An investigation of natural processes and human impact in the coastal area surrounding the ancient harbour of Kenchreai (Saronikos gulf)

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ABSTRACT

The present contribution investigates the natural processes responsible for the morphological evolution during the historical times of the broader coastal area (terrestrial and nearshore) of the ancient harbour of Kenchreai (or Kehrees). The study involves past tectonic movements, eustatic changes and modern wave regime and nearshore sedimentology, including the newly (summer 2006) formed calcarenite (with "beachrock" characteristics) related to the extensive onshore presence of dead seaweeds. Furthermore, the various anthropogenic activities (e.g. the construction of the national road, which passes through the archaeological area, nearby agricultural fields, the presence of short moorings for small fishing boats along the shoreline of Kenchreai Bay and an additional increase of sea level due to the Global Climatic Change) are discussed against their impact on the archaeological site itself and its surrounding coastal landscape.

Keywords: coastal zone, geo-archaeology, relative sea-level rise

1. INTRODUCTION

The archaic harbour of Kenchreai, built, most probably, in the 6th century B.C. constituted the eastern way out of ancient Corinth to the Saronic Gulf (Aegean Sea) (Fig.1). The harbour was formed by the construction of two jetties one at the northern and one at the southern end of the Kenchreai semicircular bay. During the Roman era (1st century A.D.), soon after the foundation of the Caesarian colony at Corinth, the harbour underwent a dramatic revival, becoming the major node of trade, travel and communication for several centuries (Rizakis, 1997).

The major remains of the ancient and Roman periods of the Kenchreai harbour are related to the temples of Venus (Aphrodisium) and Isis at the north and south jetty, respectively, a Christian basilica church of the 4th c. A.D. (built on top of the Isis temple foundations), various buildings such as warehouses, fish-tanks and pavements (all submerged), whilst in the nearshore hinterland area twelve burial sites have been identified and excavated by the archeologists (Rife et al., 2007).

The present contribution investigates the natural processes responsible for the morphological evolution of the broader coastal area (terrestrial and nearshore) of the ancient Kenchreai harbour, within historical times. Human interferences are also assessed in the present investigation.

2. DATA COLLECTION AND METHODOLOGY

The selected surficial sediment samples (for exact locations see Fig. 1) have been analysed granulometricaly by dry-sieving (fraction >0.0625mm) according to Folk's (1974) procedure. A series of aerial photographs of the coastal area have been taken with the use of an OLYMPUS Camedia 740 digital camera, in order to support geomorphological observations. Thin sections of the newly formed "beachrock" type have been investigated under the microscope.

In the absence of wave records, offshore wave characteristics have been hindcasted using the wave forecasting equations for fetch-limited conditions of CERC (1984) and the wind data from the Wind & Wave Atlas of the Eastern

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Mediterranean Sea (Athanasoulis & Skarsoulis, 1992). Subsequently, the wave run up capability has been calculated by applying Komar's (1998) equation: $R = 0.36 \cdot g^{0.5} \cdot S \cdot H_o^{0.5} \cdot T$, where S is the tangent of the mean beach slope.

3. RESULTS AND DISCUSSION

3.1. Coastal geomorphology - geology

The ancient and partially submerged harbour of Kenchreai is located at the northern end of the homonymous Bay, which is part of the northwest (Peloponnesian) coast of the Saronikos Gulf. Geologically, the study area and its surrounding region belongs to the northern block of the fault zone of Kenchreai - Ancient Corinth (trending almost W-E), Scranton et al., 1978) that is also the boundary of the Plio-Pleistocene deposits in the north and the Mesozoic limestones in the south (Fig. 2) (Papanastasiou & Gaki-Papanastasiou, 1993).

Historical evidence have revealed many earthquake socks in the broader area of Kenchreai. Earthquakes with magnitude ≥6 Richter and epicenters at distances up to 30 km from Kenchreai are presented in Table 1. In particular, the earthquake socks that took place in the 6th century A.D. may be responsible for the decline of Kenchreai.

Morphologically, the Kenchreai port is characterized by a narrow sub-aerial beach zone, a few metres wide, having the characteristics of a coastline under retreat (Fig. 2). The nearshore bottom is rather smooth sloping gradually to water depths of 5 m at a distance of approximately 100 m offshore.

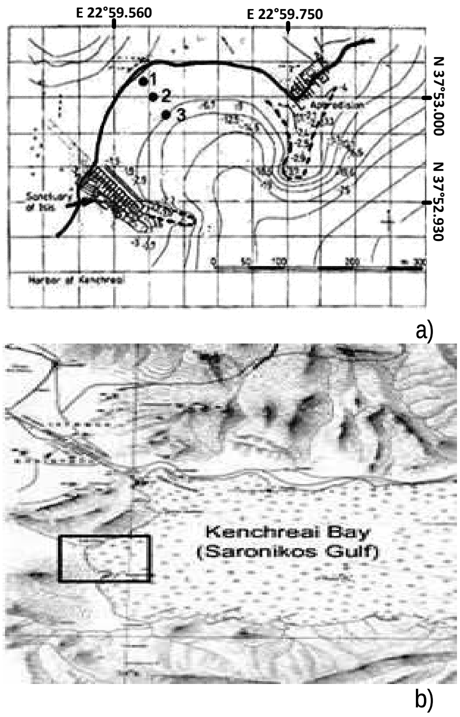

Figure 1: The location of the ancient harbour of Kenchreai (a) in the homonymous Bay (b) the neighboring area.

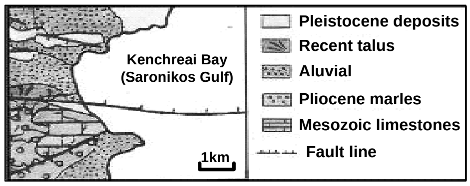

Figure 2: Lithology and major fault zone in Kenchreai Bay

Table 1: Major earthquake socks at Kenchreai and the neighboring area

Location	Year (AD) and magnitude (Richter scale; in parenthesis) of past earthquakes.
Corinth	74 (6.3), 521 (6.3), 543 (6.2), 580 (6.3), 1300 (6.0), 1725(6.0), 1775 (6.2), 1858 (6.5), 1876 (6.1), 1928 (6.3), 1930 (6.0)
Epidauros	1837 (6.3), 1873 (6.0)
Perachora	1981 (6.7)
Xylokastro	303 (6.4), 1402 (6.8), 1742 (6.7), 1753 (6.1), 1887 (6.5).

(source: Papazachos & Papazachou, 2003).

The curved bathymetric contours indicate a drowned (during the last transgression) valley enclosed by the jetties of the ancient port, as shown in Fig. 1(b). This observation is also in agreement with the present-day existence of a small ephemeral stream debouching within the Kenchreai Port (bay) coastal area.

3.2. Sea level change during Holocene

Relative sea-level rise has obviously played a major role in the evolution of the coastal morphology of the Kenchreai Bay. All the archeological remains that are submerged at various water depths up to 3.5 m, are listed in Table 2. Initially, this general submergence has been attributed exclusively to the local tectonism, expressed by intense earthquake socks (Scranton et al., 1978); this theory has also been supported by the subsequent investi-gations of Papanastasiou and Gaki-Papanastasiou (1993) who have related the various morphological changes to the presence of the fault zone shown in Figure 1(a). On the other hand, the glacio-hydro-isostatic model for the Aegean Sea provided by Lambeck (1996) states that sea level was 4.5 m below its present level at 6000 years BP and about 1.5 m below its present level at 2000 years BP. In addition, the absence of any significant tilting of the Quaternary formations indicates that local tectonism / seismicity cannot explain by itself vertical displacements of the order of a few metres. Hence, the observed submergence of the ancient port remains has to be attributed to both eustatism (primarily) and to recent neotectonism (secondarily).

3.3. Coastal sedimentology

The northern part of the shore of the Kenchreai Port consists mainly of pebbles and cobbles, while the southern part is sandy, being, most probably the dynamic output of an anti-clockwise nearshore water movement and, in particular, in the area between the two submerged jetties of the ancient port. In addition, the absence of any sandy material in the northern part indicates also that this area is under erosion without any replenishment of the fine-grained material removed by the nearshore circulation. The beach face material has poor sorting (Table 3), indicating variable granulometry and not persistent (uniform) nearshore hydrodynamic conditions. Farther offshore, the seabed consists of fine-grained (Mz=0.45φ) sediment (see Table 3) and is covered partially by sea grass (mostly by Cladophora sp.). The offshore sediments have good sorting and negative asymmetry, being the outcome of long periods of near bed wave activity.

Table 2: Submerged ruins (period of construction and submergence below present sea level (b.p.s.l.)

Submerged archaeological ruins	Period of construction	Submergence b.p.s.l. (in metres)
Jetties of ancient port	6th century B.C.	up to 3.0
Pavement (nowadays 30 m offshore)	1st - 2nd century A.C.	~2.0
Stone houses	1st century B.C.	0.8-1.3
Foundations of Isis temple	2nd century A.C.	0.75
Christian church	4th century A.C.	~1.0
Fish tank	2nd century A.C.	~ 1.5

(sources: Mourtzas and Marinos, 1994; Rizakis, 1997 Rife et al., 2007)

Table 3: Statistical parameters of surficial sandy (S) sediment samples (for location see Fig. 1).

Sample	M_z	σ_I	Sk_I	sorting	asymmetry
1	1.98	0.45	-0.15	good	negative
2	1.22	1.13	-0.22	poor	negative
3	0.31	1.62	+0.03	poor	almost symmetrical

(Note: sample 1 is from 4 m of water depth, sample 2 and 3 are from the beach face at the sandy southern part of the study area)

In the photograph of Figure 3, taken from the northern part of the backshore zone of the Kenchreai Bay, it can be seen that the sub-aerial beach sediment (mostly pebbles and cobbles) has been cemented by a white material (Fig. 3). On the basis of in-situ seasonal observations this material has been produced by the decomposition of the Cladophora species algae, which are abundant on the bay floor, usually attg proliferations whenever environ-mental conditions are favorable. After periods of intense wave activity, the algae are swept onshore where they pile up and been decomposed, providing the biogenic material (e.g. cellulose), which participates in the cementation of the surficial beach material, producing a kind of 'beachrock' formation. The exami-nation under the microscope of this slightly lithified bio-calcarenite has shown that it consists of bioclasts and lithoclasts surrounded by algae (Fig. 4).

The studied facies has suffered intense (vadose) diagenesis. Grains are covered by micritic coatings of unequal thickness (microbial), that gradually tend to assimilate the grains.

Figure 3: Photograph from the northern part of Kenchreai Bay showing lithification of thebeach material with white cement of biogenic origin (for details see text)

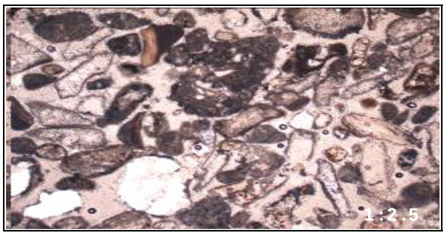

Figure 4: Photograph of the calcarenite under the microscope (for location see Fig. 3)

A thin halo of scalenohedric anisometric cement has been grown around the grains leaving open the rest of the remaining space. In places, meniscus-type cement and allochemic components occur.

3.4. Coastal oceanography

The entrance of the ancient port faces to the SE, while the Kenchreai Bay is exposed to offshore waves (wind generated) approaching mainly from the east. Eastern winds have an annual frequency of less than 4%, while the N, NE and SE winds occur with frequencies of 13.1%, 13.9% and 5.4%, respectively. The main characteristics of eastern waves are presented in Table 4. As it can be seen, the most frequent waves are those related with wind speeds <16 knots with significant wave heights <1 m and periods <4 sec, due to their limited fetch lengths (~26 km). The highest expected waves exceed 2 m in height and 5 sec in period, breaking at a depth of ~3 m and being able to reach an altitude of 0.7 m (run-up) on the beach. Apparently, the effects of wave activity upon coastal processes are enhanced substantially by temporary sea-level rises due to meteorological forcing (e.g. strong SE winds); these sea-level rises

Table 4: Characteristics of the incoming waves from the east (f: annual frequency of occurrence, H: significant wave height, T: wave period, db: breaking depth of the waves and R: run-up).

U (knot)	f (%)	Ho (m)	T (sec)	d_b (m)	R(m)
1-3	0.64	0.02	0.80	0.03	
4-6	1.12	0.19	2.47	0.24	
7-10	1.01	0.46	3.14	0.59	
11-16	0.69	0.82	3.79	1.05	
17-21	0.19	1.25	4.35	1.60	
22-27	0.07	1.70	4.83	2.18	
28-33	0.03	2.23	5.28	2.86	0.67

often exceed 0.6 m, according to the records of the tidal gauge of the harbour of Piraeus (HHS, 2005).

3.5. Human impact (modern times)

Human interference in the coastal environment of the Kenchreai ancient port includes the main road, which being in a distance of a few tens of metres from the coastline, has stopped the natural sediment exchange between the beach zone and the nearby low-lying hinterland area. In addition, the small ephemeral stream debouching naturally into the Kenchreai Bay, has been essentially blocked, depriving the nearshore area from any significant sediment influx. Recently, 2-3 small piers have been constructed along the northern part of the coastline, in order to facilitate local fishing activities; these restrict the nearshore circulation inhibiting water renewal and favoring the accumula-tion of dead seaweeds (see above).

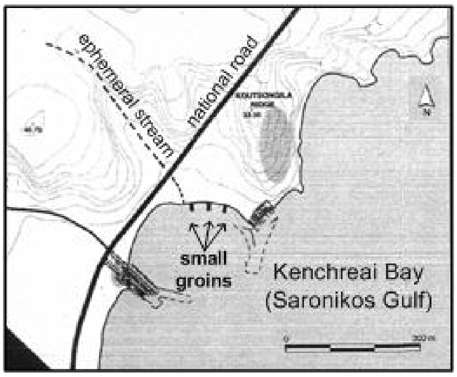

Figure 5: Human impact on the coastal area of the ancient port of Kenchreai: national road, position of small groins and mouth of ephemeral stream

Another anthropogenic, although indirect, interference is the potential sea level rise due to the global climatic change related to the 'greenhouse' effect. The measured rise is of the order of 17 cm over the part 100 years, while the prediction for the year 2100 is 38 cm according to the latest IPCC (2007) report. This potential sea level rise will not only cause a further submergence of the archaeological site, but will also enhance the coastal erosion processes due to the increased wave activity, as coastal waters become deeper.

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