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Late Holocene Geology of the Marathon Plain (Greece)[1]

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ABSTRACT

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A drill hole study in the eastern part of the Marathon Plain demonstrates late Holocene coastal changes. The backswamp in the floodbasin of the Haradros River showed a complex sedimentary record and the results are represented in profiles and fence diagrams. Radiocarbon dates and analysis of sedimentary environments provide a paleogeographic synthesis.

ADDITIONAL INDEX WORDS: *Coastal sedimentary environments, fence diagram, Holocene, Marathon Plain, paleogeography*

INTRODUCTION

The Marathon Plain, situated in the northeast of Attica (Greece) is famous for the battle of 490 BC, a triumph for Athens against the Asiatic invaders. The plain also is of great archeologic and historic significance as it has been continuously occupied by man since Neolithic time. The plain has been subject to rapid geographic change in Holocene history due to sea-level fluctuations and climatic changes, both evolving continuously (FLEMMING, 1972). A drill-hole study was initiated in the eastern part of the plain to determine the nature of the sedimentary environments and their deposits. The relatively small size of the studied area allowed a high density of coring, necessary because of the great variety of sediment types within the small basin.

GEOMORPHOLOGY

The Marathon Plain (Figure 1) lies in the shelter of a range of mountains of limestones and shales of Mesozoic age. The Kynosoura Peninsula forms its southeastern side. It is typical of the coastal plains of Greece as described by KRAFT *et al.* (1975, 1977): "An alluvial plain of relatively high angle with a terminal swamp area separated from the sea by a sand and gravel barrier."

The Marathon Plain, not affected by tides, is divided into almost equal parts by the Haradros River, which is no longer active. At present the floodplain in the surroundings of Marathon is well drained and flood-controlled. The former river meandered across a broad and triangular floodplain. The river bed consists of coarse gravel alternating with silt, slightly perched above the adjacent silt flood basins that are situated on either side and occupied by low-lying swamps; the western one is called the Vreksisa or Small Marsh; the eastern one is refered to as the Shinias or Great Marsh. A broad but low dune barrier is overgrown with scrub and trees.

GEOLOGY OF SHINIAS

The most extensive backswamp is the one east of the former river, and was selected for investigation, although a part of it was inaccessible due to the presence of a military base. A detailed study by means of hand borings was made to investigate aspects of the recent geologic history (Figure 2).

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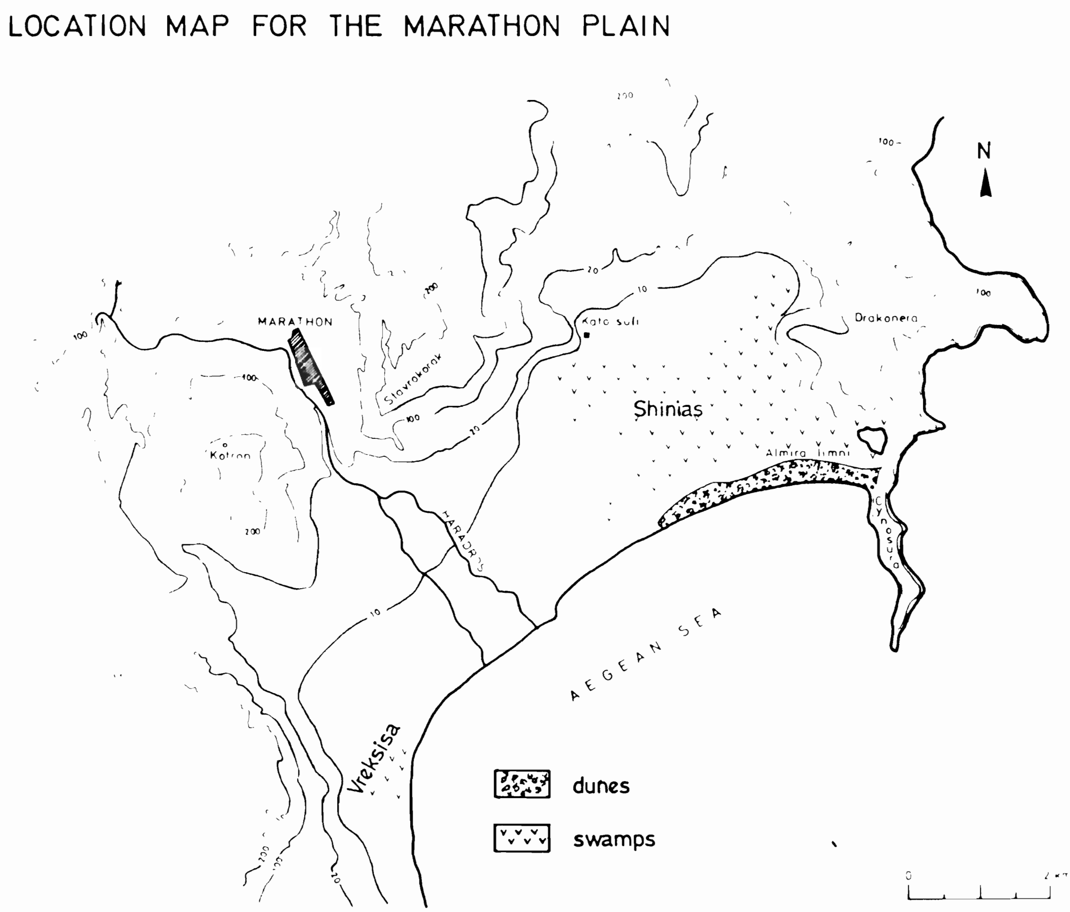


Figure 1. Location map for the Marathon Plain indicating the marshes at both sides of the Haradros River

Substratum of the Backswamp

The substratum of the backswamp consists of varied lithologic units (Figure 3). In the north and west part of the basin it is composed of fluviatile deposits consisting of clay, changing laterally into silt and sand, with pebbles toward the outer border of the depression. In the southern part of the basin, the substratum is formed by sand and gravel beach accretion.

The reconstruction of the morphology of the fluviatile substratum in a small part of the plain, just south of Kato Souli, shows clear evidence of a flood basin (Figure 3). The top of the substratum deepens quickly in a south-southeast direction into a central depression, the center of which is probably located near boring 10.

Stratigraphy of the Backswamp

Several cross-sections were drawn in order to illustrate the sedimentary depositional facies and to show the relationship of the different environments. In profiles broad lithogenetic units are correlated (READING, 1979; REINECK and SINGH, 1980).

DESCRIPTION OF THE CROSS-SECTIONS

Three parallel cross-sections, from the center of the depression to the fluviatile area, were made perpendicular to the shoreline, showing the relationship of the marine and non-marine deposits and the

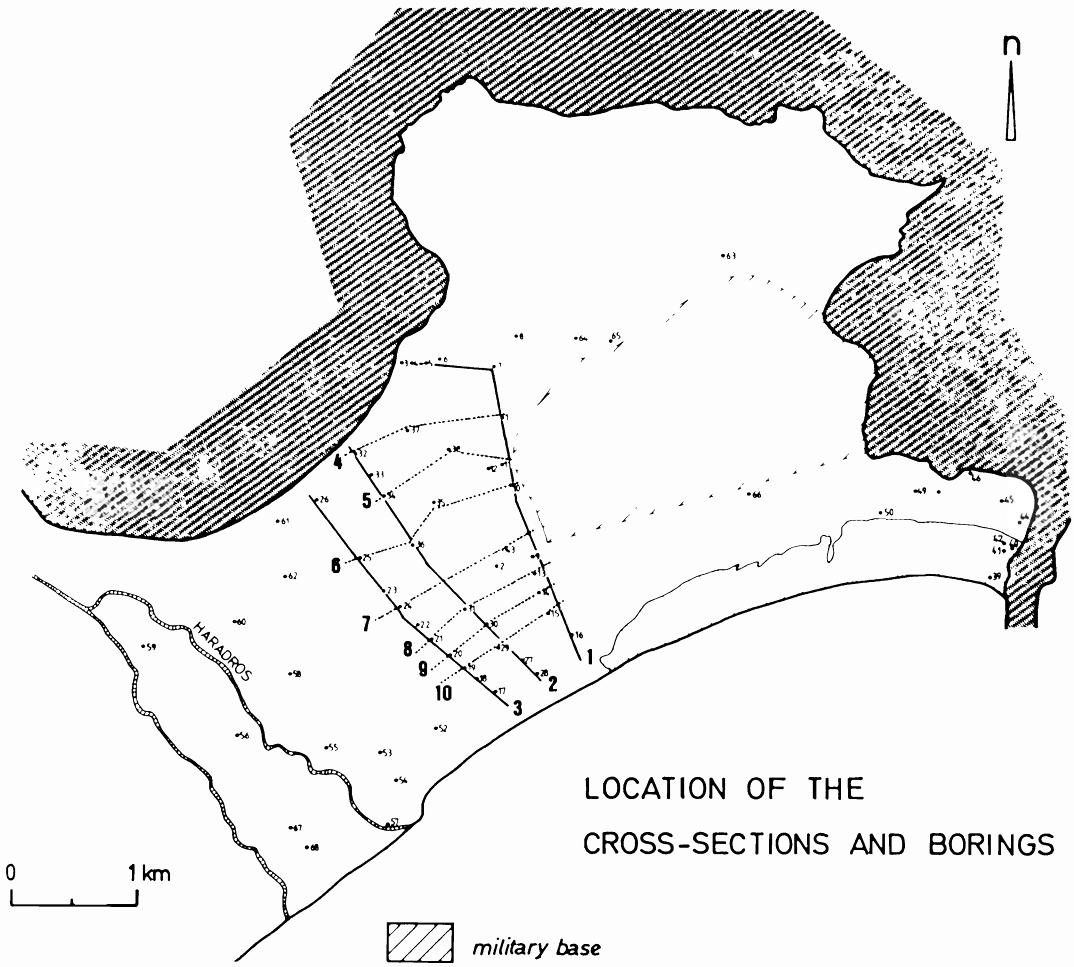


Figure 2. Location of the cross-sections and hand borings.

vertical succession of the different facies (Figures 2, 3, 4, 5, and 6). The cross-sections show that the backswamp sequence is underlain by fluviatile sediments deepening to the southeast and reaching -5.5 m in the deepest part. In the seaward zone the substratum consists of sand and gravel from beach accretion. Because the core could not penetrate the coarse beach sediments it is not known whether the fluviatile deposits are present below these beach sediments.

The backswamp deposits reach a maximum thickness of 7 m in the central part of the depression. The sediments can be divided into several groups, marked by lateral changes of facies. The initial filling of the basin is indicated by unconsolidated mud (*cf.* Cross-Section 1). This dark grey mud layer is characterized by reduction spots, numerous plant fragments and on the landward side, by fresh-water molluscs: all indicators of a shallow-lagoon condition. At the extreme western edge the lagoon was overgrown by vegetation that resulted in the development of peat (Cross-Section 1). In the deepest and central part of the basin the mud is overlain by clay with numerous marine bivalves, especially *Cardium*. Laterally, to the south-east, this layer gradually passes into a sandy clay and sand with marine shell debris. Farther to the south-east it correlates with coarse beach deposits.

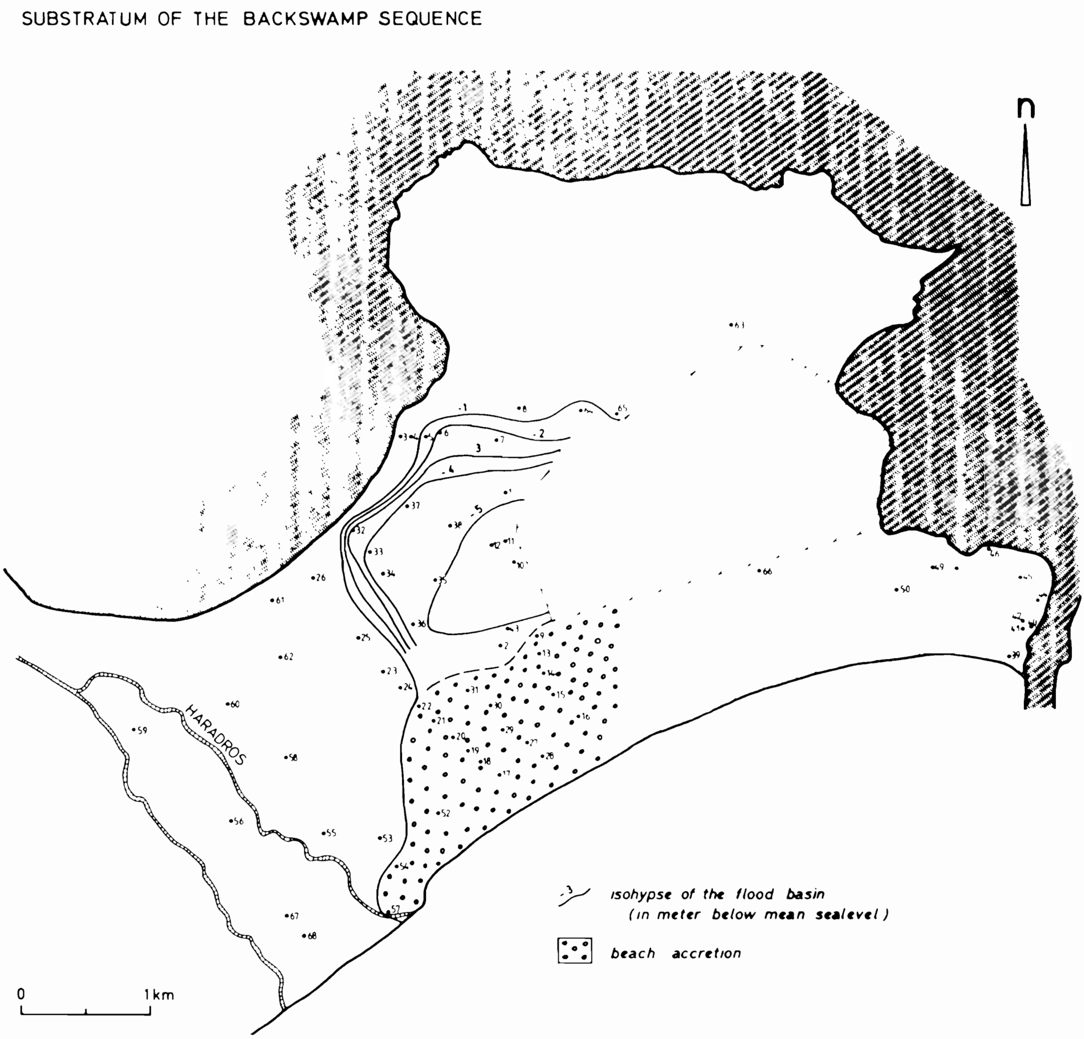


Figure 3. Map of the substratum of the backswamp sequence showing the varied lithologic units.

In the deepest part of the basin (Cross-Section 1) the thin lagoonal and marine deposits are overlain by rather heterogenous deposits, reaching a thickness of up to 3 m, and mainly consisting of white and pink colored carbonate mud. In the northern part it alternates with organic gyttja, peat, and lagoonal clay containing fresh-water gastropod shells and plant fragments. This alternation is different in each boring. To the south there is marine shell debris with numerous marine bivalves, mostly concentrated in thin layers, while the carbonate mud becomes sandy to the base. This heterogenous deposit is best developed in the central part of the depression while to the west it is restricted in extent and thickness. A peat layer extends over nearly 1 km, covering the lagoonal mud in the landward area.

Most probably these heterogenous facies were deposited in a shallow water lagoon behind a beach barrier not completely closed, permitting sea water to enter into an estuarine area. The landward zone was characterized by fresh water. The local and irregular alternation of the carbonate mud with peat, organic gyttja, and mud indicates that

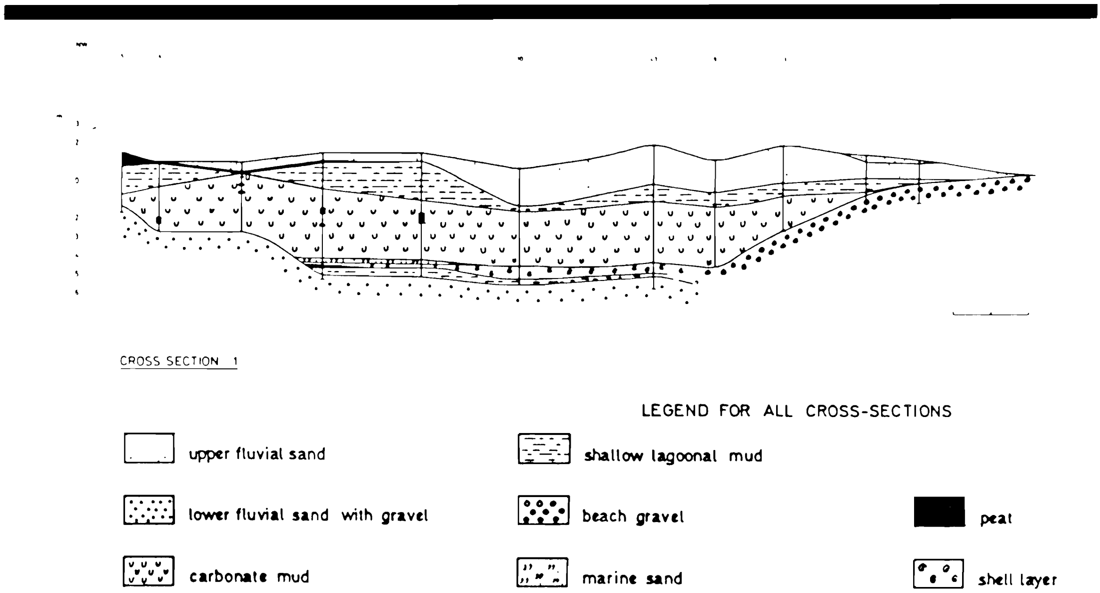


Figure 4. Cross-Section 1 (see Figure 2 for location)

carbonate mud precipitation did not occur over the entire lagoon. In the fresh-water area there was deposition of mud and where ecological conditions were suitable, the vegetation several times produced organic gyttja or a very local peat. Oxidation layers indicate that some parts of the lagoon were temporarilly emerged.

The carbonate mud unit is covered by a blue-gray unconsolidated mud containing fresh-water gastropods and plant fragments, both being more abundant on the landward side. Locally here a thin peat accumulated on the top of the mud (*cf.* Figure 4). Several characteristics of the mud suggest that it was deposited in a shallow lagoon behind a beach barrier, well protected from the sea.

Near the border of the basin (Figures 2 and 6) there is a somewhat different picture. The depression is restricted to a narrow belt just behind the beach. The carbonate mud unit is represented only at the very western part of the basin and laterally its facies gradually changes to coarse marine sand and gravels. It is covered by mud deposited in a dominantly fresh-water environment where peat was able to develop. The top of the peat gradually passes to clayey peat in turn covered by lagoonal mud. At the time the mud was deposited, the beach

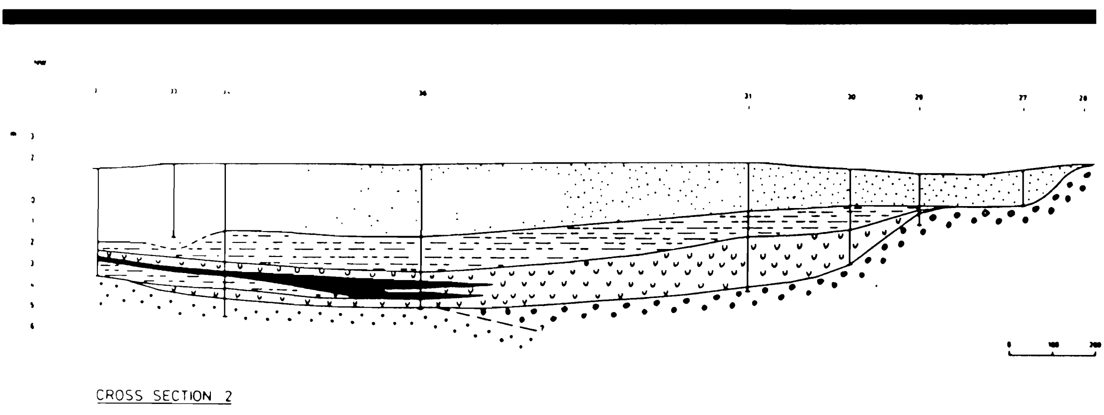


Figure 5. Cross-Section 2 (see Figure 2 for general legend and location).

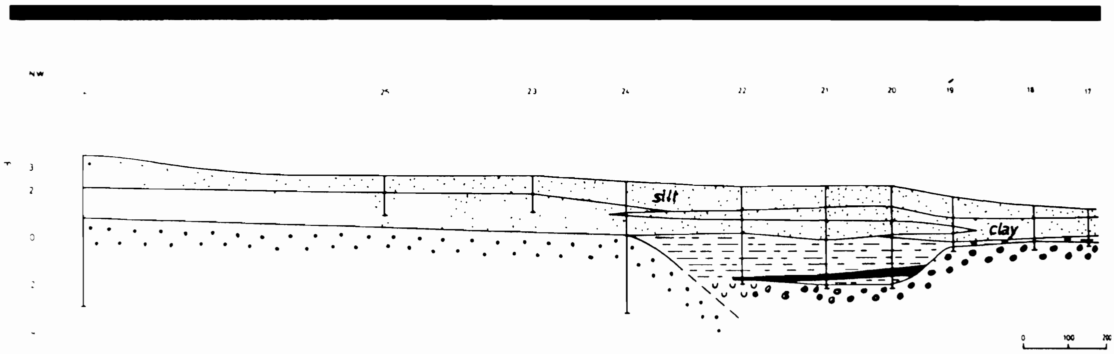


Figure 6. Cross-section 3 (see Figure 2 for general legend and location).

barrier was situated more seaward in the westward part. This lagoonal mud represents the final filling of the backswamp-sequence under marine conditions. The sequence is almost completely covered by fluviatile deposits, consisting of silt and silty sand, and found above about -1 m in the center of the plain and above about 0 m at its borders. At only one spot, just south of Kato Souli (Cross-Section 1, Borings 5 and 6), the fluviatile cover is lacking and the peat outcrops at the surface.

A series of cross-sections parallel to the present shoreline and perpendicular to the former river were made to demonstrate the relationship of the various sedimentary environments to the fluviatile deposits in the western part of the plain (Figures 2, 7, and 8). The cross-sections show the broad lithogenetic units. The western part consists only of fluviatile deposits. However a distinction can be made between the fluviatile deposits which are to be correlated with the cover and those forming the substratum of the backswamp sequence (lower fluvial deposits). The lithology is different, although not always very clear. The cover deposits consist of brown silt and silty sand, while the lower deposits are formed of brown mottled clay with some small plant fragments and few terrestrial gastropods. A clear distinction could also be established thanks to the presence of a well-developed reddish soil at the top of the lower deposit.

In the three most southern cross-sections (Figure 8) the substratum of the backswamp sequence is formed by beach sediments and the fluviatile deposits deepen very quickly to the east. From the cross-sections it is clear that the peat is limited only to the northern part of the basin and is very restricted in the south against the steep slope formed by the lower fluvial deposits.

The carbonate unit is well developed in the center of the basin, and thins to the south. In the far south, nearby the present shoreline, the backswamp sequence only consists of a thin lagoonal mud and a restricted carbonate mud layer enclosed between the high-lying beach deposits and the upper fluvial sediments (*cf.* Cross-Section 10). In short, the development of the backswamp sequence is represented in a fence diagram (Figure 9) to give a three-dimensional view.

THE SEQUENCE MAP

The lithogenetic units described above are now represented on a geological map to show their extent (Figure 10). Preference was given to a profile type map representing the whole vertical succession of the several units although restricted in depth. In the fluviatile area it is valid for a depth up to 6 m.

The map shows in plan the recent infill as well as the evolution and genesis of the area. Two different areas can be recognized. A large part in the west consists of Profile Type 1, exclusively fluviatile deposits over the entire sequence.

In the basin to the east is the backswamp sequence where two belts can be distinguished, determined by their substratum. In the northern part it is formed by fluviatile deposits (Profile Types 2, 3, 4, 5, 6, and 7), while in the southern part beach deposits occur (Profile Types 8, 9, 10, and 11). The following profile types can be recognized. In a small zone along and just behind the present shoreline the beach deposits outcrop (Profile Type 12). Slightly landward the beach deposits are covered by fluviatile sediments in a long and narrow zone (Profile Type 11) and in turn covered by eolian sand in the dune area. Still slightly northward the lagoonal mud

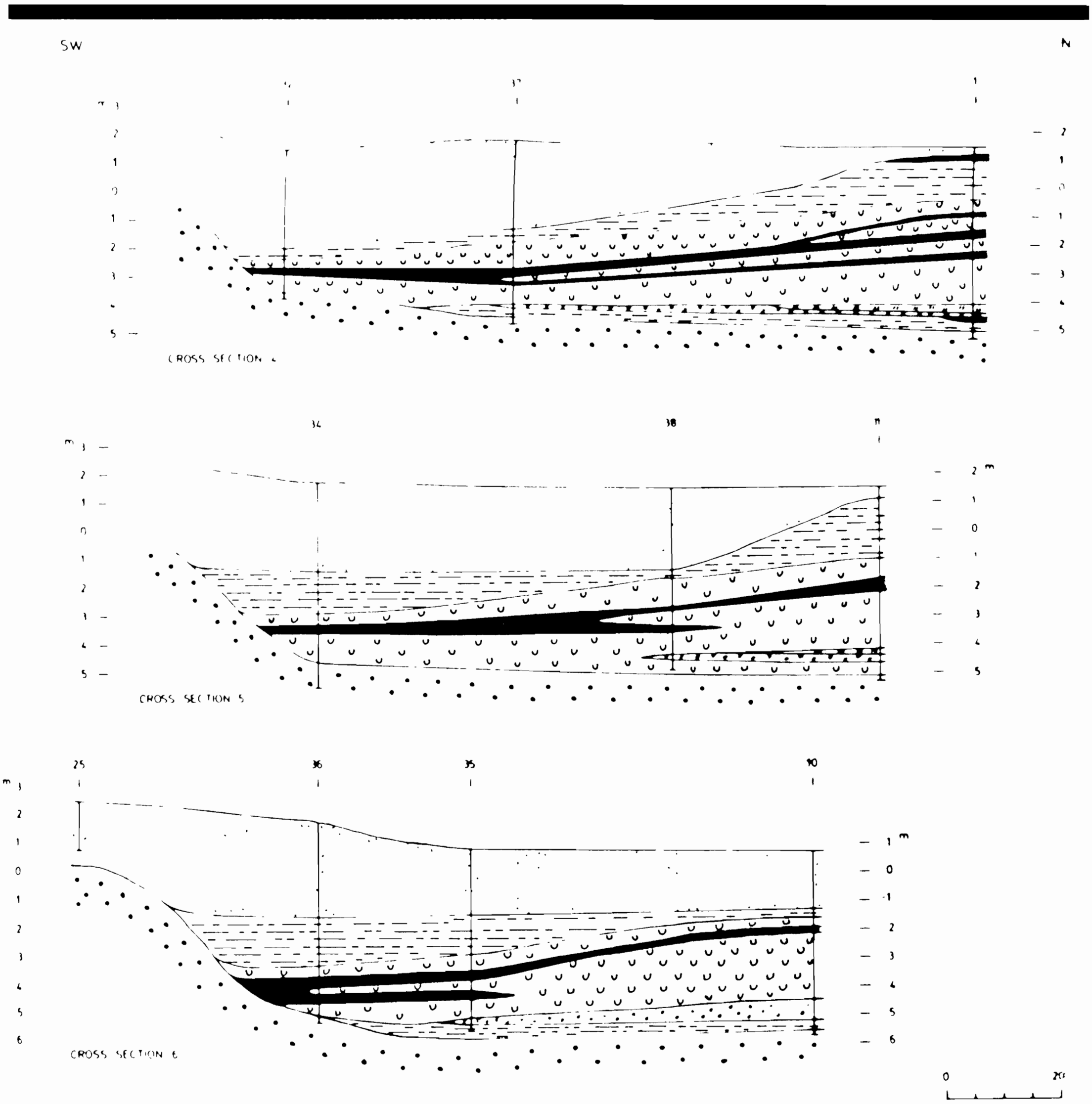
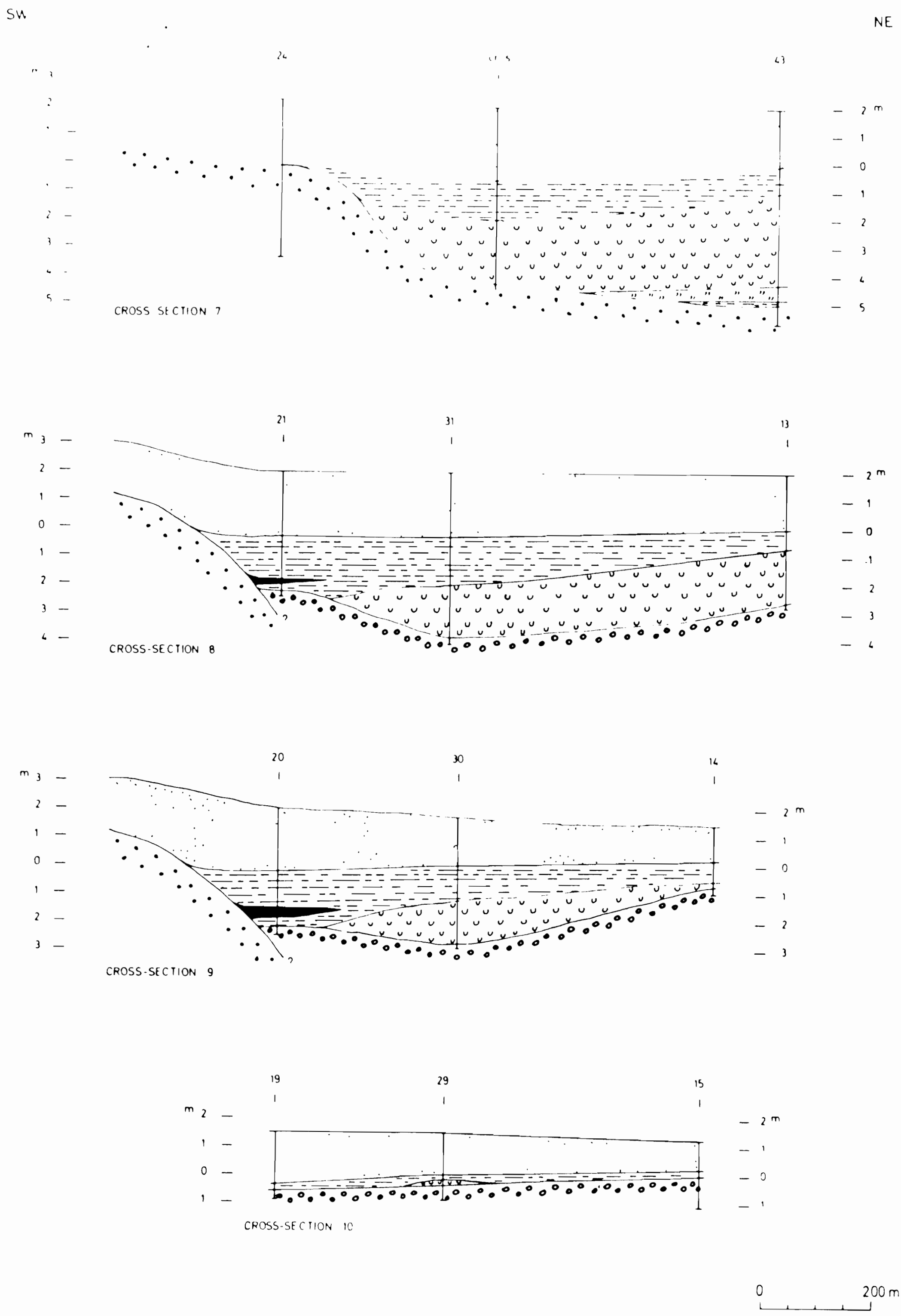


Figure 7. Series of cross-sections parallel to the present shoreline (northern part).

occurs (Profile Type 10) with a small area where peat is present (Profile Type 9). More to the center of the basin several profile types are distinguished, characterized by the occurrence of carbonate mud. A differentiation was made according to the absence (Profile Type 7 and 8) or presence of peat (Profile Type 3, 4, 5, and 6). Profile types 6 and 7 were distinguished particularly to indicate the shell layer at the base of the sequence, which can be correlated with the beach deposits occurring seaward. From this map it can be seen that the shell layer has a rather considerable extension landward. In the north of the basin, just south of Kato Souli, another profile type (3) was selected to emphasize the restricted area where peat is outcropping.

In the very eastern part of the Marathon Plain there is a third region with characteristics quite different from the fluviatile and backswamp sequences. Fluviatile deposits are here lacking completely and the Holocene sediments rest directly on bedrock of Mesozoic age. It is just possible that the base may be a beachrock, but it was impossible to recognize in hand borings.

In this easternmost area three main zones could


SW
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1
2
3
4
CROSS-SECTION 8
20
30
14
CROSS-SECTION 9
19
29
15
m 2
CROSS-SECTION 10
0
200 m

Figure 8. (Facing page) Series of cross-sections parallel to the present shoreline (southern part).

be distinguished. A rather broad area along the present shoreline (Profile Type 15) consists of carbonate mud containing marine shell fragments. It is up to 1 m thick and rests upon coarse beach deposits. In the landward direction two narrow zones occur in succession. In the zone indicated by profile type 14 the carbonate mud resting upon coarse beach deposits is covered by a marine clay with numerous shells, while in profile type 13 only the marine clay with shells is present resting directly upon bedrock (or beachrock).

CHRONOLOGIC INDICATIONS

During fieldwork the investigation focused on sedimentary facies and infilling of the basin. Only a few samples were selected for age-dating, which was not without complications. Some of the carbonate dates may be modified by the hard-water effect which could increase the 14-C ages by several thousand years (comment: M.A. Geyh). The samples unfortunately have not been taken directly in relation to the stratigraphic units, established afterwards, so that the ages of the upper and lower limits are still unknown. Further investigation is needed to set up a complete chronology.

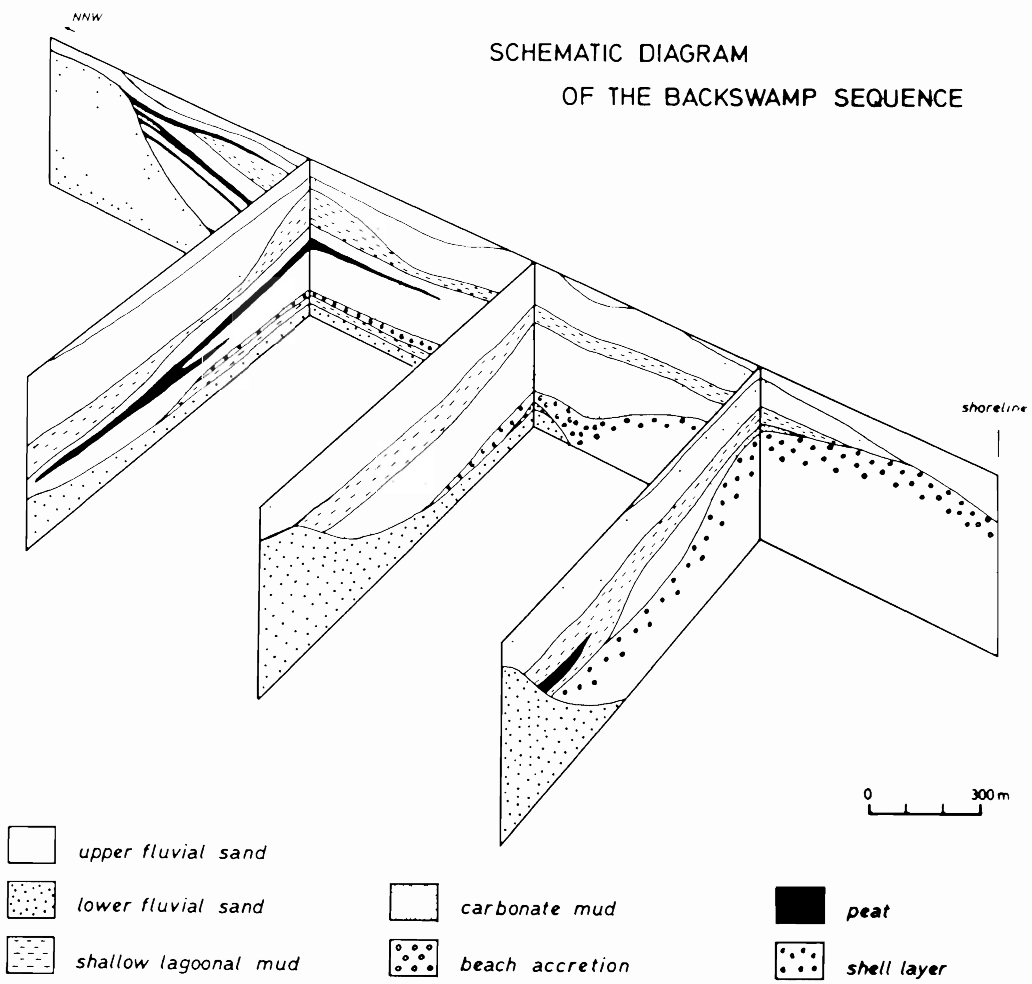

Figure 9. Fence diagram showing a three-dimensional view on the relationship of the several lithogenetic units.

GEOLOGICAL MAP OF THE MARATHON PLAIN

PROFILE TYPE MAP OF THE HOLOCENE

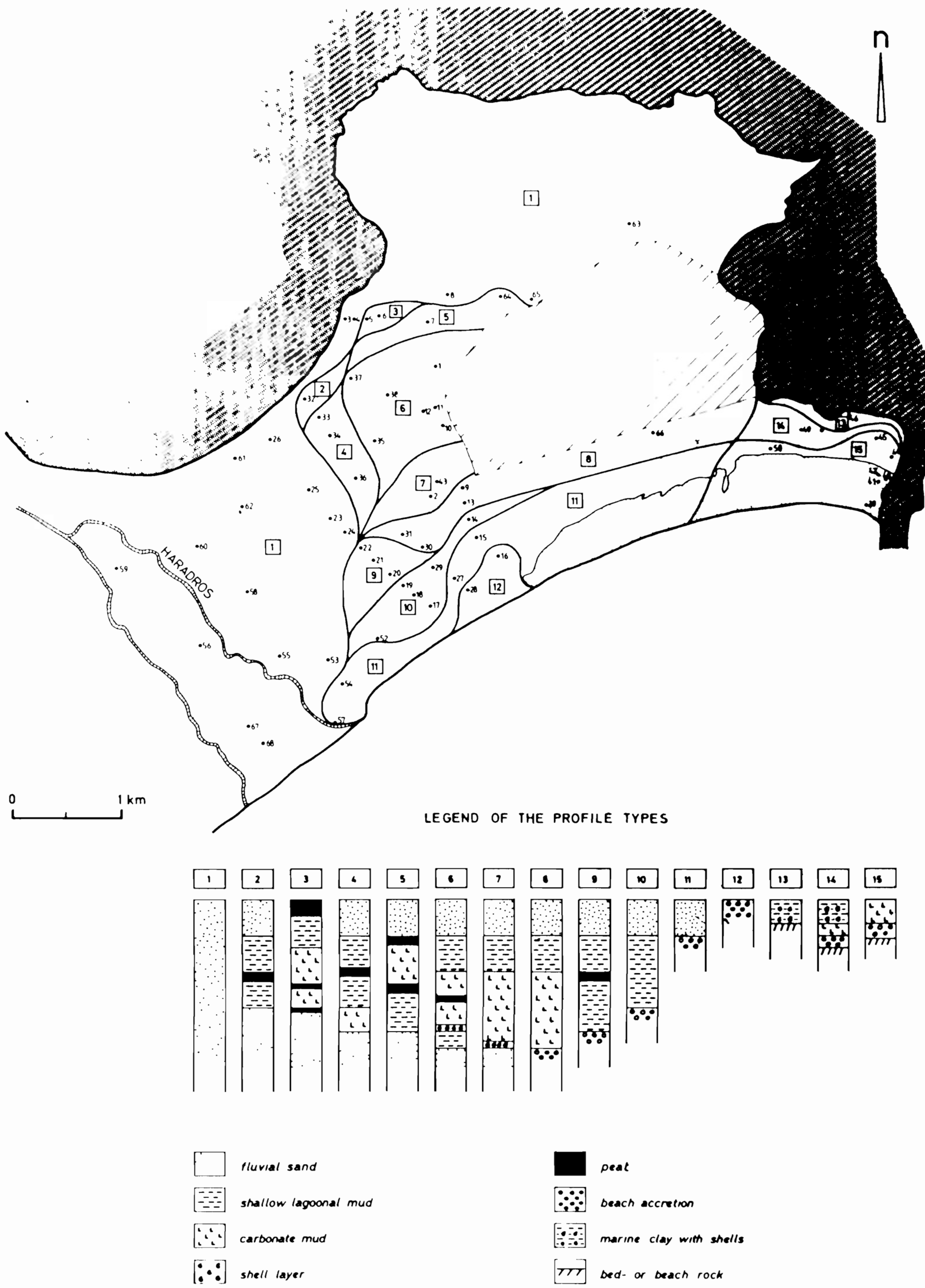

Figure 10. (Facing page) Profile type map of the recent Holocene deposits in the Shinias area representing the whole vertical succession of the several lithogenetic units.

Some samples from the carbonate mud and peat sequence in the landward area were dated as follows:

Boring 36 (*cf.* **Cross-Section 2**)
-3.50 m to -3.60 m:
carbonate mud, 3550±80 BP (Hv 8548)
-3.80 m to -3.90 m:
middle of upper peat, 4869±75 BP (Hv 8549)
-4.00 m to -4.10 m:
base of upper peat, 4570±105 BP (Hv 8550)

Boring 37 (*cf.* **Cross-Section 4**)
-2.30 m to -2.70 m:
carbonate mud, 3985±65 BP (Hv 8551)
-3.20 m to -3.30 m:
lowermost peat, mean date, 4575±60 BP (Hv 8552)

Boring 6 (*cf.* **Cross-Section 1**)
-0.60 m to -1.40 m:
carbonate mud, 4020±60 BP (Hv 8533)

Taking into account the problems concerning the samples, it may be suggested that the carbonate mud unit is approximately 4900 to 3500 yrs BP in radiocarbon years (calibrated to sidereal years: 5400 to 3800 BP, or 3450 to 1850 BC).

The uppermost peat which locally outcrops in the northwestern part of the backswamp area (*cf.* Cross-Section 1) was sampled in outcrop, where the peat is split into two thin layers. The base of the lower peat at 0.80 m above sea level was dated 2480±60 yrs BP (Hv 8547); the base of the upper peat at 1.00 m was dated 1360±40 yrs BP (Hv 8546).

SOME PALEOGEOGRAPHIC IMPLICATIONS

Although precise time limits or time-depositional horizons are lacking, some ideas concerning the succession of the several different environments, which caused the infill of the Marathon Plain, can be put forward. Possible shifting in the bed of the Haradros River has not been considered here. The infill was mainly dominated by marine influences, but not always to the same extent.

The backswamp sequence came into existence in the Haradros flood basin. The central and deepest part of the basin, a small area south of Kato Souli, was submerged first to become a shallow-water marine environment. The inundation most probably was primarily caused by the marine transgression but was modified by freshwater runoff from the surrounding areas. This was the first transgression, which forms the beginning of the Holocene coastal plain environment, occurring somewhat before 5000 BP; the exact date is still not known.

The shallow water environment was an estuarine lagoon that in the initial state shows a marine connection, although only in the outer part. This shallow lagoon became enclosed and separated from the open sea by a beach ridge and then evolved into a fresh-water environment where, especially near the landward side, plant growth was possible and locally evolved to peat. In this early stage the shoreline was situated about 1 km landward of the present one and only a narrow coastal plain existed (Figure 11).

This lagoonal stage was abruptly terminated by a second marine transgression which covered the entire newly formed coastal plain. During this transgression the configuration and extent of the coastal plain did not change at all. After this renewed phase of infill of the floodplain basin, which is represented by only a few deposits, a new and quite different stage of coastal plain development began.

The third transgression now caused an enlargement of the coastal plain (Figure 11). Notably the higher areas to the north of the coastal plain and west of the basin were now reached by the sea and became a shallow water lagoonal environment in which carbonate mud was deposited. The development of the lagoon in that period, approximately between 4900-3500 BP, was characterized by very different local developments. In the west and northwestern part several well-developed peat layers with intercalated mud came into existence, because of the fresh water that dominated that part of the basin. The central and southern parts of the plain, on the other hand, were characterized mainly by carbonate mud deposits. Toward the end of this period peat was only local and was restricted to the northern part of the central area.

However, towards the end of this transgression (before 3500 BP) the entire coastal plain was again inundated by salt water, except for a small area in the southwestern part of the plain. This small area remained separate from the flooded coastal plain long enough for a thin peat facies to accumulate.

The sharply fluctuating character of this environment, which also varied locally, indicated that the

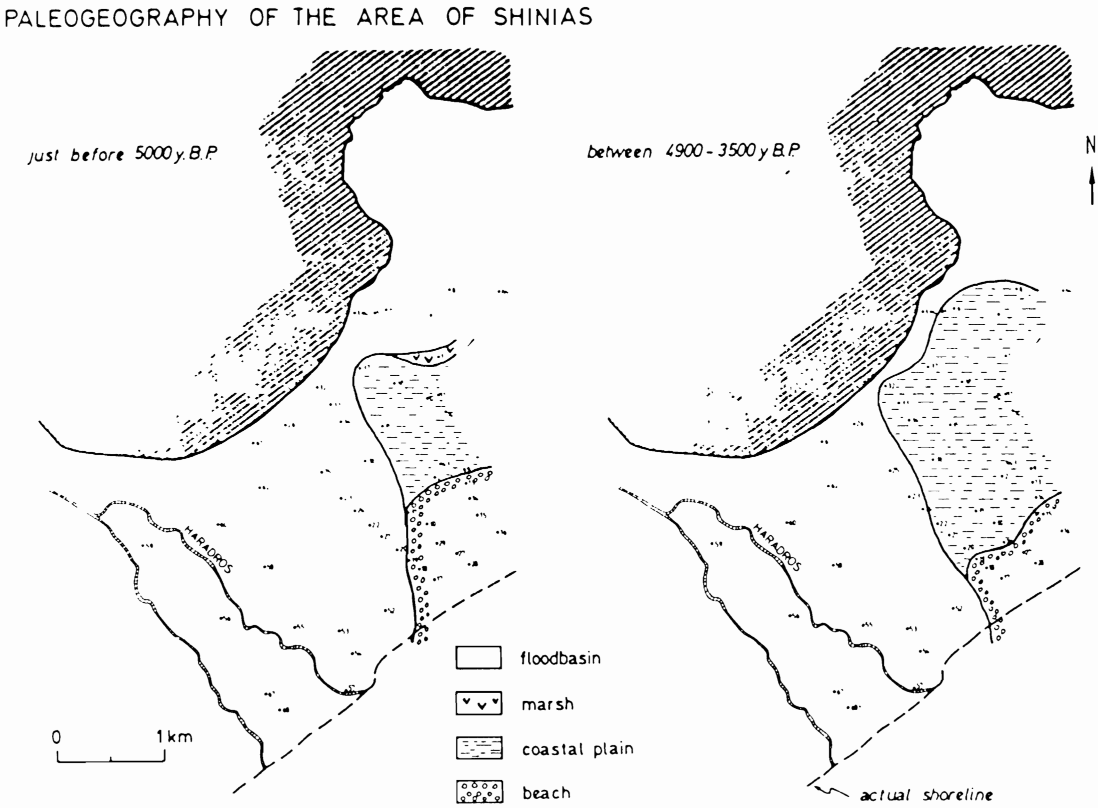

Figure 11. Paleogeographical reconstruction of the Shinias area in the periods just before 5000 BP and between 4900 to 3500 BP showing the situation of the shorelines and the extension of the coastal plain.

basin was successively influenced by salt or brackish water inundation, which did not always affect the entire area. Why the carbonate mud was deposited only in that particular period and not in the shallow lagoons occurring before and after, still remains a mystery and should be investigated further. At the end of this period (about 3500 BP) the shoreline with its coarse sand and gravel beach deposits was extended far to the south, about 500 m south of the present shoreline (Figure 11).

After this important period, characterized by oscillating fresh and salt water conditions, the basin again became a shallow lagoon which quickly evolved into a fresh water environment with plentiful vegetation. Numerous oxidation phenomena over the entire lagoonal sequence show that the area regularly became emerged. Such an area can be visualized as a wet fresh-water marsh in the rainy season alternating with areas of dry land surface during the dry season. The extension of the plain now slightly exceeded the former coastal plain in all directions. At the end of this stage of development, peat accumulation took place in the northern part of the plain.

The final stage shows a completely different picture. The Haradros and other small rivers became active again and the entire plain reverted to a backswamp. Except for a restricted area in the northernmost part of the basin (where peat accumulation continued) and the easternmost area, alluvial sediments were deposited over the entire plain. The Marathon Plain once again became a floodbasin and the last depositional stage was dominated by fluviatile systems.

Exactly when this important change occured is still problematic. The ages of the two peat layers occurring close to each other in these fluvial deposits are quite distinct: 2480±60 BP and 1360

±40 BP. KRAFT *et al.* (1975) described a similar sequence in the coastal plain of Messenia and also recognized an overlying alluvial deposition, which according to archaeological evidence was deposited in post-Roman times.

CONCLUSION

This drill-hole study in a small area of the Marathon Plain yielded the information that the stratigraphic sequence of the plain was built up under alternating fluvial and marine conditions. By studying the three-dimensional shapes of the sedimentary units deposited in each environment, the changes of landscape and coastal configuration through time and space could be understood. The stratigraphic sequence of a coastal flood plain environment contains complex lateral and vertical changes in facies and sedimentary units. Such complex coastal environments are prone to misinterpretation unless numerous cores are taken.

A greater number of radiocarbon dates are required for more precise paleogeographic reconstructions. Nevertheless, some idea of the different ancient landscapes could be put forward. Among other things, it can be assumed that in 490 BC, when the Greeks and Persians were fighting in the Shinias area, the shoreline was located farther inland than today and the landscape was dominated by a densely vegetated muddy marsh.

ACKNOWLEDGEMENTS

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LITERATURE CITED

FLEMING, N.C., 1972. Eustatic and tectonic factors in the relative vertical displacement of the Aegaen Coast. *In* D.J. Stanley (ed.), *The Mediterranean Sea.* Stroudsburg, Pennsylvania: Hutchinson and Ross, 189-201.

KRAFT, J.C.; RAPP,Jr., G.R., and ASCHENBRENNER, S.E., 1975. Late Holocene paleogeography of the coastal plain of the Gulf of Messenia, Greece, and its relationships to archaeological settings and coastal change. *Geological Society of America Bulletin*, 86(9), 1191-1208.

KRAFT, J.C.; ASCHENBRENNER, S.E., and RAPP, Jr., G.R., 1977. Paleogeographic reconstructions of coastal Aegean archaeological sites. *Science*, 195(4282), 941-947.

READING, H.G., 1979. *Sedimentary Environments and Facies.* Oxford: Blackwell, 557p.

REINECK, H.-E. and SINGH, I.B., 1980. *Depositional Sedimentary Environments.* New York: Springer-Verlag, 549p.