63 mm ka^{-1} ≥1.5 ± 1.39 m, ≥12.3 ± 11.43 mm ka^{-1}	**CF: W-NW.** Ancient quarries, 1–2 ka old, on top of the cliff. The B/SM deposit is 0.5 m thick and down-warping northwards, *Cladocora*	+	Top–BS Bottom–FS	6, 3, 1, 22 *Persististrombus latus*, *Conus ermineus*
8 Kyrenia West–Agios Georgios (Mercure Hotel)	33°15′22.14″ 35°21′01″	3–8 ± 0.5	≥8 ± 0.5	≥1.5 ± 1.58 m, ≥12.93 ± 13.63 mm ka^{-1} ≥0.8 ± 1.39 m, ≥6.56 ± 11.42 mm ka^{-1}	**CF: NW.** *Cladocora*	±	Top–BS Centre–FS Bottom–SF	5, 0, 0, 6 At least eight whole specimens of *Persististrombus latus*, found *in situ* and several more in detached blocks
9 Lapithos	33°09′53″ 35°21′8.1″	0.5–2.5 ± 0.5	≥2.5 ± 0.5	≥−4 ± 1.58 m, ≥−34 ± 13.63 mm ka^{-1} ≥−4.7 ± 1.39 m, ≥−38.52 ± 11.57 mm ka^{-1}	**CF: NW.** Lower 0.3 m of B/SM deposit is poorly sorted, with many shells	−	Top–BS Bottom–FS	4, 2, 2, 19
10 Lemba–Mylouthkia	32°23′17.1″ 34°49′39.2″	4–8 m ± 0.5 (4 m near the coast, 8 m inland)	≥8 ± 0.5	≥1.5 ± 1.58 m, ≥12.93 ± 13.63 mm ka^{-1} ≥0.8 ± 1.39 m ≥6.56 ± 11.42 mm ka^{-1}	**CF: SW.** The sections are near the early Neolithic site of Mylouthkia that include ancient water wells. Fresh water spring appear at the bottom of the cliff	+	Top–BS FS	1, 0, 0, 2
11, 12 Lemba south (Syntana hotel)	32°23′22.5″ 34°49′30.2″	16–18.2 ± 0.5	≥18.2 ± 0.5	≥11.7 ± 1.58 m, ≥100.86 ± 13.66 mm ka^{-1} ≥11 ± 1.39 m, ≥90 ± 12.25 mm ka^{-1}	**CF: SW.** Poorly sorted B/SM deposit with many whole shells.	+	Top & Bottom–FS	0, 1, 0, 3
13 Larnaca lake, inland west section	33°36′21″ 34°53′25.4″	4–5 ± 0.5	≥5 ± 0.5	≥−1.5 ± 1.58 m, ≥−12.93 ± 13.63 mm ka^{-1} ≥−2.2 ± 1.39 m, ≥−18.03 ± 11.45 mm ka^{-1}	**CF: SE.** The cliff on the west coast of the Larnaka lake.	±	Top & Bottom–SF	1, 2, 0, 18
14 Larnaca airport–terminal hill	33°37′15″ 34°53′0.1″	6–8.5 ± 0.5	≥7 ± 0.5	≥0.5 ± 1.58 m, ≥4.31 ± 13.63 mm ka^{-1} ≥−0.2 ± 1.39 m, ≥−1.64 ± 11.42 mm ka^{-1}	**CF: W-SW.** A cliff on the S/E coast of lake Larnaka, *Cladocora*.	±	Top–SF Bottom–FS	9, 4, 8, 44 *Persististrombus latus,* has been reported in the region before
15 Larnaca–east section	33°37′59.3″ 34°53′49.77″	4–6 ± 0.5	≥6 ± 0.5	≥−0.5 ± 1.58 m, ≥−4.31 ± 13.63 mm ka^{-1} ≥−1.2 ± 1.39 m, ≥−9.84 ± 11.43 mm ka^{-1}	**CF: N.** A hill some 500 m inland, between Larnaka lake and the Mediterranean coastline.	±	Top & Bottom–FS	2, 1, 1, 14

(*Continued*)

Table 1. *Summary description of the studied sites: For practical considerations, sections 11, 12, 16, 17, 18 and 19 were converged, and so were sections 17, 18 and sections 19, 20* (*Continued*)

Site No. and name	Longitude Latitude	Present elevation of the B/SM deposit (m)	Inferred MIS 5e sea level (m asl*)	Vertical magnitude and rate of uplift since the MIS 5e stage referred to sea levels of 6.5 m since 116 ka or 7.2 m since 122 ka	Direction of the cliff face (CF) Pointing to the East (E.), West (W.), West-North West (W-NW), North-North West (N-NW), etc., and comments	Inner Edge Visible	Deposition Environments of the Late Pleistocene Deposits	No. of mollusc species living at a water depth of up to 5, 10, 20 m, total No. of mollusc species, index fossils in the deposit
16, 17 Cape Greco–south bay–south and north sections	34°04′50.9″ 34°57′42.8″	0–10 ± 0.5	≥10 ± 0.5	≥3.5 ± 1.58 m, ≥30.17 ± 13.63 mm ka^{-1} ≥2.8 ± 1.39 m, ≥22.95 ± 11.47 mm ka^{-1}	**CF: N-NW.** The marl is not visible ASL	−	Top–BS Bottom–SF&FS	2, 0, 2, 9
18, 19 Cape Greco–north bay section	34°04′40.43″ 34°57′58.7″	3–10 ± 0.5	≥10 ± 0.5	≥3.5 ± 1.58 m, ≥30.17 ± 13.63 mm ka^{-1} ≥2.8 ± 1.39 m, ≥22.95 ± 11.47 mm ka^{-1}	**CF: NW.** The uppermost section of the B/SM deposit is micro laminated, with cross bedding, *Cladocora.*	±	Top–BS Bottom–FS	1, 0, 0, 11
20 Cape Greco north (chapel) section	34°04′33″ 34°58′32″	8–18 ± 0.5	≥18 ± 0.5	≥11.5 ± 1.58 m, ≥00.14 ± 13.66 mm ka^{-1} ≥10.8 ± 1.39 m, ≥88.52 ± 12.22 mm ka^{-1}	**CF: NW.** A limestone deposit with fossil shells is sandwiched between the underlying marl and overlaying B/SM deposit, *Cladocora.*	±	Top & Bottom–SF	0, 0, 0, 3
21 Famagusta bay (Sea side Hotel)	33°53′59″ 35°12′28″	5–7 ± 0.5	≥7 ± 0.5	≥0.5 ± 1.58 m ≥4.31 ± 13.63 mm ka^{-1} ≥−0.2 ± 1.39 m, ≥−1.64 ± 11.42 mm ka^{-1}	**CF**: **E.** The upper 0.3 m of B/SM deposit contain many whole and broken shells	+	Top–FS Bottom–SF	1, 0, 0, 3
22 Famagusta bay (Cristal Rock Hotel)	33°53′58″ 35°12′42.5″	0.7–8 ± 0.5 0.7–2.5 m at the coast, and 8 m asl 70 m inland	≥8 ± 0.5	≥1.5 ± 1.58, ≥12.93 ± 13.63 mm ka^{-1} ≥0.8 ± 1.39 m, ≥6.56 ± 11.42 mm ka^{-1}	**CF**: **E.** Beachrocks with pottery sherds at present SL	+	Top–FS Bottom–SF	7, 3, 2, 20 A broken specimen of *Persististrombus latus,*found *in situ* 1 m above SL.

Elevations are given in metres asl with ±0.5 m measuring error. The magnitude (in m) and rate (in mm ka^{-1}) of vertical changes are calculated taking into account that all of the studied beach deposits belong to the last interglacial highstand MIS 5e (see the Discussion). The average elevation of 7.2 m asl and the age of 122 ka proposed for the MIS 5e stage by Kopp *et al.* (2009) were used for the calculations. We also referred to the age of 116 ka and the elevations of 5 and 8 m asl used in previous studies on the Cyprus coasts (i.e. Poole *et al.* 1990; Poole & Robertson 1991). The deposition environment (SF, shoreface; FS, foreshore; BS, backshore) is assumed based on lithofacies considerations (grain size, lamination, sorting, dipping and index fossils) and the presence of mollusc species that lived in the shoreface and foreshore environments (Table 2). Given that the inner edge of the B/SM deposits is not always visible and may be higher than observed, the values of vertical change and rate of change are considered here as the minimal possible ones, while the true values may be even higher (see the Discussion). The Comments column also indicates the existence of coral and archaeological indicators. The inner edge column indicates the existence or lack of visible inner edge (marked with + or −) or indications of the possible existence of a nearby inner edge which is not visible (marked with + or −). The right-hand column of the table summarizes the number of mollusc species living at a water depth of up to 5 m, up to 10 m and up to 20 m, as well as the total number of mollusc species identified in the deposit, including those that live in deeper water and those for which the depth cannot be determined. Also in this column are notes about the presence of index fossil molluscs.

Table 2. *Palaeo-mollusc species in the studied sites and their common habitat*

Taxon, species	General distribution*	Depth (m)/habitat†	Sites on Cyprus coast
Haliotis tuberculata lamellosa	Med.	1–30/R	5
Diodora italica	Med.	0–2/R	4, 7, 14, 16, 21
Diodora gibberula	Med. & E. A.	0–2/R	2, 5, 6
Fissurella nubecula	Med & NW Af.	0–2/R	5, 13
Patella caerulea	Med.	0–1/R	8, 10, 22
Calliostoma laugieri	Med.	5–60/AMS	2
Clanculus corallinus	Med.	5–230/R	2, 4, 5, 6, 14, 16
Clelandella miliaris	Med & E. A.	35–800/MS	4
Forskalena fanulum	Med. & S. Po.	1–15/A	14
Gibbula adansonii	Med.	1–4/A	15
Gibbula albida	Med.	1–20/AS	2, 4, 5, 14
Gibbula ardens	Med.	1–20/A	4, 5, 6, 7, 9, 14
Gibbula guttadauri	Med.	4–15/AS	4, 14
Gibbula magus	Med. & E. A.	8–70/M	2
Gibbula varia	Med.	1–4/R	16
Jujubinus exasperatus	Med. & E. A.	1–18/A	6, 9, 14
Jujubinus striatus	Med. & E. A.	3–200/AR	2, 4, 15
Phorcus turbinatus	Med.	0–1/R	6, 18, 22
Bolma rugosa	Med. & E. A.	4–50/R	5, 11, 14, 16, 19
Tricolia pullus	Med. & E. A.	1–35/A	2, 4, 5, 14
Tricolia tenuis	Med.	1–20/A	2, 4, 5, 14
Circulus striatus	Med. & E. A.	1–30/A	2
Bittium jadertinum	Med. & E. A.	2–10/AR	2, 5, 7, 9, 14, 15, 22
Bittium reticulatum	Med. & E. A.	2–10/AR	2, 4, 5, 6, 7, 9, 13, 14, 22
Cerithium lividulum	Med.	1–5/RS	6
Cerithium renovatum	Med.	1–5/RS	2, 5, 7
Cerithium rupestre	Med.	1–5/RS	6
Cerithium vulgatum	Med.	1–5/MS	4, 6, 8, 14, 22
Alvania amatii	E. Med.	1–3/ARS	2
Alvania aspera	E. Med.	1–3/ARS	2
Alvania beani	Med. & E. A.	1–3/ARS	15
Alvania cimex	Med.	1–3/ARS	2, 4, 14
Alvania colossophilus	E. Med.	1–3/ARS	9, 14
Alvania discors	Med.	1–3/ARS	2, 4, 15, 22
Alvania fractospira	E. Med.	1–3/ARS	22
Alvania hallgassi	Med.	1–3/ARS	2, 5
Alvania lactea	Med. & E. A.	1–3/ARS	7
Alvania mamillata	Med.	1–3/ARS	2
Alvania rudis	Med.	1–3/ARS	2
Alvania testae	M Med.	1–3/ARS	14
Manzonia crassa	Med. & E. A.	1–3/ARS	2
Rissoa guerini	Med. & E. A.	1–3/A	2
Rissoa labiosa	Med. & E. A.	1–3/A	2
Rissoa monodonta	Med.	1–3/A	2
Rissoa scurra	Med.	1–3/A	7
Rissoa similis	Med. & S. Po.	1–3/A	5
Rissoa variabilis	Med. & E. A.	1–3/A	2, 5
Rissoina bruguieri	Med. & E. A.	1–3/A	2, 5, 7
Setia species	Unknown	–	7
Caecum trachea	Med. & E. A.	2–250/S	2, 14
Tornus subcarinatus	Med. & E. A.	1–3/RS	6, 14
Petaloconchus glomeratus	Med. & E. A.	1–20/MS	14
Vermetus granulatus	Med.	1–5/R	7
Vermetus triqueter	Med.	1–5/R	14
Turritella communis	Med. & E. A.	10–200/MS	2, 6, 9, 15, 18, 20
Capulus ungaricus	Med. & E. A.	5–850/R	2
Persististrombus latus	West Africa	2–15/S	6, 7, 8, 22
Erosaria spurca	Med. & E. A.	1–100/R	6

(*Continued*)

Table 2. *Palaeo-mollusc species in the studied sites and their common habitat* (*Continued*)

Taxon, species	General distribution*	Depth (m)/habitat†	Sites on Cyprus coast
Luria lurida	Med. & E. A.	1–60/RS	6
Euspira nitida	Med. & E. A.	2–200/S	5
Notocochlis dillwynii	Med. & E. A.	1–25/S	4, 15
Neverita josephinia	Med.	1–30/S	2
Semicassis granulatum undulatum	Med. & E. A.	1–80/S	2, 3
Cabestana cutacea	Med. & E. A.	10–60/MS	6, 22
Cymatium parthenopeum	Med. & E. A.	10–30/MRS	5
Bursa granularis s.l.	West Africa	5–20/R	6
Strobiligera brychia	Med. & E. A.	1–3/AS	5
Cerithiopsis diadema	Med.	1–3/AS	9
Cerithiopsis minima	Med.	1–3/AS	4
Cerithiopsis species	Unknown	–	7
Dizoniopsis bilineata	Med.	1–3/AS	5
Vitreolina levantina	E. Med.	1–3/P	9
Vitreolina philippii	Med.	1–3/P	5
Hexaplex trunculus	Med. & S. Po.	1–130/MRS	2, 5, 6, 21, 22
Ocinebrina edwardsi	Med. & E. A.	0.5–5/RS	2
Stramonita haemastoma	Med. & E. A.	1–10/R	22
Pollia dorbignyi	Med.	0–2/R	5, 8
Pollia scabra	Med.	1–60/R	5
Engina leucozona	Med.	1–37/R	5
Pisania striata	Med.	0.5–5/R	6
Columbella rustica	Med. & E. A.	1–37/AR	2, 5, 6, 14, 15, 16, 22
Mitrella gervillii	Med.	2–90/AR	14
Nassarius cuvierii	Med. & E. A.	2–8/M	4, 5
Nassarius louisi	E. Med.	1–5/M	2, 14
Nassarius mutabilis	Med. & E. A.	1–5/M	5
Nassarius nitidus	Med. & E. A.	1–5/M	8, 9
Fasciolaria lignaria	Med.	1–8/R	5, 11
Volvarina mitrella	Med. & E. A.	1–100/A	2
Mitra cornicula	Med. & E. A.	1–40/RS	15
Mitra species	Unknown	–	2
Pusia littoralis	E. Med.	1–5/ARS	2, 8
Conus mediterraneus	Med. & S. Po.	0.5–25/RS	2, 4, 5, 6, 14, 15, 16, 22
Conus ermineus	West Africa	10–20/RS	6, 7
Conus species	Unknown	–	5, 21
Mangelia vauquelini	Med.	1–5/S	2
Mangiliella multilineolata	Med.	1–5/S	2
Turridae I	Unknown	–	5
Turridae II	Unknown	–	5
Chrysallida fenestrata	Med. & E. A.	1–3/P	2
Chrysallida species	Unknown	–	2
Odostomia conoidea	Med. & E. A.	1–3/P	2
Turbonilla species I	Unknown	–	2
Turbonilla species II	Unknown	–	2
Ringicula auriculata	Med. & E. A.	6–40/?	2
Ringicula conformis	Med.	6–20/?	2
Retusa mammillata	Med. & S. Po.	?/MS	14
Retusa truncatula	Med. & E. A.	2–200/MS	2, 4, 14
Retusa umbilicata	Med.	?/MS	2
‘*Chiton*’		R	2, 6, 7
Nuculana commutata	Med. & E. A.	40–200/MS	2, 5
Nuculana pella	Med. & E. A.	4–180/MS	2
Nucula nitidosa	Med. & E. A.	7–250/MS	2, 13, 14
Nucula sulcata	Med. & E. A.	10–400/MS	2
Arca noae	Med. & E. A.	1–120/R	2, 5, 6, 7, 13, 14, 18, 22
Arca tetragona	Med. & E. A.	5–120/R	2
Barbatia barbata	Med.	2–280/R	2, 4

(*Continued*)

Table 2. *Palaeo-mollusc species in the studied sites and their common habitat* (*Continued*)

Taxon, species	General distribution*	Depth (m)/habitat†	Sites on Cyprus coast
Striarca lactea	Med. & E. A.	1–130/R	14
Glycymeris bimaculata	Med.	5–20/MS	2, 4, 5, 16
Glycymeris pilosa	Med.	9–90/MS	4, 5, 9, 14
Glycymeris nummaria	Med.	20–65/MS	2, 5, 6, 9, 18
Glycymeris spec.	Unknown	–	1, 3
Lithophaga lithophaga	Med.	1–100/R	5, 6, 7
Pinna nobilis	Med.	4–60/MS	13
Aequipecten opercularis	Med. & E. A.	4–400/MS	6
Chlamys bruei	Med. & E. A.	5–2000/MS	6
Manupecten pesfelis	Med. & E. A.	10–250/R	19
Mimachlamys varius	Med. & E. A.	1–80/R	6, 13, 18
Pecten jacobaeus	Med.	25–250/MS	2, 3, 6, 10, 13, 18, 20
Proteopecten glabra	Med. & Po.	6–900/MRS	13
Pseudamussium clavatum	Med. & E. A.	5–1400/M	22
Spondylus gaederopus	Med.	5–50/R	5, 6, 7, 11, 13, 14, 16, 20
Lima lima	Med. & E. A.	3–100/R	2, 5
Limaria inflata	Med. & E. A.	2–10/MRS	14
Ostrea edulis	Med. & E. A.	1–90/R	2, 5, 6, 14, 19, 22
Ostrea species	Unknown	–	1, 3, 14
Ostreola stentina	Med.	1–90/R	2, 5
Goodalli triangularis	Med. & E. A.	?/MS	2, 14
Ctena decussata	Med. & E. A.	2–10/MS	2, 4, 5, 6, 7, 14
Loripes lucinalis	Med. & E. A.	3–150/MS	2, 13, 22
Lucina borealis	Med. & E. A.	3–500/MS	9
Lucinella divaricata	Med. & E. A.	2–60/MS	2, 5
Tellimya ferruginosa	Med. & E. A.	?/RS	2
Chama gryphoides	Med. & E. A.	2–200/R	6, 7, 16
Cardita calyculata	Med. & E. A.	2–200/RS	2, 4
Cardites antiquata	Med.	2–40/RS	2, 5, 6, 9, 13, 14
Glans aculeata	Med. & E. A.	10–200/RS	7
Glans trapezia	Med. & E. A.	2–75/RS	2, 4, 7, 14
Pteromeris corbis	Med.	?	2
Acanthocardia tuberculata	Med. & E. A.	2–100/MS	2, 5, 9, 13
Cerastoderma glaucum	Med. & E. A.	1–5/MS	22
Laevicardium crassum	Med. & E. A.	5–180/MS	5
Laevicardium oblongum	Med. & E. A.	5–250/MS	14
Plagiocardium papillosum	Med. & E. A.	1–60/MS	14, 15
Mactra stultorum	Med. & E. A.	1–60/MS	2
Spisula subtruncata	Med. & E. A.	3–200/MS	18
Peronaea planata	Med. & E. A.	2–20/S	5
Peronidia nitida	Med.	1–8/S	13
Tellinella pulchella	Med.	3–6/S	13
Donax trunculus	Med. & E. A.	1–6/S	2, 22
Donax venustus	Med.	1–6/S	14
Gastrana fragilis	Med. & E. A.	2–5/M	6
Callista chione	Med. & E. A.	5–180/S	18
Chamalea gallina	Med.	5–20/S	22
Clausinella brongniartii	Med.	8–500/S	2
Dosinia lupinus	Med. & E. A.	2–200/MS	2, 13
Paphia rhomboides	Med. & E. A.	2–180/S	13
Pitar rudis	Med. & E. A.	3–80/S	5
Ruditapes decussatus	Med. & E. A.	3–8/S	2
Timoclea ovata	Med. & E. A.	4–200/S	2
Venus verrucosus	Med. & E. A.	2–100/S	2, 5, 7, 14, 15
Sphenia binghami	Med. & E. A.	8–65/R	2
Corbula gibba	Med. & E. A.	6–250/MS	2, 6
Hiatella arctica	Med. & E. A.	3–1400/R	14
Antalis entalis	NE Atlantic	6–3200/MS	5

(*Continued*)

Table 2. *Palaeo-mollusc species in the studied sites and their common habitat* (*Continued*)

Taxon, species	General distribution*	Depth (m)/habitat†	Sites on Cyprus coast
Antalis inaequicostata	Med.	5–130/MS	2, 6, 9, 13, 15
Antalis vulgare	Med. & E. A.	1–50/MS	2, 4, 5, 9, 14, 15
Barnacles	Unknown	–	18, 21
Brachiopods	Unknown	–	2
Corals	Unknown	–	3, 4, 5, 6, 7, 8, 14, 18, 19, 20
Crabs	Unknown	–	5
Polychaetes	Unknown	–	18

*General distribution: Med., Mediterranean; E.A., eastern Atlantic; NW Af., NW Africa; NE Atlantic, NE Atlantic; S. Po., southern Portugal.

†Bottom habitat: A., algae; M., mud; P., parasitic; R., rock/shells; S., sand.

In 20 of the 22 sites, molluscs were sampled and studied, and they contained at least 176 different taxa. In addition, some remains of barnacles, brachiopods, corals, crabs and polychaetes were encountered.

Persististrombus latus, *Bursa granularis* and *Conus ermineus* are of West African origin and no longer live in the Mediterranean Sea.

the age of the 22 B/SM deposits on the Cyprus coasts was determined as MIS 5e (see the discussion below).

Depositional depth of the marine fauna

Most marine shell species live within a wide range of water depths, while a few of them live in the tidal zone or close to it and, hence, are considered good sea-level markers (Petersen 1986). Thus, reconstructing the depth of deposition of the sediments relevant to this work should rely on the distribution of species living today in shallow water (Table 2). Given that the MIS 5e high sea stand has been at its highest in the last 500 ka or more, the presence of marine shells and corals of any kind above the present sea-level suggests that the last highest interglacial coastline was close to the elevation of the deposits containing these marine shells.

Vertical changes

Determining the present elevation of the palaeocoastline. The highest part of the B/SM deposit was considered most probably as the minimal elevation of the ancient coastline at the time of deposition, and the inferred sea-levels were close to, or even higher than, those deposits. Consequently, the total net changes and the rate of vertical changes between the present sea-level and the highest observed B/SM deposit are minimal estimates, while the actual ones may have been higher.

Determining the net magnitude and average rate of the vertical changes. The vertical changes were estimated by comparing the present elevation of the inner edge of the MIS 5e B/SM in relation to the assumed elevation at the time of deposition (7.2 ± 1.3 m asl according to Kopp *et al.* 2009; and 122 ± 6 ka after Pedoja *et al.* 2011). To enable comparison with the other studies carried out in Cyprus (i.e. Poole *et al.* 1990; Poole & Robertson 1991), we also referred to the elevations of 5–8 m asl (average of 6.5 ±1.5 m asl according to Poole *et al.* 1990) and 116 ± 1 ka after Stirling *et al.* (1998).

The magnitude of the net vertical change (Et) in metres was calculated using the subtraction $Et-E-e$, where E is the above-mentioned elevations of the MIS 5e sea-level and e represents the observed MIS 5e elevation of the beach deposit (Table 1).

The rate of vertical change (V) in mm ka^{-1} was calculated using the equation:

$$V = \frac{(E-e)}{A}$$

(after Pedoja *et al.* 2011), where A represents the above-mentioned time estimates of the MIS 5e high sea stands.

The error of the net vertical change (δEt) in metres was calculated using the formula:

$$\delta Et = \sqrt{(\delta E)^2 + (\delta e)^2}.$$

The error for the rate of the vertical change (δV) in mm ka^{-1} was calculated using the formula:

$$\delta V = V\sqrt{\left(\frac{\delta A}{A}\right)^2 + \left(\frac{\delta Et}{Et}\right)^2}.$$

In addition to these errors, there is also the uncertainty resulting from the fieldwork, which is assessed at ±0.5 m. Since the total vertical change is a minimum estimate of the actual one, the rate of uplift is also considered a minimal estimate. The equation was solved for each of the 22 deposits and the errors calculated for each.

The isostatic effects. Glacio-isostatic or hydro-isostatic adjustments of the Earth's crust (subsidence or uplifting) caused by the changing load of ice or water is more crucial in low latitudes, while isostatic changes caused by sediment load are common in deltaic regions. The changes of the last glacial are still active (Siddall *et al.* 2007). Isostatic corrections for the MIS 5e shoreline deposits were suggested by Pedoja *et al.* (2011) to reach 0.2 mm a^{-1} for active margins and are thus significant. However, the focus in the current study is on the net vertical changes and, therefore, we ignored the relative contribution of isostasy to the net vertical changes in the study area.

Observations on the coastal sites around Cyprus

Overall, 22 sites of Late Pleistocene B/SM deposits around the island of Cyprus were studied (Fig. 2) and are reported here in detail, with special emphasis on the Late Pleistocene and Holocene formations and prehistoric remains. Selected natural Holocene sea-level markers, such as abrasion platforms, wave notches and beachrocks, were also observed, as were indicative Middle–Late Holocene archaeological features. Of the 22 sites, seven are along the northern coast, three on the Karpasia Peninsula, six along the eastern and SE coasts, another three on the southern coast and three on the western coast (Fig. 2).

Site 1: Apostolos Andreas Monastery (Karpasia Peninsula)

The exposure is visible on a coastal cliff approximately 8 m-high, north of the Apostolos Andreas monastery, 4 km away from the easternmost point of Cyprus where the Pre-Pottery Neolithic Cape Andreas Castros site is located (Fig. 2, Site 1 & Fig. 8). The lower part of the cliff consists of Miocene–Pliocene grey green marl overlain by a 5–6 m-thick, finely sorted, coarse- to medium-sized calcareous sandstone, possibly of marine foreshore origin or coastal aeolian origin. This is overlain by 0.2 m-thick patches of B/SM deposit containing many whole and broken shells. The B/SM deposit dips seawards and reaches an elevation of up to 12.5 m asl, some 80 m inland. Horowitz (1964) has already described these coastal sediments and reported the presence of numerous mollusc shells including *Sb*.

Site 2: Yialousa, Karpasia Bay (Yeni Erenköy) (northern coast of Cyprus)

An artificial road-cut at the fishermen's port (Fig. 2, Site 2) exposes a sequence of B/SM deposits above the Miocene–Pliocene marls. The B/SM deposit is 2–2.5 m thick, and consists of poorly sorted and weakly consolidated coarse sand (sand-sized grains of different mineralogy) with whole and broken mollusc shells and some *Cladocora* corals. The top of the section consists of 1.5–2 m-thick soil. The base of the B/SM deposit is situated at 8–10.5 m asl and the inner edge is at 13 m asl (Fig. 9). Interestingly, the present coast, some 200 m west of the above-mentioned deposits, exposes beachrocks at the present sea-level that contain Greek/Roman sherds (Fig. 10).

Site 3: Flamoudhi (Mersinlik) (northern coast of Cyprus)

This is an artificial road-cut (Fig. 2, Site 3) that exposes a sequence of B/SM deposits overlying the Miocene–Pliocene marls. The B/SM deposits are 2–2.5 m thick, and consist of poorly sorted, friable coarse calcareous sand with many whole and broken mollusc shells. The B/SM deposit dips seawards, its base is at 19.5 m asl and its inner edge elevation is at 23.5 m asl, some 80 m inland (Fig. 11). The lower section of the beach deposit (0.5 m thick) is composed of large metamorphic pebbles (up to 0.5 m long), coarse sand, *Cladocora* corals, and whole and fragmented mollusc shells. The upper section of the B/SM deposit is composed of coarse sand with whole and broken shells. The B/SM deposit is overlain by a 3 m-thick layer of coarse- to medium-sized grain, finely sorted calcareous sandstone of possibly coastal aeolian origin, but containing no shells, cross-bedding or plant roots. The top of the section consists of 1.5–2 m-thick soil and reaches an elevation of 29 m asl.

Site 4: Davlos (Kaplıca) (northern coast of Cyprus)

This exposure is visible on a coastal cliff about 20 m-high, located on the east coast of a small local bay (Fig. 2, Site 4). The lower part of the cliff consists of marl and above it there is a 3 m-thick B/SM deposit at 17–20 m asl, composed of fine- to medium-sized grain, finely sorted calcareous sandstone with whole and broken shells, and fragments of *Cladocora* corals.

Site 5: Akanthou (Tatlısu) (northern coast of Cyprus)

The 1.5–2 m-thick B/SM deposit (Fig. 2, Site 5) is exposed at the front of a natural cliff, some 13–15.5 m asl and about 45 m away from the shoreline (Fig. 12). The lower part of the deposit (*c.* 1 m thick) overlies the Miocene–Pliocene marls and consists of well-sorted, coarse- to medium-sized,

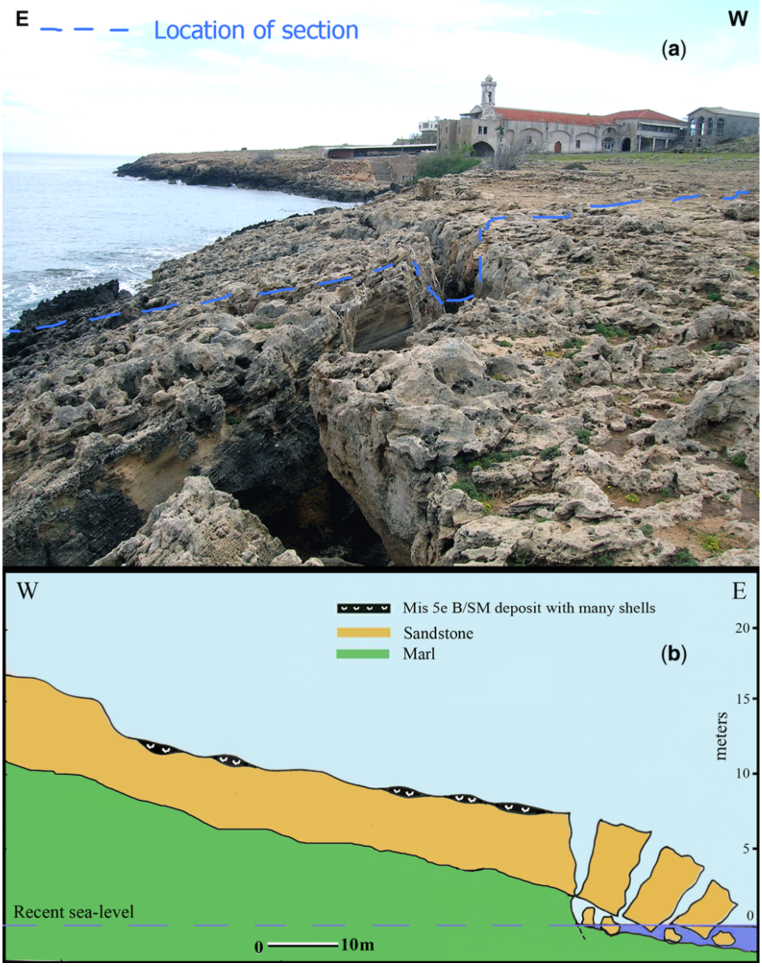

Fig. 8. Site 1: Apostolos Andreas Monastery, Karpasia Peninsula: (**a**) general view; and (**b**) cross-section.

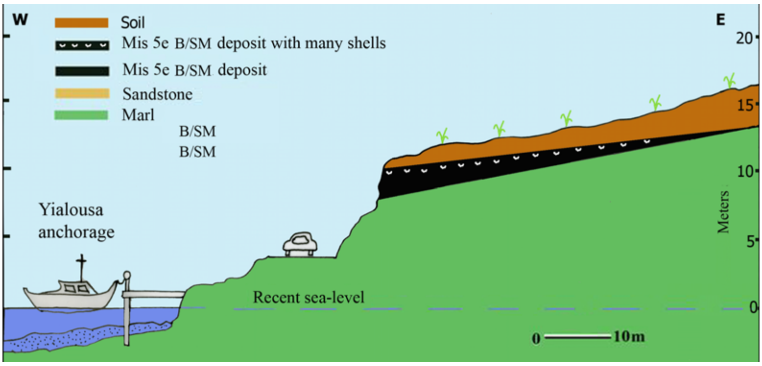

Fig. 9. Cross-section of Site 2, Karpasia Bay, northern coast of Cyprus.

Fig. 10. Roman Byzantine pottery sherds in a beachrock deposit in Karpasia Bay, associated with the present sea-level.

carbonate-cemented (refers in this work to cement containing carbonate minerals) calcareous sandstone (refers to rock made mostly of carbonate grains) with a few shells. The upper part of the B/SM deposit is a poorly sorted sandstone containing many broken and whole shells, and fragments of *Cladocora* corals. Above the deposit, there is a 1.5–2 m layer of soil that contains prehistoric remains of the Akanthou (Tatlısu) archaeological site (Şevketoğlu 2008). On the wide slope between the cliff and the shoreline, there are two small terraces (at 8 and 13 m asl) where large blocks of the B/SM deposit up to 4 m long accumulated. Travertine 1 m thick and with dense vegetation, probably associated with the presence of a freshwater spring, was observed on the western side of the upper terrace. Beachrock exposures together with some rock cuttings, as well as wave-cut abrasion platforms and notches on the nearby coast, are associated with the present sea-level (Fig. 13). Excavations at the Akanthou site revealed a Pre-Pottery Neolithic (PPN, 10 ka BP) coastal village that subsisted on agro-pastoral and marine resources. The site, the earliest known fishing village associated with seafaring on the north coast of Cyprus, may have been settled by one of the early communities that colonized the island at the beginning of the Holocene. Thousands of obsidian blades of Anatolian origin that were found at the site point to regular crossings between the mainland and the island over a long period, transporting the obsidian blades in finished form from the Kömürcü/Kaletepe workshop on the Anatolian coast to Cyprus. Eroded *in situ* structures and paved surfaces on the coastal cliff (Fig. 3) indicate the effect of the ongoing erosive processes on the archaeological remains.

Site 6: Agia Marina (Küçük Erenköy) (northern coast of Cyprus)

This section (Fig. 2, Site 6) is adjacent to the sea, in front of a 17 m-high natural coastal cliff formed by marine erosion (Fig. 14). It consists of marls at the base of the cliff and B/SM deposits above it. The latter are composed of an approximately 3–4 m-thick calcareous cemented, finely sorted, coarse- to medium-grain-sized calcareous sandstone, with a few shells fragments. It is overlain by a 1.5–2 m-thick, poorly sorted B/SM deposit that contains whole and fragmented shells and *Cladocora* corals, including intact and fragmented *Sb* shells (Fig. 15). Another important species that was found in this

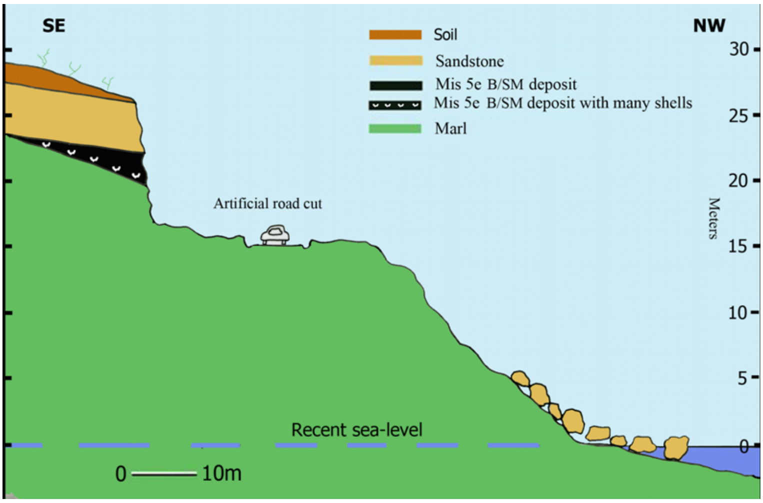

Fig. 11. Cross-section of Site 3, Flamoudhi, northern coast of Cyprus.

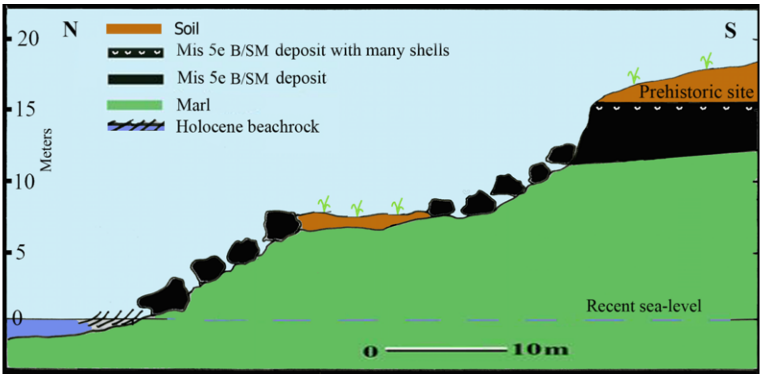

Fig. 12. Cross-section of Site 5, Akanthou, northern coast of Cyprus.

area is the *Luria lurida*, which was unknown in the Mediterranean Basin before the Pleistocene period. The upper part of the B/SM deposit is at 15–17 m asl. Eroded material from the coastal cliff, including large-sized sandstone blocks up to 5 m long, accumulated between the cliff and the coastline. Of significant importance are the line of vegetation and the presence of travertine deposits, clearly visible along the face of the cliff. These originated from freshwater springs flowing on top of the impermeable marls (Figs 16 & 17). Interestingly, Şevketoğlu (2000, p. 74) reported on a Pottery Neolithic site adjacent to one of the springs along that cliff.

Site 7: Kyrenia Memorial (northern coast of Cyprus)

This site (Fig. 2, Site 7) is located on the sea side and faces a 10 m-high natural cliff on the eastern coast of a small bay situated east of Kyrenia Castle (Fig. 18). The underlying marly layers contain nannofossils such as *Discoaster tamalis* and *Discoaster brouweri*, which most probably indicate a Middle Pliocene age. The marls are overlain by a 0.3 m-thick B/SM deposit of carbonate-cemented, poorly sorted, coarse calcareous sand that also contains whole and fragmented shells and *Cladocora* corals. The B/SM deposit dips northwards, and is at an elevation of 6 m asl in the north and up to 8.7 m to the south. An intact specimen of *Sb* was found in the beach deposit *in situ* (Fig. 19), and another half specimen was found in the cliff debris at the coastline. Above the B/SM deposit there is a 2–3 m-thick layer of coarse- to medium-sized-grain, finely sorted, carbonate-cemented, calcareous sandstone, possibly of aeolian backshore origin, that contains no shells, no cross-bedding and no plant roots. On top of the cliff and on some of the detached blocks it was possible to identify features of a quarry that produced building stones during historical periods (most probably 2–1 ka).

Fig. 13. Abrasion platform and associated notch at Site 5, associated with the present sea-level.

Site 8: Kyrenia West, Agios Georgios (Karaoğlanoğlu) (northern coast of Cyprus)

This site is a 13 m-high cliff on the northern side of a small headland, a few kilometres west of Kyrenia, at Agios Georgios (Fig. 2, Site 8). The marl at the base of the cliff is overlain by a 2 m-thick coarse, finely sorted, carbonate-cemented calcareous sandstone of marine origin, with a few broken shells (Fig. 20). Above this layer and up to 8 m asl, there is a 2 m-thick B/SM deposit similar in nature, but contains many whole and fragmented shells and fragments *of Cladocora* corals. More than eight whole specimens of *Sb* were found *in situ*, as well as in blocks detached from the cliff (Fig. 21). The top of the cliff consists of a 4–5 m-thick layer of finely sorted, coarse- to medium-sized, carbonate-cemented calcareous sandstone, reaching an elevation up to 13 m asl. It is of possible aeolian backshore origin, but contains no shells, no cross-bedding and no reed roots. In a previous study of this area,

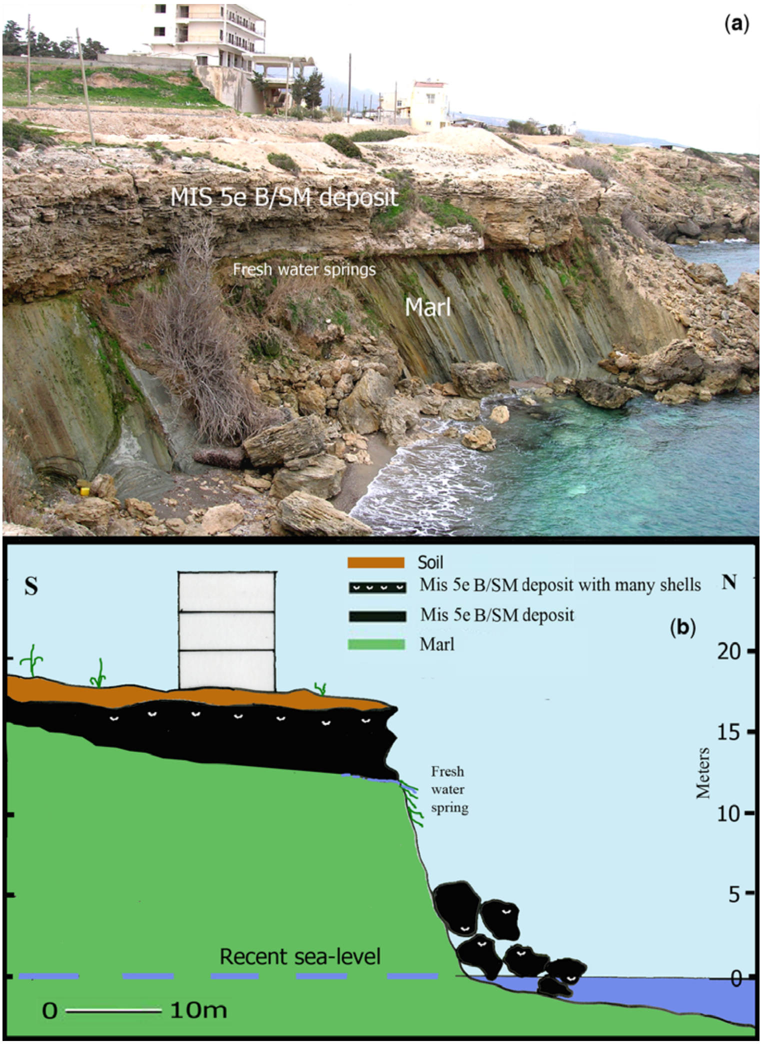

Fig. 14. Site 6, Agia Marina, northern coast of Cyprus: (**a**) general view; and (**b**) cross-section.

Moshkovitz (1965, 1966) reported the presence of numerous mollusc species, including *Polinices lacteu*, which like *Sb* is an index fossil that penetrated the Mediterranean Sea during the Late Pleistocene.

Site 9: Lambousa, Lapithos (Lapta) (northern coast of Cyprus)

The section is a natural 2 m-high cliff located in a small bay (Fig. 2, Site 9), some 15 km west of Kyrenia. Similar to Site 4, the marls below the Tyrrhenian deposits also contain a Middle Pliocene nannofossil assemblage. The underlying marls (0–1 m asl) are overlain by a coarse, poorly sorted, carbonate-cemented B/SM deposit (0.6 m thick) containing whole and fragmented shells. This deposit is covered by 1 m thick, medium-sized grain, finely sorted, calcareous sandstone with few shell fragments. The top of the section is a 0.5 m-thick fine-grained, finely sorted carbonate-cemented calcareous sandstone containing no shells. At one place a 0.5 m-thick lens, 2 × 2 m, of white limestone crust (calcrete?), containing land snails, was found overlying the B/SM deposit.

Site 10: Lemba-Mylouthkia (western coast of Cyprus)

This site lies on a small peninsula situated between two bays opposite the village of Lemba, some 7 km north of Paphos (Fig. 2, Site 10). A natural cliff

Fig. 15. *In situ* index fossil *Persististrombus latus* (former name *Strombus bubonius*) from Site 6.

shows a 0.2–1 m-thick B/SM deposit in-between two layers of sandstone, which all together overlie grey-green marls. The B/SM deposit dips westwards towards the sea, where in the inland side of the section it is approximately 0.2 m thick at a maximum elevation of 8 m asl, and in the sea side it is 1 m thick at a maximum elevation of 4 m asl (Figs 22 & 23). The B/SM deposit consists of poorly sorted, coarse calcareous sand with many whole and broken shells, and maintains the same thickness throughout. The Early Neolithic site of Mylouthkiya is situated on a high plateau, east of the peninsula, where construction work exposed several water wells, the oldest known so far. The wells are 6–9 m deep and were dug by the early inhabitants into the soft Pleistocene Havara deposits in order to exploit the local coastal aquifer above the impermeable Pliocene marls (Peltenburg *et al.* 2001*a*, *b*). This aquifer is also the origin of a present-day local freshwater spring at the bottom of the cliff (Galili *et al.* 2004*a*, *b*).

Fig. 16. Site 6, freshwater spring.

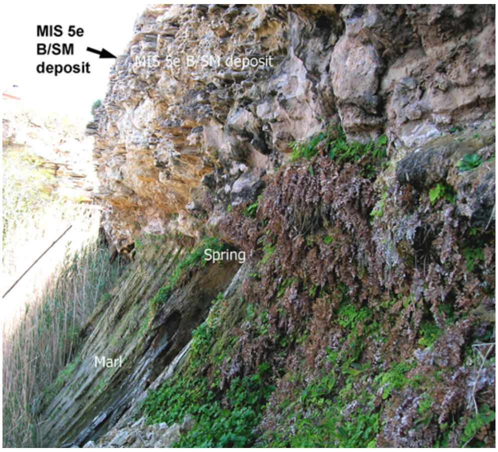

Fig. 17. Site 6, Freshwater spring and associated vegetation along the coastal cliff.

Sites 11 and 12: Lemba south, Sintana Hotel (western coast of Cyprus)

The section of site 11 is located some 300 m east of Mylouthkiya (Site 10 above) (Fig. 2, Site 11 & Fig. 24). It consists of an 18 m-high coastal cliff. The marls at the base of the section are overlain by a coarse, poorly sorted and carbonate-cemented B/SM deposit (2.2 m thick) reaching up to the top of the cliff, at a maximum elevation of 18.2 m asl. The B/SM deposit contains coarse- to medium-sized calcareous sand with whole and broken shells. Site 12 is located some 60 m north of site 11 and is similar in nature.

Site 13: Larnaca salt lake–inland west section (southern coast of Cyprus)

The sequence of B/SM deposits above the Miocene–Pliocene marls is exposed in the abraded cliff on the west coast of the Larnaca Lake (Fig. 2, Site 13). The B/SM deposit is 1 m thick, at about 4–5 m asl, and consists of finely sorted coarse- to medium-sized, weakly consolidated, calcareous sand, with whole and broken mollusc shells. The top of the section is at 6.5 m asl and consists of 1.5-2 m-thick soil. The lower section of the B/SM deposit (0.2 m thick) is composed mostly of shells associated with some patches of sand with a few shells.

Site 14: Larnaca airport terminal hill (Larnaca Lake, southern coast of Cyprus)

The section is located on the western slopes of a small hill located on the southern coast of the Larnaca salt lake, about 500 m north of the entrance

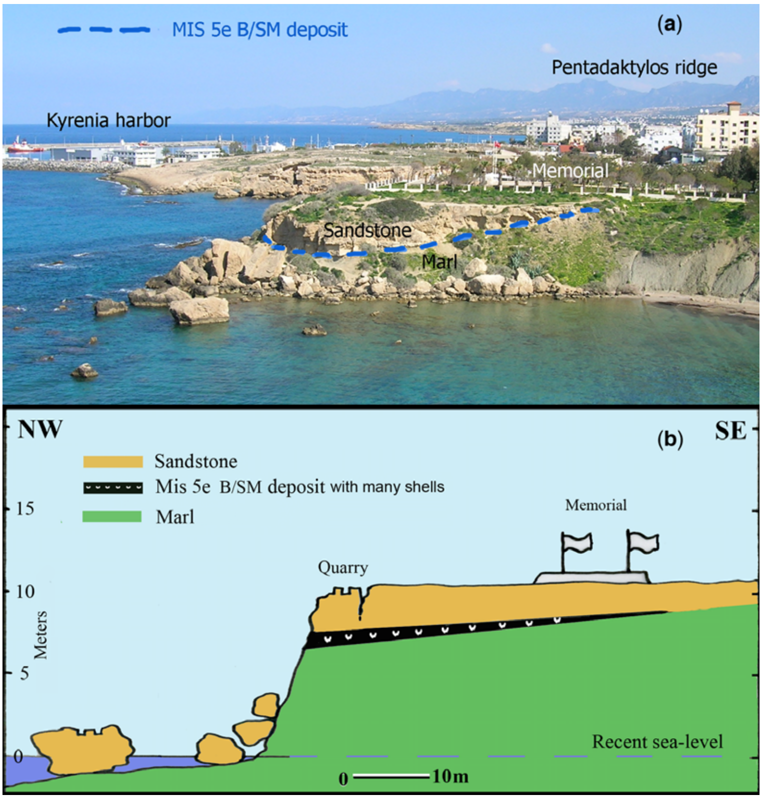

Fig. 18. Site 7, Kyrenia Memorial, northern coast of Cyprus: (**a**) general view; and (**b**) Cross-section.

to the Larnaca airport terminal (Fig. 2, Site 14 & Fig. 25). Grey marl forms the base of the section and reaches an elevation of up to 6 m asl. The marl is overlain by a 2.5 m-thick B/SM deposit. Its lower 0.5 m is made up of poorly sorted, coarse calcareous sand and gravel that contains whole and broken shells, and fragments of *Cladocora* corals. The upper 2 m of the B/SM deposit is a conglomerate that contains pebbles (0.03–0.15 m in diameter), plates (0.3–0.6 m long), and few whole and broken shells, reaching 8.5 m asl. On the NE coast of this lake, a similar B/SM deposit containing numerous well-preserved *Sb* provided the first report of Indo-Pacific fauna from Cyprus (Gaudry 1862; Pantazis 1967; Moshkovitz 1968; Vita-Finzy 1990, 1993; Poole *et al.* 1990; Poole & Robertson 1991, 2000). The conglomerate is overlain by unconsolidated material several metres thick up to about 15 m asl and some soil topping at 15 m asl.

Fig. 19. Site 7, *in situ Persististrombus latus.*

Site 15: Larnaca salt lake, east section (southern coast of Cyprus)

Similar to Site 9 near Larnaca airport, a sequence of B/SM deposits overlying Miocene–Pliocene marls is exposed on the eastern coast of the Larnaca Lake (Fig. 2, Site 15). The deposit is 2 m thick (at 4–6 m asl) and consists of weakly consolidated, fine- to medium-sized sand with whole and broken mollusc shells. The top of the section is 7 m asl and consists of 1–1.5 m thick soil. The lower section of the B/SM deposit (0.5 m thick) contains

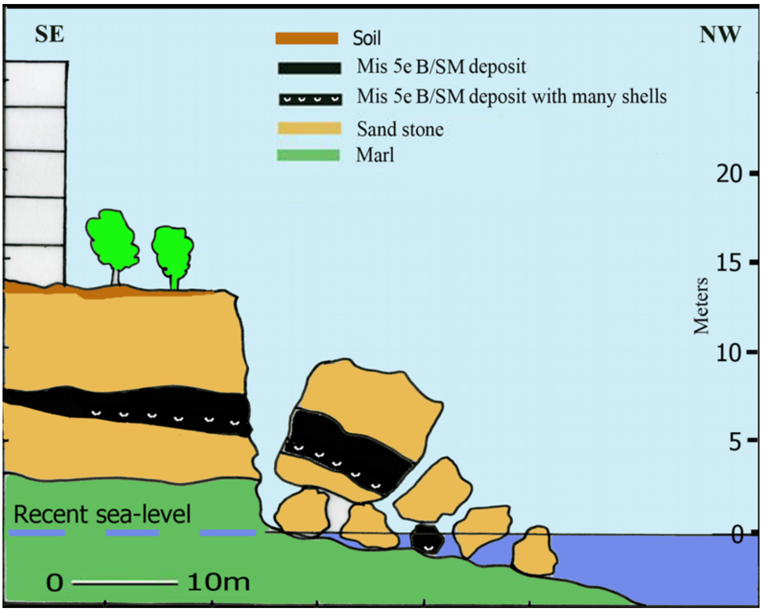

Fig. 20. Cross-section of Site 8, Kyrenia west, northern coast of Cyprus.

pebbles and boulders (up to 0.3 m long), and many shells, while the rest contains finely sorted sand with a few shells.

Sites 16 and 17: Cape Greco, south bay sections (SE coast of Cyprus)

The sections (Fig. 2, sites 16 and 17) appear on a 10 m-high coastal cliff facing the sea that was formed by marine erosion. Here, the underlying marl deposit is not visible asl. The B/SM deposit is composed of poorly sorted, coarse calcareous sandstone, containing many whole and broken shells. The top of the B/SM deposit in sections 16 and 17 is at 6 and 10 m asl, respectively. It is overlain by a layer several metres thick of finely sorted, coarse- to medium-sized calcareous sandstone with no shells, possibly of aeolian origin.

Fig. 21. Index fossil *Persististrombus latus*, *in situ*, Site 8.

Sites 18 and 19: Cape Greco, north bay section (SE coast of Cyprus)

The section of these two sites (Fig. 2, sites 18 and 19 & Fig. 26) is exposed on an 11 m-high natural coastal cliff in which the marls are overlain by a sequence of 7 m-thick B/SM deposit at elevations of 3–10 m asl. The lowest 2 m of the B/SM deposits are composed of poorly sorted, coarse sand, mixed with chunks of marl and some broken shells. Above, there is a 1 m of poorly sorted and poorly laminated coarse sand with many whole and broken shells. The uppermost section of the B/SM deposit (6–10 m asl) is composed of finely laminated and cross-bedded, finely sorted, coarse sand, containing whole and fragmented shells and *Cladocora* corals. The top of the section, slightly inland, is a 1.5 m-thick, finely sorted, coarse- to medium-grained-sized calcareous sandstone, with no shells, possibly of backshore aeolian origin.

Site 20: Cape Greco north, chapel section (SE coast of Cyprus)

This section (Fig. 2, Site 20 & Fig. 27) is on the sea-side face of a 18 m-high coastal cliff formed

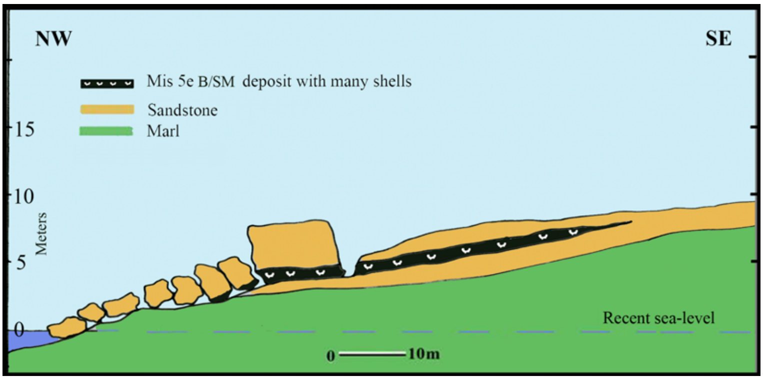

Fig. 22. Cross-section of Site 10, Mylouthkia, Lemba, SW coast of Cyprus.

by marine erosion, in which marls and limestone are overlain by 10 m-thick B/SM deposits at elevations of 8–18 m asl where its inner edge is visible. The top of the marl is at 5.5 m asl and is overlain by a layer of conglomerate (0.5 m thick) that, in turn, is overlain by a layer of limestone with fossil shells (1.5 m thick), and a sandy marl topping up to an elevation of 7.5 m asl. This sequence is overlain by an approximately 0.5 m-thick B/SM deposit composed of carbonate-cemented, finely sorted coarse sandstone, with many shell fragments (*Oysters* sp.), and overlain by a 9.5 m-thick, coarse calcareous sandstone containing some whole and fragmented shells and *Cladocora* corals (Tables 1 & 2).

Site 21: Famagusta Bay, Seaside Hotel (eastern coast)

This section is exposed on a 7 m-high artificial cliff, opposite a small shallow anchorage north of the deserted hotel (Fig. 2, Site 21 & Fig. 28). The cliff is made up of a B/SM deposit up to 5 m asl that overlies green-yellow marls. The B/SM is a 1.7 m-thick deposit of fine-grained, finely sorted, sandstone with few fragmented shells. The upper 0.3 m-thick B/SM deposit, at the top of the cliff, is similar in nature to the one below but contains many whole and fragmented shells. Opposite the deserted hotel, some 80 m offshore, there is an elongated sandstone ridge that runs parallel to the coast and creates a sheltered shallow anchorage basin used nowadays for small boats (Fig. 28). This rock is similar in nature to the B/SM deposits identified on the opposite coast. It comprises coarse sandstone with fragmented and whole shells, and appears to be comparable to the remaining part of the B/SM deposit on the coast. The main section of this deposit may have been eroded by the latest sea-level rise, and only the more resistant lower and upper parts survived. The B/SM deposit in Site 21 seems similar to that of Site 22, which is located a few hundred metres northwards and, therefore, might be its continuation.

Fig. 23. Mylouthkia Pre-Pottery Neolithic settlement, Site 10: note the location of the recent water spring and the Neolithic wells.

Site 22: Famagusta Bay, Christal Rock Hotel (eastern coast)

This section is located some 3 km north of ancient Salamis (Fig. 2, Site 22 & Fig. 29), and consists of a small coastal cliff made up of a B/SM deposit and the adjacent rocky slope made of sandstone with B/SM lenses at the backshore. At the base of the cliff, there is a 0.7 m-thick layer of yellow-brown, fine-grained, sandstone with elongated limestone nodules (palaeo-roots?), and a few crushed shells. A hard B/SM layer, approximately 1 m thick, that dips seawards overlies the sandstone at elevations of 0.7–2.5 m asl on the coastline, and up to an elevation of about 8 m asl some 70 m away inland. It is composed of coarse- to medium-sized carbonate sand, redeposited blocks of sandstone about 10–30 cm long, and whole and fragmented

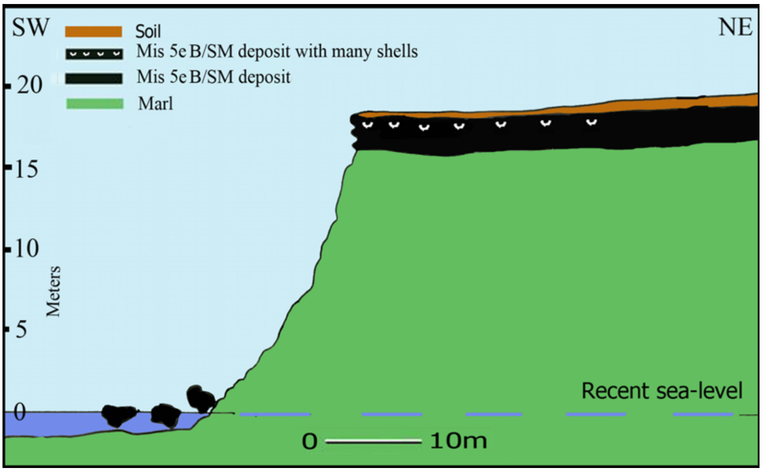

Fig. 24. Cross-section of sites 11 and 12, Lemba south, Sintana Hotel, western coast of Cyprus.

shells of various types. Close to the coastline, the B/SM deposit is relatively thick, up to 1.5 m, while up the slope, about 8 m asl, it thins to around 0.3 m. A broken specimen of *Sb* was found *in situ* at an elevation of 1 m asl (Fig. 29). Plates of beachrock, consisting of poorly sorted, coarse calcareous sand, as well as rounded, granite and basalt pebbles (0.1–0.5 m) and some ceramic sherds, were found embedded within a more recent beachrock in the present intertidal zone (Fig. 30). This beachrock is finely laminated and trends gently seawards. The presence of anthropogenic artefacts, possibly spanning the last 2500 years judging by their character, suggests that this beachrock was consolidated afterwards and conforms to the present sea-level.

Summary of the field observations on the B/SM deposits

All the sites show similar geological and archaeological characteristics (Tables 1 & 2). In general, the base of the exposed sections consists of grey, yellow or green Miocene–Pliocene marls that contain the rather common marine species of *Discoaster brouweri*, a few *D. asymmetricus*, and the rare *D. tamalis*, which points most probably to a Middle Pliocene age. These nannofossils are usually accompanied by many reworked forms typical to the Lower and Middle Miocene, such as *Discoaster deflandrei*, *D. intercalaris*, *D. druggii*, *D. tristelifer*, *D. challangeri* and *D. neorectus*. Altogether, the evidence verifies the assumed age of the marls at the

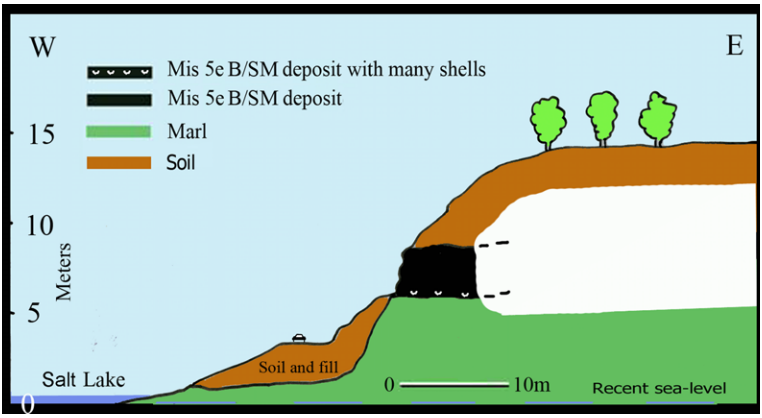

Fig. 25. Cross-section of Site 14, Larnaca airport, southern coast of Cyprus.

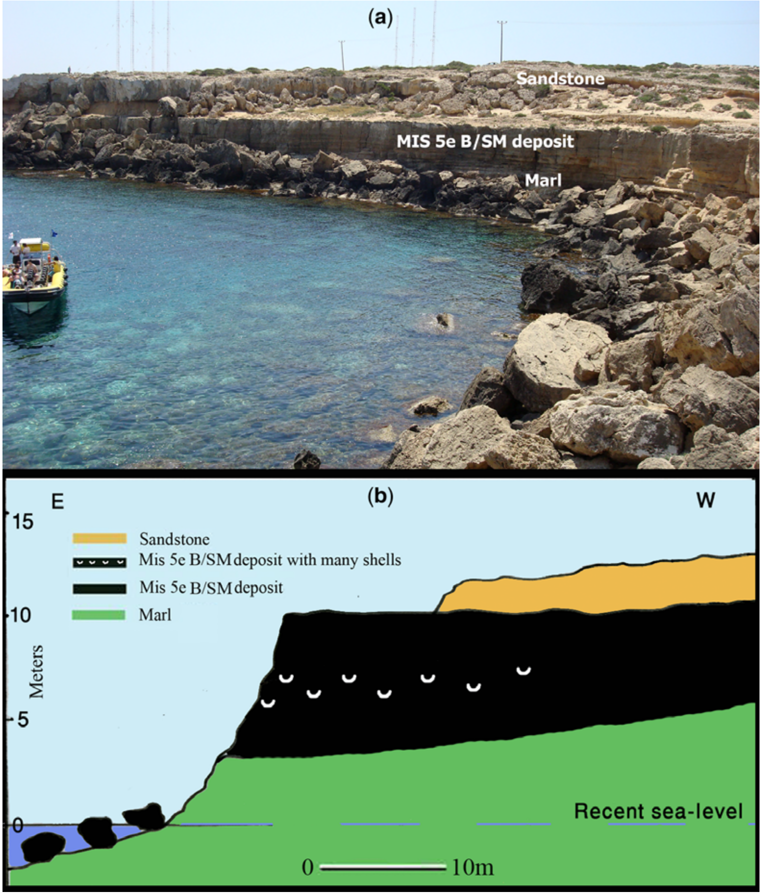

Fig. 26. Sites 18 and 19 in Cape Greco, north bay, SE coast of Cyprus: (**a**) general view; and (**b**) cross-section.

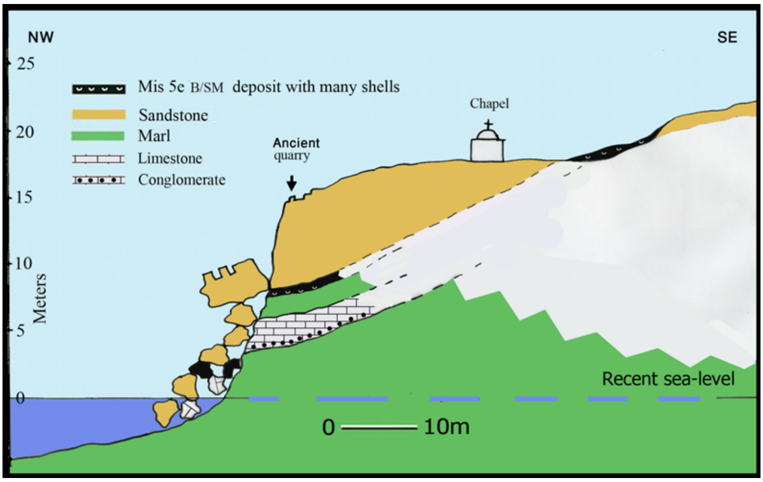

Fig. 27. Cross-section of Site 20, Cape Greco Chapel, SE coast of Cyprus.

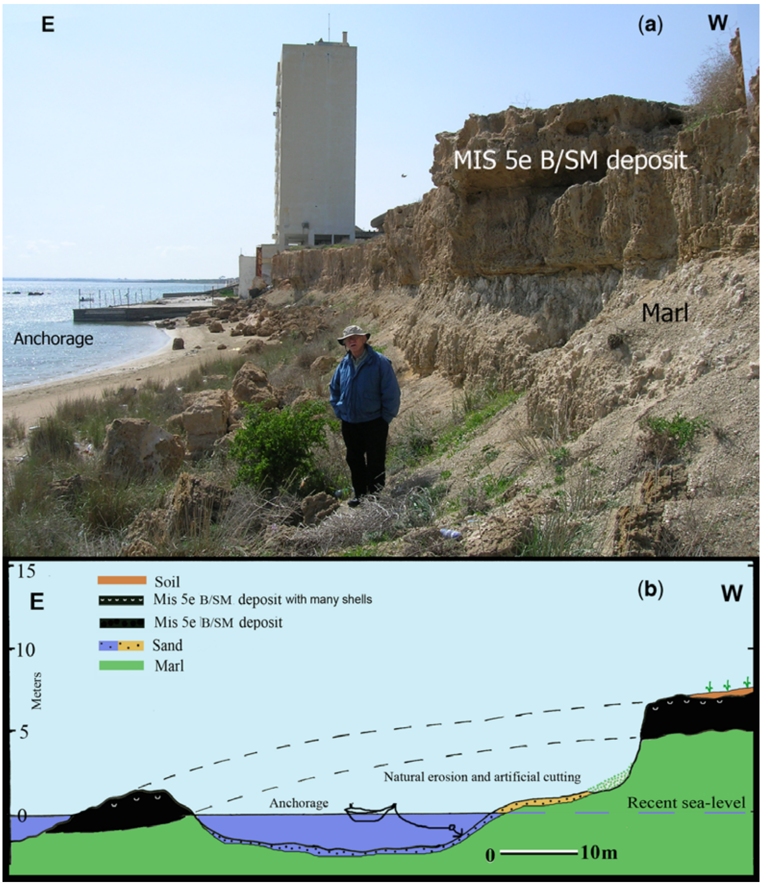

Fig. 28. Site 21 near the Seaside Hotel, SE coast of Cyprus: (**a**) general view; and (**b**) cross-section.

base of the exposed coastal section all around Cyprus.

The B/SM deposits unconformably overlie these marls and are embedded in a Pleistocene sequence of up to about 10 m thick. They are related to the Kyrenia Formation, and are composed of poorly to finely sorted, carbonate-cemented, coarse- to medium-grained-sized calcareous sandstone, and various quantities of whole and fragmented shells and corals. The uppermost elevations of the inner, landwards part of the B/SM range between 2.5 and 23.5 m above the present sea-level.

The 20 mollusc assemblages from the Late Pleistocene B/SM deposits studied contained 176 different taxa (Tables 1 & 2). Most identified species are common in the entire Mediterranean (58 species), many are common in the Mediterranean and the eastern Atlantic (94 species), and some are common in the eastern Mediterranean only (six species). Three species are Senegalese of West African origin and no longer live in the Mediterranean, and one species is from the NE Atlantic. For 11 of the identified species, the distribution and living conditions are not known.

The Senegalese species *Sb* was found at sites 6, 7, 8 and 22, *Bursa granularis* at Site 3, and *Conus ermineus* at sites 6 and 7. These three index species lived in water depths of up to 20 m (2–15, 5–20 and 10–20 m, respectively) (Table 2). In addition, barnacles were found at two sites (21 and 18) and *Cladocora* corals at ten sites (sites 3–8, 14, 18, 19 and 20). Among the species identified, 35 are living in water depths of up to 3 m, 19 in water depths of up to 6 m and 10 species are living in water depths of up to 10 m. Thus, with the exception of sites 1, 3 and 20, all other sites contain molluscs that live in water depths of up to 10 m, and can be considered as relatively good indicators of shallow-marine environments (shoreface, foreshore and backshore). Further sedimentological criteria such as cross-bedding, lamination and sorting patterns were also used for determining

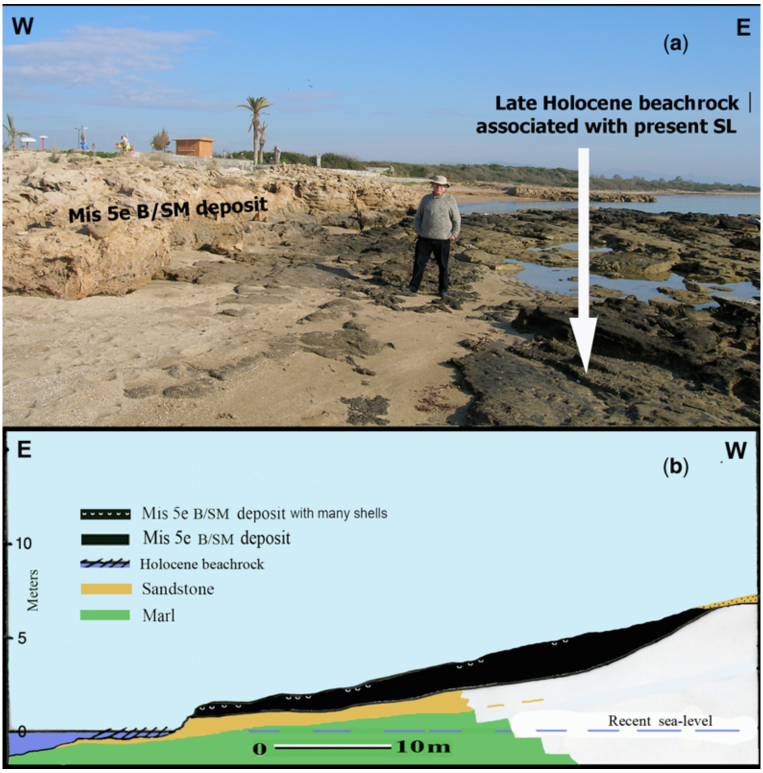

Fig. 29. Site 22, Christal Rock Hotel, SE coast of Cyprus: (**a**) general view; and (**b**) cross-section.

the depositional environment in relation to the palaeo-coast at the time. The top of the section is usually weathered to soil, sometimes containing archaeological deposits. In most sites, the sedimentary sequence is exposed in a natural coastal cliff that is associated with a talus of eroded materials and large blocks lying at the foot of the cliff or in the shallow water opposite the cliff. The blocks collapsed from the cliff due to marine erosion of the soft marls underlying the relatively hard B/SM deposits.

Fig. 30. Site 22, Roman Byzantine pottery sherds in a beachrock deposit associated with the present sea-level.

Discussion

Age of the Late Pleistocene B/SM deposits

Limitations of potential dating methods for the Late Pleistocene B/SM deposits. Determining the absolute age of B/SM deposits raises severe difficulties in general as well as in relation to the local conditions in Cyprus. The ^{14}C method is limited to 50 ka or less. Because of the scarcity of quartz grains in the local deposits, the optically stimulated luminescence (OSL) method might not be efficient for dating the Cyprus coasts as it requires micro-picking and tracing of sufficient amounts of quartz grains from large size sandstone samples (B. Mauze pers. comm. 2010), and this was beyond the scope of this research. Using the U–Th method for dating shells and corals is also problematic owing to the 'open-system' nature of these faunal remains, which may strongly bias the results (Mauze & Antonioli 2009). Moreover, the geology and associated rock properties of Cyprus are such that the annual dose emitted by natural radioactivity is not constant, and depends on seasons and the amount of precipitation. Seasonal variations of the alpha-radioactivity in groundwater and seawater are significant, and have to be considered in radiological impact assessments (Tsiaili *et al.* 2011). Bellumini *et al.* (2002) claimed that a combination of facies, sedimentological studies, stratigraphy and lateral relationship considerations, together with U–Th, thermoluminescence (TL) and amino-acid D/L ratios, could provide satisfactory dating. They concluded that the reliability of U-series ages is supported by the results of dating obtained from molluscs. Hearty & Dai Pra (2003) disagreed with these conclusions.

Dating the Late Pleistocene B/SM deposits by index fossils. Given the difficulties in absolute dating and in order to assess the net vertical displacement of the Cyprus coasts, we rely on correlations of the lithological units, stratigraphical and morphological considerations, and, most importantly, the presence of index fossils.

The possibility that the Senegalese species *Sb* entered the Mediterranean during the last interglacial high sea stand and also lived in the Mediterranean during isotopic stages 7, 9 and 11 has been widely discussed (Butzer 1975; Goy *et al.* 1986, 1993; Hillaire-Marcel *et al.* 1986; Poole & Robertson 1991; Zazo 1999; Zazo *et al.* 2003, 1999; Bardají *et al.* 2009). Based on U-series dating of corals and molluscs in coastal sediments in the western Mediterranean, mainly in Spain, Hillaire-Marcel *et al.* (1986) concluded that *Sb* entered the Mediterranean, at least in the western basin, as early as stage 7. Bardají *et al.* (2009), Zazo *et al.* (2003, 1999) and Zazo (1999) suggested that the Senegalese fauna entered the western Mediterranean during stages 9 or 11. Bardají *et al.* (2009, p. 25) also stated that ‘The entry of *Strombus bubonius* into the Mediterranean is controversial, given its apparent absence from marine deposits other than those of MIS 5e on central and eastern Mediterranean coasts’. Using U-series dating, Poole & Robertson (1991) reported the presence of *Sb* from deposits dated to MIS stage 7 in Cyprus. Conversely, Mauze & Antonioli (2009) pointed out the unreliability of dating corals and molluscs using the U-series method. They noted that most of the reported *Sb* from the Mediterranean, which are earlier than MIS 5e, are based on the unreliable U-series dating of molluscs. In parallel, Bordoni & Valensise (1998, p. 71) and Ferranti *et al.* (2006) suggested that, in the Mediterranean, *Sb* was restricted to MIS 5e. Thus, we suggest relating the B/SM deposits containing *Sb*, as well as the other 19 studied B/SM deposits, to the last interglacial high sea stand, MIS 5e.

Vertical changes along the Cyprus coast since the Late Pleistocene

The 22 B/SM investigated along the coastal cliffs of Cyprus were deposited during the last interglacial highest sea stand (the MIS 5e, 130–114 ka; 2σ error of data: from Shackleton *et al.* 2003) and are thus used to identify the vertical changes along the Cyprus coast since the last high sea stand.

Preservation of the B/SM deposits during high sea-level stands. In general, B/SM deposits may have been deposited at different elevations during sea-level rise (transgression) or fall (regression). However, those deposited in the maximal high sea stand, had better chances of surviving *in situ*, as they were less vulnerable to erosion during the rise and fall of the sea during the later high sea-stand events (Galili *et al.* 2007). This is similar to deposition of murrain ridges at the frontal edge of a glacier, which also records the maximal reach of the glacier.

Thus, the MIS 5e latest and highest deposition had the best chance of survival (Siddall *et al.* 2003, 2007, p. 10) and should be favoured over the other stages (5a and 5c) that did not reach above the present sea-level (Fig. 5). Stage 7, for example, only reached 5–15 m below the present sea-level, as did other such earlier stages (e.g. stages 9 and 11) that were exposed to marine erosion of the later transgressions.

Determining the magnitude and direction of the Late Pleistocene vertical changes. The vertical changes in the Earth’s crust along the coast of Cyprus are the products of several agents: tectonics of the island induced by the regional collision between the African and the Anatolian plates; activity of local structural elements, such as faults and folds; isostatic crustal changes due to an increase or decrease in the load of seawater and ice on the land. Resolving the cumulative vertical changes into their particular components is a subject for further investigation. Here we focus on determining the total vertical changes only.

The estimated values given here should be considered as minimal, as the innermost edge of many of the B/SM deposits could not be traced in conventional fieldwork because either it was not visible or its uppermost part was higher but eroded and had disappeared. In addition, there still might be sites along the coast that have been uplifted higher or even subsided lower but have not yet been identified. The magnitudes and rates of the vertical changes are presented in Table 1 and Figures 31 and

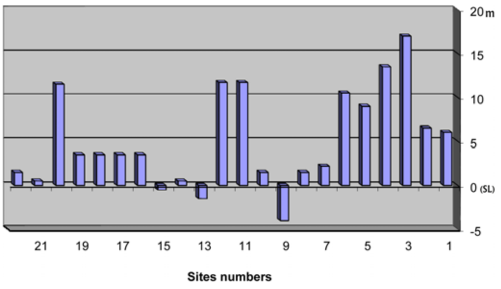

Fig. 31. A diagram demonstrating the vertical changes in the studied sites, assuming an elevation of 7.2 m asl and 122 ka BP for the MIS 5e high sea stand.

32. The results mostly suggest uplift along the northern coast of Cyprus (Fig. 33), although with variable magnitudes: up to 6.5 m on the Karpasia Peninsula (sites 1 and 2); and a gradual decrease westwards from 17 m at Site 3 (Flamoudhi) up to only 1.5 m at Site 8 (Agios Georgios), and even a subsidence of about 4 m at Site 4 (Lapithos). The variable uplifting values traced in this region can be attributed to the series of low-angle north-dipping faults that were identified along the Kyrenia Range on the northern coast of Cyprus, from Cape Andreas in the east to Cape Kormakitis in the west (Harrison *et al.* 2004, p. 193), that divides the coast into small blocks, each rising (or even subsiding) separately at a different rate.

The western coast also shows a significant uplift of up to 11.7 m (sites 10–12), and this is also the case in the east: up to 11.5 m at Cape Greco (sites 16–20) and up to 1.5 m at Famagusta Bay (sites 21 and 22). The Larnaka area in the south, however, seems to be the least active, almost stable or even with a minor subsidence (up to 0.5 m) at sites 13–15, and the actual reason for that has yet to be studied. The uplift rates of the sections on the NE coast are higher than previously suggested for the southern and western coasts of Cyprus for that time span (6 m uplift, 0.048 mm a^{-1}: i.e. Poole *et al.* 1990; Poole & Robertson 1991). Assuming that the uplift was gradual and linear with time, our findings suggest that the overall uplift of the NE and western coasts of Cyprus over the last 10 ka, which is the time of the earliest known colonization of the island, was not more than 1.4 m. The contemporaneous uplift values along the central sections of the northern and southern coasts were considerably lower (Fig. 33). Had we used the 2 to 4 m maximal sea-level during the MIS 5e in our calculations as suggested by Pedoja *et al.* (2011), all of our uplift values proposed above would have increased by about +3 m and the uplift rates would have increased accordingly.

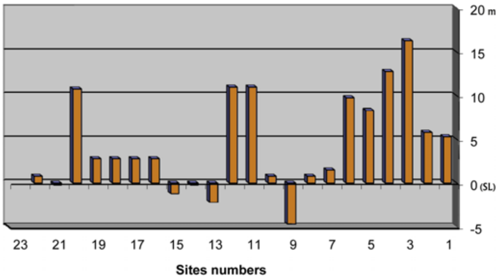

Fig. 32. Diagram demonstrating the vertical changes in the studied sites, assuming elevation of 6.5 m asl and 116 ka BP for the MIS 5e high sea stand.

Indications from Late Holocene depositional, bioconstruction and erosional features. In coasts such as those of Cyprus, the vertical range of the surf notches may be high and their uppermost elevation may reach up considerably higher than the sea-level (Pirazzoli 1986, pp. 362–365). Dreghorn (1981) reported on elevated notches and beachrock deposits that point to an uplift of about 1 m in several parts of the northern coast. Flemming (1978), however, did not identify submerged or uplifted notches there and, instead, suggested stable conditions for this coast. It should be noted that surf notches with their top at elevations of 1 m asl, such as observed on Cyprus coasts (Figs 34–36), are typical of exposed rocky coasts and may not be an indication of uplifting (Pirazzoli 1986, pp. 362–365). Given the typical tidal range in Cyprus (+40 cm in the spring; −20 cm neap: Flemming 1978), the above characteristics of marine notches as well as our observations, it is suggested that the abrasion platforms and the wave notches around the island are associated with the present sea-level.

Indications from Mid- to Late Holocene beachrocks. It is generally agreed that beachrocks are formed in the intertidal zone, although the exact upper limit of cementation is uncertain (Hopley 1986). The Late Pleistocene B/SM deposits of Cyprus that were studied here differ considerably from the beachrocks that form under the current sea-level stand. Those of today demonstrate the typical characteristics of Mid-Holocene beachrocks, as described by Hopley (1986): they are laminated and the laminations dip slightly seawards, and their uppermost level of cementation is usually horizontal. In addition, in many cases they contain pottery sherds from historical periods, as well as other reworked products, *in situ*, at the present sea-level or close to it, within the range of the local tide, and never above the highest atmospheric tidal level. So far, no submerged Holocene beachrock has been found in Cyprus (Dreghorn 1981)

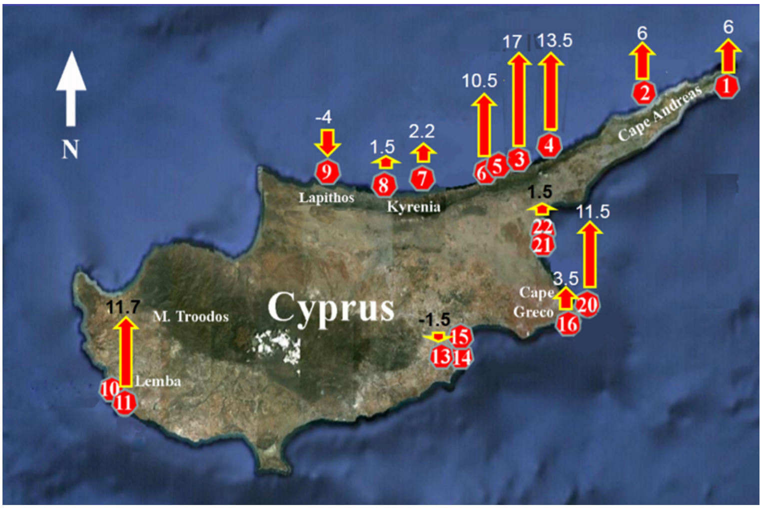

Fig. 33. A map presenting the suggested total minimal vertical changes along the Cyprus coast since the last high sea stand, assuming the MIS 5 sea-level was 7.2 asl (Fig. 31), modified after Google Earth.

and, according to our fieldwork, no such rocks have been observed beyond their original elevations of deposition. Since sea-level changes in the eastern Mediterranean during the last millennia were minor (Flemming 1978, 1969; Galili *et al.* 2005; Galili & Rosen 2011*a*, *b*) and within the range of the tide in Cyprus (*c.* 60 cm), it is suggested that the beachrocks observed along the island at, or close to, the present sea-level (±30 cm) have been embedded and consolidated during the last millennia. Thus, the observed beachrocks, together with the marine notches and abrasion platforms mentioned above, are associated with the present-day sea-level, indicating relatively stable conditions along the coasts of Cyprus during the last 4 ka.

Indications from Late Holocene archaeological features – the Salamis case. In several cases, ancient harbour installations on Cyprus were reported at 1–2 m below present sea-level and interpreted as indications of submergence: for example, Amathus and Marion (Raban 1995), a harbour near Cape Akrotiry (Flemming 1978), and Salamis. Here we refer in detail to Salamis, which was studied comprehensively by several scholars (Munro & Tubbs 1890–1891; Flemming 1978, 1980; Raban 1995; Malcolm Davies 2012) and thus may be considered as a representative case study.

Flemming (1978) investigated 32 sites along the Cyprus coast and reported the submergence of ancient harbour constructions in Salamis at rates

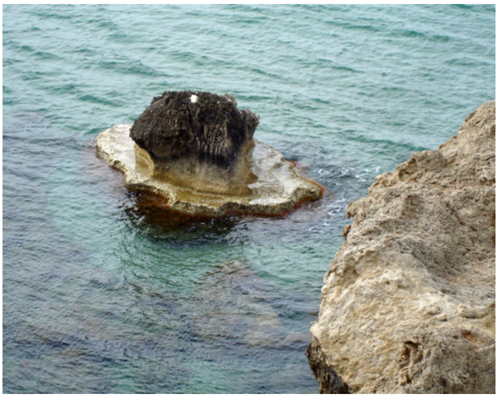

Fig. 34. Wave notch and abrasion platform at present sea-level, during low tide, east of Kyrenia.

Fig. 35. Wave notch at the present sea-level at Cape Greco.

Fig. 36. Wave notches and mushroom features at the present sea-level on the south Karpasia Peninsula coast.

of up to 1 m ka^{-1}. He noted a subsidence of 0.5–1 m ka^{-1} in historical times in the SE and southern coasts, and relative stability on the northern coast of the island. Given the uplift of Cyprus as a massive unit, as has already been reported in previous works and also in accordance with this study, the findings of suspected subsidence at Salamis need to be reconsidered.

The underwater and coastal surveys reported on two main marine sections: the north lagoon, protected by a natural reef (here an elongated ridge made of beachrock) parallel to the coast, some 100 m offshore, currently at sea-level; and a southern basin, at the outlet of the Pedieos River, protected by a headland. In the northern lagoon, two ashlar-built crossroads and foundations of several structures were documented, some are currently submerged at 1.8 m below sea-level. In the southern basin, no structures were found. In his report, Flemming (1978) noted that before subsidence the depth of the northern lagoon was 0–0.7 m, a depth insufficient for a harbour. He had no explanation for this enigma and pointed out that the site is open to high winds from the east and the SE, and that there may have been some coastal erosion: that is, the ancient coast could have been more seaward and straight. Raban (1995) suggested that the southern basin was a commercial harbour, outside the city walls, and that there were two additional basins north of the headland, that were protected by the city walls. Malcolm Davies (2012) accepted Raban's suggestions, but noted that these were speculative interpretations requiring further research and approval. Malcolm Davies (2012) also suggested that the sea-level today is approximately 1.8–2 m higher than that at the time the harbour was constructed by Evagoras, some 2500 years ago.

The north lagoon: In this area, most of the inland sections of the rock identified by Flemming as beachrock were abraded during the last sea transgression. The sea-side section of these beachrock deposits, which was probably more resistant, was left as a longitudinal rocky reef parallel to the coastline. When the site was first occupied, the area between the reef and the coast was probably dry land, used for buildings and installations, as attested by the local finds. During the last three millennia, marine erosion caused significant coastal retreat under relatively stable sea-level conditions. The artificial structures reported from the northern lagoon may be currently underwater due to several local effects, such as settling of the foundations, marine erosion and/or liquefaction of the unconsolidated sediments on which the structures were built. The AD 342 earthquake that caused significant damage to ancient Salamis (Guidoboni *et al.* 1994) was also mentioned as a possible cause of the 2 m subsidence in the region (Flemming 1978, 1980), possibly by liquefaction or compaction of the unconsolidated sediments in this region. To date, no geological faults have been reported in this region (Geological Survey Department 1995; Harrison *et al.* 2004).

Summarizing the Salamis case: Given the terrestrial character of the structures found in the northern lagoon (e.g. crossroads) and the present sea-level setting, it is unlikely that this area functioned as a harbour during its occupation. Rather, in our opinion it was a terrestrial section of the site with typical land and shore facilities, and the settling of the man-made structures, which are today at a depth of 2 m, could be attributed to local effects or seismic shaking as opposed to regional tectonics.

Other archaeological studies associated with Holocene sea-level changes. Dreghorn (1981, pp. 283–284) summarized the work dealing with tectonic and sea-level changes on the northern coast of Cyprus, and concluded that as part of the ongoing orogeny since the Pliocene, the tectonic uplift was the major change during historical times. However, in his opinion, fishponds from the

Fig. 37. Rock-cut fish tank at Lambousa in Lapithos associated with the present sea-level.

Roman–Byzantine periods in Lambousa operated in a sea-level about 1 m higher than that of today and are no longer functional. Our recent observations, however, suggest that proper maintenance of the channels and the sluice gates of these fishponds would most probably enable them to function sufficiently even today (Fig. 37).

Ancient coastal quarries on the northern coast of the island are asl and, so far, no submerged quarries have been reported (Dreghorn 1981), suggesting stable sea-level conditions. Dreghorn (1981) also reported the presence of a Neolithic jetty at the Troulli site, which at present is not at an elevation that enables it to function. Given that 7000 years ago, at the time of occupation, sea-level in the region was about 9 m lower (Galili *et al.* 1988, 2005), the presence of a jetty at this elevation is most unlikely. Green (1973, p. 150) conducted marine archaeological research in the Cape Andreas area of the eastern Karpasia Peninsula and reported on relatively stable sea-level conditions ‘in recent geological time’. Morhange *et al.* (2000), who studied sedimentological sequences in the ancient harbour of Kition and reconstructed palaeo-environments and coastal changes over the last 4 ka, suggested tectonic uplift of the coast of Kition, whereas Gifford (1980, 1985) suggested just the opposite, a higher sea-level and subsidence. A pattern of uplift was also reported by Yon (1994) at Cape Kiti, south of Larnaca. Poole & Robertson (1991) stated that, in some coastal areas of south and west Cyprus, beachrock deposits and archaeological sites are partially submerged, indicating that some sections of the island subsided during historical times.

The above studies reflect different opinions regarding the direction, magnitude and rate of vertical movements during the Late Holocene along the Cyprus coasts. Given that the sea-level in the eastern Mediterranean over the last 2 ka was relatively stable (less than ±0.3 m, the local tidal range), such proposed vertical changes should be treated with caution. On the basis of our observations, and after re-evaluating the records and studies mentioned above, we suggest that there has been no significant vertical land changes or relative sea-level change (less than ±0.3 m) of the Cyprus coasts in the last 2 ka. Any smaller changes that may have occurred are below the resolution of the conventional archaeological and geological sea-level markers or fell within their error bars. This is in accordance with the larger timescale measurements obtained from the MIS 5e B/SM deposits for the last 120 ka.

Impact of tectonics and sea-level changes on ancient populations of Cyprus. Assuming that the vertical changes in the Earth’s crust are gradual and steady processes occurring over time since the Late Pleistocene (Siddall *et al.* 2007, p. 10), it is reasonable to infer the long-term changes to those that occurred during the Holocene. An uplift of approximately 17 m (at an average rate of 146 mm ka^{-1}) in sections of the NE coast of Cyprus since the last interglacial (Site 3) suggest an uplift of about 1.5 m during the Holocene, at the time of early colonization of the island, and an uplift of about 0.6 m for the last 4 ka when the sea-level reached its present elevation. These values are too small and hard to detect from stone-built or rock-cut coastal installations, most of which were built over the last 2 ka. In parallel, studies of sea-level indicate that in the Early Holocene it was about 40–50 m below that at present (Van Andel & Lianos 1983; Fairbanks 1989; Van Andel 1989; Stanley 1995; Lambeck 1996). Thus, the effect of tectonic uplift since the time of early colonization of Cyprus was, at the most, 1.5 m, which, in fact, is negligible compared with the magnitude of the sea-level changes. Sea-level rise at the beginning of the Holocene may have reached a rate of about 13 mm a^{-1} (Galili *et al.* 2005), which means a rise of around 32 cm per life span (about 25 years during the Neolithic period: see Eshed & Galili 2011). This is a rapid change in geological terms, although it could have been masked by changes in tides and winter storms, and could hardly have been detected by the Neolithic people. Once the sea-level stabilized after the Middle Holocene, the dominant factors responsible for the coastal modification and human activity during the historical periods became marine erosion, sedimentation and surface runoff processes. A major earthquake could have also disturbed the coast but they seem to be of secondary effect only.

The exposure of water springs along the coastal cliffs. The presence of freshwater flowing along the coast of Cyprus was first mentioned in the *Survey of Ground Water and Mineral Resources of Cyprus* (Anonymous 1970). The unconformity between the impermeable Pliocene marls and the porous Pleistocene deposits is the origin of freshwater springs and associated vegetation, which are clearly visible nowadays in several places along the coastal cliffs around Cyprus. The cliffs were formed in historical times by marine erosion, and it is reasonable to assume that the same hydrological setting also existed along the coast during the Neolithic times, and attracted the attention of the early colonizers who migrated from southern Turkey to Cyprus. They dug wells, so far the earliest known ones, and thus clearly recognized the potential of this essential permanent source of water. The locations of Mylouthkia and Akanthou, the earliest known prehistoric settlements along the island coasts and adjacent to visible water springs along the cliffs, support this hypothesis. Not surprisingly, recent wells dug in the coastal Pleistocene deposits rely on the very same hydrological and landscape settings.

Akanthou prehistoric site (Site 5). Sea-level changes may have played an important role in this settlement. On clear days, the Turkish coast is visible from this site, and vice versa. During low sea stands, the island was slightly closer to the mainland. Numerous imported obsidian finds recovered from that site suggest regular ongoing maritime relationships between the settlement and the mainland. The faunal and floral remains from the site indicate agro-pastoral and marine subsistence and sophisticated exploitation of the environment. The last post-glacial sea-level rise most probably eroded significant sections of the northern part of the site, and the relationship between the site and the sea may have been considerably different to that at present. Hence, scattered artefacts originating from what exists from the site may possibly be found on the present-day seafloor, out of context and mixed with other later marine-orientated artefacts. Given the recent sea-bottom bathymetry opposite the site and assuming that the sea-level was approximately 40 m lower during habitation, the village could have been located some 150 m inland from the Neolithic coastline and about 50 m asl at the time. This location probably enabled sufficient access to marine recourses, whilst also providing protection from harmful marine agents (e.g. wind, waves and sea-spray) and enabling gardening and agriculture to be undertaken. Mediterranean Neolithic fishing villages located at lower locations (e.g. Atlit–Yam, Israel) had to be relocated several hundred metres inland to enable sufficient exploitation of marine and terrestrial resources simultaneously (Galili *et al.* 2002, 2004*b*).

Mylouthkia prehistoric site (Site 10). No Early Neolithic settlement that can be related to the Mylouthkia wells was found in the region. Therefore, it was suggested that this place was used as an observatory and that the wells were associated with the small, nearby bay that was used as an anchorage by the PPN population (Peltenburg *et al.* 2000, 2001*a*, *b*; Peltenburg 2012). The excavators raised the possibility that the Holocene sea-level rise and the local tectonic uplift of the island had the same trend and values, and may have compensated each other, suggesting that the configuration of the small bay of Mylouthkia had not changed during the Holocene since the early settlers had dug the wells. Based on the current study, it is estimated that the net uplift on the west coast in the last 10 ka was around 1 m at the most, while the sea-level rise during the Holocene was approximately 40 m. Thus, the assumption that the tectonic uplift and the sea-level rise compensated each other is not supported by the current study. An alternative explanation for the lack of settlement features is that surface structures that may have existed in this settlement may have been totally eroded and only the deep shafts of the wells have survived.

Conclusions

- The 22 beach and shallow-marine (B/SM) deposits along the coasts of Cyprus studied in this work were most probably deposited during the last interglacial, MIS 5e high sea stand.
- Based on these Late Pleistocene deposits, it is suggested that sections on the NE coast of Cyprus were uplifted by at least 17 m, at an average rate of 146 mm ka^{-1}since the last interglacial high sea stand. Using the maximal sea-level rise during MIS 5e as suggested by Pedoja *et al.* (2011), these values would go even higher.
- The total vertical uplift during the Holocene along the coasts of Cyprus was at a magnitude of approximately 0.6 m in east Karpasia, 1.4 m on the NE coast, 0.2 m in the central part of the northern coast, 1 m in the west, a few centimetres (0.04 m) on the southern coast, 1 m at Cape Greco and 0.1 m in Famagusta Bay. Thus, the effect of the tectonic uplift on the Neolithic coastal populations of Cyprus is negligible compared to the around 40–50 m rise in sea-level since that time.
- The unconformity between the impermeable Pliocene marls and the porous Pleistocene deposits results in a permanent source of freshwater. The early colonizers of Cyprus recognized that potential and dug wells, so far the earliest known in the world, and settled there (Mylouthkia and Akanthou). Recent wells along the coast rely on the very same hydrological setting.
- Late Holocene archaeological and geological features studied along the Cyprus coast indicate that the relative sea-level changes over the last 2 ka, when most of the ancient coastal installations were constructed, were minor (less then ±0.3 m). The MIS 5e B/SM deposits studied in this work confirm this, and suggest the following vertical Earth crust changes during the last 2 ka: about 0.1 m on the Karpasia Peninsula, around 0.3 m on the NE coast, approximately 0.04 m on the northern central coast, about 0.2 m on the west coast, less than 1 cm (0.008 m) on the south coast, around 0.2 m at Cape Greco and approximately 0.024 m at Famagusta Bay. Such rates are hard to detect directly by archaeological or geological sea-level indicators, as they are about half the local tidal range.

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