Coastal changes and human activities at Istron-Kalo Chorio (NE Crete, Greece) during the Upper Holocene

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The Istron area is located in northeastern Crete, Gulf of Mirabello, on an alluvial fan of Holocene age. The archaeological importance of this area is pointed out not only by its archaeological remains, but also by its significant location. Many important Minoan sites, like Gournia, Kavousi, Pseira, have been discovered near Istro. There are indications of human installations from the Neolithic to the Roman period, proving the continuous human activity in this area. The significant geological location, as it represents an area with intense tectonic activity, the geomorphological regime of the area and the climatic changes, influenced human installations as well as the evolution of the civilization. The study of sea-land interactions during the last seven millennia in relation to the eustatic sea level oscillations and the regional neotectonic regime, as well as the geomorphologic observations and analyses on deposited sediments, aims to reveal the paleogeographic evolution of the landscape and its impact on prehistoric, classical and Roman establishments. Therefore, a geomorphological mapping of the coastal area along with the drilling of five boreholes and the excavation of six trenches, have been accomplished. Moreover, pollen and microfaunal (benthic foraminifera and ostracodes) analyses have been performed. Six samples were dated using AMS and Conventional radiocarbon techniques providing temporal control of the sediments. Sea level rise along with sea-land interactions to the landscape evolution and the transgression of sea in 5000 BP have been verified. Additionally, several implications for the use of land and human impact civilization have been concluded.

Introduction

The Istro area is located in northeastern Crete, Gulf of Mirabello, on an alluvial fan of Holocene age. It has been inhabited since the Final Neolithic period, demonstrating great historical and archaeological importance. Its significant location, near important minoan settlements like Gournia, Kavousi, Pseira, as well as its archaeological remains, give evidence for a prominent minoan center with its 'commercial' harbor. First archaeological researches of the area started in 1903 by Richard Seager and Harriet Boyd, resulting to the excavation of the area in 1910–1912, by Edith Hall, supported by the University Museum in Philadelphia. (Hall 1914). In 1986, an intensive survey project of the area was undertaken by the University of Pennsylvania Museum and Baylor University, directed by Barbara Hayden and Jeniffer Moody. Fieldwork and laboratory analyses have been done, whereas several scientific activities have been performing until today.

Series of boreholes and backhoes had been done in 2004, under the direction of the Laboratory of Archaeometry of N.C.S.R 'Demokritos' in Athens. Several analyses have been performed on cores taken from the area, although more results are needed for a detailed scientific approach.

This study attempts to determine the depositional environments the last 6.000 years, as well as climate and sea level changes recorded during that period, with the use of micromorphological , micropaleontological and palynological methods, in addition to radiocarbon dating of plant remains.

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Fig. 1. Location map of the area.

Geographical and geological setting

The broader survey area of Istron extends from the north coast of Crete, where it flanks the central to western portion of the Gulf of Mirabello, south to encompass the Meseleroi Valley, and from the Kentromouri area, just west of the small plain around Gournia, west to the Kalo Chorio or Istron River valley. The two main riverine systems are the Istron (today known as Kalos Potamos), which extends into the Kalo Chorio or Istron Valley from the west. Its main tributary flows into the sea, just east of the small headland of Priniatikos Pyrgos. The other system, the Xeropotamos river, which is always dry during summer months, extends east and north, to merge with the sea in the small Phrouzi basin, near the eastern edge of the survey area.

From the west to east the four main promontories are Ioannimiti, Nisi Panteleimon, Elias to Nisi and Vrionisi. The small sandy headland of Priniatikos Pyrgos projects from a long beach that extends from the base of Ioannimiti to Nisi Panteleimon. (Fig. 1)

In Istro area, as in most of Crete, the mountains and sea have been largely stable since the earliest phases of human settlement. The main topography was formed in the Pleistocene or earlier .

There are 6 broad geomorphic units and two main drainage systems in the survey area. The geomorphic units comprise a) the coast strip and promontories, b) the Istron river valley and flood plain, c) the Prina basin, d) the Meseleroi basin, e) the Scinavria massif and f) the hills and ridges south of Vrokastro and the Koloumbous hills to the south. (Hayden 2004, Moody 1997)

Six bedrocks dominate the area: crystalline limestones, marls, sandstones, granodiorites, greenstone conglomerates and limestone breccio-conglomerates (I.G.M.E, Ag. Nikolaos sheet 1/50.000, 1987). The crystalline limestones are of Upper Cretaceous date and are considered part of a tectonic nappe. The greenstone conglomerate, which forms the base of Neogene series, includes pebbles of limestone, dolomites, phyllites, quartzies, cherts and greenstone. With the reemergence of the island in the upper Pliocene, the soft Neogene deposits began to erode. (Fytrolakis 1980, Fassoulas 2001) (Fig. 2)

Millennia of erosion reexposed the older, buried, hard limestones and igneous rocks. The product of this weathering process is a sandy sediment full of black and gold mica, white to pink angular feldspar and milky quartz. (Hayden 2004, Myer 1984).

Many of the limestone cliffs that tower above the wider valleys and coast are the result of local faulting. Subsidence along the coast is also largely the result of local tectonism. (Fleming 1978, Dermitzakis 1969, Karotsieris et al.2000). This is evidenced by walls of Middle or Late Minoan I date submerged to at least one meter immediately west of Priniatikos Pyrgos.

In the cliffs of the coastal promontories at least one submerged solution notch was observed about 1.80m below sea level. (Mourtzos 1988, Moody 1987). Solution notches are formed in the littoral splash zone by boring animals like *Dendropoma,* which can dissolve the bedrock and are indicative of earlier sea levels. All this also suggests that relative sea level around the Gulf of Mirabello was lower than it is today, at least

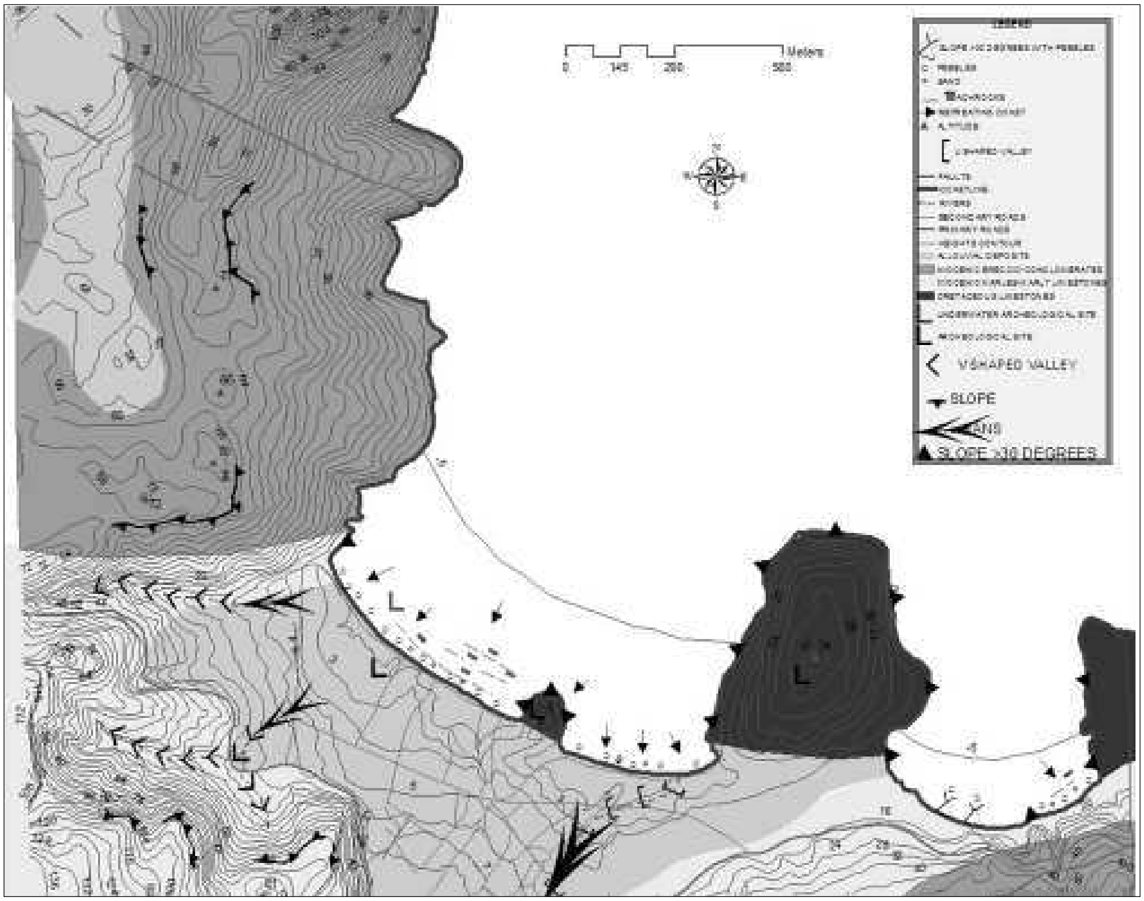


Fig. 2. The geomorphological map of Istro.

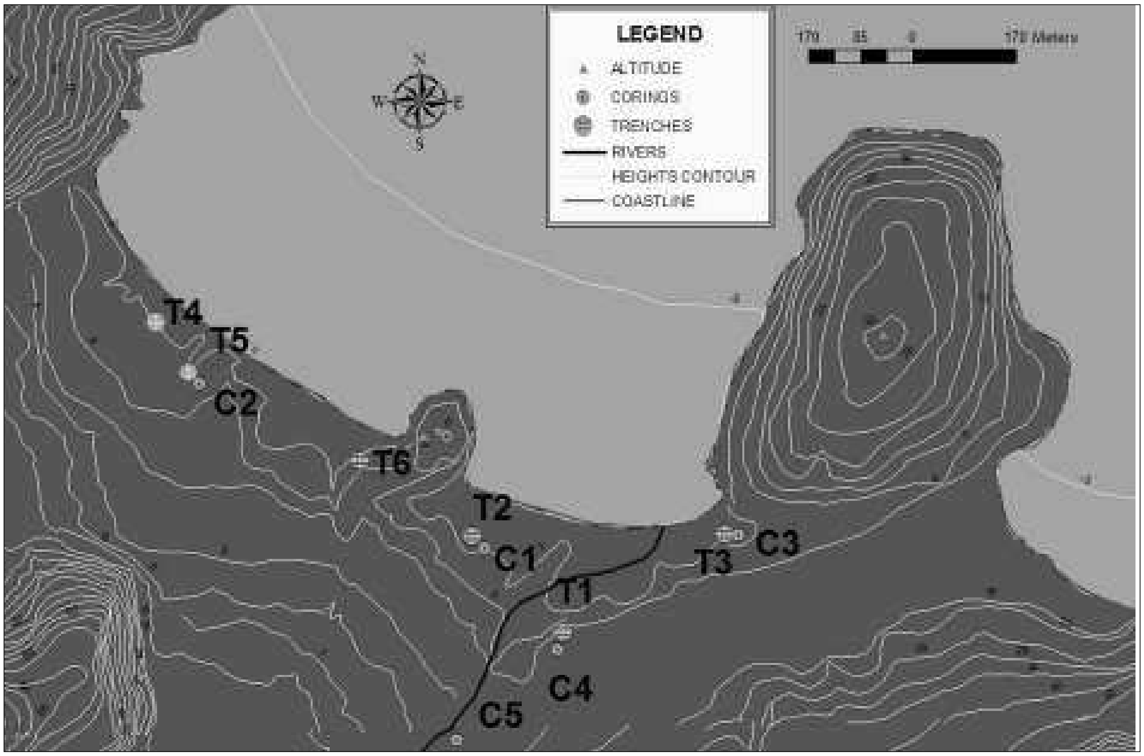


Fig. 3. Coring and trenches sites.

during the Bronze Age, possible until the Roman period. The sea level during the Bronze Age may have been at least two meters lower. It is not clear, however, if relative sea level has risen continuously or fluctuated from roman times to present. (Fig. 3)

Archaeological investigations — human evolution

First archaeological researches of the area started as mentioned before in 1903 by Richard Seager and Harriet Boyd, resulting to the excavation of the area in 1910–1912, by Edith Hall, supported by the University Museum in Philadelphia. (Hall 1914). In 1986, an intensive survey project of the area was undertaken by the University of Pennsylvania Museum and Baylor University, directed by Barbara Hayden and Jeniffer Moody.

Continuous human activity is confirmed since the Final Neolithic period (4500 BC). During the *Final Neolithic-Early Minoan I* (4500–2700 BC) period, most of the human activities have been detected along the coastal area, where Ioanimiti, Priniatikos Pyrgos, Nisi Panteleimon and Elias to Nisi, consisted the main archaeological sites. There are no architectural remains in this area, except from many ceramic shreds, stone tools and some obsidian flakes, indicating commercial relations with Melos island. Priniatikos Pyrgos may have been the main Minoan-commercial harbour. (Hayden 2004).

During the *Early Minoan II-III* (2700–2100 BC), 70% of sites are located 1.5 km from the coast, whereas duplication of sites is mentioned in relation with the precedent period. This is probably owned to the prosperity and wealth that also characterizes most of the contemporaneous sites in Crete. The discovery of ceramic shreds of 'Vasilike ware' confirms the commercial relations with other Minoan centers. (Cherry 1983, Branigan 1988, Haggis 1999)

Priniatikos Pyrgos, Phrouzi and Ioanimiti continue to be the main sites of the period.

In *Middle Minoan I-II period* (2100–1700 BC) a decrease of sites (36%) in the coastal area is mentioned with an increase inland. It is noted that during this period in Crete, many sites are installed on hills or naturally protected areas. Priniatikos Pyrgos, Ioanimiti, Vryonisis and Elias to Nisi had also been the main sites of the period. There are indications of commercial relations with the Palatial center of Malia. (Cadogan 1990).

In *Middle III-Late Minoan I* (1700–1450 BC) the decrease of installations and population is more evident This phenomenon is usual to other contemporaneous sites in Crete. Possible tectonic activity or immigration resulted to the abandonment of the precedent sites. (Watrous & Blitzer 1999) During *Late Minoan II–IIIB* (1450–1200 BC) few installations are indicated along the coastal area. Most of them are found around Vrokastro area. Many Minoan sites have been abandoned or destructed hence tectonic activity, the Thera eruption or the Mycenaean invasion. This is a transitional period not only in Istro but all over Crete. (Driessen & Mac Gillivray 1989) (?aggis 1992).

The next period, *Late Minoan IIIC-Geometric* (1200–700 BC) is also a transitional period, where the reduction of sites and population is generalized not only in Crete but also in Greek Mainland. There is a preference for walled settlements and Vrokastro with its harbor Elias to Nisi, is the most important site of the period. .(Hall 1914) It is noted that during this 'Dark period' the invasion of Dorians has been occurred. (Coldstream 1991).

During *Archaic, Classical and Hellenistic period* (700–31BC), Nisi Panteleimon has been the main 'town' of Istro. Oleros, in Messeleroi basin has been the Southern center of the region. After 2nd BC , Oleros and Istro had been under the control of Hierapytna. .(Sanders 1982, Hayden 2004)

Finally, during the *Roman period* (31BC–800AD), Priniatikos Pyrgos had been the main Town-harbor. Many architectural remains, ceramic shreds etc were discovered near Priniatikos Pyrgos. There are also indications of a sunken Roman town near

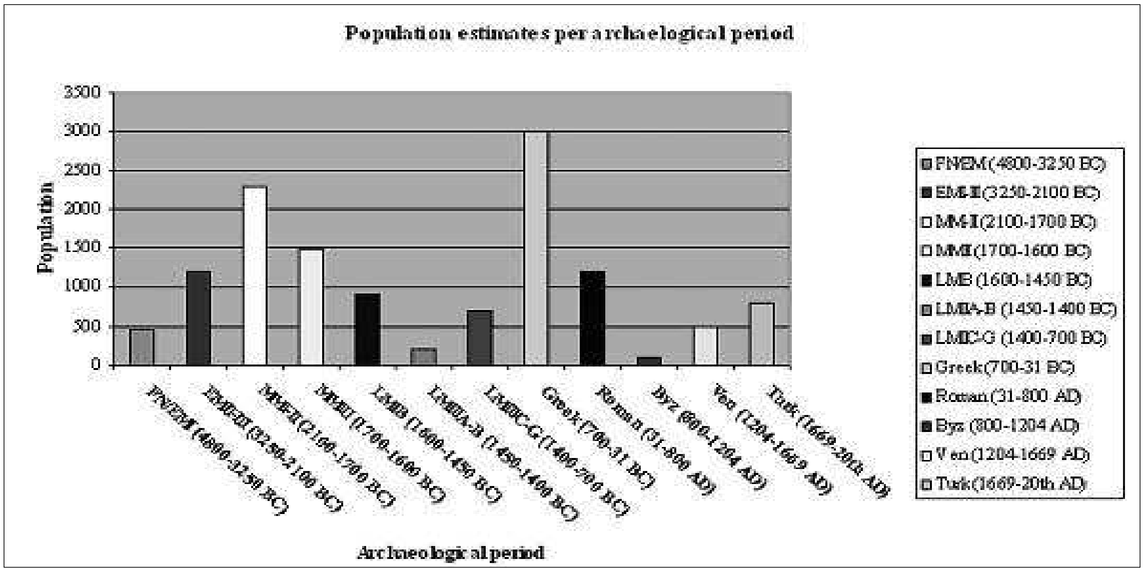


Fig. 4. Graph showing the population estimates per archaeological period.

Ioanimiti and some architectural remains of a probable monastery or watch station in Vryonisi. (Hayden 2004) An increase in population and establishment of rural installations is also noted during this period. (Wagstaff & Cherry 1982)

The habitation in the area is continuous until the Modern times. Some estimates have been done for the evolution of population in this area. There is an increase from the Final Neolithic to Middle Minoan period, a significant decrease from Middle Minoan III-Archaic period and a peak of population during the Classical period (around 3.000 habitants). These fluctuations are strongly connected with the cultural evolution and the main characteristics of each period. The tendencies of the increase or decrease of population rates are also found in other archaeological sites in mainland Greece. (Fig. 4)

Methods

To obtain information about the Holocene stratigraphy , six trenches were excavated with a mechanical digger (trenches 1–6). The trenches were restricted parallel to the coastal area. In addition, five boreholes were drilled with a drilling machine. Trenches were opened 3.50 m below mean sea level, whereas the deepest borehole reached ~13 m in depth. (Fig. 5) Five sedimentary units, named A, B, C, D, E, F and G, respectively, were recognized after grouping of the sedimentary phase characteristics. The units will be described in detail below.

Moreover, undisturbed sediment samples were collected in dark plastic tubes from the cores of boreholes, in several depths, for the performance of OSL dating technique (Aitken 1990, Huntley 1985) in the Laboratory of Demokritos in Athens. Plant and charred material were also collected from several layers of the sedimentary sequence for the use of ^{14}C dating method. These samples were analyzed in Beta Analytic Inc. and the results will be discussed below.

Undisturbed blocks of sediment were selected from the excavated trenches and boreholes for micromorphological study, micropaleontological and pollen analysis.

Additionally, the geomorphological mapping of the coastal area provided several information for the alluvial fan delta of Kalos Potamos, for the submerged beach-rocks and Roman ruins at –1.5m and revealed the geomorphological evolution of the area through the centuries. GIS techniques were used for the geomorphological mapping of the area

The results of the above mentioned analyses along with the observations of the archaeological remains, gave evidence for sea – land interactions during the last 6.000 years and impact on human installations.

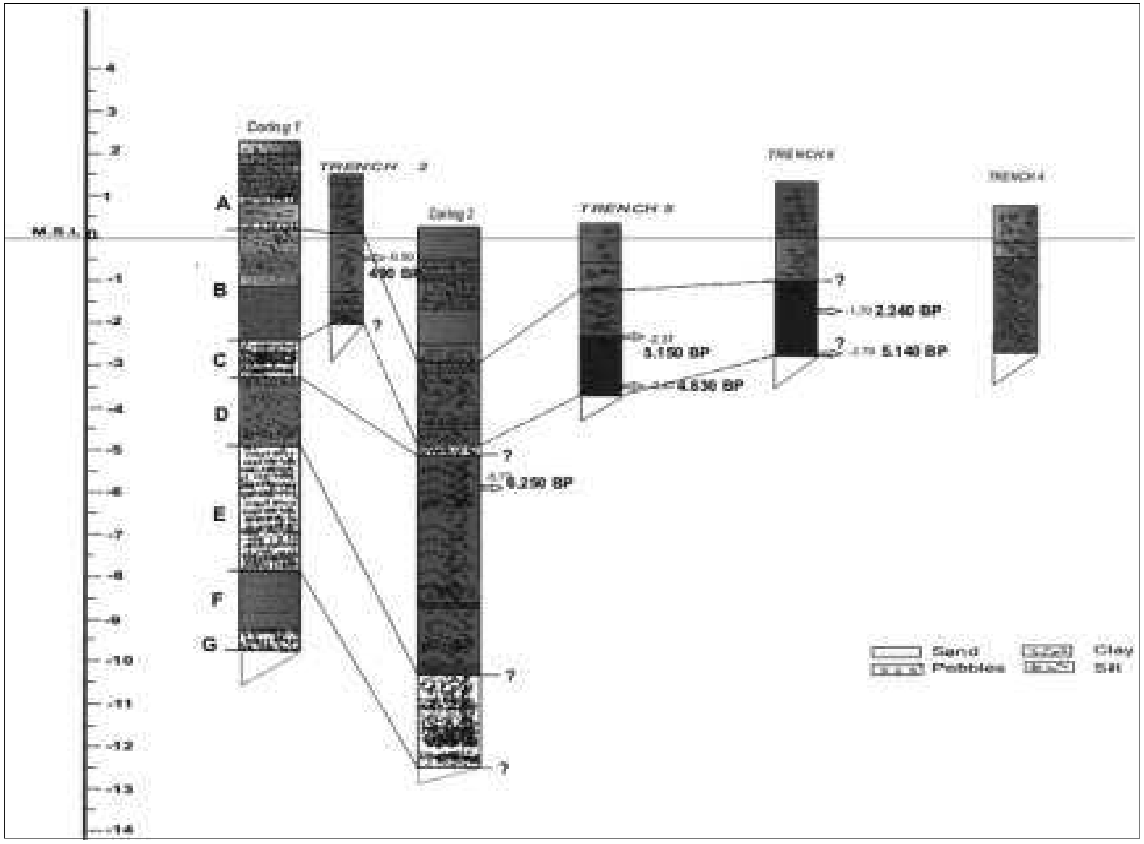


Fig. 5. The main sedimentological units.

Sampling site	Depth	Dating (Cal.)
Trench 2	2m, plant material	490 BP/1460 A.D
Trench 5	2.80m, charred material	5.150 BP/3180BC
Trenh 5	3.90m, charred material	4.830 BP/2880BC
Trench 6	3m, plant material	2.240 BP/290BC
Trench 6	4m, charred material	5.150 BP/3200BC
Coring 2	6.30m, plant material	6.250 BP /4300BC

Table 1. Results of radiocarbon datings 14C. (Beta Analytic Inc)

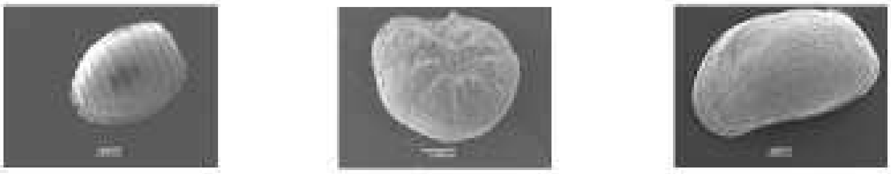
Results

Dating. The ^{14}C method was used to date charred and plant material from layers of the sedimentary sequence. Six samples were analyzed by AMS technique to Beta Analytic Inc. (Table 1)

Five samples were collected from trenches 2, 5 and 6 and one from the coring 2. In trench 2, plant material was collected at 2m depth consisting of gray silt. It gave an age of about 490 Cal BP/1460 AD.

Two samples of charred material were collected from trench 5, at 2.80 m and 3.90 m depth, in a dark gray silty sand sequence, giving an age of about 5.150 Cal BP/3180 BC and 4830 Cal BP/2880 BC respectively. There is an inconsistency to these datings, probably related to transferred material from overlaying layers.

In trench 6, two samples in 3 and 4 m depth of plant and charred material, in a dark gray silty sequence, were collected respectively. The upper was dated to about 2240 Cal BP and the lower to 5150 Cal BP.



Chara sp. *Ammonia becarrii.* *Thzrenoczthere — left valve*

Fig. 6. Ostracods and foraminifera detected in micropaleontological analysis.

Finally, in core 2, plant material from 6m depth in a gray silty sand sequence, was dated to about 6.250 Cal BP.

Sedimentological analyses. After grouping of the sedimentary phase characteristics in trenches and cores, we recognized 5 sedimentological units (Fig. 5): Sedimentary unit A is the youngest and is represented by topsoil with human activities remains. Most of the sequence is consisted of dry brown/olive brown clay, sand or silty sand with small pebbles, indicating a terrestrial environment, whereas some layers of pebbles in core 1 revealed fluvial interferences. The layer of pebbles does not appear in other cores or trenches. Considering that the drilling place of core 1 is near to the river flux, it is clear that river's influence is more intense in core 1 than the others.

Unit B (2240-5150 BP) is mainly consisted of gray-dark gray sand or silty sand/clay with some pebbles. It is characterized by overbank deposits of the river with influence of brackish and sea storm water. Traces of planktonic and benthic foraminifera in a very bad state of preservation were found, indicating that they had been transported.

The predominance of conglomerates stream bed deposits characterized Unit C (5000–5.500 BP ?). This unit is mainly presented in core 1 and to lesser extent in core 2, related to the possible flow of the river.

This sedimentary unit is followed by a sequence of gray-dark gray silt/silty sand, composing Unit D (5500–6250 BP). Over bank deposits, with some swallow stagnant fresh water predominate to this sequence, revealing low-energy events and quiet conditions. This unit is mainly represented in core 2, indicating that a possible swamp with stagnant fresh water may have been in this site between 6250–5500 BP.

Finally, Unit E (E, F, G) (>6500–10000 BP) is characterized by fluvio-torrential streambed and over banking deposits. This unit is also presented in core 2, indicating a possible influence or removal of the river's flow during this period. This sequence is possible related to the 'Older Fill'. (Vita-Finzi 1966, 1969)

Micropaleontological analyses. Seven samples from trenches 2, 3, 5 and 6 were selected for micropaleontological analyses. All the samples belonged to the sedimentological unit B, which is mainly consisted of gray-dark gray sand or silty sand/clay with some pebbles and is characterized by overbank deposits of the river with influence of brackish and sea storm water. Traces of benthic and planktonic foraminifers along with some types of ostracodes, were detected after the analyses of the samples.

In trench 2, two samples were selected in 1.7 m and 2 m respectively. In 1.7 m depth, nor planktonic or bentic foraminifers were detected, whereas 1–2 specimens of *Tyrrhenocythere amnicola* from the ostracodes were documented. *Tyrrhenocythere amnicola* characterises brackish-water deposits of the Mediterranean region (Bate et al., 1985. A stereo-Atlas of Ostracod shells). In 2 m depth, very few (< 5) planktonic and benthic foraminifera in a very bad state of preservation were found, showing that they were transported. Moreover, few (< 5) ostracodes specimens of *Tyrrhenocythere amnicola* and *Candona* spp were detected. These types of ostracodes, indicate freshwater to brackish environment. (Fig. 6)

Trench 3 was proven barren. In trench 5,

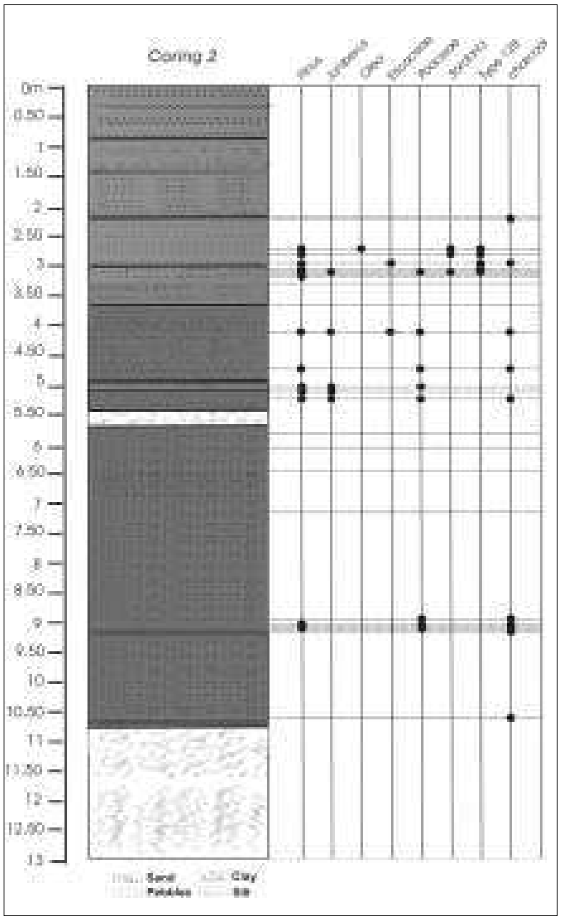


Fig. 7. The palynological diagram of Istro.

only one sample from 2.8 m depth was analysed and very few (< 5) planktonic and benthic foraminifera were also found in a very bad state of preservation and 1–2 specimens of *Candona* spp. from the ostracodes. These species indicate also freshwater to brackish environment.

In trench 6, two samples were selected in 3m and 4m respectively. In 3 m depth, very few (< 5) planktonic and benthic foraminifera in a very bad state of preservation were detected and few (< 5) ostracod specimens of *Tyrrhenocythere amnicola*, which characterise brackish-water deposits of the Mediterranean region. In 4 m depth, very few (< 5) benthic foraminifera along with ostracod specimens of *Tyrrhenocythere amnicola*) which also characterises brackish-water deposits of the Mediterranean region, were documented.

Pollen analyses. 26 samples from core C2 were studied palynologically, 12 of them were proved barren. (Fig. 7) Abundant charcoal was detected in levels 215, 293, 410, 450–490 and 515–520 cm. The layer in 210–215 cm depth, was proven barren with abundant of charcoal. The species detected in 270–307 cm depth had been: *Pinus, Olea, Juniperus, Ericaceae, Helianthus, Sinapis, Tubuliflorae, Liguliflorae, Sordaria*, Type 128. The layer in 312–390 cm was almost barren with few traces of *Pinus* and charcoal. In 410 cm–520 cm depth several types of pollen were detected, like *Pinus, Ericaceae, Juniperus, Quercus, Poaceae, Sinapis, Teucrium, Convovulus.* The layers in 570–650 cm and 707–713 cm were also proven barren.

Pinus, Poaceae, Cerealia type, Liguliflorae were documented in 890–910 cm depth, whereas the layers in 910 920 cm and 1050 1060 cm were also proven barren with organic material.

Pollen concentrations were very low, while pollen diversity was relatively high in the first part of the core and extremely low in the lower part (890–910 m).

The pollen content of the upper samples points to open xerophytic vegetation with scarce pine and juniper trees and high herb diversity. The presence of *Olea* at the level of 270 cm is interesting as a big discussion has risen on whether this — typical Meditarranean —tree occurs in Crete by origin (Bottema and Sarpaki, 2003).

Poaceae values are too low and no cereal pollen was detected on the upper part of the core, while on the lower part Poaceae are abundant and *Cerealia*-type pollen were found. The presence of spores of *Sordaria* in the level 270–307 indicates human activity-herding in the area. Closing level 270–307 shows characters of shallow stagnant to slowly moving (fresh) waters (*type 128*).

Palynofacies analysis of the barren samples divides them into two distinct groups: barren samples with organic material remains such as plant tissues, hyphas ect. and completely barren samples. The latter could possibly point depositional conditions not favoring the preservation of any organic material or oxidizing conditions.

Sea level changes. The melting of ice-sheets covered North Europe and America during the end of the Last Glacial period and the onset of the Holocene, resulted in sea level rising. Sea transgressed about 120–130 m. Especially during 16000–8000 BP the annual rates of sea level rise, have been estimated about 15–20 mm/y (Lambeck 1996)

The evidence for sea-level change along the Greek coastline is inferred from a variety of geological and archaeological indicators, the latter being more plentiful for about the last 4 000 years. (Fouache et al 2005) The archaeological evidence consists of the positions of structures that, at their time of construction, are believed to bear a known relation to the position of the sea. (Flemming 1978).

According to Lambeck's sea level curve for the island of Crete, sea level had been at –130 m at 18000 BP, –56 m at 10000 BP, –6 m at 6000 BP and –1.5 m at 2000 BP. (Lambeck 1995, 1996). It is obvious that from 6000 BP–2000 BP, sea rose at about 4.5 m, therefore, the estimated rate of sea level rise is about 1.12 mm/y.

Conclusions

From the above mentioned observations and results, we can conclude the following for the impact of environmental changes to human activities and evolution of civilization. Continuous human activities in the area since the Final Neolithic period to Roman times are confirmed by the archaeological remains. Most of the remains found in the coastal area consisted of ceramic shreds, stone tools, etc whereas some architectural remains were found submerged near Priniatikos Pyrgos (Minoan period) and between Ioanimiti and Priniatikos Pyrgos (Roman period).

The sedimentological analysis of cores and trenches resulted the identification of 5 main sedimentological units. It is obvious that the influence of Kalos Potamos river is more intensive to core 1 than others. Taking into consideration the results from the radiocarbon datings with the sedimentological analyses, we can assume that since 6250 BP, the river's flow was near to coring site 1 (east of Priniatikos Pyrgos). Moreover, considering the presence of stream bed deposits in coring 2, in layers older than 6250 BP, we can also assume that the river's flow was near to coring site 2 (western of Priniatikos Pyrgos). Nevertheless, it is assumed from the sedimentological analysis, that sediment deposits in the area between Ioanimiti and Priniatikos Pyrgos insinuate slow and quiet conditions of deposition while river's influence is less intense than in Priniatikos Pyrgos area. Furthermore, the existence of some ostracods in trench 5 of *Candona* spp that indicate brackish-fresh water environment along with the occurrence of pollen *?.128* in Core 2 implying stagnant, shallow, fresh water, give evidence for the existence of a possible small swamp in the area of coring 2, during the Bronze Age.

Generally, from the pollen analyses we can conclude that: The pollen content of the samples points to open xerophytic vegetation with scarce pine and juniper trees and high herb diversity. The presence of *Olea* in the level of 270 cm 5000 BP is interesting since it starts a big discussion on whether this -typical Meditarranean- tree occurs in Crete by origin (Bottema and Sarpaki, 2003).

Poaceae values are to low and no cereal pollen was detected. The presence of spores of *Sordaria* in the level 270–307 indicates human activity-herding in the area.

According to Istro sea level curve, coming from radiocarbon datings along with underwater observations, from 6250–2240 BP, sea level rose about 4 m. The rate of sea level rise for this region per year is estimated at 0,99 mm/y approximately and agrees with Lambeck's sea lever curve for Crete and Eastern Mediterranean region.

For the complete palaeoenvironmental reconstruction of this area more analyses, observations and data are needed to give evidence on the geologic, geomorphologic and environmental changes that interfered with human activities and influenced the cultural evolution of the area.

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