AEGAEUM 37
Annales liégeoises et PASPiennes d'archéologie égéenne

PHYSIS

L'ENVIRONNEMENT NATUREL ET LA RELATION HOMME-MILIEU DANS LE MONDE ÉGÉEN PROTOHISTORIQUE

Actes de la 14e Rencontre égéenne internationale, Paris, Institut National d'Histoire de l'Art (INHA), 11-14 décembre 2012

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LEUVEN - LIEGE
2014

SOMMAIRE

C. Paysage et climat :

D. Iconographie :

E. Agriculture :

GEOMORPHOLOGICAL EVOLUTION AND PALEOENVIRONMENT RECONSTRUCTION IN THE NORTHEASTERN PART OF LEMNOS ISLAND (NORTH AEGEAN SEA)*

Abstract

The area where the study was made is located in the northeastern coast of Lemnos Island (Greece-North Aegean Sea). This area covers the archaeological settlement of Hephestia which is located in the north part of Purnia Gulf and the coastal area of Alyki Lagoon, which is located in the southeast part of Lemnos coast. The archaeological importance of this area is pointed out not only by its archaeological remains but also by its significant location. The most important site which has been discovered close Hephestia is Poliochni. This is an ancient city considered to have the same date with Troy. The excavations of archaeological site of Hephestia indicate continuous human presence from Late Bronze Age till Byzantine time.

The study of the eustatic sea level oscillation in correlation with the neotectonic regimes and the geomorphological observations, and also the analyses of the deposed sediments, helps us to make a palaeogeographycal reconstruction of the landscape and its impotence to human societies. Therefore, detailed geomorphological mapping, micromorphological, sedimentological and micropaleontological studies of the Holocene coastal deposits have been accomplished. Six boreholes at Alyki lagoon were drilled at selected locations, the deepest one reaches a depth of 11m, and two other boreholes were drilled in Hephestia. The stratigraphy of the late Holocene sediments was studied in detail and samples collected from selected sedimentary layers, were analysed by using micropaleontological techniques.

The calculated age from the boreholes gives dates between 5100 B.C. till 820 A.D. Twenty samples of shells and roots were dated using the AMS radiocarbon method in Lyon C14 Laboratory. Geomorphological mapping was carried out using topographic maps at scale of 1:50.000, geological map at a scale of 1:50.000 and observations on the field. Landforms of the coastal alluvial plain, in the shoreline and in the inland were marked and recorded at a scale of 1:50.000.

Sea level rise along the interaction of landscape evolution and the impact of human civilization were concluded.

Introduction

The area where the study was made is situated in the northeastern coast of Lemnos Island North Aegean Sea (Greece). This covers the archaeological settlement of Hephestia located in the north part of Purnia Gulf and the coastal area of Alyki Lagoon, which is located in the southeast part of Lemnos coast. The archaeological site of Hephestia covers the significant area of Palaeopoli peninsula, which has a great archaeological importance. Archeological surveys show that a skillful society occupied the site with a continuous presence from Late Bronze Age till Byzantine time. Preliminary excavations which began in 1926 by the Italian Archeological School continued until today. The excavation findings are: cemetery of 8 century B.C., sanctuary of the Great Goddess of Lemnos, which was built in the west part of the peninsula, inside of the city, used from 8 till 6 century B.C. when it has been destroyed from fire. Also part of the excavation area is the Hellenistic theater which was modified during Roman time.[1] After that period in the 12th century A.D. the location was probably abandoned, because of the insecurity from the Pirates or from the illuviation of the harbour. Significant archaeological sites in Lemnos island are also Poliochni and Murina. They have parallel development from the Late Neolithic period till 2000 B.C. when they were destroyed by an earthquake from volcanic activity.

Alyki Lagoon is a coastal brackish lagoon that covers an area of 6,5 km^2, and because of its environmental significanve it is protected by National and European laws such as a Nature 2000 site. Alyki lagoon is separated from the Aegean Sea by a sand barrier while it communicates with the open sea by a short and narrow inlet.

* Acknowledgements: This article is a contribution to the research project led by the Italian School of Athens in Hephestia (Lemnos Island, Greece).

1 E. BENVENUTI, *Lemnos Amichthaloessa* (2004) 35-38; L. SOUXAS, *Ascent Theater of Hephestia* (2004) 80-83.

Lemnos Island covers 477 km^2 and has a 260 km coastline. Geographical location of the Island is significant because of its position close to the centre of North Aegean Sea, also 34 miles from Dardanelles and 32 miles from Halkidiki. Lemnos is a big island in the North Aegean with the lowest relief reaching 430 m in Vigla Mountain.[2]

The main geological formations are quaternary alluvial and colluvial deposits, and large areas are covered with polygenic conglomerate, marine and Aeolian sands. There quaternary superficial deposits include shallow marine limestone to calcarinites, in the NE part of the island. In the NW part of the island the main formation consists of lower Miocene volcanic rocks, alsos lavas in form of dome, dyke, andesites, dacites and conglomerate marls and marly limestone. These deposits overlain on Late Eocene Early Oligocene, sandstone sediments, flysch type sediments (sandstone, siltstone and clays) and yellowish marls with abundant plant remains. The substrate's type of sediments of Lemnos Island is Upper Eocene Lower Oligocene molasses.[3]

Lemnos Island is located in the central part of the North Aegean Trough. The evidence of recent and active tectonic movements is in the form of polished surfaces and superposed Plio-Pleistocene sediments. The North Aegean Trough represents the continuation of the North Anatolian Fault and its westward propagation into the Aegean. The faulting of the Island is well exposed in the central and western part forming narrow and shallow basins, disrupting the hilly morphology. Faulting is more intense in SE of Moudros (Fanos-Agia Sofia fault), which is less hazardous, and in the NW part of the Island with Kontias - Kotsinas fault which affects the coastal zone. Kaspakas fault affects the capital of the island, the city of Myrina.[4] According to Pavlides and Caputo the earthquake in 330 B.C. caused land subsidence (2004).[5]

The purpose of the research is geomorphological observation in Lemnos Island in order to produce its geomorhological map. Also our aim is paleogeographycal reconstruction of the landscape and the indication of its importance to human societies, by analyzing the deposed sediments.

Methodology

In order to reconstruct the palaeoenvironment and the landscape evolution of the coastal area geomorphological mapping, the estimation of sea level changes, the lithostratographical description, the sampling for radiocarbon dating, and also the microfauna analysis of the Holocene coastal deposits have been conducted. Geomorphological mapping was carried out using topographic maps (Murina and Moudros) at a scale of 1:50.000, geological map at a scale of 1:50.000 and also by using the observations on the field. The maps were imported into GIS (ArcMap 9.1) through geo-referencing and their digitization produced geographic elements and layers for the topographic relief, the hydrology and the geomorphological map. Six boreholes in Alyki lagoon and two in Hephestia, were drilled with a portable drilling Vibracoring, the deepest one at 11m depth, approximately in Alyki lagoon. Sedimentary sequences have been studied through visual inspection of the sediments. Twenty samples of shells and roots were dated by using the AMS radiocarbon method in Lyon C14 Laboratory. The calibration of the samples was made with Oxcal software[6] and the correction of the marine reservoir was

2 T. KOMNINOS and H. KAPSIDELIS, *Lemnos* (1982) 23-26.

3 E. ROSSO, *Geological Map of Lemnos Island* (1987).

4 S. PAVLIDES, D. MOUNTRAKIS, A. KILIAS, M. TRANOS, "The role of strike-slip movements in the extensional area of Northern Aegean Greece. A case of transtensional tectonics," *Annales Tectonicae* Special issue Vol. IV n. 2 (1990) 196-211; S. PAVLIDES, Th. TSAPANOS, N. ZOUROS, S. SBORAS, G. KORAVOS, A. CHATZIPETROS, "Using Active Fault Data for Assessing Seismic Hazard: A Case Study from NE Aegean Sea, Greece," *Earthquake Geotechnical Engineering Satellite Conference* (2009) 160-166; M.D. TRANOS, "Faulting of Lemnos Island; A Mirror of Faulting of the North Aegean Trough, Northern Greece," *Tectonophysics* 467 (2009) 72-88.

5 S. PAVLIDES, R. CAPUTO, "Magnitude Versus Faults Surface Parameters: Quantitative Relationships from the Aegean Region," *Tectonophysics* 380 (2004) 159-188.

6 J. RAMSEY 2010. Program developer of radiocarbon correction software: http://c14.arch.ox.ac.uk/embed.php?file=oxcal.html.

establish with ΔR – 151y.[7] The 14C method was used for dating of the revealed organic matter and shell (Cerastoderma). Dry sediments (5g) have been sieved through 125μm sieve mesh and the residue was used for benthic foraminiferal analysis. The subset of each sample was obtained using an Otto microsplitter until aliquots of at least 200 benthic foraminifers remained. Benthic foraminifers have been identified under Leica APO S8 and Motic SMZ - 140 stereoscopes. Foraminiferal assemblages have been expressed as percentage. Estimations of sea level change from Lampeck & Purcell (2005) model were used and compared to the calibrated data from the studied boreholes.

Results

Geomorphology

From a geomorphological point of view, the landscape processes are imprinted by important colluvial activity and the absence of any permanent hydrological network.

Coastal sand dunes are the dominant landform in the eastern coasts, creating the barrier between the sea and Alyki lagoon. Dunes are also present in the northwestern part of the island inland over the sandstone formations. There is trapped sand from the wind that is coming from the coastal area. Volcanic formations are mainly present in the southwest part of the island with characteristic domes, dykes and locally tuffs. The coast in the northeast part of the Palaeopoli peninsula, is covered with beach rock from 5 to 8 meter wide, therefore is good sea-level indicator and record of a general trend of relative sea-level rise in the area. In the western part of the peninsula there was also an underwater, harbour probably for the construction of ships. The opening of Hephestia bay to Tigani bay may be a natural harbour because it is protected from winds. The remaining stones 30 meter long which were found there look like a harbour. From the hydrographic point of view there are a lot of streams with temporal flow and a V valley shape (Pl. XIIb).

Lithostratigraphical analysis

After grouping the sedimentary phase characteristics of cores in Alyki lagoon, four lithostratigrapical units were recognized, and named A, B, C, and D, respectively (older to youngest) (Pl. XIIIa). The units are described below. The D sedimentary unit is represented by silty sand and clay with olive brown color. Sedimentary unit C ranges from fine sand to silt with dark and very dark grey color, and is deposed between 330 B.C. and 1000 B.C. The unit B is represented by fine sand, silty sand with layer of silt. The color of this unit varies from dark grey to very dark grey. The deposition of this unit dates from 5100 B.C. to 2500 B.C. The last unit, A, represents the Pre Holocenic “bedrock” and consist of Oligocenic sandstone and siltstone of flysch formation.

Sedimentological description of Hephestia site shows three units, B, C, and D (older to youngest) (Pl. XIIIb). Unit B is composed of fine sand, silty sand and clay with dark grey, very dark grey and olive brown color. This unit is deposed later than 2000 B.C. The sedimentation in unit C in general is silty sand with layers of silt and fine sand. The colour of the unit is very dark grey. The deposition of this unit dates between 2000 B.C. and 400 B.C. And the upper unit D presents the top soil of claylish sand with a light olive brown colour. Another borehole from Hephestia area IFE1 gives ages with a big gap and introverted stratigrahic order because of the deposition of sediment from the excavation area. Because of that, we didn’t take this into consideration in the research.

7 G. SIANI, M. PATERNE, M. ARNOLD, E. BARD, B.M.TIVIER, N. TISNERAT, F. BASSINOT, “Radiocarbon Reservoir Ages in the Mediterranean Sea And Black Sea,” *Radiocarbon* 42 (2000) 271-280.

Radiocarbon dating

The results of the twenty samples that are dated are shown in Pl. XIIa. Because of the introverted stratigrahic order of the sediments, we cannot estimate the date that gives borehole IFE1 from Hephestia area. The 14C method was used for radiocarbon dating of the revealed organic matter and shell (*Cerastoderma*) in layers of the sedimentary sequence. Six samples of organic material (peat, plant remains) and fourteen shell samples from boreholes were dated. The dating results for Hephestia area are between 1950 B.C. and 390 B.C.

In the Alyki lagoon, the borehole HAL1 reached 11 meters depth, and gave results of the greater age intervals from 5100 B.C. to 520 A.D. Samples from HAL4 show time interval from 390 B.C. till 820 B.C. In boreholes HAL5 one sample was used for radiocarbon dating giving dates from 330 A.D. to 620 A.D. The samples from borehole HAL 6 give dates from 3070 B.C. to 590 A.D.

Microfaunal analysis

Microfaunal analysis was carried out in boreholes IFE2 from Hephestia and HAL1, HAL2, HAL4 and HAL6 from Alyki lagoon. Twelve foraminiferal species were identified in the studied samples.

Microfauna in Hephestia borehole is represented by a predominance of *Ammonia* spp. (20-70%), *Elphidium* spp. (20-60%) also Miliolids (10-40%). *Rosalina* species and Ostracods less than 30%, are present (Pl. XIVa). This combination of microfauna is representative of a shallow marine mesohaline environment, with freshwater input. Fluctuation between marine species (Miliolids, *Rosalina* spp.) and euryhaline species (*Ammonia* spp, *Elphidium* spp.) indicates a shallow marine environment that exhibits lagoonal features.[8]

By considering the Microfauna diagrams in Alyki, it is evident that they are characterized by species diversity. In HAL 1 the dominant species are mainly Miliolids (20-70%), *Ammonia* spp. (40-60%), and *Elphidium* spp. (10-40%). The presence of *Rosalina, Peneroplis, Cibicides* and Ostracoda species is less than 20%. To a lesser extent, *Haynesina germanica, Planorbulina mediterranensis, Porosononion granosum* and *Sripilina* (<10%) are also present, indicating a shallow marine environment with freshwater influence (Pl. XIVb). HAL 2 is characterized by the predominance of the species *Ammonia* spp. (30-60%), Miliolids (20-50%) and *Elphidium* spp. (10-30%). The presence of *Rosalina* spp. is attested (10-16%), in a lower percentage (>10) compared to *Cibicides* spp. and *Haynesina germanica* that are also present. All those facts indicate the existence of a shallow marine environment with freshwater influence (Pl. XIVc).

The abundance of forams in HAL3 consists of Miliolids (20-60%), and *Ammonia* spp. (20-80%), the same percentage of 10-30 % is present for *Rosalina, Peneroplis* and *Elphidium* species (Pl. XIVd).

The abundance of forams in HAL4 is characterized by its dominant species *Ammonia* spp. (20-80%), Miliolids (20-60%) and *Planorbulina mediterranensis* (20-40%). Species such as *Neoconobrina* spp., *Cibicides* spp and *Haynesina germanica* are also present in lower amounts (>20)(Pl. XVa). In contrast to the other boreholes, HAL5's abundance of forams in (Pl. XVb) is different. In HAL5, species such as Miliolids, *Peneroplis, Cibicides* and *Ammonia* species are present (20-60%) and the presentage of *Elphidium* species is lower than 20%. Thus the analysis indicates a shallow marine environment.[9]

HAL6 is characterized by the presence of Miliolids (20-60%), *Ammonia* (20-60%) and *Ostracoda* (20-40%). Also species such as *Elphidium Haynesina germanica*, and *Rosalina* are found in lower amounts (>20) in HAL6. The presence of *Peneroplis* and *Cibicides* species is less than 10% in HAL6 (Pl. XVc). Thus these data indicate a shallow marine environment with fresh water input.[10]

8 J. Ph. GOIRAN, K. PAVLOPOULOS, E. FOUACHE, M. TRIANTAPHYLLOU, E. ROLAND, "Piraeus, The Ancient Island of Athens: Evidence from Holocene Sediments and Historical Archives," *Geology,* v.39 no. 6 (2011) 531-534.

9 O. KOUKOUSIORA, M. TRIANTAPHYLLOU, M. DIMIZA, K. PAVLOPOULOS, G. SYRIDES, K. VOUVALIDIS, "Benthic Foraminifera Evidence and Paleoenvironmental Evolution of Holocene Coastal Plains in the Aegean Sea," *Quaternary International* 261 (2011) 105-117.

10 K. PAVLOPOULOS, M. TRIANTAPHYLLOU, P. KARKANAS, K. KOULI, G. SYRIDES, K. VOUVALIDIS,

Discussion

Sea level changes

The sea level change in the Mediterranean has shown a continuous sea level rise since 6.000 B.P. The estimation of sea level changes in Alyki and Hephestia coastal areas is based on the dated sedimentary layers. If we compare the sea level index points in Hephestia with the Lambeck (2004)[11] and Lambeck & Purcell (2005)[12] models, the sea level index points obtained from Hephestia are generally well correlated with Lambeck curve with a vertical difference of 0,5-1m. The obtained dataset in Alyki shows a very good correspondence with Lambeck's curve, with the same points being below Lambeck sea-level curve.

The research results show that in the obtained dataset in Alyki matches very well with the model of sea level change of Lampeck, except for some points that are below the sea level curve. Also according to the Mean Sea Level curve in Hephestia in correlation with Lampeck (2004) and Lampeck & Purcell (2005) models, there is a decrease of -1m in relative sea level change. This difference is probably connected with sediment compaction, or land subsidence. The reason why the points of the dataset of Hephestia and Alyki are below sea level curve of Lambeck, is probably connected with the sediment compaction in the area.

A continuous sea level rise is observed in Lemnos Island during the last 5100 years B.C. This fact can be confirmed by the ancient quarry and also by the submerged beach rock located in the northeast coast of Palaeopoli peninsula, near the Hephestia archeological site.[13]

Palaeogeographycal evolution

According to our palaeoenvironmental reconstruction (Pl. XVd), the bay in the south of the Palaeopoli peninsula, in Hephestia area, during the period 1950 B.C. to 390 B.C., had been a shallow bay that temporarily may have developed into an open lagoon. This corresponds to the time period between the Late Bronze Age and the Classical times, when there was a continuous human presence in the archaeological site of Hephestia. This means that the harbour could have been situated in the Hephestia bay at that time.

The same evolution was observed in the Alyki lagoon. In the period between 5100 cal B.C.-820 A.D. there had been a shallow marine environment with fresh water influx.

The high sedimentation rate of 11 mm/y in HAL4 (HAL4 is located close to the present barrier) probably reveals the place of a sediment trap and the creation of a lagoon barrier. This fact can be proved by the findings of HAL1, which indicate an area where the opening and the point of marine influence of the lagoon had been located. Later from 820 A.D. the combination of coastal marine and Aeolian processes has probably shaped the present landscape.

Conclusion

The area of the archaeological site of Hephestia between 1950 B.C and 390 B.C was a shallow bay. By that time there is a continuous human presence in this area, beginning from Late Bronze Age to Classical time period. The configuration of the environment could indicate the possible presence of a port in the opening of Hephestia bay. Environmental changes are also observed in Alyki lagoon. During the period between 5100 B.C. and 820 A.D., there had

N. PALYVOS, Th. TSOUROU, "Paleoenvironmental Evolution and Prehistoric Human Environment in the Embayment of Palamari (Skyros Island, Greece) during Middle Holocene," *Quaternary International* 216 (2010) 41-53; M. TRIANTAPHYLLOU, K. KOULI, Th. TSOUROU, O. KOUKOUSIOURA, K. PAVLOPOULOS, M. DERMITZAKIS, "Paleoenvironmental Changes since 3000 BC in the Coastal Marsh of Vravron (Attica, SE Greece)," *Quaternary International* 216 (2010) 14-22.

11 K. LAMBECK, "Sea-Level Change through the Last Glacial Cycle: Geophysical, Glaciological and Palaeogeographic Consequences," *Geoscience* 336 (2004) 677-689.

12 K. LAMBECK, A. PURCELL, "Sea-Level Change in the Mediterranean Sea Since the LGM: Model Predictions for Tectonically Stable Areas," *Quaternary Science Reviews* 24 (2005) 1969-1988.

13 K. PAVLOPOULOS, E. FOUACH, M. SIDIROPOULOU, M. TRIANTAPHYLLOU, K. VOUVALIDIS, G. SYRIDES, A. GONNET, E. GRECO, "Palaeoenvironmental Evolution and Sea-Level Changes in the Coastal Area of NE Lemnos Island (Greece) during Holocene," *Quaternary International* 308-309 (2013) 80-88.

been a shallow marine environment, with significant fresh water input. The paleo- shoreline had been located 500 m in front of the present day shoreline. A periodically open lagoon had developed, and gradually a sand barrier had been created probably later than 820 A.D.

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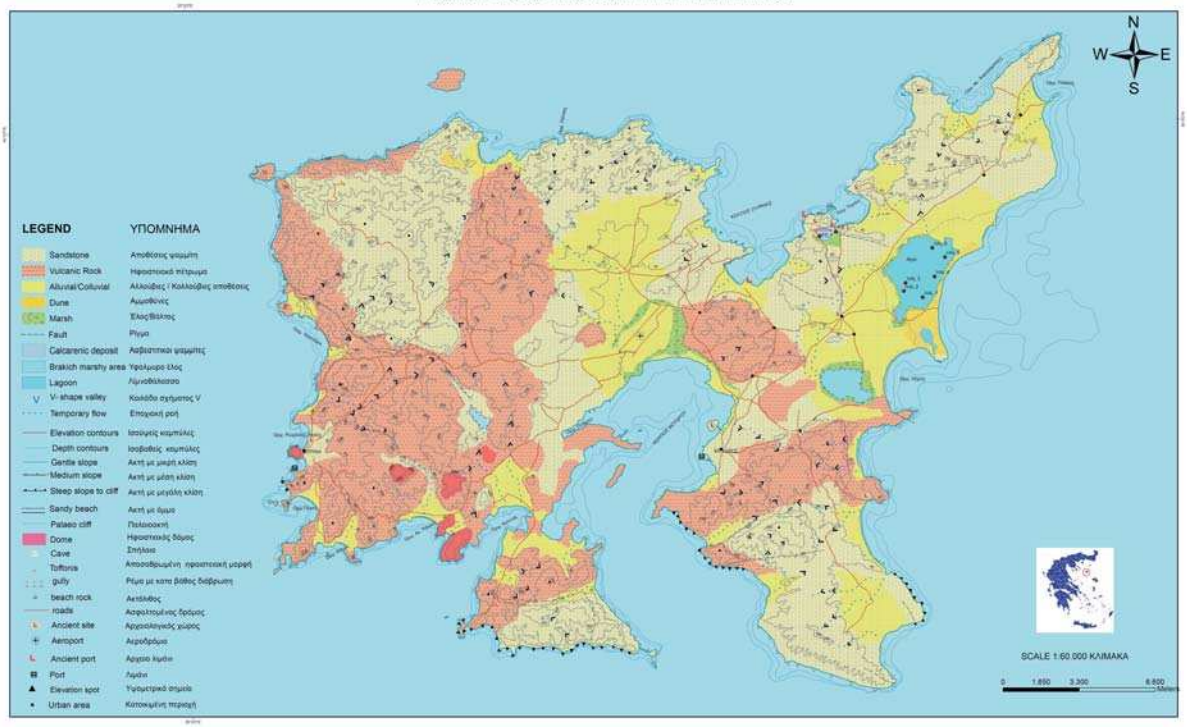
George SYRIDES
Emanuele GRECO

LIST OF ILLUSTRATIONS

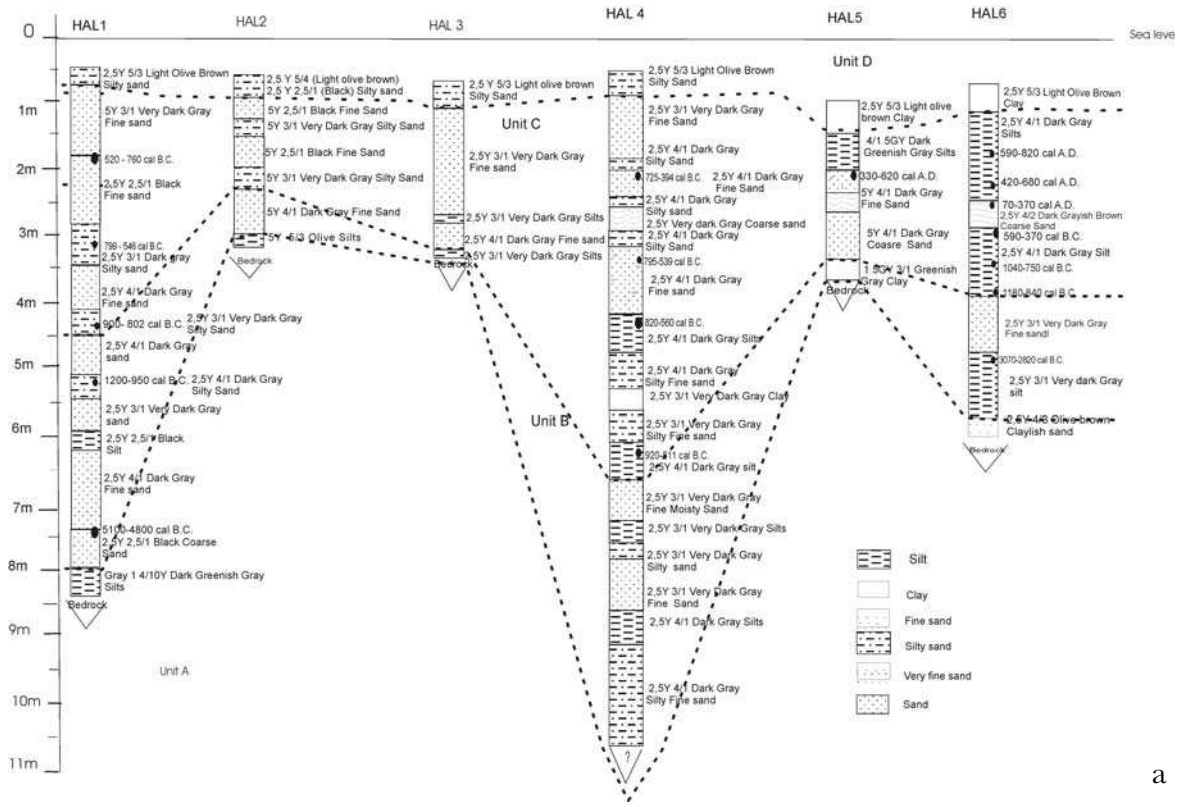
Sample	depth below m.s.l.(m)	material	calculated age
HAL 1	1.44	Shell	520-760 A.D.
HAL 1	2.42	organic material	799-546 B.C.
HAL 1	3.89	organic material	900-802 B.C.
HAL 1	4.84	Shell	1270-950 B.C.
HAL 1	6.96	Shell	5100-4800 B.C.
HAL 4	1.80	organic material	725-394 B.C.
HAL 4	2.5	organic material	792-539 B.C.
HAL 4	3.7	organic material	820-596 B.C.
HAL 4	5.57	organic material	928-811 B.C.
HAL 5	1.34	Shell	330-620 A.D.
HAL 6	1.35	Shell	590-820 A.D.
HAL 6	1.66	Shell	420-680 A.D.
HAL 6	1.87	Shell	70-370 A.D.
HAL 6	2.63	Shell	590-370 B.C.
HAL 6	2.93	Shell	1040 - 750 B.C.
HAL 6	3.09	Shell	1180 - 840 B.C.
HAL 6	4.8	Shell	3070 -2820 B.C.
IFE 2	1.49	Shell	740-390 B.C.
IFE 2	2.29	Shell	1150-830 B.C.
IFE 2	3.35	Shell	1950 - 1160 B.C.

a

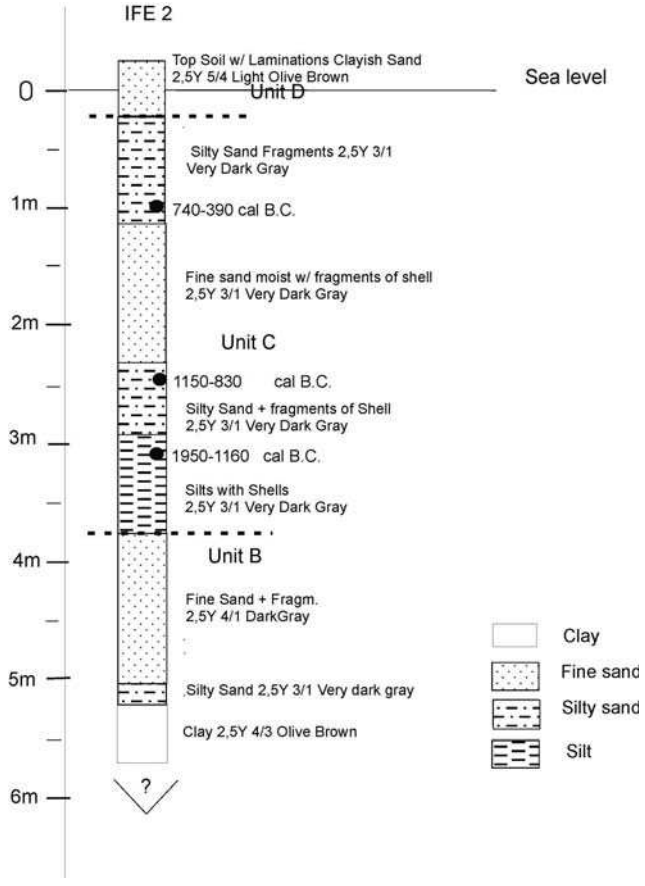
GEOMORPHOLOGIC MAP OF LEMNOS
ΓΕΩΜΟΡΦΟΛΟΓΙΚΟΣ ΧΑΡΤΗΣ ΤΗΣ ΛΗΜΝΟΥ



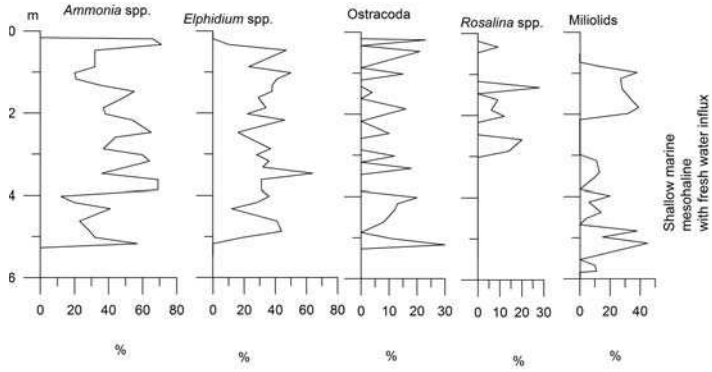
b


HAL1
HAL2
HAL 3
HAL 4
HAL5
HAL6
Sea level
Unit A
Unit B
Unit C
Unit D
Bedrock
Silt
Clay
Fine sand
Silty sand
Very fine sand
Sand

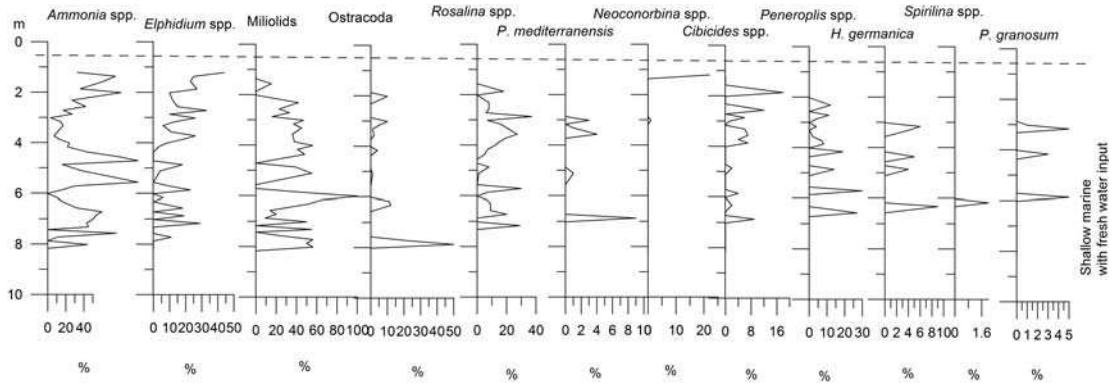
a


IFE 2
Top Soil w/ Laminations Clayish Sand
2,5Y 5/4 Light Olive Brown
Unit D
Sea level
Silty Sand Fragments 2,5Y 3/1
Very Dark Gray
740-390 cal B.C.
Fine sand moist w/ fragments of shell
2,5Y 3/1 Very Dark Gray
Unit C
1150-830 cal B.C.
Silty Sand + fragments of Shell
2,5Y 3/1 Very Dark Gray
1950-1160 cal B.C.
Silts with Shells
2,5Y 3/1 Very Dark Gray
Unit B
Fine Sand + Fragm.
2,5Y 4/1 DarkGray
Silty Sand 2,5Y 3/1 Very dark gray
Clay 2,5Y 4/3 Olive Brown
Clay
Fine sand
Silty sand
Silt

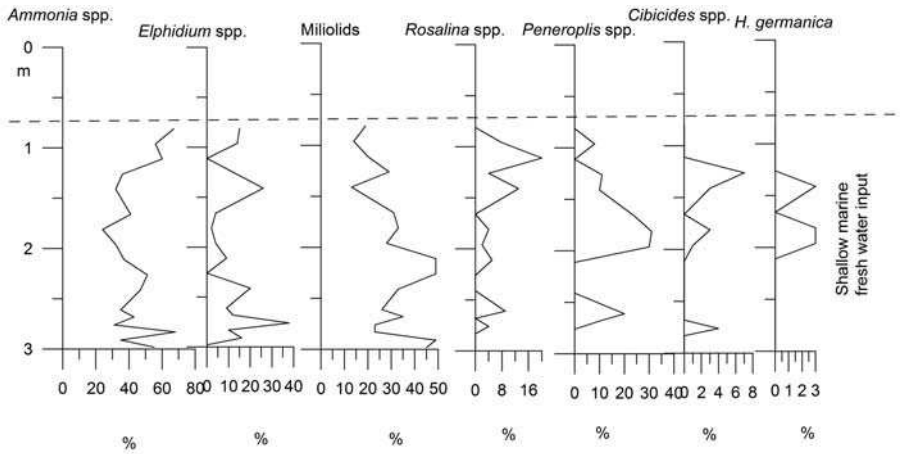
b


m
Ammonia spp.
Elphidium spp.
Ostracoda
Rosalina spp.
Miliolids
0
2
4
6
0 20 40 60 80
0 20 40 60 80
0 10 20 30
0 10 20 30
0 20 40
%
%
%
%
%
Shallow marine
mesohaline
with fresh water influx

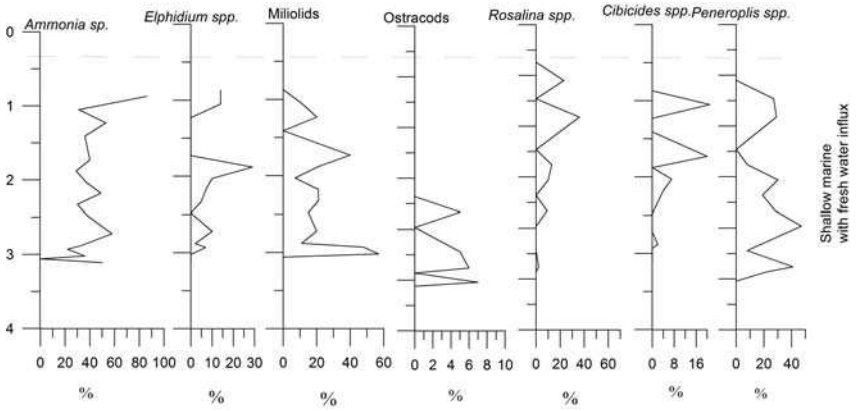
a


m
Ammonia spp.
Elphidium spp.
Miliolids
Ostracoda
Rosalina spp.
P. mediterranensis
Neoconorbina spp.
Cibicides spp.
Peneroplis spp.
H. germanica
Spirilina spp.
P. granosum
0
2
4
6
8
10
0 20 40
0 10 20 30 40 50
0 20 40 60 80 100
0 10 20 30 40 50
0 20 40
0 2 4 6 8 10
10 20
0 8 16
0 10 20 30
0 2 4 6 8 10
0 1.6
0 1 2 3 4 5
%
Shallow marine
with fresh water input

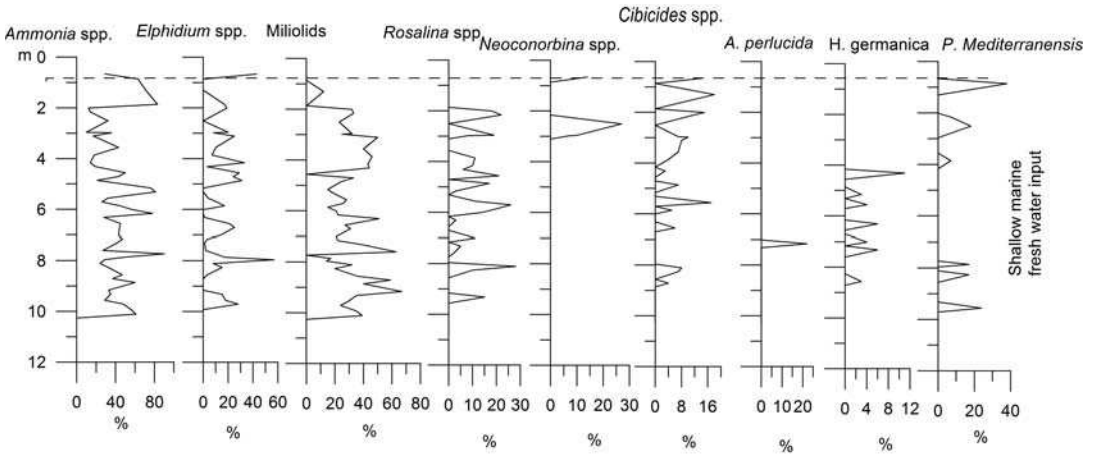
b


Ammonia spp.
Elphidium spp.
Miliolids
Rosalina spp.
Peneroplis spp.
Cibicides spp.
H. germanica
0
m
1
2
3
0 20 40 60 80
0 10 20 30 40
0 10 20 30 40 50
0 8 16
0 10 20 30 40
0 2 4 6 8
0 1 2 3
%
Shallow marine
fresh water input

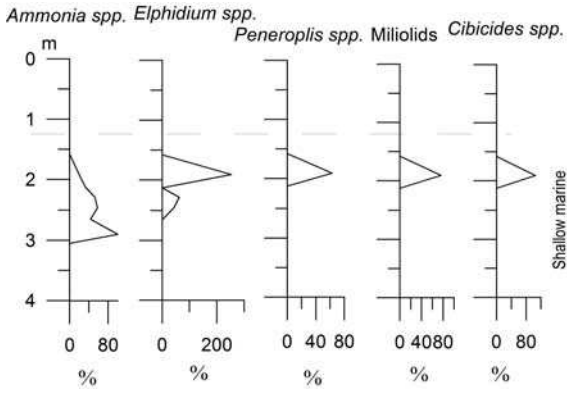
c


Ammonia sp.
Elphidium spp.
Miliolids
Ostracods
Rosalina spp.
Cibicides spp.
Peneroplis spp.
0
1
2
3
4
0 20 40 60 80 100
0 10 20 30
0 20 40 60
0 2 4 6 8 10
0 20 40 60
0 8 16
0 20 40
%
Shallow marine
with fresh water influx

d



a



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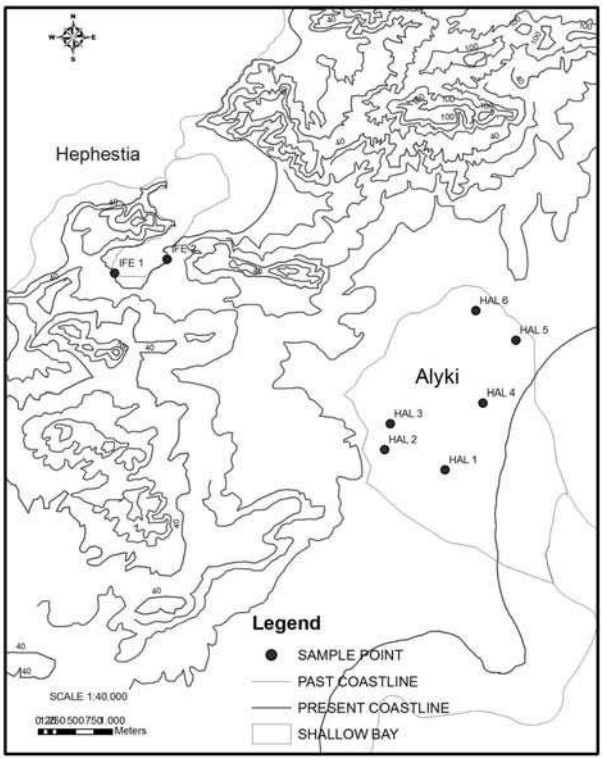

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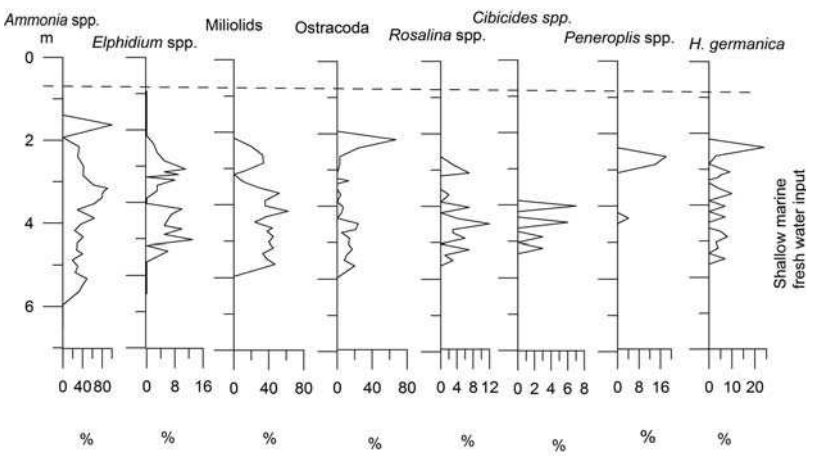

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