HOLOCENE COASTAL DUNE DEVELOPMENT AND ENVIRONMENTAL CHANGES IN HELIS AREA (NW PELOPONNESE), GREECE

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Abstract

The coastal area of western Peloponnese is characterized by Pleistocene and Holocene marine deposits. The study area shows the effects of different phases of coastal morphology evolution and is located along a wave-dominated and microtidal coast in the northwestern Peloponnese, 40 km southwest of Patras city.

Three significant morphogenetic phases occurred during the Holocene.

The first was radiometrically aged from 7000 to 3810 years BP, marking the end of the rapid postglacial transgression.

The second, between 3810 and 1400 years BP, was characterized by high rates of sedimentation, possibly because of the proximity of the mouth of the Peneus River, and resulted in the accumulation of predominantly fluvial sediments.

During the third and younger phase, from 1400 years BP to the present, landward migration of the coast and deposition of aeolian sands occurred. Archaeological and morphological evidences suggest that this last phase should be related to a low sea-level stand followed by a slow sea-level rise, up to the present-day position and by humid-temperate climate.

The collected data concerning the Holocene coastal dune belts, suggest that main phases of dune development could be related to the effects of sea-level changes, climatic conditions, and in a subordinate way, to human activity.

Keywords: *Dunes, coastal geomorphology, granulometric analysis, Helis area, Greece*

Introduction

Stratigraphic, sedimentologic and geomorphological studies allow the recognition of shoreline changes and coastal dunes evolution, which are controlled by rates of sediment supply, glacioeustatic sea-level fluctuations and rates and types of tectonic movements (Einsele, 1993; Orford *et al.*, 2000; Maüz*et al*., 2013). Furthermore, tectonic dislocations and variations in water flow and sediment yield from streams are associated with coastal change, while human activity such as agricultural practices may favor sand remobilization on a regional scale

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(Pye & Tsoar, 2013). The coastal area under investigation is located in Helis region, northwestern Greece.

Sand dune systems, one of the most common geomorphological elements of sandy beaches, are present. There, fine sediments are transported landward by a combination of wind and sea wave actions (Logan, 2010). In this way, dunes are formed and shaped by aeolian and hydrodynamic processes and usually are stabilized with vegetation. They act as a natural barrier against wind and waves, protecting inland areas from damage due to intense storms. They also provide habitat for plants, as Mediterranean maquis, and animals.

The source of their genesis and development is usually the transported sand from eroded neighboring cliffs or glacial till residing offshore or is eroded from nearby cliffs by sea waves, and transported along the shoreline by longshore currents. It could also be river transported sand from inland deposits (Eurosion, 2001).

The area under study is located within the Helis area in the northwestern sector of the Peloponnese, Greece (*Fig. 1*). The main purpose of this study is to attempt a chronologic reconstruction of the Late Holocene environmental evolution of Helis area, the relationships between the relative sea-level changes and the rate of sedimentation, and the human impact on the historical evolution of the area. The coastal dune development in Helis area was examined, and a recognition of the stratigraphic variations, sea-level changes and tectonics was attempted. Finally, the relationship between coastal dune development and environmental changes was also analyzed.

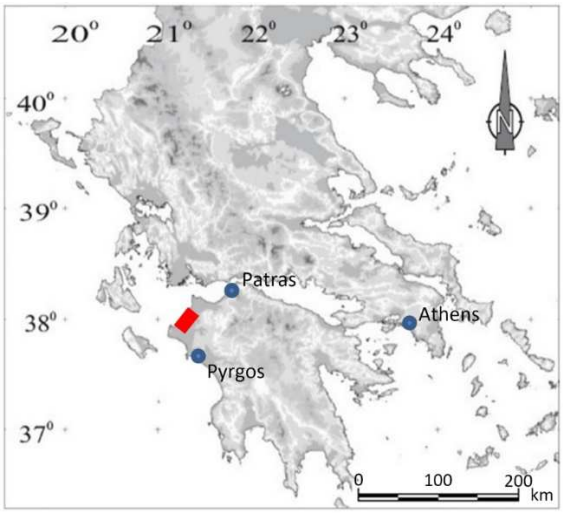

Figure 1: View of the study area location marked in red colour. Geographic coordinate system is WGS84

Geological outline

The study area is located in the northwestern Greece, along a wave-dominated and microtidal coast in the northwestern Peloponnese, about 40 km southwest of the city of Patras (forming a rectangular zone between 38° 06'N – 21°21'E, 38° 06'N – 21°27'E, 37° 57'N – 21°22'E and 37°59'N – 21°16'E), in the north sector of the Helis area.

The area is located in the north sector of the Helis graben. It lies very close to the convergent boundary between the African and European plates and the diapirism area of the evaporates that belong to the Alpine basement. The recent tectonic fault zones that occur in this area display a complex pattern, comprising NNW-SSE, NNE-SSW and WNW-ESE trending faults (Kontopoulos & Koutsios, 2008). Tectonic activity occurred through the Holocene (Lekkas *et al*., 1992) and the most recent strong earthquake (Mw 6.3) was on June 8, 2008. During this event, significant vertical displacements, up to 25 cm, were identified along a major high angle NNW-striking, 6 km long coseismic rupture segment (Kokkalas *et al*., 2008).

Methods

Wave action and aeolian activity play a significant role in the formation of coastal dunes in the study area. During winter, sea wave action increases, causing the beach to be steeper and its deposits coarser. In summer, gentle waves transport sand onshore and the beach takes on a shallower gradient with finer sediments.

The investigation included an analytical on-desk study to examine any records mentioning the existence of the aforementioned changes and attempted to ascribe them to certain geomorphological and geological processes.

Once this study was completed, 34 sediment samples in total were collected from each of the five separate locations. The sampling was carried out along six transects transverse to the coastline and, where possible due to structures and vegetation, near the coast and coastal plain (*Fig. 2*).

This plain extends over 80 km^2 to the west of Patras – Pyrgos state road with a very low gradient, and is cut by narrow, shallow and ephemeral rivers. Grain size analysis was performed and the sediment types, structure, color and physical characteristics according to Folk and Ward (1957) were recorded.

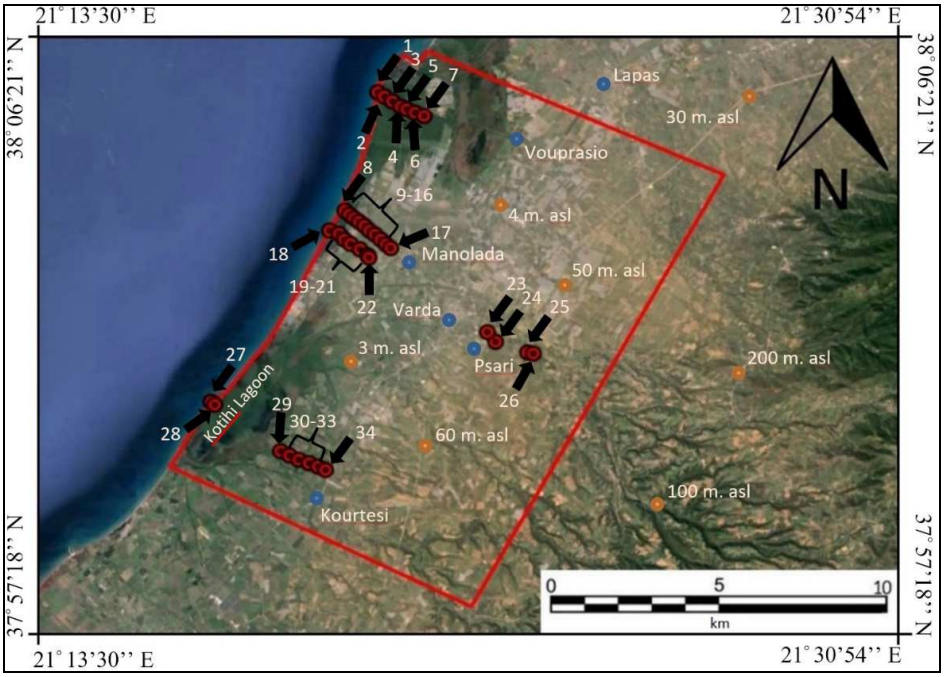

Figure 2: Panoramic view of study area with marked sampling locations and corresponding sample number (*Table 1*) (Google Earth™ Pro – TerraMetrics).
Geographic coordinate system is WGS84

Results and discussion

The coastal area of western Peloponnese, located within the Helis area, shows marine deposits of the Pleistocene and Holocene, characterized by coastal sand dunes of different phases. These dunes help to recognize the main phases of coastal morphoevolution related to sea-level changes, climatic and recent anthropic influence.

Holocene deposits are of particular importance, as they are close to the coastline and are eroded by sea waves in several locations. They are found along the entire coast and, at present, nourish beaches which generally show a negative sedimentary budget due to poor river sediment supply.

Sand dunes are generally of positive asymmetry. Grain size analysis of the 34 samples showed that almost all are well sorted (< 0.35) and characterized by positive asymmetry, statistically ranging from –0.094 to 0.075: these deposits are formed by sand and silty sand particles (*Table 1*, *Fig. 3*).

Three important morphogenetic phases occurred during the Holocene (Kontopoulos & Koutsios, 2008).

The first phase was radiometrically dated between 7000 and 3810 years BP. Earlier than this time, the rate of global sea-level rise had begun to diminish (Lambeck, 1995). Since 7000 years BP, the sedimentation appears to have approximately kept pace with rising sea level, and only two extremely high flow events were recorded. This phase is characterized by a static coastline with deposition of beach sediments, and by consequent formation of dune belts. This event marks the end of the rapid postglacial transgression that occurred during the Holocene Climatic Optimum.

During the second morphogenetic phase, between 3810 and 1400 years BP, the rate of sedimentation was higher than the rate of relative sea-level change. The cause of this high rate of sedimentation was possibly the proximity of the Peneus River mouth, and it resulted in the accumulation of predominantly fluvial sediments. Some studies attribute this high rate of sedimentation to the predominant human activity in the area (Pope & Van Andel, 1984; Bruckner, 1986, 1997, 1998; Cherry *et al*., 1988; Van Andel *et al*., 1990; Fuchs, 2007, Lespez (2003)).

The hypothesis of rapid climate change during this period is also mentioned as a probable scenario (Vita-Vinzi 1969, 1976; Bintliff 1975, 1977, 1982; Bintliff (2002) and Pope *et al*. (2003)).

Fuchs (2007) distinguishes four phases of high sedimentation rates in southern Greece:

a. Middle and Late Neolithic phase
b. Middle-Late Bronze phase
c. Classical/Roman phase
d. Ottoman phase

The Middle-Late Bronze phase falls into the studied second morphogenetic phase. During the third and last phase, from 1400 years BP to the present, landward migration of the coast and deposition of aeolian sands occurred. Aeolian deposits are very often associated with terraced marine deposits. Archaeological and morphological evidences suggest that this phase should be related to a low sea-level stand followed by a slow sea-level rise, up to the current position and featured by humid and temperate climate.

The progradation took place approximately 6000 years BP through the advance of beach ridges. These beach ridges, usually covered by aeolian dunes, established the coastal plain which is currently being re-eroded, while the narrow barrier that separates the Kotihi lagoon from the sea has migrated inland in recent years (Donadio *et al*., 2017; Stamatopoulos *et al*., 2014). Conditions favorable to the progradation in the studied wave-dominated coast occurred when the rate of sea-level rise slowed or stabilized. Additionally, according to the literature and radiocarbon dating, the last morphogenetic phase is dated as younger than 150 years BP (Kontopoulos & Koutsios, 2008).

Moreover, as a result of the low average gradient of the coastal sector of the study area, the energy of sea waves is dissipated and the suspended grains of sand are deposited, resulting in greater potential for the dune.

These younger deposits, formed by discontinuous yellow-grey incoherent sand and silty sand, outcrop along the coastland. Plants and generally dense vegetation of Mediterranean maquis colonize many sand dunes, anchoring the shifting sand and contributing to develop small pockets of protection from the wind, so favoring a higher sand accumulation (*Figs. 4 & 5*).

Table 1

Granulometric analysis results and statistical indexes for the beach, dune and plain samples. Mz, mean size; σ, standard deviation; S_{KI}, skewness; K_G, kurtosis: (φ). Sample number with normal font: Dune samples. Sample number with bold font: Plain samples. Geographic coordinate system is WGS84

SAMPLE	LOCATION		INDEX				GRAIN SIZE (%)		
	Latitude N	Longitude E	Mz	σ	S_{KI}	K_G	SAND	SILT	CLAY
1	38°5'36.7"	21°20'23.9"	2.607	1.016	0.448	2.180	99.0%	0.7%	0.3%
2	38°5'34.14"	21°20'28.84"	2.437	1.837	0.035	0.851	72.3%	27.40%	0.3%
3	38°5'32.5"	21°20'31.9"	2.698	0.735	0.309	2.065	97.4%	0.40%	2.2%
4	38°5'29.98"	21°20'37.39"	1.798	1.154	0.425	1.304	99.1%	0.50%	0.4%
5	38°5'27.6"	21°20'41.6"	2.087	0.401	0.008	0.948	99.9%	0.1%	0.0%
6	38°5'23.59"	21°20'49.53"	1.992	0.409	0.004	0.958	100.0%	0	0.0%
7	38°3'39.40"	21°19'40.55"	2.110	0.393	0.019	0.992	99.8%	0.20%	0.0%
8	38°03'37.3"	21°19'44.0"	2.167	0.462	0.048	1.048	100.0%	0	0.0%
9	38° 3'35.16"	21°19'46.81"	1.983	0.467	0.058	1.134	100.0%	0	0.0%
10	38°03'33.3"	21°19'49.7"	2.006	0.379	0.141	0.870	100.0%	0	0.0%
11	38° 3'31.75"	21°19'52.31"	1.958	0.712	0.287	2.018	100.0%	0	0.0%
12	38° 3'28.33"	21°19'57.42"	2.050	0.411	0.097	0.912	99.9%	0	0.0%
13	38° 3'28.33"	21°19'57.42"	2.123	0.397	0.039	1.008	99.9%	0.10%	0.0%
14	38° 3'25.57"	21°20'1.94"	1.961	0.415	0.019	0.981	100.0%	0	0.0%
15	38° 3'17.04"	21°20'14.69"	2.080	0.389	0.021	0.939	100.0%	0	0.0%
16	38° 3'11.91"	21°20'21.84"	1.939	0.385	0.024	0.922	100.0%	0	0.0%
17	38°03'17.2"	21°19'25.2"	1.998	0.392	0.106	0.905	100.0%	0	0.0%
18	38° 3'15.07"	21°19'30.43"	2.033	0.404	0.065	0.926	99.9%	0.10%	0.0%
19	38°03'14.5"	21°19'36.9"	2.064	0.381	0.017	0.911	100.0%	0	0.0%
20	38° 3'11.34"	21°19'40.60"	1.952	0.393	0.077	0.946	100.0%	0	0.0%
21	38°03'08.0"	21°19'43.3"	1.991	0.419	0.017	0.999	100.0%	0	0.0%
22	38° 3'5.92"	21°19'43.53"	2.004	0.387	0.067	0.893	100.0%	0	0.0%
23	38°01'34.7"	21°22'38.0"	1.804	0.585	0.043	1.253	99.7%	0.30%	0.0%
24	38° 1'27.49"	21°22'45.44"	1.831	0.586	0.013	1.204	99.3%	0.70%	0.0%
25	38°01'14.3"	21°23'27.4"	1.953	0.430	0.075	1.022	100.0%	0	0.0%
26	38°01'09.9"	21°23'40.1"	2.020	0.442	0.002	1.014	100.0%	0	0.0%
27	38°00'24.2"	21°17'1.0"	1.959	0.407	0.076	0.971	100.0%	0	0.0%
28	38° 0'21.43"	21°17'5.15"	1.850	0.431	0.023	1.070	100.0%	0	0.0%
29	37°59'33.76"	21°18'28.03"	1.978	0.372	0.056	0.857	100.0%	0	0.0%
30	37°59'30.92"	21°18'36.05"	1.963	0.389	0.029	0.894	100.0%	0	0.0%
31	37°59'26.62"	21°18'48.05"	2.037	0.383	0.025	0.890	100.0%	0	0.0%
32	37°59'23.84"	21°18'57.81"	1.991	0.373	0.013	0.855	100.0%	0	0.0%
33	37°59'21.72"	21°19'4.45"	1.980	0.385	0.040	0.896	100.0%	0	0.0%
34	37°59'14.63"	21°19'24.12"	1.876	0.420	0.015	0.993	99.9%	0.1%	0.0%

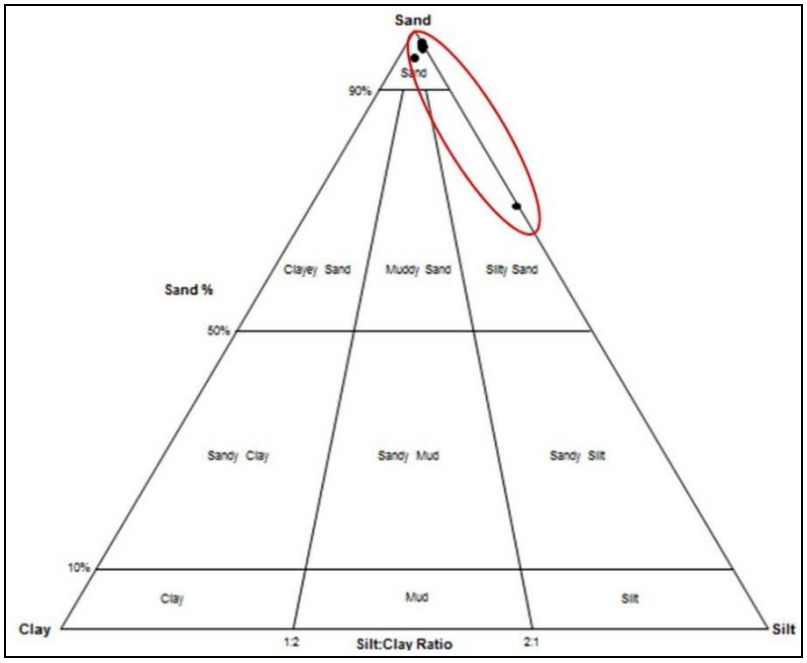

Figure 3: Ternary plot of analyzed sediment samples (Folk, 1974). The majority of the examined samples in the red ellipse, fall into sand class except two which fall into the silty sand class

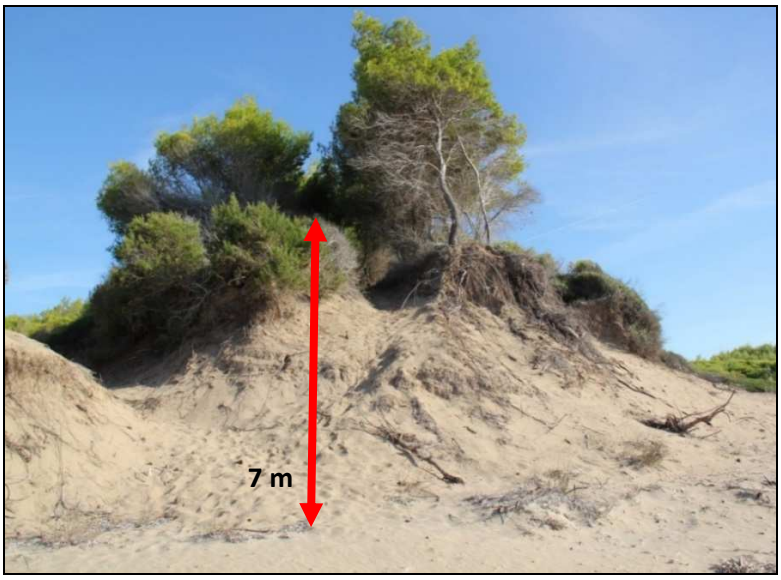

Figure 4: Partial view and morphological aspects of sand dune in the study area. Red arrows indicate the height of the investigated landforms

Figure 5: Partial view and morphological aspects of sand dune in the study area. Red arrows indicate the height of the investigated landforms

Conclusions

The available chronologic data and the sedimentological analysis enabled the determination of the coastal dune and environmental changes in the study area.

Three important morphogenetic phases of evolution during the Holocene were determined. All of them are characterized by drastic changes to the sea level, depositional processes and sediment supply, which played a determinant role in the coastal dune development.

During the first phase, from 7000 to 3810 years BP, there was a balance between rate of relative sea-level change and rate of sedimentation, as sea level continued to rise.

During the second phase, between 3810 and 1400 years BP, the rate of sedimentation was higher than that of relative sea-level fluctuation due to the proximity of the Peneus River mouth and the high volume of supplied sediments.

During the third and last phase, from 1400 years BP to the present, the landward migration of the coast was probably the result of the avulsion sediment over mining by the Peneus riverbed. Moreover, according to our research, based on radiocarbon dating and bibliographic data, the last phase of the dune development occurred as younger than 150 years BP.

The collected data concerning the Holocene dune belts along the Helis coastland, suggest that the main phases of dune development could be related to the effects of sea-level changes, climatic variations and, in a subordinate way, to human activity. A close relationship between coastal dune development and environmental changes was identified as a coastal progradation during the Hellenistic, Roman and Early Medieval times but also throughout the last two millennium BC.

At present, the Holocene coastal dune belts are featured by erosion because of natural and anthropogenic factors and due to sea-level rise, which continues until today. Additionally, they constitute the main reservoir of sand for the natural nourishment of the littoral in the Helis region.

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