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Recent Holocene paleo-environmental evolution and coastline changes of Kition, Larnaca, Cyprus, Mediterranean Sea

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Abstract

Sedimentological, paleontological analysis and ^{14}C dating of 17 cores obtained in the vicinity of the Phoenician military harbor (VIII–IV BC) of Kition Bamboula (Cyprus) provide new paleo-environmental information for the reconstruction of shoreline changes for Kition and Larnaca Bay over the last 4000 years. We propose that a communication existed between the inner harbor of Bamboula (presently 400 m inland) and the northern district of Lichines, which was a marine embayment. Our core data led us to revisit the previous hypothesis of a direct east–west channel between the harbor and the open sea (Nicolaou, K., 1976. The historical topography of Kition. Studies in Mediterranean Archaeology, Göteborg, vol. 153, pp. 1–373; Gifford, J.A., 1978. Paleogeography of archaelogical sites of the Larnaca lowlands, southeastern Cyprus. PhD Thesis, University of Minnesota, pp. 1–192). We propose instead that a spit of coarse material isolated the lagoon from the open sea from 2600 to 1600 years BP.

Keywords: Recent Holocene; Coastal changes; Relative Sea level changes; Mediterranean; Cyprus; Larnaca; Kition; Geomorphology; Geoarcheology

1. Introduction

Since 1976, a French archeological team has been excavating the Kition Bamboula site below Larnaca, in collaboration with the Department of Antiquities and the University of Cyprus. The site is approximately 400 m inland from the current coastline. The land surface is situated 2 m above sea level.

The floor of Larnaca bay, which opens to the southeast, slopes down rather steeply: 1500 m offshore, the depth is 35 and 2000 m out, the depth is 50 m (Fig. 1). Coastal currents run SW–NE at the surface but this direction is reversed in deeper waters. Tide range varies between 25 and 40 cm in amplitude (Heikell, 1993).

Larnaca is situated on a gently sloping coastal plain, with small hills 300–500 m in altitude. Small coastal rivers with intermittent flow (wadis) drain modest watersheds with a diversified substrate including Cretaceous strata from the Ophiolitic Troodos massif and peripheral sedimentary series from the

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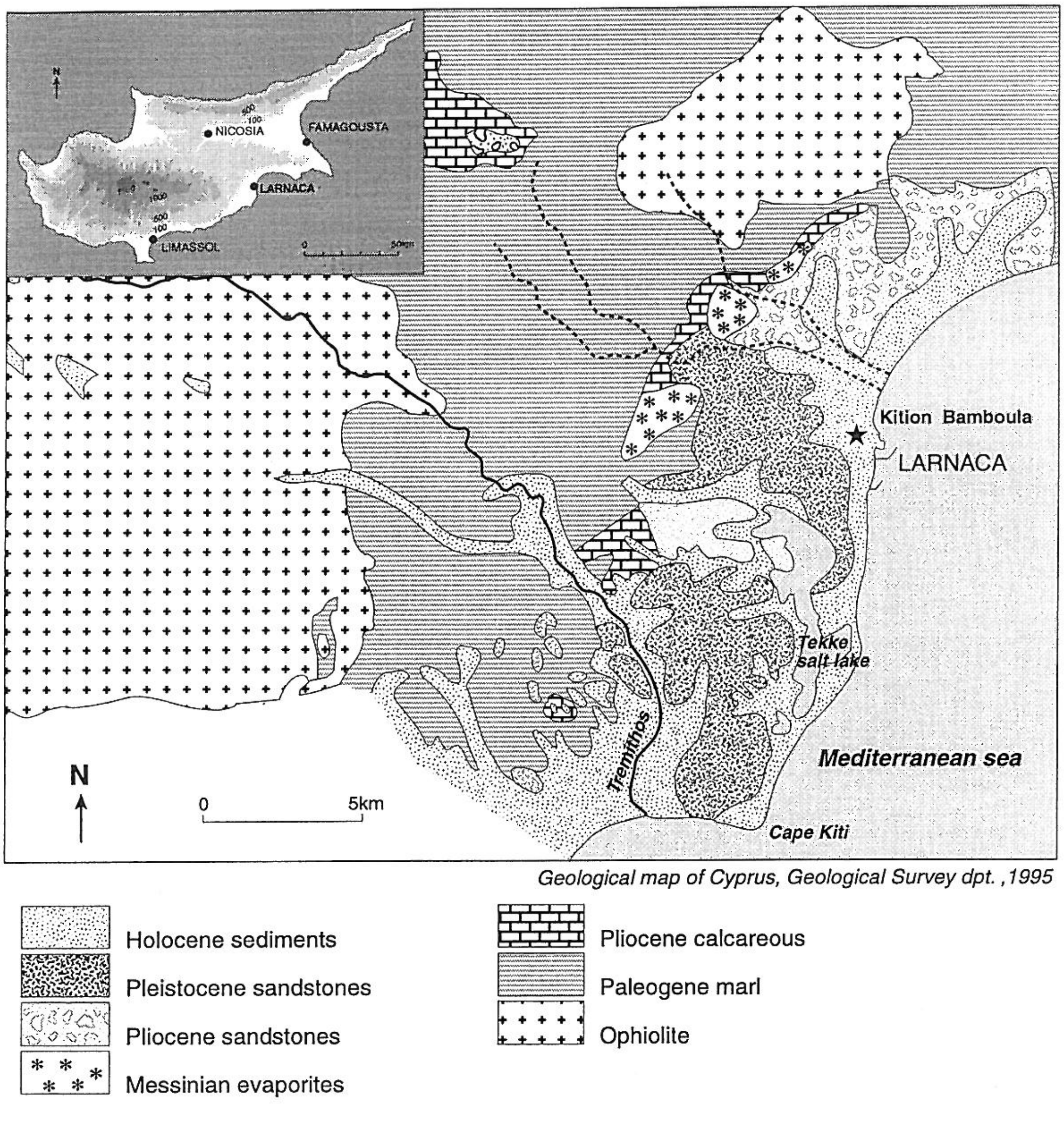
Fig. 1. Localization of Kition Bamboula, Larnaca, Cyprus, showing location of coring sites. Bathymetric contour lines from Admiralty map of Larnaca, Hydrographic office, no 848, 1992.



Geological map of Cyprus, Geological Survey dpt. ,1995

Fig. 2. Simplified geological map of Larnaca area, Cyprus.

Neogene with diverse facies (lime, limestone, sandstone, Messinian gypsum…, Fig. 2; Bagnall, 1960). Holocene sediments rest upon a marly substrate, of marine origin, which was dated by its coccolithic nannoflora to 0.9–1.1 M years old (L. Beaufort, pers. comm.).

The purpose of this study, based upon the study of seventeen cores (Fig. 1) was to reconstitute the history of the coastline near the Bronze Age harbor of Kition Bamboula for the last 4000 years.

2. Methods

Seventeen cores were drilled by the Cyprus Geological Survey in 1996 and 1997. Elevations of cores

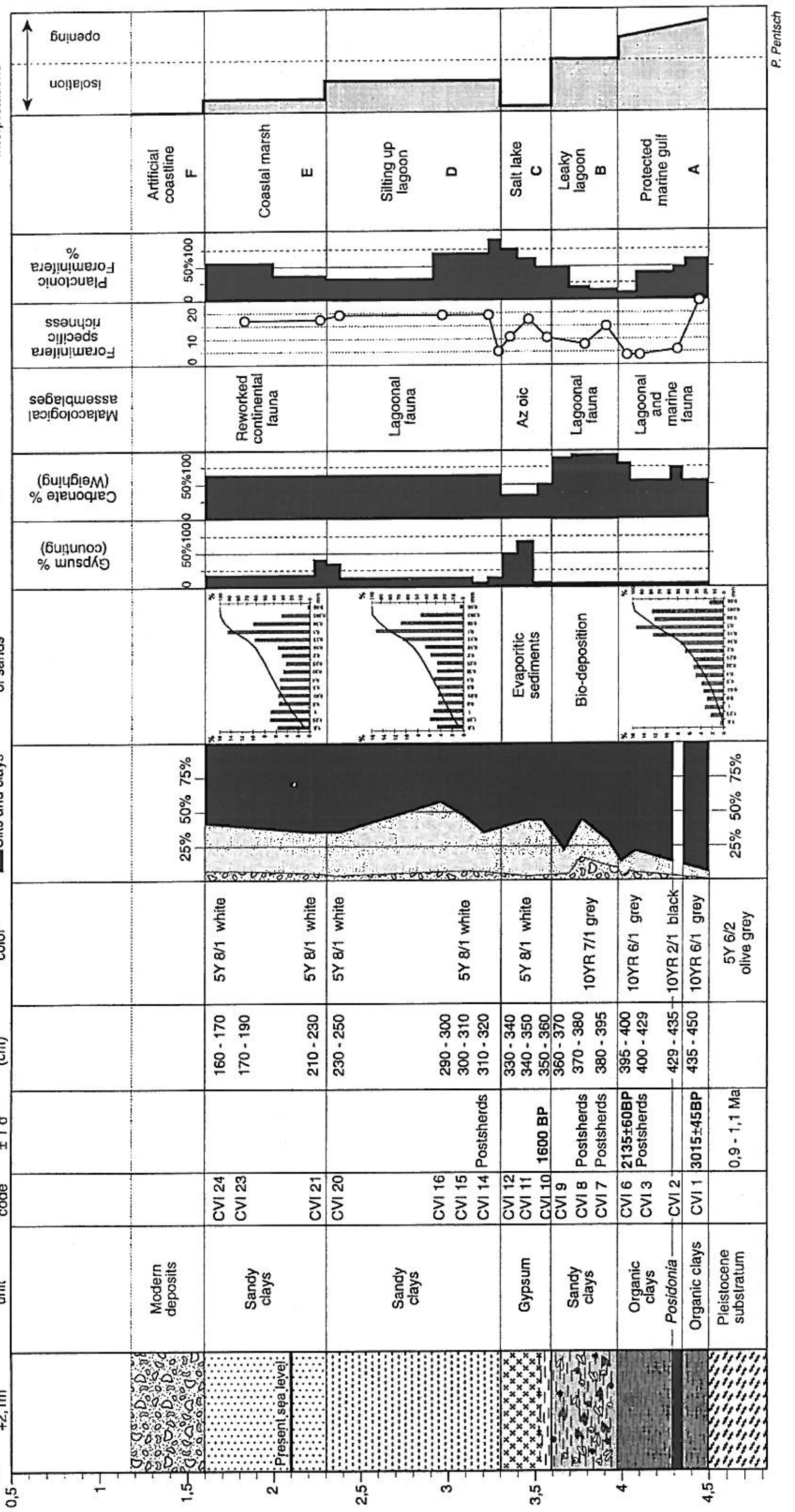


Fig. 3. Core C VI results of analysis, Kition Bamboula, Larnaca, Cyprus.

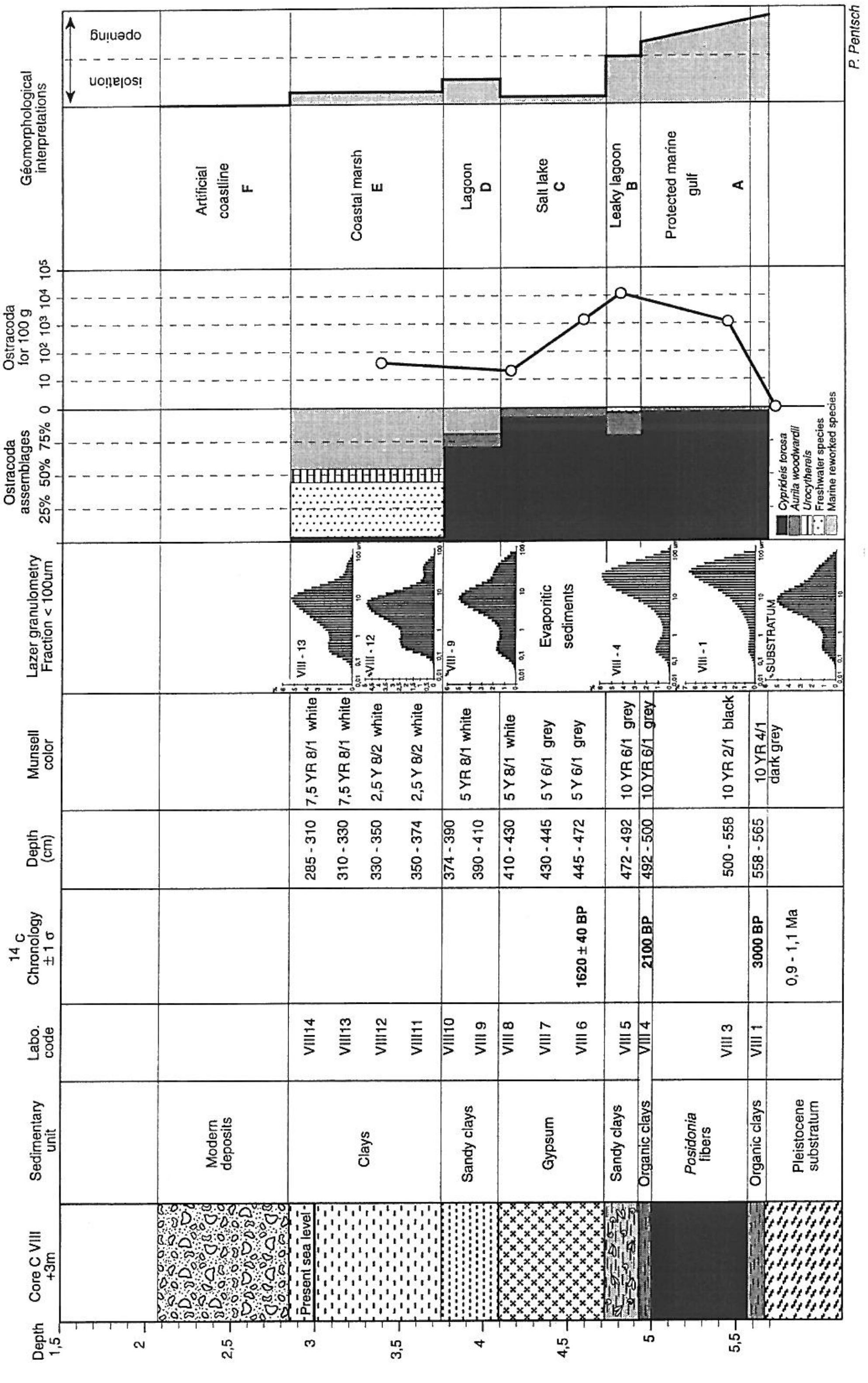


Fig. 4. Core C VIII results of analysis, Kition Bamboula, Larnaca, Cyprus.

Table 1
Biological content of cores C VI and C VIII, Kition Bamboula, Larnaca, Cyprus (* = presence)

	C VI Unit A	C VI Unit B	C VI Unit D	C VIII Unit A	C VIII Unit B	C XI Unit A	C XVIII Unit A	C XVIII Unit B	C XII Unit B	C XII Unit C
GASTEROPODA										
Abra tenuis	*									
Abra sp.		*								
Alvania cimex									*	
Alvania llneata						*				
Alvania montagui							*		*	
Alvania reticulata						*				
Alcularia sp.		*								
Bittium cf. reticulatum	*	*	*		*					
Bittium reticulatum latreilli		*				*				
Buccinidae sp.							*			
Calliostoma granulatum									*	
Cerithium rupestre	*	*			*	*				
Cerithium vulgatum	*	*		*						
Clanculau sp.							*			
Clanculus corallinus									*	
Clanculus iussieui									*	
Columbella rustica							*		*	
Conus mediterraneus						*	*		*	
Coralliophila lamellosa						*				
Cyclope donovani		*			*					
Cyclope neritea		*								
Cythara multilineolata									*	
Gibbula albida										
Gibbula nivosa					*					
Gibbula cf. phiberti		*								
Gibulla racketti				*					*	
Gibbula varia		*								
Haminea navicula	*									
Hinia incrassata							*			
Hinia limata		*								
Hinia reticulata		*					*			
Hydrobia ventrosa		*	*		*					
Jujubinus exasperatus						*			*	
Jujibinus milliaris									*	
Jujubinus striatus						*			*	
Mitra ebenus		*								
Mitrella cf. scripta				*						
Muricidae sp.							*	* (?)		
Nassarius sp				*						
Naveritia josephinia				*	*					
Ostrea edulis	*									
Parvicardium sp.		*								
Pirenella conica								*		
Pirenella scripta		*		*						
Petricola lithophaga									*	
Putilla cf. ambigua	*	*		*	*					
Raphitoma sp.										*
Raphitoma purpurea						*			*	
Raphitoma reticulata						*			*	
Rissoidae		*	*						*	*

Table 1 (*continued*)

	C VI Unit A	C VI Unit B	C VI Unit D	C VIII Unit A	C VIII Unit B	C XI Unit A	C XVIII Unit A	C XVIII Unit B	C XII Unit B	C XII Unit C
Rissoa lineolata									*	
Scalaria sp.									*	
Smaragdia viridis						*			*	
Sphaeronassa mutabilis		*							*	
Tornus sp.										*
Tornus subcarinatus								*		
Tricolia pullus									*	*
Tricolia tenuis							*		*	
Tricolia speciosa						*			*	*
Turbonilla lactea										
PELECYPODA										
Cardlidae sp.			*				*			
Cardita aculeata						*				
Cerastoderma lamarckii	*				*					
Cerastoderma cf. Edula							*			
Cerastoderma glaucum edule	*									
Cerastoderma glaucum		*								
Ctena decussata						*				
Diplodonta rotundata		*								
Donax sp.										
Dosinia lupinus									*	
Loripes laceteus		*							*	
Loripinus fragilis							*		*	
Macoma tenuis		*			*					
Nucula hanleyi									*	
Nucula nucleus									*	
Nucula sulcata						*			*	
Odostomia sp.		*								
Odostomia conoidea	*	*		*						
Peringia salinasi		*								
Putilla cf. Ambigua	*	*		*						
Truncatella hammersmithi	*	*								
Venericardia antiquata							*		*	
Venerupis aurea	*	*								
Venerupis rhomboides		*								
SCAPHOPODA							*			
Dentalium cf. Vulgare							*			
CRUSTACEA										
Balanidae	*	*								
Decapoda grip			*			*			*	
POLYCHETA										
Ditrupa arietina			*							
Spirorbidae, janua sp.	*	*								
Vermiliopsis sp.			*							
VARIA										
Rodophyceae			*						*	
Sphoerozoum ovodimare	*	*	*		*					
Parancentrotus lividus			*			*			*	

were geodetically measured relative to the 0 of the cadastral survey. Our levellings showed that this datum fitted closely, in this area, the biological mean sea level (e.g.: upper limit of the infralittoral fringe; Pérès and Picard, 1964; Lipkin and Safriel, 1971; Laborel and Laborel-Deguen, 1994).

The rotative sampler used in this study had a 10 cm bit diameter and could be extended by addition of one meter pipe segments. Each core was described in the field. The stratigraphy of the cores was divided into units and described according to texture, grain size, color and macrofossil content.

In the laboratory, colors were described using the Munsell Soil Color Chart. The sand fraction (between 50 μm and 2 mm) was sieved and examined under a binocular microscope. Microfossils of Ostracoda and Foraminifera were removed and identified. Grain size analyses of the sand were made following the techniques described by Folk and Ward (1957) and Folk (1980). Silt and clay grain size (smaller than 50 mm) were studied using a laser particle size analyzer (Malvern Mastersizer). Radiocarbon dating was performed at the Radiocarbon Dating Center of the University of Lyon I; the conventional results beeing expressed at +/−1 Standard Deviation. Dates were then calibrated according to Stuiver and Braziunas (1993) curves for marine samples and expressed at +/−2 Standard Deviation.

3. Analysis of the 12 cores located in the inner harbor (C VI and C VIII)

They all display the same stratigraphy, with five different sedimentary units. We selected cores C VI and C VIII, in the middle part of the harbor basin, for detailed analysis (Figs. 3 and 4).

3.1. Sedimentary unit A

This basal unit is made up of horizontal packs of fibers and rhizomes of the marine phanerogam *Posidonia oceanica*, alternating with beds of sandy mud. Sediment color ranges from gray-black to black, characteristic of organic matter. Posidonia fibers are not in situ but derive from partially decomposed leaves and rhizomes from sublittoral meadows nearby. These flaky layers are deposited in the winter, when leaves fall (Molinier and Picard, 1952).

Posidonia fibers from the lower and upper sections of core C VI were dated by radiocarbon. Base (CVI 1) was 3015 ± 45 years BP (Ly 7986), or 907–764 years cal. BC old. Top (CVI 6) was only 2135 ± 60 BP (Ly 7987), or 97–402 years cal. AD old.

3.1.1. Granulometry

A ballast of shells and *Posidonia* rhizomes makes 1–5% of the total dry weight of the sample. A few pottery shards attest to human impact. The sandy portion (5–26% of total sample dry weight) yields concave cumulative curves typical of silting areas. The unimodal histograms have a peak at 100 μm. Sorting (1.3) is indicative of poorly sorted sediment. Skewness (−0.4) indicates a marked enrichment in fine sands, in correlation to a sheltered area (Folk and Ward, 1957). Silts and clays are dominant (72–94% of total dry weight) and yield linear cumulative curves typical of poorly sorted sedimentation. Histograms show no clear mode. Mean grain diameter ranges from 5 to 7 μm. These micro-particles were deposited in a calm environment. The source of these particles seems to be an outcropping of early quaternary substrate, the histograms of which are very similar to those of the Holocene strata. On core C VIII, analysis yielded concave cumulative curves typical of settling processes. Histograms present a clear mode between 20 and 30 μm, corresponding to biological debris and microfauna (Fig. 4).

3.1.2. Fauna

The macrofauna reveals a mix of three main types or biological assemblages (Table 1). The first group (*Abra tenuis, Venerupis aureus*...) is represented by the greatest number of individuals and belongs to marine sandy mud sublittoral assemblage (Pérès and Picard, 1964). A second group of species (*Bittium reticulatum*) is linked to the *Posidonia* bed biocoenosis. A third one (*Cerastoderma glaucum, C. lamarckii*...) indicates euryhaline and eurythermal lagoonal environments. The copresence of these three groups suggests that the area was at first marine, but was beginning to evolve into a confined environment.

A first group of benthonic Foraminifera (Table 2 and Fig. 3, *Discorbis* sp., *Peneroplis pertusus, Cibicides* sp.) is characteristic of marine algal and phanerogamic meadows as well as coastal muds

Table 2
Foraminifera content of core C VI, Kition Bamboula, Larnaca, Cyprus (* = presence)

	C VI 1	C VI 2	C VI 4	C VI 6	C VI 7	C VI 8	C VI 10	C VI 11	C VI 12	C VI 13	C VI 14 and 16	C VI 20	C VI 21	C VI 23
Ammonia beccarii	*						*	*						
Ammonia beccarii var. tepida	*	*	*	*	*	*					*	*	*	*
Astigerinita mamilla							*		*					*
Bolivina sp.	*								*	*				
Bulimina marginata	*													
Cassidulina crassa	*													
Cibicides sp.			*											*
Cibicides lobatulus								*	*				*	*
Cibicides pseudoungerianus														*
Cibicides refulgens					*									
Discorbis sp.	*						*	*	*		*	*		
Discorbis globularis								*			*	*		
Discorbis mira									*					
Elphidium excavatum	*					*					*			
Elphidium crispum											*	*	*	*
Elphidium lidoense	*				*									
Elphidium macellum								*	*		*	*	*	
Eponides sp.					*									
Eponides repanda	*				*						*	*		*
Globulina gibba				*										*
Gyroidina neosoldanii	*								*					
Glabratella patelliformis												*		
Hyalinea baltica														*
Lagena clavata	*													
Nodosaria sp.												*		
Nonion depressulum	*									*				
Nonion pompilioides								*						
Nonionella turgida											*		*	
Quinqueloculina sp.	*	*	*	*	*		*				*			
Quinqueloculina bethelotiana						*		*						
Quinqueloculina cliarensis					*		*	*			*	*		
Quinqueloculina costata						*		*					*	
Quinqueloculina disparilis	*	*			*			*			*	*		
Quinqueloculina laevigata						*	*							
Quinqueloculina seminulum	*						*	*			*		*	
Quinqueloculina viennensis					*			*				*		
Robulus sp.					*							*		
Sphaeroidina bulloides												*		
Spiroloculina sp.					*									
Spiroloculina angulata								*						
Triloculina inflata					*							*		

Table 2 (*continued*)

	C VI 1	C VI 2	C VI 4	C VI 6	C VI 7	C VI 8	C VI 10	C VI 11	C VI 12	C VI 13	C VI 14 and 16	C VI 20	C VI 21	C VI 23
Triloculina rotunda								*						
Triloculina trigonula							*					*		
Uvigerina sp.													*	
No. of BENTHONIC SP.	15	3	3	3	13	5	8	14	7	2	12	15	8	9
Orbulina universa						*			*		*	*	*	*
Globigerinoides conglobatus	*	*							*		*	*	*	
Globigerinoides ruber	*		*		*						*	*	*	*
Globigerinoides trilobus	*				*	*		*	*	*	*	*	*	*
Globigerinoides trilobus sacculifer	*										*			
Globigerina pachyderma	*						*							
Globigerina humilis	*													
Globigerina bulloides	*	*		*		*	*				*			*
Globigerina qinqueloba	*							*		*			*	
Globigerinella aequilateralis	*						*	*						
Globigerinata glutinata								*						
Globoquadrina dutertrei	*								*	*	*		*	
Globorotalia inflata						*		*				*	*	*
Globorotalia crassaformis														
No. of PLANKTONIC SP.	10	2	1	1	2	4	3	5	4	3	7	5	7	5
% of PLANKTONIC (SP.)	40%	40%	25%	25%	13%	44%	27%	26%	36%	60%	37%	25%	47%	36%

(Blanc-Vernet, 1969). This group decreases, both in number of species and in individuals, from base to top of the cores. One species (*Ammonia beccarii* var. *tepida*) indicates confined environments, the number of its individuals increases topwards from C VI 1 to C VI 6. Occurence of anomalous structure in some *Ammonia* tests may be indicative of ecological stress (Debenay et al., 1996). Conversely, the number of planktonic Foraminifera decreases (both in species and individuals) from CVI 1 to CVI 6 and the mean test diameter decreases.

Ostracods (Fig. 4) are abundant (1000 individuals per 100 g of sediment). Almost 99% of the fauna is represented by the species *Cyprideis torosa.* A few individuals of *Aurila woodwardii* are also present. The almost exclusive dominance of a single species suggests a semi-closed marine environments (Atersuch, 1979).

3.2. Sedimentary unit B

Facies changes dramatically, passing without any transition from very dark organic mud up to sandy carbonated mud rich in microfauna and without *Posidonia* fibers. Two levels (CVI 7 and CVI 8) contain numerous pottery shards, too small to be identified. At the top of this unit, CVIII 6 section was dated 1620 ± 40 years BP (Ly 745 OxA, based on organic matter), or 691–880 years cal. AD.

3.2.1. Granulometry

This unit is characterized by an increased amount of macrofauna and pottery fragments (4–17% of total weight). The sandy portion (17–25% of sample), contains almost exclusively microfauna. 95% total sample weight is made of bio-detrital carbonates. The silts and clays (between 58 and 78% of the total) indicate a period of calm sedimentation.

3.2.2. Fauna

The molluscan fauna consists of a mixed population: first group is represented by reworked and corroded marine shells (*B. reticulatum*...), related to *Posidonia* bed and coastal detrital sands (Table 1; Bourcier, 1976). Most individuals died during the juvenile stage: these open sea species could not develop completely in a confined environment. A second group (*Cyclope* sp., *Diplodonta rotundata*...) is characteristic of lagoon environment. Such mixed populations are common in muddy lagoons.

Benthonic Foraminifera (Table 2 and Fig. 3) are mixed up in a similar manner: some species (*A. beccarii, Cibicides refulgens*...), typical of sublittoral coastal mud, are mixed with species of paralic environments (*A. beccarii tepida, Elphidium lidoense, Elphidium excavatum*). The presence of intact tests of *Globorotalia crassaformis* indicates connection to the open sea.

Ostracods are abundant in the sandy part of the samples (up to 10,000 individuals per 100 g of sediment, Fig. 4). Most individuals still have connected valves. *C. torosa* represents 98% of an abundant fauna. Individuals of all size, juveniles as well as adults presenting thick and punctuated valves, suggest seasonal water concentration and a more confined environment than previously observed. The remaining 2% ostracod species are *A. woodwardii* and *Urocythereis* sp., which live in shallow sublittoral zone. They are incrusted with sediment and therefore have been reworked. Occasional *Cyprinotus* sp. suggest seasonal rises in salinity.

3.3. Sedimentary unit C

3.3.1. Mineralogy (Fig. 5)

This unit is made up of partially stratified gypsum crystals and contains no macrofauna. At the base of this unit, the CVIII 6 section was dated 1620 ± 40 years BP (Ly 745 OxA), or 691–880 years cal. AD. Gypsum occurs as isolated grains or polycrystalline aggregates. Grain diameter varies from 30 μm to 3 mm. Signs of fragmentation in large grains as well as in aggregates suggest synsedimentary deformations, these detrital gypsum particles appear to have been transported over short distances. This observation contradicts the hypothesis that Messinian gypsum was reworked by erosion at the head of the watershed.

We think that gypsum crystallized during deposition of the original sediment, by direct precipitation in a pellicular body of water, interstitial crystallization during periods of desiccation, or probably by the two processes in conjunction. Unit C is thicker in core C VIII, (over 50 cm as compared to 20 cm in C VI). The gradual thickening of the gypsum layer from the edge (C VI) towards the middle of the salt lake

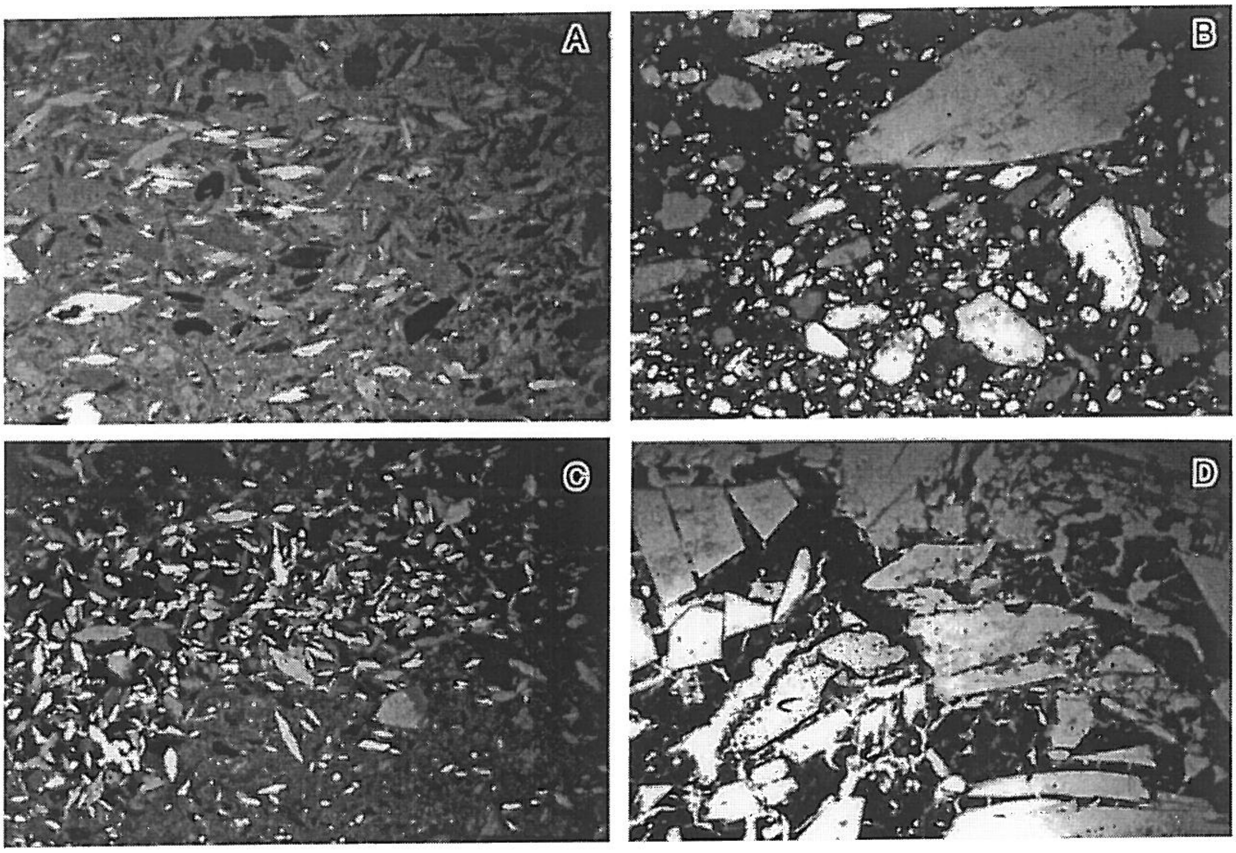


Fig. 5. Pictures of mineral organization, sedimentary unit C, core C VII from the inner harbor, Kition Bamboula, Larnaca, Cyprus (J.-M. Rouchy). (A) Idiomorphic lenticular gypsum crystals disseminated within a fine-grained matrix or xenotypic larger crystals with irregular boundaries. (B) The abundant inclusions in the gypsum crystals of particles of the host sediment suggests that these crystals developed preferentially by in-situ interstitial growth within the sediment. The irregular morphologies of the large crystals as well as their different grain size indicate that they are reworked from gypsum-rich deposits formed in the same area. Thin-section photomicrograph: crossed nichols, X 17. (C) Elongated aggregates of lenticular gypsum crystals within a fine-grained carbonate matrix. Both the shape of the aggregates and the reorientation of the crystals along the boundaries indicate they could result of sediment burrowing. Thin-section photomicrograph: crossed nichols, X 17. (D) This sediment is characterized by the presence of large fragments of crystals broken along the main clivages planes with no evidence of transport. These crystals are disseminated within a carbonate matrix displaying a peloidal-like texture resulting from in situ fragmentation of the sediment by small curved cracks. These features may be interpreted as resulting from a pedogenic alteration of the sediment which occurred during periods of desiccation. Thin-section photomicrograph: crossed nichols, X 17.

(CVIII) suggests that sub-aquatic precipitation was dominant.

3.3.2. Microfauna (Table 2)

Rare and small remains of open sea planktonic Foraminifera (*A. beccarii, Cibicides lobatulus, Discorbis globularis, Quinqueloculina cliarensis*…, Table 2 and Fig. 3) occur in the sediment, suggesting a more or less temporary connection to the ocean. Their skeletons show no traces of eolian reworking. This is in contrast with sediments of nearby Lake Tekke, a closed salt lake south of Larnaca (Fig. 1).

The ostracods do not change significantly from unit B to unit C (Fig. 4). 94% of the individuals belong to the hypersaline species (*C. torosa*) whereas 6% only are reworked tests of the open water species *A. woodwardii.*

3.4. Sedimentary unit D

3.4.1. Granulometry

In core C VI, the ballast (3–7.5% total dry weight) is made up of pottery fragments. The sandy portion (30–50% of the total dry weight) shows linear cumulative curves, characteristic of poorly sorted deposits. Histograms have a mode at 100 μm. The sorting index varies from 1.4 to 1.5, characteristic of a poorly sorted sediment. The skewness index (−0.4) shows an enrichment in fine sands, typical of a calm silting environment. Silts and clays (44–64% total dry weight) yield a linear and concave cumulative curves, identical to that of the substrate, out of which most of the fine sediments originate.

3.4.2. Fauna

Marine macrofauna (Table 1) is scarce with two main species: *Hydrobia ventrosa* from brackish water and *B. reticulatum* (reworked) from the *Posidonia* meadow.

Benthonic Foraminifera are worn and sometimes broken (*D. globularis, Eponides repanda*..., Table 2 and Fig. 3). Planktonic foraminifera are well preserved. These observations suggest a lagoonal environment that was temporarily connected to the sea (storms ?). The presence of *Globorotalia inflata* in C VI 20 confirms this hypothesis.

The distribution of ostracods is like that of unit C (70% *C. torosa* and 11% *A. woodwardii*, Fig. 4). However, there are two differences. The overall number of individuals falls dramatically (30 individuals per 100 g of sediment). Marine ostracods are reworked, suggesting periodic communication with the open sea. Conversely, numerous remains of charophytes indicate fresh water input. The paleo-environment was therefore subject to two concurrent influences, one marine and the other fluvial.

3.5. Sedimentary unit E

3.5.1. Granulometry

Our results are very similar to those for the preceding unit. The ballast (6–7% total dry weight) is composed of continental pulmonate gastropods and gravel. Cumulative curves for the sandy fraction (around 30% total dry weight) are linear (bulk deposition) and histograms mode is at 100 μm. Sorting (1.5) is poor and the skewness of 0.2 points to a marked enrichment in fine sands, typical of decantation processes. Cumulative curves of silts and clays (>60% total dry weight) are linear or concave and most histograms show no mode, typical of settling areas.

3.5.2. Fauna

No marine macrofauna was found but a few reworked terrestrial gastropods (*Helicellinae* mainly, *Theba pisana* and *Cochlicella acuta*) characteristic of the Mediterranean herbaceous coastline (B. Kabouche and F. Magnin, pers. comm.).

A few reworked Foraminifera (*C. lobatulus, E. repanda*..., Table 2) are however present like in the former unit. Ostracods are scarce (60 individuals per 100 g sediment). Freshwater species account for 40% of the total. *C. torosa* only accounts for 4% and there are no *A. woodwardii*, but *Urocythereis* sp. (9%) from *Posidonia* beds. Charophytes are still plentiful. The area thus became progressively terrestrial, marine microfauna was brought in by storm events.

The uppermost layers of the core are an irregular fill, deposited during the XIX century, when marshy areas were intensively filled in by the British administration.

4. Cores from the spit (C X and C XI)

The paleogeography of the coastal bar that isolated the lagoon from the bay remains to be drawn. Gifford (1978, 1985) found accumulations of gravel in his cores K 6 and K 7 (slightly west of Bamboula) that he interpreted as an accretion ridge or spit (Fig. 1). We decided to core on the top of this hypothetical formation. Our two cores (C X, C XI) present two different sedimentary units (Fig. 6).

4.1. Sedimentary unit A

This lower unit lies in discordance over the marl substrate. It is made up of sandy mud, with intercalated *Posidonia* layers. The color is gray (5 Y 5/1). Base of C XI 10 section was dated 3855 ± 60 years BP (Ly 9341, based on organic matter, or 2005–1686 years cal. BC). Top of C XI 2 section was dated 2655 ± 60 years BP (Ly 8607, based on organic matter, or 518–228 years cal. BC). This unit is similar with unit A of previous cores (dated between 3000 years BP and 2100 years BP, section 3 of this text).

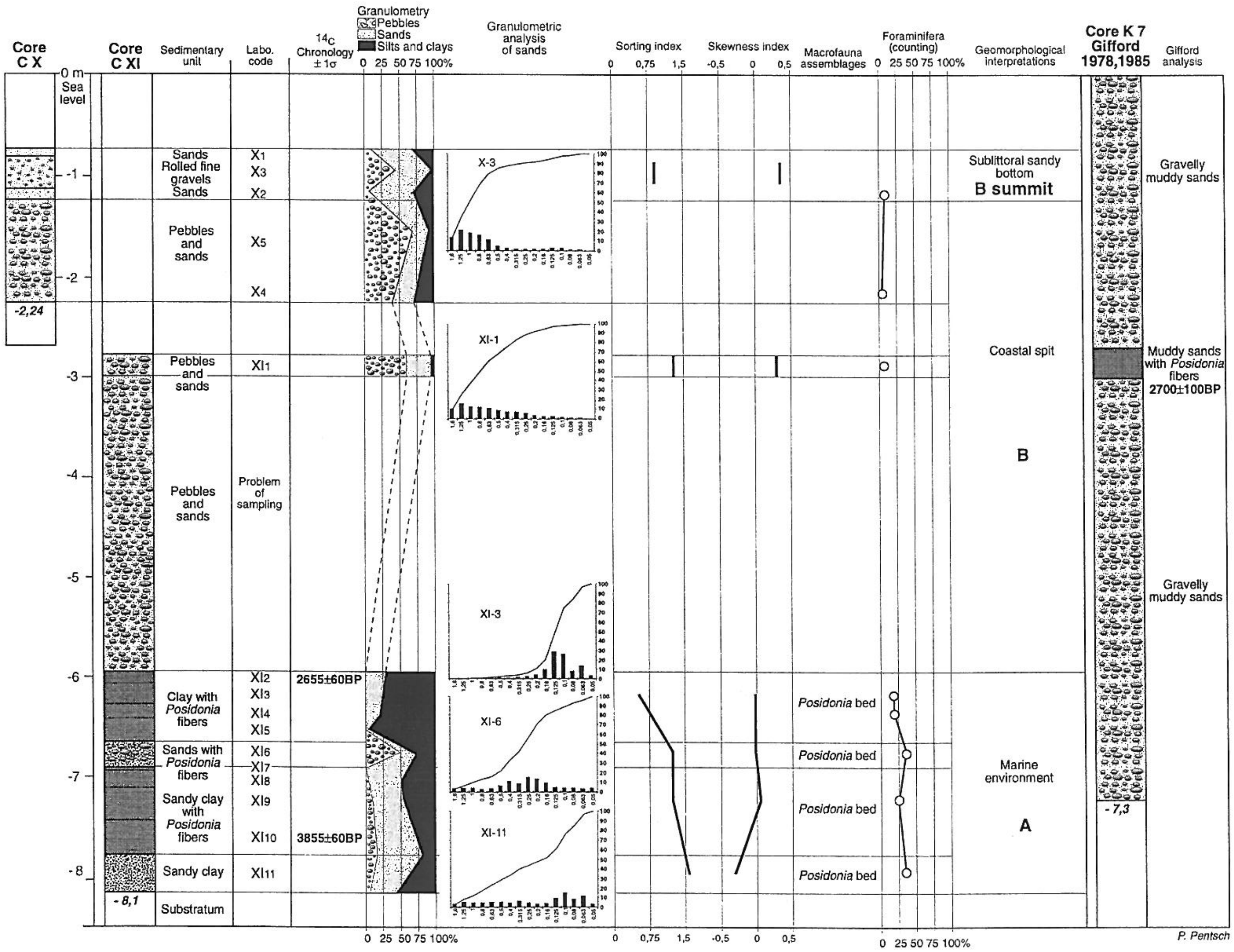


Fig. 6. Core C X and C XI results of analysis, Kition Bamboula, Larnaca, Cyprus. Stratigraphy of core K 7 (from Gifford (1985), modified).

4.1.1. Granulometry

Ballast (up to 17% total dry weight) consists of a few pebbles, rolled beach-rock fragments and broken marine shells. Sandy portion (21–61% total dry weight) yielded linear or concave cumulative curves typical of settling areas. The poorly sorted sediment contains many *Posidonia* fibers. Predominant silts and clays (46–96% total dry weight, but samples C XI 6 and C XI 10 are coarser) indicate a settling environment.

4.1.2. Fauna

The macrofauna (*Paracentrotus lividus*, *Jujubinus exasperatus*, *B. reticulatum latreilli*, Table 1) indicates both marine *Posidonia* assemblage and sublittoral rocky bottom (*Tricolia speciosa*).

Benthonic intact Foraminifera (*Miliolidae* sp. and *D. globularis*, Table 3) make up more than 80% total number of species and individuals and characterize *Posidonia* beds. Species richness is high. Conversely, planktonic Foraminifera are scarce and reworked. This suggests the proximity of *Posidonia* beds in an open water environment more energetic than in the previous cores from the back of the bay (absence of ostracods).

4.2. Sedimentary unit B

It is an accumulation of pebbles overlying the preceding unit (date posterior to 2655 ± 60 years BP) and very difficult to core. In this unit Gifford (1978, core K 7, very near our cores C X - C XI, Figs. 1 and 7) had dated (Table 4) a lens of *Posidonia* fragments 2700 years ± 100 BP (I-9151, or 753–181 years cal. BC, according to Stuiver and Braziunas, 1993).

4.2.1. Granulometry

Ballast. (39–70% total dry weight) consists in well-rounded pebbles and beach rock fragments. Mean diameter is 7 cm. The poorly sorted (1.1) sandy portion (16–34% total dry weight) gave convex cumulative curves typical of deposition in agitated areas. Skewness (0.3) shows an enrichment in coarse sands. A matrix of silt and clay (3–29% total dry weight) suggests that the ridge was below sea level. Presence of chlorite grains (Gifford, 1985) indicates that an important part of the sediments came from the igneous region northwest of Larnaca via the Tremithos river.

4.2.2. Fauna

Marine shells and Foraminifera are scarce, reworked and broken. Ostracods are also absent from this rough coastal zone. These observations suggest that an accreting sublittoral spit of coarse pebbles cut off the lagoon from the open sea. The rapidity of this accretion can be seen by comparing the two radiocarbon dates (2655 ± 60 years BP at 6 m (core C XI) and 2700 years ± 100 BP at around 3 m, core K 7 of Gifford). Such a high speed of sedimentation requires large quantities of pebbles, transported by the Tremithos and reworked by the longshore drift. Nevertheless, it should be noted that heavy reworking may have homogenized the ^{14}C record so that it does not necessarily prove a rapid accumulation.

4.3. Summit of unit B

As in core K 7 (Gifford, 1978, 1985), the top of this unit is made up of coarse sands overlying the pebbly coastal ridge. Ballast (7–32% total dry weight) consists of small well-rounded pebbles. The poorly sorted (1) sandy portion (54–65% total dry weight) has convex cumulative curves typical of agitated areas. Skewness (0.4) indicates a marked enrichment in coarse sands. Silts and clays (7–32% total dry weight) are patchy. Fauna is absent. This sediment may be interpreted as a marine sandy beach at the top of a gravel spit.

5. Cores from the northern district (C XVIII and C XII)

Our goal was to reconstruct the evolution of the coastline on the northern part of the ancient harbor of Bamboula, in a district known as Lichines (marshy area in Greek). This area was recognized by Gifford (1978) but his study does not correlate with the ancient harbor of Bamboula. We were able to drill and analyze two cores (Fig. 1).

5.1. Core C XVIII (Fig. 7)

5.1.1. Sedimentary unit A

This first unit is found at the base of the core. It consists of fine sand with fibers of *Posidonia*. The color is gray (10 Y 5/1) to olive (5 Y 5/4, 5Y 9/3).

A ballast of broken marine shells and coarse subrounded granules of calcareous and igneous rock makes up to 46% total dry weight. The sandy portion is predominant (26–37% total dry weight). Cumulative curves are typical marine "S shaped" curves. The unimodal histograms show a peak at 130–100 μm. The sorting index (0.5 to 0.6) characterizes a moderately sorted sediment and the skewness index (−0.2 to −0.3) indicates a modest enrichment in fine sands. Silts and clays (12–34% total dry weight) present a linear to convex cumulative curve typical of badly sorted sedimentation. The histograms show no clear mode.

Faunistical analysis of the few shells reveals a hard sublittoral bottom and a *Posidonia* sea-grass biocoenosis (Table 1). Most Foraminifera are reworked (Table 3). A few specimens are intact and untransported: *P. pertusus, Cibicides* sp., *Quinqueloculina* sp., which are typical of soft bottoms with metaphytes, like *Posidonia*, and *A. beccarii*, from a coastal sandy bottom.

5.1.2. Sedimentary unit B

This second unit consists of fine muddy sand with *Posidonia* fibers. Ballast represents 5–16% of total dry weight. It consists of a few broken marine and continental shells and coarse granules (mainly beach-rock fragments). Sandy portion varies from 26 to 42% of total dry weight. Curve is a poorly S shaped cumulative curve. The unimodal histograms show a peak at 130–100 μm. Sorting index (0.6–1.3) is of a moderately to poorly sorted sediment and the skewness index (−0.4 to −0.1) indicates a modest enrichment in fine sands. Silts and clays are predominant (52–65% total dry weight). Linear to convex cumulative curves are typical of poorly sorted sedimentation, similar to the previous sedimentary unit A.

The macrofauna reveals a brackish environment (*Pyrenella conica*, Table 1). Reworked Foraminifera (*C. lobatulus, Elphidium crispum, Triloculina rotunda*, Table 3) come from *Posidonia* beds. Cysts of *Artemia salina* suggest that the environment became progressively more confined (Hadjistephanou, 1989). *Posidonia* fibers nevertheless indicate intermittent communication with the open sea.

5.2. Core C XII (Fig. 7)

Most of a basal sandy unit (unit A) was lost during the coring operation. In sample C XII 16, intact Foraminifera (*D. globularis, C. lobatulus, Planorbulina mediterranensis*....) are typical of *Posidonia* bottoms (Table 3).

5.2.1. Sedimentary unit B

It is a grayish-black marine mud with *Posidonia* fibers and organic matter (2.2–3.4%). *Posidonia* fibers from the base of the CXII 15 section, were dated at 4320 ± 50 years BP (Ly 8608) or 2605–2339 years cal. BC. A core drilled by Gifford (1978, core K 3) at a distance of a few meters presented similar strata, with a top dated at 2375 ± 85 years BP (I-9148, based on *Posidonia*, or 242 years cal. BC-155 years cal. AD, according to Stuiver and Braziunas, 1993).

Shells and a few beach-rock fragments make up 5–7% total dry weight. The sandy portion represents 27–52% of total dry weight with *Posidonia* fibers and broken shells. Linear cumulative curves are typical of loose sedimentation. Sorting index of 1.4 is that of a poorly sorted sediment. Silts and clays represent 55–67%, except for sample C XII 13 (40%). Linear or convex cumulative curves are typical of poorly sorted sedimentation.

Macrofauna reveals a mix of three ecological assemblages (Table 1), respectively, Posidonia beds, upper muddy sands (*Calliostoma granulatum*) and brackish sands (*Loripes lacteus*). Foraminifera (Table 3) show 50–60% well-preserved benthonic species (*D. globularis, Discorbis mira, Quinqueloculina costata*...) from *Posidonia* beds.

5.2.2. Sedimentary unit C

This third unit consists of heterogeneous fine muddy sand with *Posidonia* fibers. The color is gray (10 Y 5/1) to white (5 Y 6/1). 1–30% of the total dry weight of the sample is a ballast of rare broken marine and terrestrial shells with fragments of beach-rock. The sandy portion grades from 14 to 77% of total dry weight. Analysis indicates an S shaped cumulative curve. The unimodal histograms present a peak at 130–100 μm. The sorting index (0.4 to 0.6) is indicative of moderately sorted sediment. Silts and clays represent 22–84% of total dry weight. The convex cumulative curve is typical of poorly sorted sedimentation. Rare fragments of shells indicate a *Posidonia* sea-grass bottom (Table 1). Foraminifera are few (Table 3) and reworked.

6. Interpretation

Results obtained above are summarized in Figs. 8 and 9 and allow to separate five periods in the sedimentological record of Kition coastal evolution.

6.1. First period (4000–2100 years BP)

This was a period of settling and fine sediments and *Posidonia* fibers were trapped in a calm and protected marine back-bay behind a *Posidonia* layer. Deposition of the transgressive sedimentary body accompanied the global Holocene sea level rise. The presence of *Posidonia* fibers and rhizomes in the strata is interpreted as a direct marine influence (Thornton et al., 1980; Diaz del Rio, 1993; Pacheco et al., 1996). Because it served as a coastal barrier (or "reef"), the phanerogam bed played a major role in coastal sedimentary evolution by absorbing swells and trapping fine particles.

Macro and microfaunae from core C VI and C VIII (inner harbor) suggest the initiation of confinement in the marine environment (Guelorget and Perthuisot, 1983). Since 2600 years BP, a growing coastal spit (C X and C XI) progressed quickly toward the north–east, progressively isolating a lagoon from the sea. This zone, however, remained constantly connected to the sea. The bay of Larnaca was therefore open but protected; its floor being built up behind a *Posidonia* meadow. From this period dates the initial phase of a barrier spit at the landward edge of the erosional front (Tremithos estuary and cliffs of cape Kiti, Fig. 1; Orford et al., 1991, 1996).

6.2. Second period (2100–1600 years BP)

The inner harbor was still open to the sea by an inlet as appears from the presence of marine shells and of reworked pelagic Foraminifera. Lagoonal fauna associated with settling mud nevertheless suggest sheltered conditions. The absence of *Posidonia* leaves in the sediments can be explained by the separation of the lagoon from the open sea by a spit. Confinement is higher than during the preceding period. The semi-closed lagoon may have been a "leaky lagoon", in constant communication with the sea (Kjerfve, 1986) which was then partially closed and used as a military harbor for Kition, capital of a Phoenician kingdom, during the first millennium BC. This probably was the "closed harbor" mentioned by Strabo (*Geogr. XIV*,6,3; Calvet, 1993). In the Northern district of Lichines, however, the environment remained a marine open embayment.

6.3. Third period (after 1600 years BP)

The scene has changed. In the closed harbor, mineralogical indicators suggest an hypersaline coastal sabkha with alternating haline deposition and occasional flooding ("choked lagoon") and the initial bay closed and turned to a near-isolated state (Bidet et al., 1982). The landscape was probably fairly similar to that of nearby salt lake Tekke, or to some hypersaline lagoons of southwestern Sicily (Dongarrà et al., 1985). Water input was occasional, it came from rain, coastal rivers, or from the sea, especially during storms when it flew through temporary inlets or percolated through the bar. This third period corresponds to the established barrier phase of Orford et al. (1991).

6.4. Fourth period (dates in process)

In the closed harbor, this unit constitutes an anomaly, the environment opened again, and the coastal salt lake was in part submerged by the sea. As during the second period, the sediments show a lagoonal environment connected to the northern district marine gulf and the sea. It was nevertheless more confined, and hydrologic communication with the sea remained limited. The inflow of fresh water induced considerable seasonal variations of salinity.

6.5. Fifth period (XVIII–XIX centuries)

Silting up of the harbor arrived at its logical conclusion: the Bamboula lagoon became sealed off, and the water level shallower. The environment was similar to a coastal marsh described by Dozon (1881), with populations of freshwater ostracods and abundant charophytes. No marsh foraminifera were found.

Table 3
Foraminifera content of cores C X, C XI, C XVIII and C XII, Kition Bamboula, Larnaca, Cyprus (* = presence)

	C XI 3	C XI 6	C XI 11	C XII 2	C XII 3	C XII 5	C XII 6	C XII 8	C XII 9
Ammonia beccarii	*	*	*			*	*	*	*
Ammonia beccarii var. tepida		*							
Bulimina marginata	*				*				
Cibicides sp.	*		*		*				
Cibicides lobatulus			*					*	
Discorbis sp.				*	*	*	*		*
Discorbis globularis			*				*		*
Discorbis mira							*		
Elphidium sp.	*						*	*	*
Elphidium crispum	*	*			*		*	*	
Elphidium macellum	*		*					*	*
Hyalinea baltica									
Massilina secans		*	*						
Nonion sp.		*	*						
Nonion pompilloides	*						*		
Planorbulina mediterranensis	*	*	*					*	*
Peneroplis pertusus	*	*	*					*	*
Pyrgo sp.			*						
Quinqueloculina sp.	*					*		*	*
Quinqueloculina cliarensis	*	*						*	*
Quinqueloculina costata			*						*
Quinqueloculina disparilis					*				*
Quinqueloculina laevigata		*	*				*	*	*
Quinqueloculina seminulum		*	*						*
Robulus sp.					*				
Siphonina tubulosa									
Spiroloculina sp.	*	*	*						*
Triloculina cuneata	*	*	*				*	*	*
Triloculina rotunda	*	*	*				*	*	*
Triloculina marioni	*	*	*				*	*	*
Uvigerina sp.	*		*	*	*	*			
No. of BENTHONIC SP.	16	14	18	2	7	4	11	13	17
Orbulina universa	*	*	*		*	*	*	*	*
Globigerinoides ruber				*	*	*	*	*	*
Globigerinoides trilobus	*		*	*	*	*	*	*	*
Globigerina sp.	*	*	*		*	*	*	*	
Globigerina bulloides					*	*			
Globigerina quinqueloba									
Globorotalia sp.		*							
Globorotalia inflata				*			*		
No. of PLANKTONIC SP.	3	3	3	3	5	5	5	4	3
% of PLANKTONIC (SP.)	16%	18%	14%	60%	42%	55%	31%	23%	15%

7. Discussion

The Paleo-environmental reconstruction of the coastal sector of Kition Bamboula demonstrates that this area was an open bay that became separated from the Mediterranean Sea. This evolution is both common and unique. It is common insofar as the general direction of change, as for most Mediterranean coasts, was towards silting up, coastline regularization, here in a fairly short period of 2600 years. This evolution took place in an area of early settling and was therefore modified by man from the Bronze Age onward (Karageorghis, 1976).

The evolution was basically led by relative sea-level variations, tectonic mobility and variations in sediment supply which are studied separately by Dalongeville (in prep.). We wish nevertheless to underline two main problems:

Table 3 (*continued*)

	C XII 12	C XII 13	C XII 16	C XII 17	C XVIII 2	C XVIII 4	C XVIII 6	C XVIII 7	C XVIII 9	C XVIII 13
Ammonia beccarii	*			*	*	*	*	*	*	*
Ammonia beccarii var. tepida										
Bulimina marginata			*							
Cibicides sp.		*	*		*	*			*	*
Cibicides lobatulus	*									
Discorbis sp.	*	*	*	*	*	*	*	*	*	*
Discorbis globularis	*		*					*		
Discorbis mira	*						*	*		
Elphidium sp.			*	*					*	*
Elphidium crispum	*		*	*		*	*	*		*
Elphidium macellum	*	*	*					*	*	
Hyalinea baltica				*						
Massilina secans	*									
Nonion sp.									*	
Nonion pompilloides		*	*				*			
Planorbulina mediterranensis	*		*					*		
Peneroplis pertusus							*	*		
Pyrgo sp.										
Quinqueloculina sp.		*			*	*	*	*	*	
Quinqueloculina cliarensis	*		*			*	*	*	*	*
Quinqueloculina costata	*									
Quinqueloculina disparilis					*				*	
Quinqueloculina laevigata	*		*			*				
Quinqueloculina seminulum	*		*			*		*	*	*
Robulus sp.				*						
Siphonina tubulosa				*						
Spiroloculina sp.	*	*	*			*	*	*	*	*
Triloculina cuneata	*	*	*						*	
Triloculina rotunda	*		*			*	*	*	*	
Triloculina marioni	*		*					*		
Uvigerina sp.					*				*	*
No. of BENTHONIC SP.	17	7	16	7	7	8	9	12	13	9
Orbulina universa	*			*		*	*		*	*
Globigerinoides ruber	*		*	*	*				*	*
Globigerinoides trilobus	*		*	*	*	*	*	*	*	*
Globigerina sp.	*		*	*		*	*	*	*	
Globigerina bulloides	*				*			*		
Globigerina quinqueloba										
Globorotalia sp.						*	*			
Globorotalia inflata					*	*		*		*
No. of PLANKTONIC SP.	5	0	3	4	4	5	4	4	4	3
% of PLANKTONIC (SP.)	23%	0%	16%	37%	37%	38%	31%	25%	23%	25%

7.1. Problem one: coastline evolution versus relative sea level changes

The lagoon was cut-off because this sector of the coast was uplifted: archeological excavations in progress at Bamboula, at a very short distance from core C VI, uncovered a marine layer of mud from the Bronze Age, with a rich macrofauna. This layer is similar to and contemporaneous with the base of unit A of cores C VI and CVIII. It contains many ceramics from the 13th century BC. In the excavation, the natural upper limit of this strata is found abnormally at 40 cm above present sea level, or approximately 2 m above the relative level of the sea expected for the period (Pirazzoli, 1991).

Such a pattern suggests a tectonic uplift. Dalongeville (in Yon, 1994) observed a similar phenomenon in the sector of cape Kiti, south of Larnaca, finding fossil sea levels at an altitude of +2 to +3 m, which were dated on marine shells, 4830 ± 50 years BP and

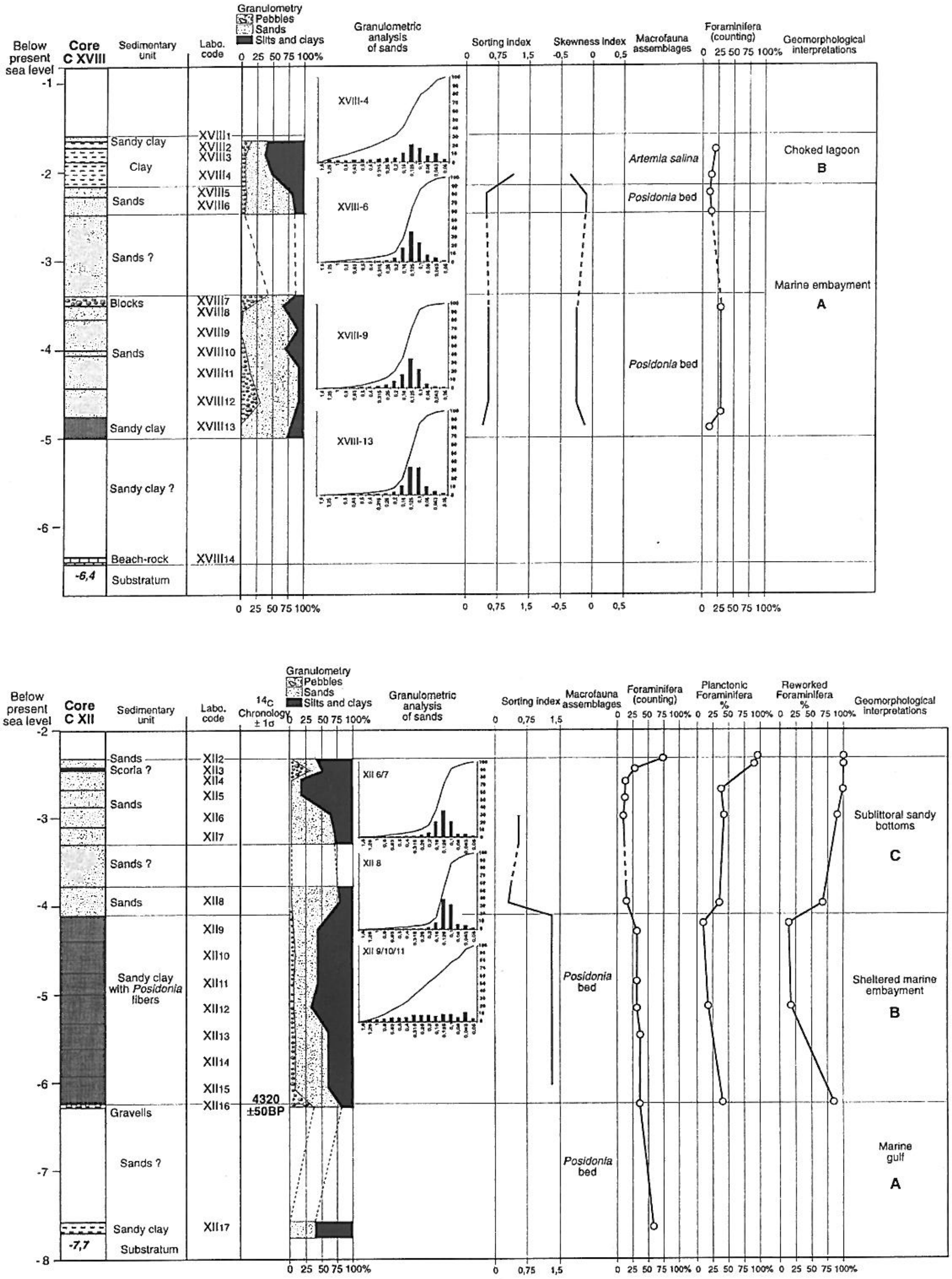


Fig. 7. Core C XVIII and C XII results of analysis, Kition Bamboula, Larnaca, Cyprus.

Table 4
List of dated samples

Lab. Code	Sample	Material	13C (0/00)	Age (yrs. BP)	Cal. Age	Ref.
Ly 7986	C VI 1	Posidonia clay	−22,63	3015 + /−45	907–764 BC	
Ly 7987	C VI 6	Posidonia clay	−20,02	2135 + /−60	97–402 AD	
Ly 745 (Oxa)	C VIII 6	Lagoonal clay	−20,47	1620 + /−40	691–880 AD	
Ly 9341	C XI 10	Posidonia clay	−16,55	3855 + /−60	2005–1686 BC	
Ly 8607	C XI 2	Posidonia clay	Est. −15	2655 + /−60	518–228 BC	
Ly 8608	C XII 15	Posidonia clay	−14,21	4320 + /−50	2605–2339 BC	
I 9148	K3	Posidonia clay	Est. −15	2375 + /−85	242–155 AD	Gifford, 1978
I 9151	K7	Posidonia clay	Est. −15	2700 + /−100	753–181 BC	Gifford, 1978

865 ± 45 years BP at +1 m, south of Larnaca. Sanlaville (in Yon, 1991) also found marine sediments from the Roman era (865 ± 75 years BP, on marine shells) slightly above present sea level in the harbor of Bamboula.

These results obtained on the southeastern coast of Cyprus are different from the uplift measured on the east coast (Flemming, 1974) or on the north coast (Nicolaou and Flinder, 1976; Dreghorn, 1981; Pirazzoli, 1986; Pirazzoli et al., 1996) in a different structural context. Our results, however, do not confirm the data of Gifford (1978, 1980) which document in Kition a regular rise in relative sea level, and a constant position of sea levels below the present one, although this author does admit a slight uplifting of the coast (Gifford, 1985).

In the tectonic context of Cyprus, at the border between the African tectonic plate and the Anatolian tectonic microplate, it is not so surprising to detect tectonic movements (Bousquet and Péchoux, 1980; Poole et al., 1990). The rapidity of evolution might be an indicator of tectonic impact on a lowland coastal environment (Koss et al., 1994). Under these circumstances, sea level signatures may be ambiguous. Nevertheless, the salt lake phase can reflect equally restrictions in water circulation at the harbor entrance or reduction of freshwater influx and relative sea level changes.

7.2. Problem two: evolution versus sediment supply and man impact

We have seen that a spit kept on prograding since 2600 years BP. This important change in sedimentation from a muddy sand sea-bottom to loose pebbles suggests an important modification in the sedimentary budget at the scale of Larnaca bay. How can we explain such a sudden development of coarse sediments originating from the Tremitos watershed, west Larnaca districts? Might it be linked to a detritic event, correlated with Bronze age human impact upstream?

The spit-protected lagoon was used as a closed military harbor (Bamboula) during classic and hellenistic times. The presence of a bar of pebbles made the location of the channel between the closed harbor (the Phoenician cothon) and the open sea quite difficult (Fig. 10). Nicolaou (1976) proposed a direct west–east connection between the closed harbor and the open sea. Our study suggests that this hypothesis might be unrealistic, because of the difficulty of dredging and maintaining a channel through a considerable mass of unconsolidated pebbles. Conversely, cores C XVIII and C XII show that, in the northern district of Kition, the spit was still discontinuous 4300 years BP and remained so for about two millennia. We imagine that Phoenician, Greek and Roman sailors alike would have used this indirect but easier way to connect the harbor to the sea (Fig. 10).

7.3. Comparison with other ancient harbors

Occurrence of submersed archeological remains is usual along Mediterranean coasts (Flemming and Webb, 1986). Much less frequent is evidence of uplift movements having affected archeological sites. Three examples clarify our work on Bamboula harbor.

On the rocky coast of Western Crete, ancient Phalasarna harbor shows a sudden uplift of around 6.6 m about 1530 years BP, probably during the seismic event of 365 years AD. Then, this harbor was

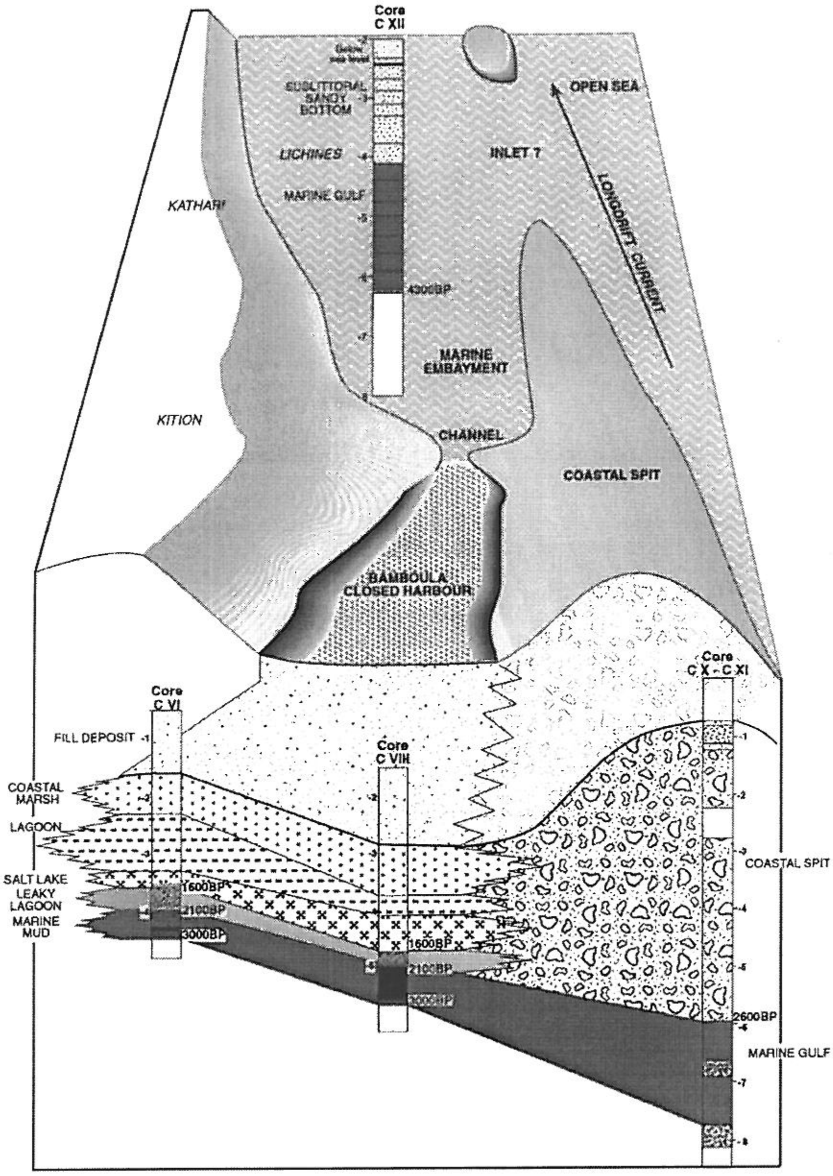


Fig. 8. Schematic stratigraphic diagram of the west/east transect from core C VI to core C XI and south/north transect from core C VI to core C XII, showing a reconstruction of the depositional environments.

removed from marine influence (Pirazzoli et al., 1992).

On the sandy coast of the western part of the Isthmus of Corinth, the ancient harbor of Lechaion is very similar to Bamboula. The entrance channel and the inner basin of Lechaion was elevated by about 1 m above present sea level. Various coastal remains testify to complex up-and-down displacements, with clearly predominant uplift since 2500 years BP (Stiros et al., 1996; Pirazzoli, 1998).

In the region of the Orontes delta, the ancient Greek harbor of Seleucia Pieria, (Turkey), was submitted to two uplifts about 2500 years BP and in 562 years AD. The second seismotectonic event caused rapid silting up of the closed basin, preventing further use (Erol and Pirazzoli, 1992).

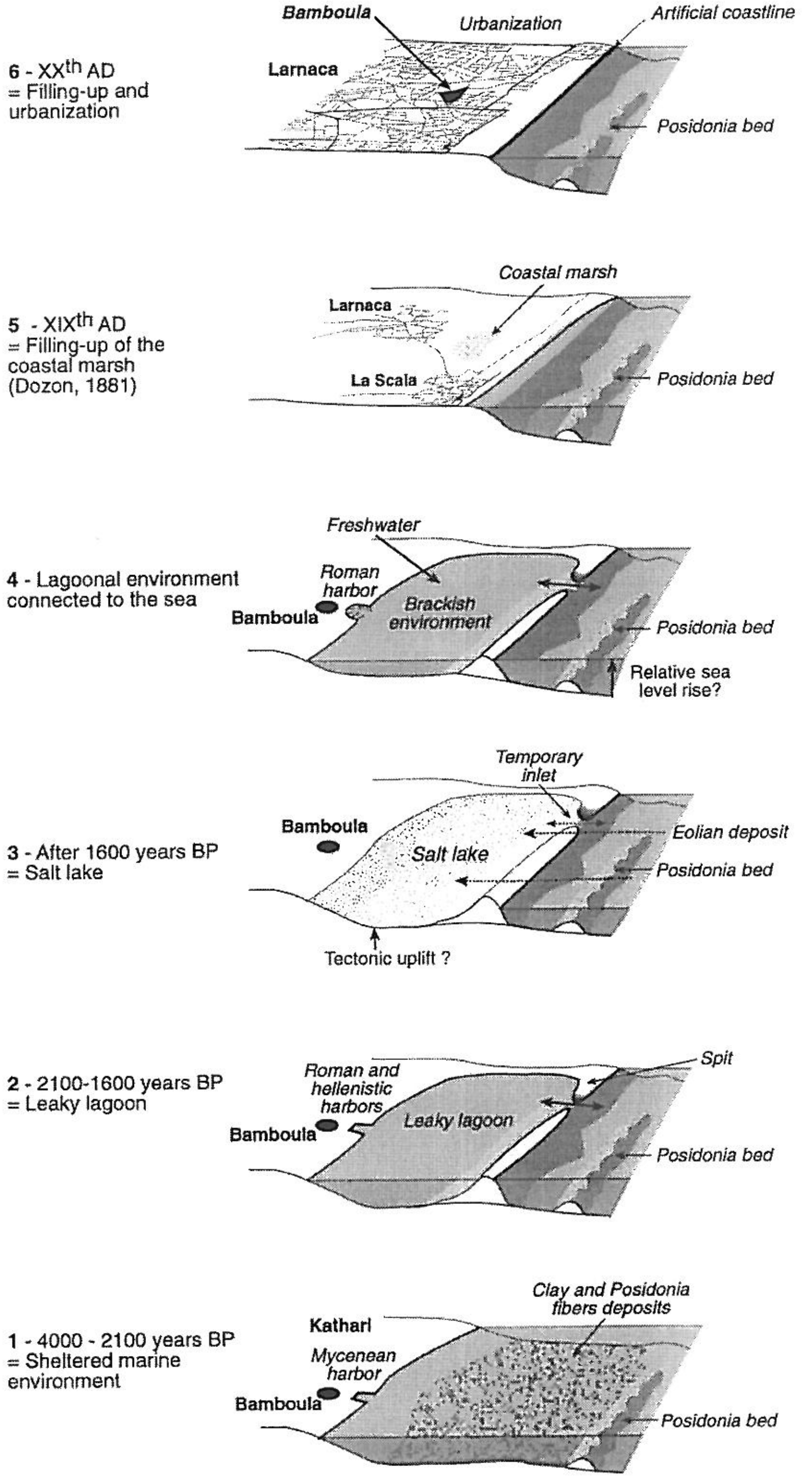
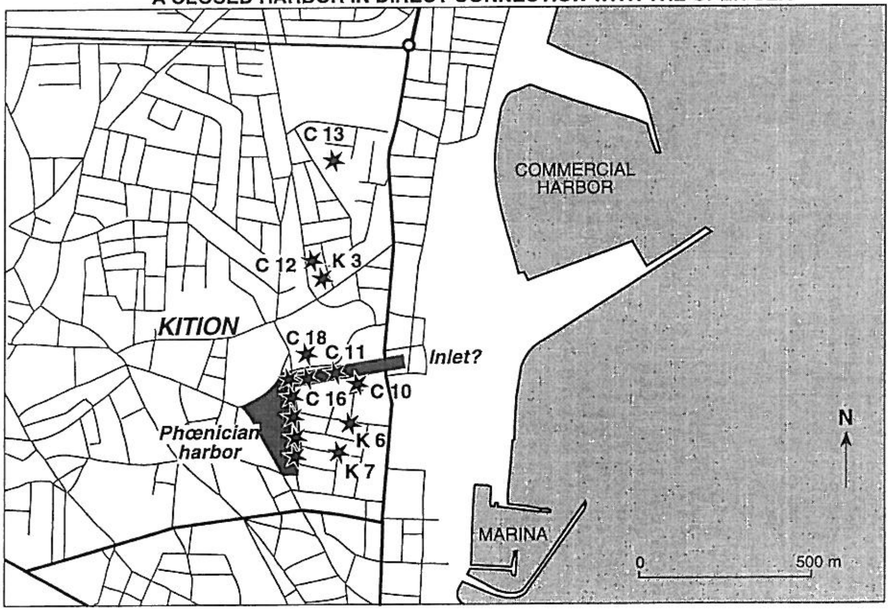
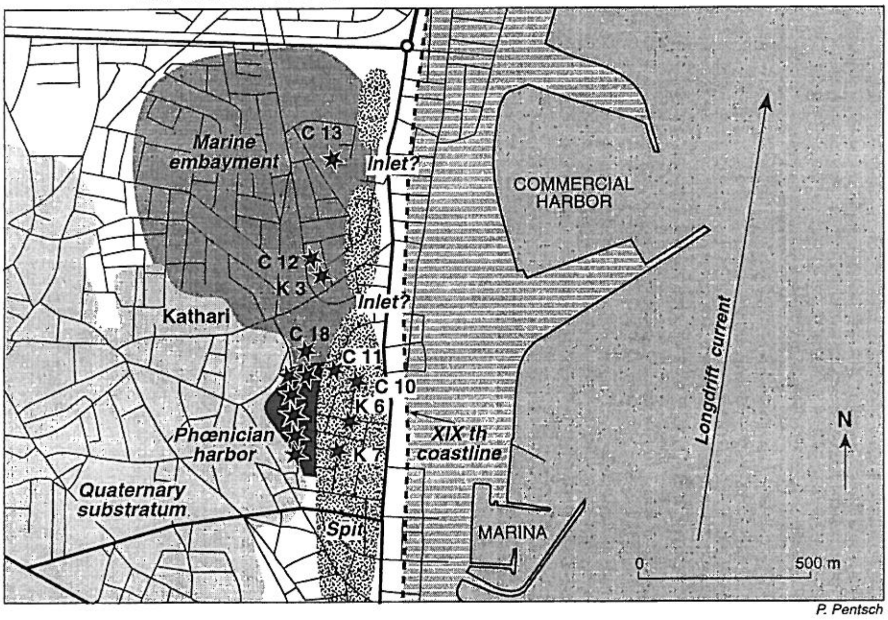


Fig. 9. 4000 years of paleo-environmental evolution of Larnaca coastal sites.


NICOLAOU HYPOTHESIS, 1976 :
A CLOSED HARBOR IN DIRECT CONNECTION WITH THE OPEN SEA


HYPOTHESIS 1999 : A SHELTERED BAY OF A MARINE EMBAYMENT

P. Pentsch

Fig. 10. Coastal paleogeography ot the sector of Kition Bamboula during classical times, Hypothesis of Nicolaou (1976) and our new proposal.

The direct consequence of a relative fall in sea level is the ending of marine influence, which often causes the harbor to be abandoned. These three examples clearly show that tectonic mobility provides a partial explanation for the rapid transformation of the lagoon of Bamboula. Our data also point to the major role of the gravel spit in controlling environmental changes from the initial barrier phase (period between 2600 and 2100 years BP) to the established barrier phase (period after 2100 years BP).

8. Conclusion

The paleo-environmental reconstruction of the coastal sector of Kition Bamboula demonstrates that this area was an open bay that became separated from the Mediterranean Sea. An integrated biological, sedimentological and radiometric approach is a new tool for solving marine archeological and paleo-geographical problems (Kraft et al., 1980; Gifford et al., 1992; Reinhardt et al., 1994; Brückner, 1996; Morhange et al., 1996).

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