ARCHAEOLOGY
OF
COASTAL CHANGES

PROCEEDINGS
OF THE FIRST INTERNATIONAL SYMPOSIUM
"CITIES ON THE SEA–PAST AND PRESENT"

Haifa, Israel, September 22–29, 1986

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In collaboration with C.A.H.E.P.,
Caesarea Ancient Harbours Excavation Project

Publication No. 2

BAR International Series 404
1988

B.A.R.

5, Centremead, Osney Mead, Oxford OX2 0DQ, England.

BAR S404, 1988 : 'Archaeology of Coastal Changes'.

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ISBN 0 86054 519 9

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Printed in Great Britain

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The Application of Remote Sensing to Coastline Reconstruction in the Argive Plain, Greece

ABSTRACT

Landsat-1 coverage of the Argive plain, Greece, is examined to address whether units observed on the satellite image can provide specific information about the paleogeography of the coastal area. Boundaries identified on the Landsat image and the computer-generated land cover map were compared to the Holocene stratigraphy known from subsurface investigations. From analysis of the Landsat-1 spectral data and generation of a computer-classified land cover map, areas with similar spectral reflectance properties were identified and mapped. There is a sharp boundary between the agricultural-rich alluvial valley and the coastal plain. A change in vegetation across this boundary enables us to detect it on the satellite image.

The Holocene stratigraphy is characterized by a lower late Pleistocene-early Holocene sequence of soils overlain by marine to lagoonal silts and clays and Neolithic to recent alluvium and soils. The inland limit of the marine to lagoonal muds marks the maximum paleoshoreline of a transgression. Landward of a beach barrier which developed during the transgression, peat dating to the mid-Holocene was deposited in a lagoon. The shoreline has subsequently prograded seaward by the infilling of the lagoon and deposition of alluvial sediments. The floodplain/coastal plain boundary seen on the satellite image correlates to the inland limit of the subsurface subaqueous mud unit, marking the maximum early to middle Holocene transgressive shoreline.

INTRODUCTION

> "The plain of Argos was apparently in early prehistoric times a bay running far inland; this was gradually filled up by the deposit of the numerous streams descending from the surrounding hills."
>
> Heinrich Schliemann, Tiryns (1885, 11)

The ruins of ancient coastal settlements now stranded from the seashore have provoked a long tradition of study of the Holocene coastline shifts in the Mediterranean. Rapid sediment accumulation on the coastal plains of Greece causes coastal progradation, thus preserving marine deposits under young alluvial fill. Recognition and investigation of these buried marine deposits allow for geologic reconstruction of the environmental setting of coastal archaeological sites.

Coring is a common and successful technique to determine the stratigraphy of Holocene coastal sediments. Some examples from Greece utilizing this method are discussed by Baetemann (1985), Finke (1984), Gifford (1985), Kraft (1972), and Kraft and others (1977). When cores are aligned in a traverse, a two dimensional section of the coastal deposits can be drawn. From the cross section, the relationship and character of the sedimentary units are described and used to interpret the environmental history. For example, the extent and thickness of buried marine deposits indicate former transgressions, soil horizons reflect land stability, and alluvial deposits record times of enhanced land erosion. Samples from the cores can also be analyzed to determine the past physical and biological environment, including fauna, flora, water temperature, current activity, and salinity.

In this paper, however, we introduce an approach combining both remote sensing analysis and subsurface core data to reconstruct past coastal environments of the Argive plain. From photogeologic interpretation of a Landsat image, several geomorphic and geographic features are defined. Then analysis of the spectral data allows us to produce a computer-generated land cover map which emphasizes areas with varying surficial cover. Finally, we compared the map produced from the satellite data with the Holocene stratigraphy known from subsurface investigations to test the results of the remote sensing techniques.

The Argive plain in the Peloponnese region of southern Greece is an especially suitable location for an investigation of the application of remote sensing (satellite) to shoreline reconstructions because of extensive historical data, archaeological and geological work. Data presented here are part of an ongoing investigation of the environmental history of the Argive plain.

STUDY AREA

The Argive plain is a broad alluvial valley with an areal extent of 243 square kilometres (Figure 1). The valley is seated in a graben between two geologic units. To the west, the Artemision-Ktenia Mountains are composed of Mesozoic limestones and cherts of the Pindos zone. To the east, Cretaceous flysch and limestones make up the Arachnaion mountains of the Pelagonian platform.

Two streams traverse the west side of the valley. The perennial Erasinos River is fed by springs in the limestone caves at Kefalari.

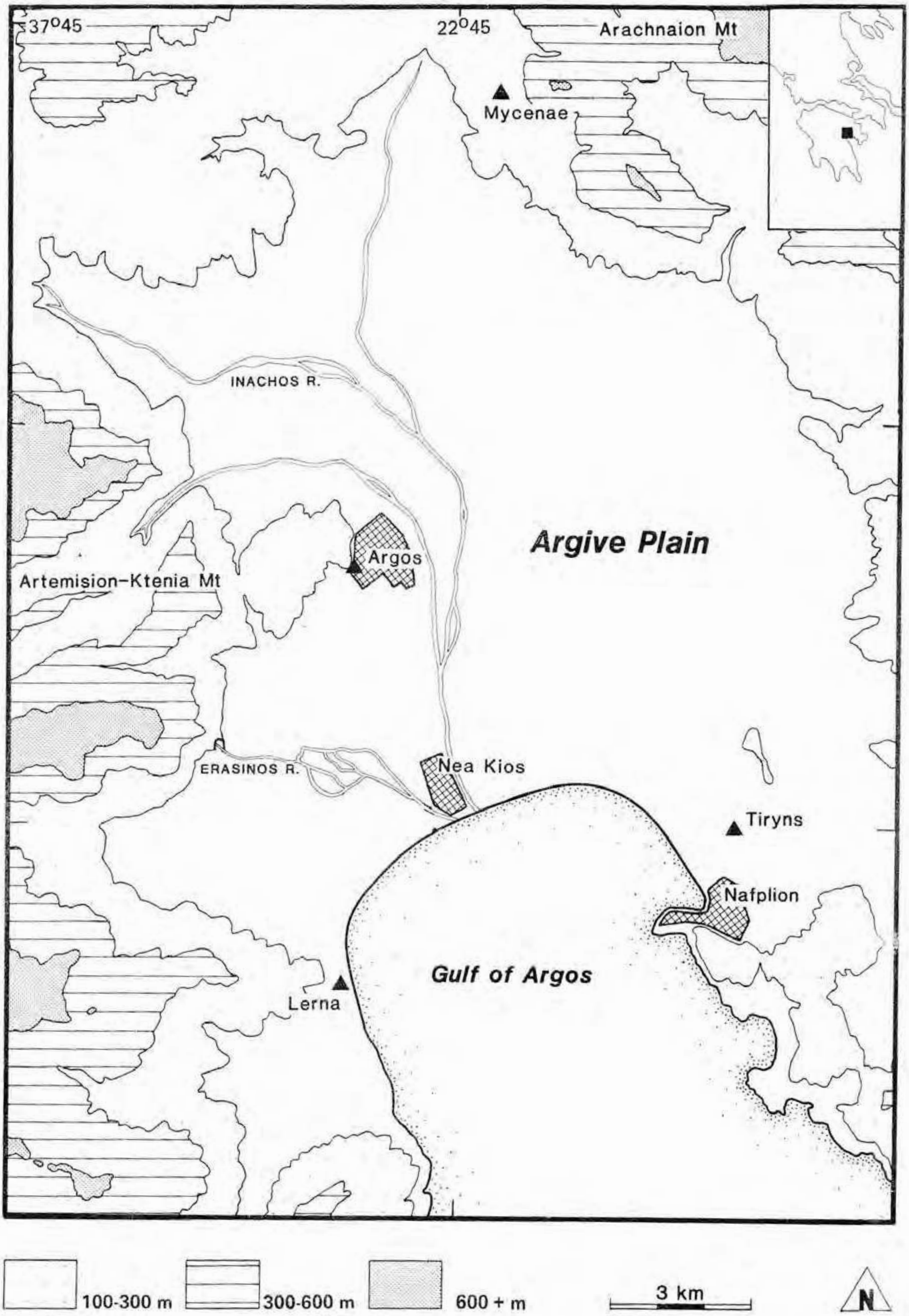


Figure 1: Location Map of the Argive plain in the Peloponnese region of southern Greece illustrating the major geographic features in the study area. Triangles represent major achaeological sites and cross hatched pattern marks the location of modern cities.

The sediment load of the Erasinos River is negligible due to its origin from water draining through fractures and caves in the limestone mountains. A seasonal stream, the Inachos River, carries most of its sediment load during flood stages. Major floods occur about once every 15 years. Sediments are either deposited on the valley floor, or are carried to the Gulf of Argos.

A broad arcuate coastal zone with very low relief separates the floodplain from the Gulf of Argos. Deposits of the coastal plain have a very high preservation potential because of the rapid sediment accumulation. Beach sand and gravel near the mouth of the Inachos River protect a portion of the coastal plain from wave action. At present, the beach barrier effectively ponds water in a small swamp near Lerna.

HISTORY AND PREVIOUS WORK

The coastal region of the Argive plain has a rich cultural history. The Neolithic (6000-3000 B.C.E.) and Bronze age site of Lerna rests upon a gentle cliff, west of the Gulf of Argos. The site of Tiryns, a Bronze age (3000-1200 B.C.E.) sister city of Mycenae, is located on a limestone knoll, 1.5 kilometres east of the present shoreline. These ancient ruins and others in the Argive plain, have given rise to century-old speculation regarding the past landscape of these sites.

Aristotle was among the first to describe environmental changes in the Argive area. In the Meteorologica, Aristotle stated that in the Late Bronze Age the area around Argos was swampy while Mycenae had excellent soil. By Aristotle's time (4th century B.C.E.), the land around Mycenae had become too dry for agriculture, but the land of Argos was arable. According to Curtius (1851), by Roman times, Pausanias (2nd century C.E.) described the Lake of Alcyon in the wetlands near Lerna as a "bottomless" lake for which Nero endeavoured, in vain, to ascertain its depth. This lake persisted into the 19th century. Other early travellers, Leake (1830) and Gell (1840), deduced that the sea must once have been as far inland as Tiryns.

In the nineteenth century, the French "Expedition scientifique de Morée" (Boblaye & Virlet 1883) took a core approximately 200 m inland from the beach. Marine gastropod shells were found in a deposit below the modern floodplain sediments. This was the earliest scientific documentation for the progradation of the coastline. Later authors often cited this data as evidence that the sea once extended farther inland (Schliemann 1885; Philippson 1892; Maull 1921). Further evidence for a transgression of the sea came from Lehmann (1937) who calculated, from the slope of the coastal plain and the lowest excavated occupational layer at Tiryns, that the coast may have been only 350 m from Tiryns. More recently, Kraft and others (1977) studied four cores drilled between Tiryns and the shore. Based on this data, they postulated an extensive middle Holocene swamp along the present coast.

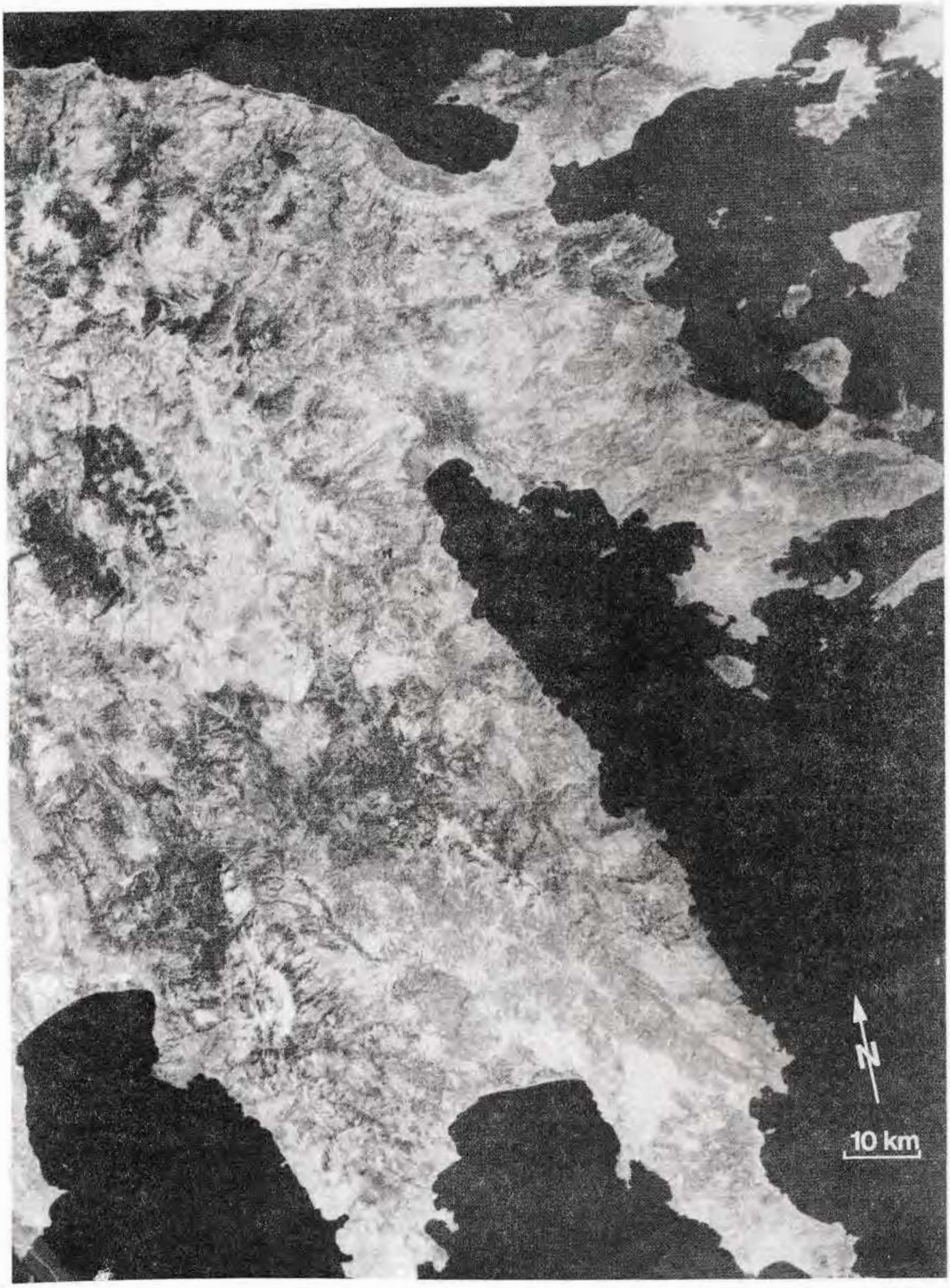


Figure 2: A photograph of a portion of a Landsat-1 image of the Peloponnese, Greece from August 2, 1972. The image is produced from reflectance information from MSS channel 5 (red wavelengths).

METHODS OF REMOTE SENSING

We will now examine the Landsat-1 coverage of the Argive plain and address whether units observed on the satellite image can provide specific information about the paleogeography of this coastal area. A section of the November 18, 1972 Landsat-1 image of the Peloponnese, Greece (scene identification #1118-08384) is used here. The area covered by one Landsat scene is approximately 185 km by 185 km; a standard photographic product of this scene is at an approximate scale of 1:1,000,000. Rotation of the earth during imaging creates a diagonal distortion in the satellite image. Figure 2 is a portion of a typical single band Landsat photographic scene of the Peloponnese from August 2, 1972 (scene identification #1010-08375).

The Landsat satellite system is equipped with a multispectral scanner (MSS) and spectral data of the Earth's surface is collected by the scanner from an orbit of about 900 km. The Landsat scanner has a spatial resolution that corresponds to a ground cell (called a pixel) of approximately 79 metres on a side. The data are recorded in four wavelength bands. Two bands (channels 4 and 5) are in the visible spectrum and correspond to 0.50-0.60 μm or green and 0.60-0.70 μm or red wavelengths. The remaining two bands, channels 6 and 7, are near infrared bands corresponding to 0.60-0.70 μm and 0.80-1.1 μm wavelengths. For additional information on Landsat instrumentation and spectral scanners, the reader is referred to Lillesand and Kiefer (1979) and Sabins (1987).

The Landsat-1 image used in this study is in a digital computer-compatible tape format (CCT). The data were analyzed using two approaches. First, we compared the visible features on the Landsat image with the known geology and vegetative cover to define geomorphic units. We then analyzed the spectral data from these units and produced a computer-classified land cover map which distinguishes areas with similar surface cover. Interpretation of the satellite data was done on a coloured computer display of the image, but for logistical reasons, are here presented in black and white.

THE ARGIVE PLAIN AS SEEN ON LANDSAT

The first level of interpretation of the data involves standard photogeologic interpretation of the satellite image. Four general geomorphic units (the bedrock, the alluvial fans, the floodplain, and the coastal area) and the bay waters are mapped on a reproduction of the Argive plain image (Figure 3a and 3b). There are clouds in the northeastern portion over the Arachnaion mountains.

UNIT 1 The bedrock consists of Triassic and Upper Cretaceous limestones as well as Tertiary marls and siliclastic flysch deposits. On the satellite image, this unit appears as bright regions with dark shadows on the northwestern face of the mountains creating a sense of the vertical relief.

UNIT 2 The alluvial fans, mostly Pleistocene in age, are present between the vegetation-rich floodplains and the barren and mountainous bedrock. The fans are mainly covered with olive trees and appear grey on MSS channel 5.

UNIT 3 The central portion of the image is the location of the Holocene floodplain deposits. These are planted with apricot and orange orchards. The November date of the image accounts for the strong infrared response (very dark on Figure 3) of the winter wet season growth.

UNIT 4 An asymmetrically-shaped coastal zone, characterized by a few artichoke fields and marshlands, separates the bay from the orchards. This zone varies texturally on the image from bright to dark.

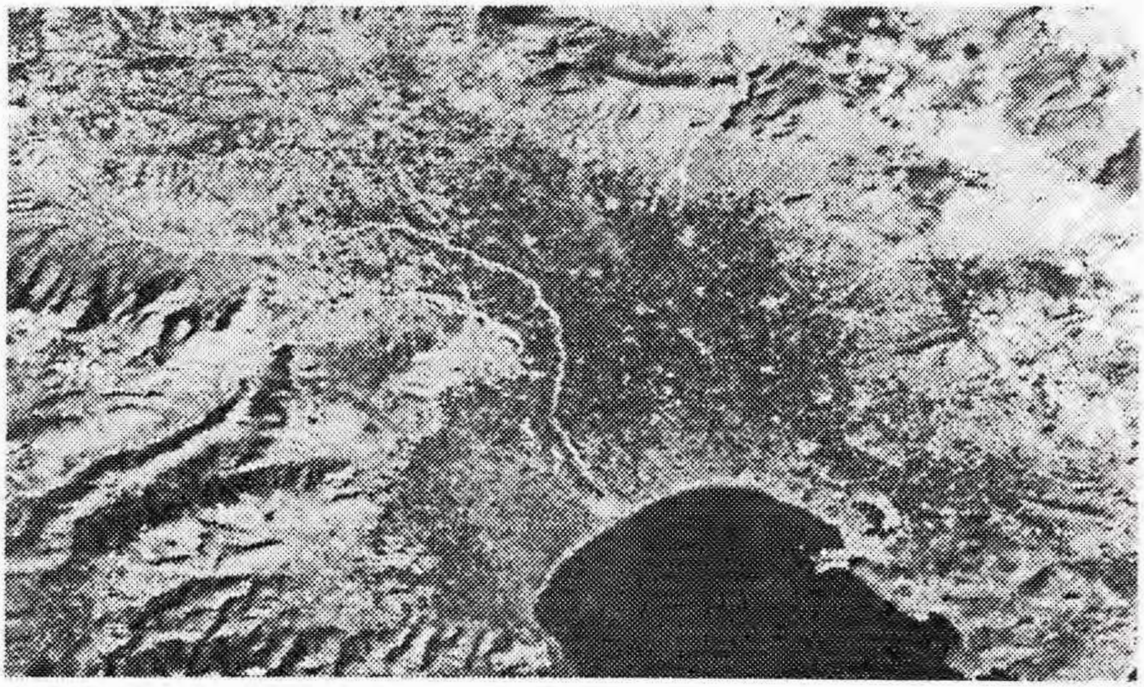
UNIT 5 The gulf water is black on the Landsat image.

The harbour town Nafplion in the southeast, the town of Nea Kios on the shore at the mouth of the Inachos River, the modern city of Argos in the west central plain, and several smaller villages are also distinguishable on the image (Figure 3).

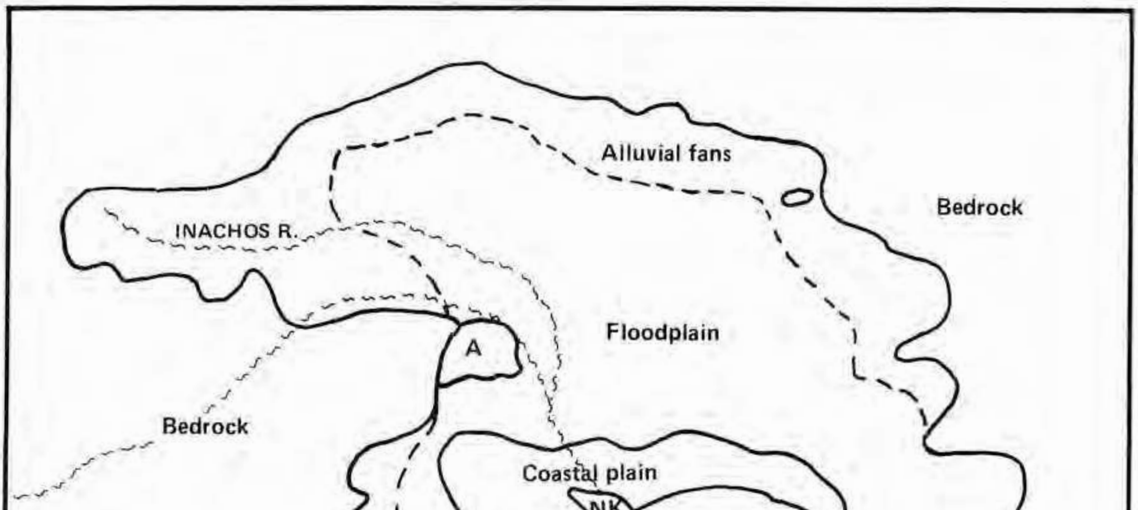
CLASSIFICATION OF THE IMAGE

The digital format of the image permits a computer analysis of the spectral data. This process involves choosing small areas on the Argive plain image to represent a distinct surface cover. The spectral data from the cover types are entered into a computer program which identifies other areas on the image with similar spectral reflectance characteristics. A description of the method involved in the computer classification method is given below.

A group of pixels, representing a known ground cover, is first delineated on the image. On the Argive plain image, seven cover types (Table 1) were defined on the basis of: vegetation density, land use, soil properties, and water variations. The reflectance information for each cover type is stored as a training set file. Next, a statistics program computes the mean and standard deviation of each of the wavelength bands in the cover type training sets. Cover types with large standard deviations indicate a greater variability in the reflectance properties. A computer classification program compares the four mean digital numbers (proportional to reflectance values) for each of the cover types to the image pixel value. If the image pixel lies within two standard deviations of the mean values of a cover type, it is assigned to that cover type. Pixels not within two standard deviations of the means for any of the cover types remain unclassified. The training set of each cover type must contain enough pixels to represent the spectral characteristics of the group but be limited



a)



b)

Figure 3: a) A portion of the Landsat-1 image from November 18, 1972 of the Argive plain, Greece used in this study. The image is here displayed in MSS channel 5. b) Diagrammatic map of the above portion of the satellite image identifying five geomorphic and geographic units. The modern cities of Argos (A), Napflion (N), and Nea Kios (NK) are marked.

enough in size to reduce large variances which might overlap other groups.

A general spectral reflectance curve (Figure 4) is a plot of the multispectral scanner (MSS) channel against the relative reflectance value for each cover type and graphically represents similarities between the groups. The graph illustrates that three major groups have distinct spectral properties -- vegetated, non- to sparsely-vegetated, and water. MSS channel 5 is the wavelength band with the maximum separation of cover types.

Table I: Cover Types used in Classification

Cover type	Description
1	Alluvial sediments
2	Dense vegetation
3	High density vegetation
4	Coastal vegetation
5	Shallow water
6	Deeper Gulf water
7	Urban areas

Cover types 2, 3 and 4 exhibit characteristic vegetation spectral reflectance -- high green and near infrared (NIR) reflection values and low red wavelengths values due to the absorption of energy by chlorophyll within the plants. Variation in relative reflectance magnitude distinguishes the coastal vegetation cover type (4) from the other vegetation. A lower NIR response in the coastal vegetation may be due to an increased amount of water retention in this coastal setting.

Bright and dry surfaces of the non- to sparsely-vegetated alluvial deposits and urbanized areas (cover types 1 and 7, respectively) have a high reflectance in the green and red wavelength bands. The values in the urban cover type have relatively stronger responses possibly due to smooth concrete walls and roofs of the buildings creating large bright surfaces which increase reflectance.

Water has a characteristic low near infrared reflectance and its presence in any of the cover types will effectively lower the NIR value. The shallower nearshore water has a higher reflectance value in each of the band wavelengths than the deeper water. This is probably due to either a brownish colour of the suspended sediments in the water or to detection of the bottom in very shallow water.

RESULTS OF REMOTE SENSING TECHNIQUES

The outcome of the spectral analysis is a computer-classified land cover map (Figure 5) which emphasises areas with similar spectral reflectance. The spectral data varies according to the soil, vegetation,

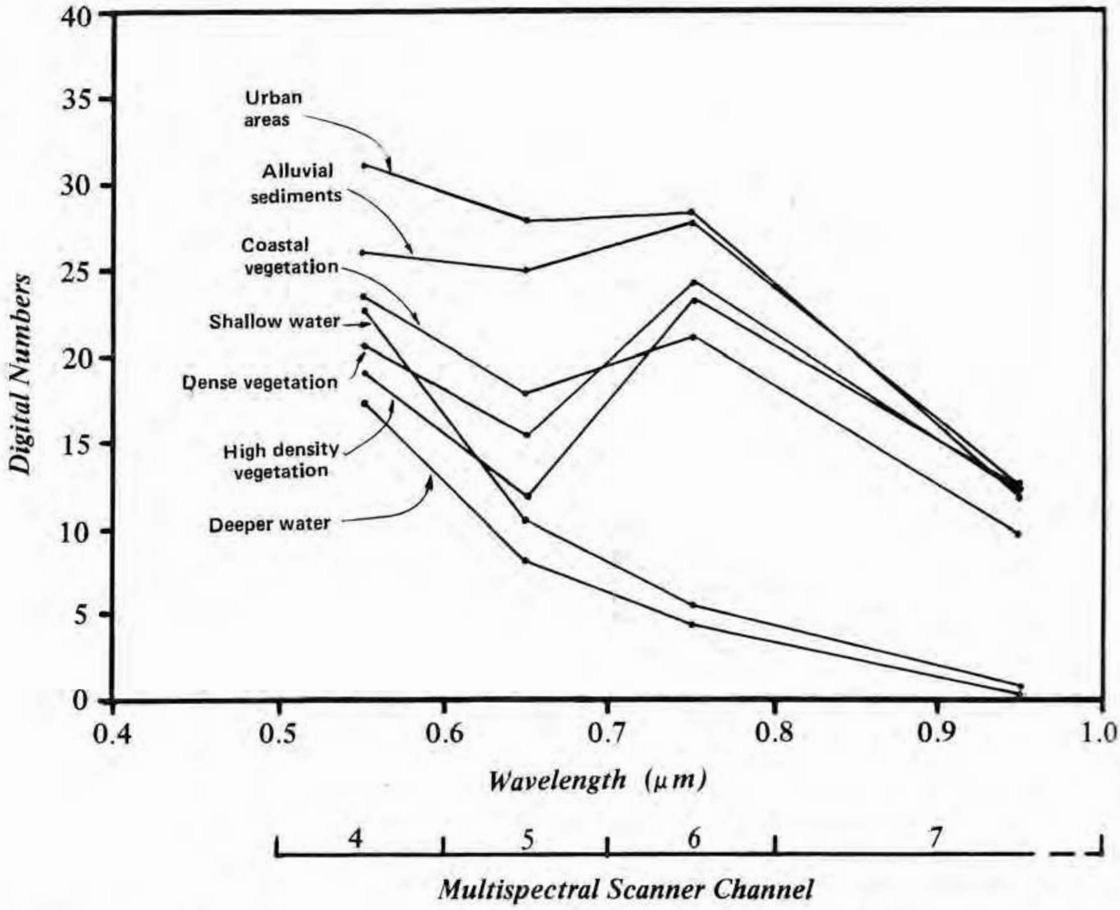
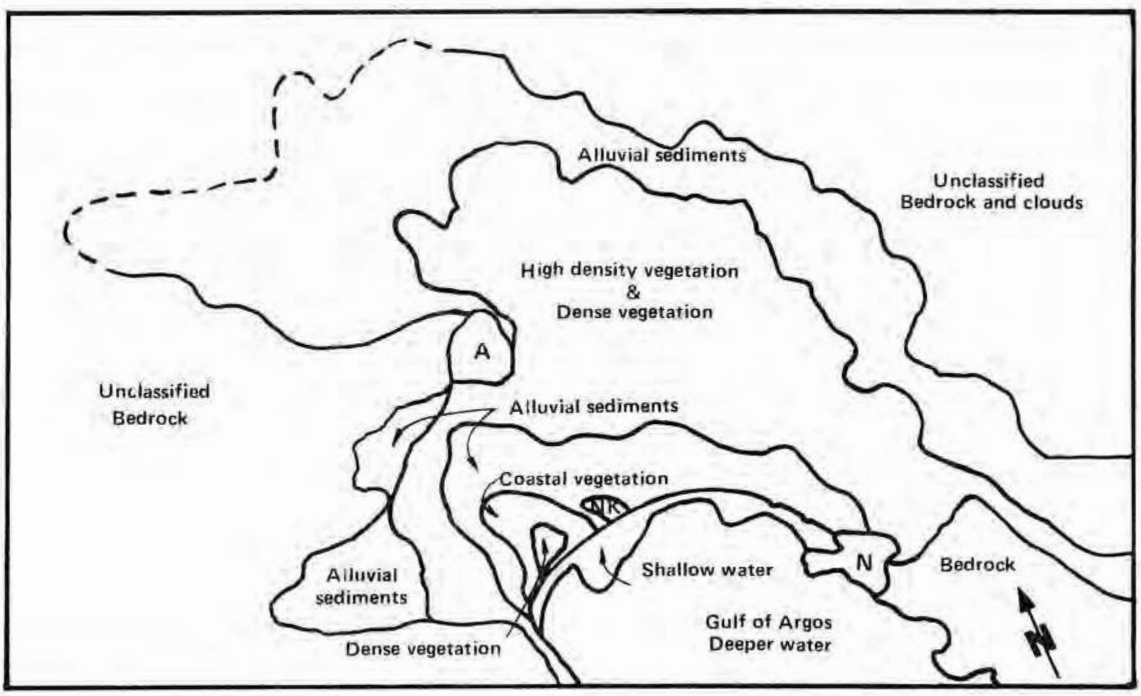


Figure 4: Relative spectral reflectance curve is a plot of the mean digital numbers (proportional to the reflectance values) for each of the cover types against the median wavelength of each of the MSS channels of the Landsat-1 satellite.

water content and other factors controlling the surficial cover. The main geomorphic features identifiable on the computer-generated land cover map are: 1) the boundary between the alluvial fans and the floodplain of the central valley, 2) the boundary between alluvial plain and coastal plain, 3) the various vegetated and non-vegetated zones within the coastal zone, and 4) the characteristics of the nearshore waters.

The non- to sparsely-vegetated alluvial fans which predominantly flank the mountains east of the Argive plain are classified as alluvial sediments. The densely vegetated valley has a strong vegetation spectral reflectance which allows the central floodplain to be distinguished from the alluvial fans. There is also a rather sharp boundary between the agriculturally-rich floodplain and the coastal plain. A change of vegetation across this boundary enables us to detect it on the satellite image. The crescent-shaped coastal plain is characterized by an outer zone of vegetation-poor alluvial deposits and an inner area of coastal vegetation. The coastal vegetation is distinct enough in spectral properties to allow its separation from the other vegetation groups. In the centre of the coastal vegetation is a zone of dense vegetation. A lush growth of reeds in this location allows for its distinction from the other coastal vegetation.

a)



b)

Figure 5: a) A computer-classified land cover map of the Argive plain showing the distribution of cover types. Seven cover types were chosen on the basis of vegetation density, land use, soil properties, and water variations. b) Sketch map of the computer- generated map. Cover types are labelled.

Along the present shoreline is an unclassified area (black) which represents modern beach deposits. Just offshore, the distribution of cover type 5 (shallow water) indicates a concentration of shallow or muddier waters along the shoreline. The lobate shallow water area at the mouth of the Inachos River is a submerged delta front. The direction of longshore transport is seen on the computer classified land cover map in the westward skewing of the deltaic deposits.

Do the boundaries observed provide specific information about the Holocene paleogeography? To test our observations and methods of remote sensing, we compared the results of the image interpretation to subsurface core data.

SUBSURFACE INVESTIGATION OF COASTAL SEDIMENTS

METHODS

Subsurface data presented in this paper are based on 11 drill sites. Nine cores to a depth range of 4.1 to 10 metres were taken with a 10 cm diameter Eijkelkamp hand auger. Two 30 cm diameter holes (17 and 20 m deep) were drilled using a bailer rig by a commercial drilling company. The auger and drill sites are aligned in one cross section stretching 5.0 km from the margin of the town of Argos to the Gulf of Argos. In addition to the 11 core sites aligned in cross section, stratigraphic information from 14 other core sites is compiled here (Figure 6).

Auger cores were described in the field. Descriptions include: lithology, colour, soil properties, and macrofossil content. Samples were taken for laboratory analysis of soil properties, grain size, microfossil identification, and dating. Samples from the bailer drilling were taken at one metre intervals and sieved in the field. Mesh widths of 0.063 and 2.0 mm were used to split the sample into sand and gravel fractions. The sand fraction was analyzed using a binocular microscope to recover microfossils and to describe shape, composition and texture of the grains.

Potsherds found in the cores were used to assign maximum ages to the strata. These ages were determined by archaeologists of the Deutsches Archäologisches Institut in Athens. In addition, one radiocarbon date was obtained from a peat in core AP 49 at a depth of 5.8 metres. Correlation between cores is based on radiocarbon date, relative ages determined from soil development, archaeological dates, and sedimentary units which were used as marker horizons.

STRATIGRAPHY

The lowest sedimentary layer (Unit A, Figure 7) is a sequence of consolidated , red soils developed in alluvial sediments. The well developed soil properties -- thick clay films and calcium carbonate nodules >1 cm in diameter -- indicate that this unit is of Pleistocene

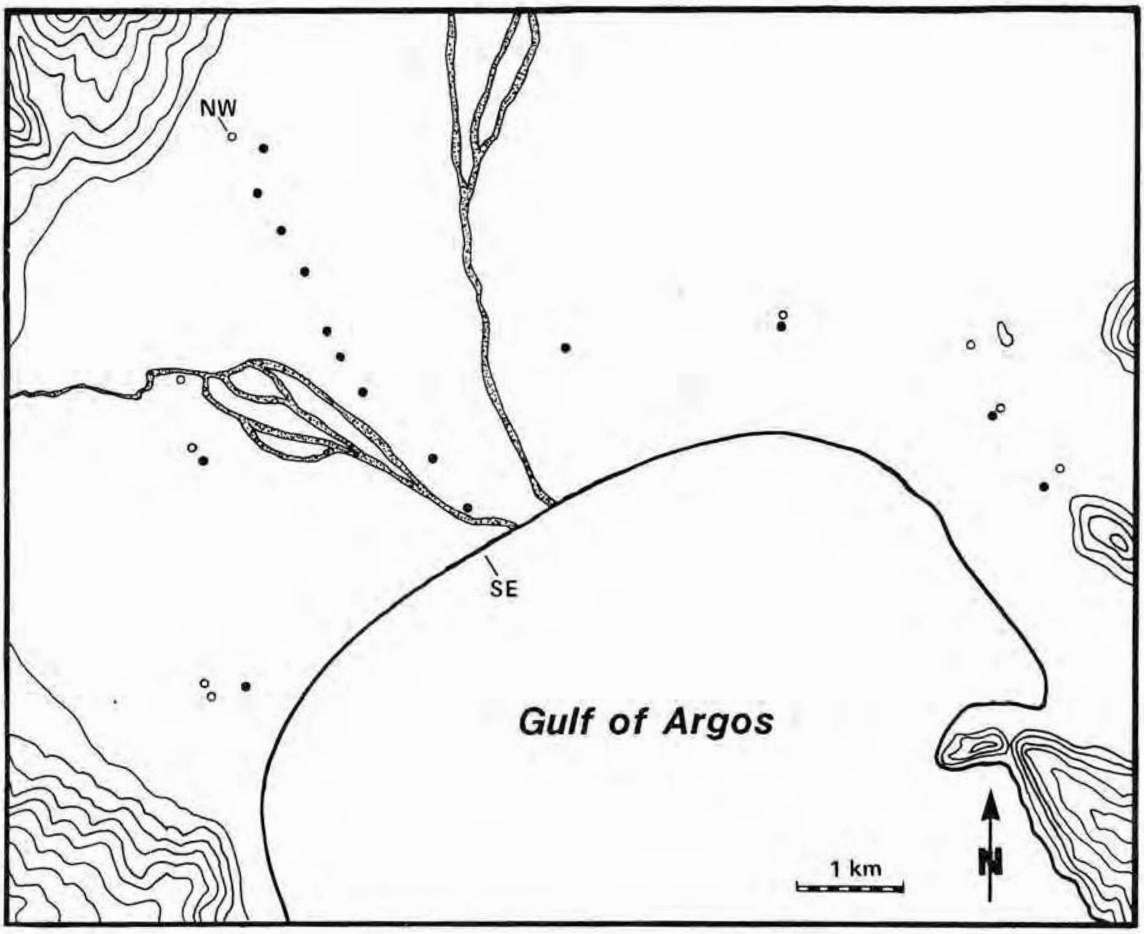


Figure 6: The Argive plain coastal zone with core location. Transgressive deposits are present in sites marked with filled circles, and are absent in sites marked with open circles. The stratigraphic sequence of the NW-SE line of section is described in this paper. Contour interval = 50 m.

age. Locally, the Pleistocene soil unit is overlain by a younger soil (Unit B). Unit B lacks the nodular carbonate, advanced clay films, and red coloration found in the older soil, and it does not contain potsherds. This soil is therefore inferred to be early Holocene in age.

Blue-grey silts and clays (Unit C), deposited in a marine to lagoonal environment, bury the early Holocene and Pleistocene sediments. These Unit C muds thin landward, reaching a maximum thickness of six metres near the shore, and disappear about 4.8 kilometres inland. Peat beds which include both brackish and freshwater shells, are intercalated with the muds. One peat sample (AP 49-5.8) from approximately 3 metres above the late Pleistocene-early Holocene soil and 900 metres inland, yielded a corrected radiocarbon age of 3820 ± 100 B.C. (calibrated after Pearson et al., 1986). The distribution of the Unit C facies can be mapped using stratigraphic data from cores off of the line of section (Figure 6). Unit C is characterized by a landward thinning and a definable inland extent.

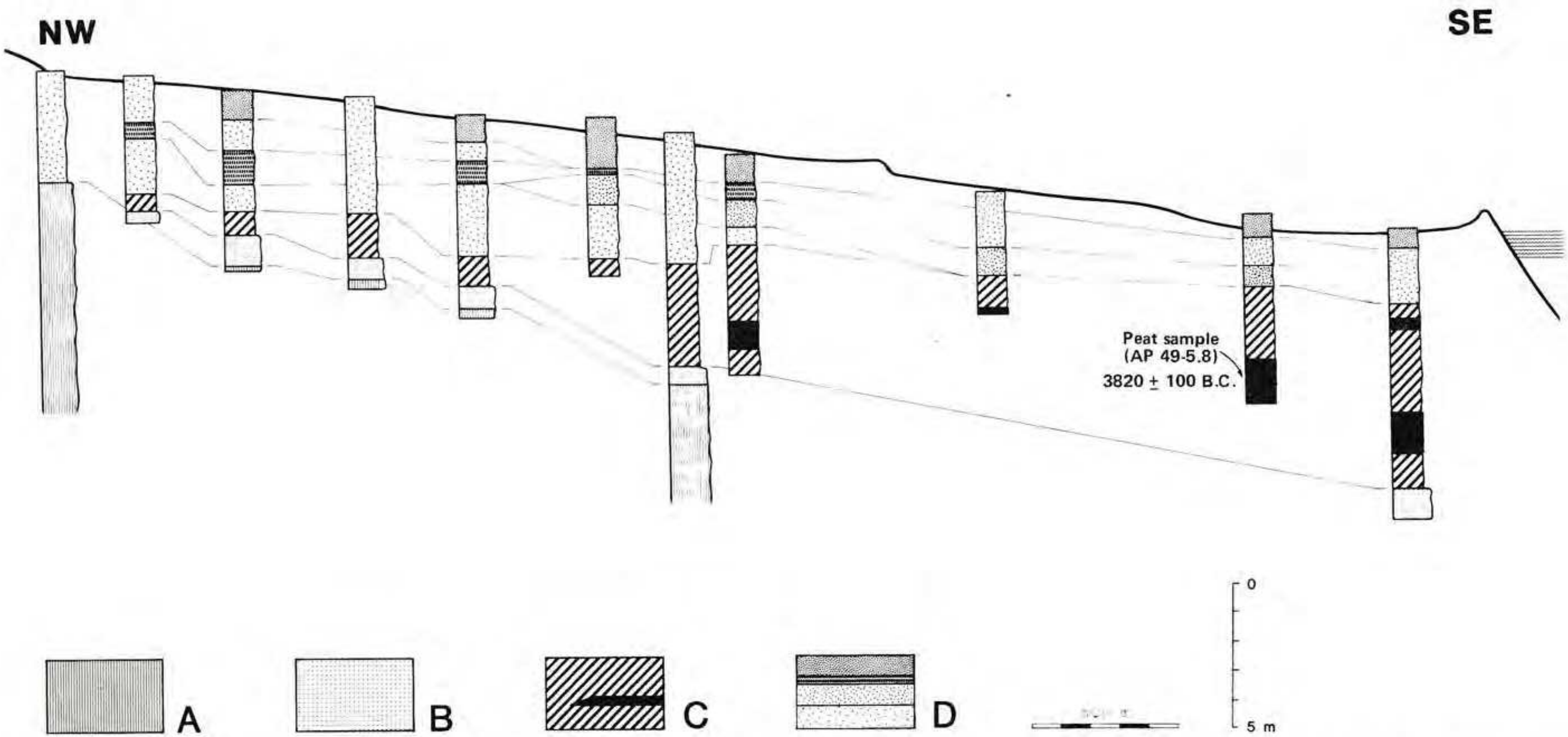


Figure 7: Cross section of drill core data with designated stratigraphic units. Unit A is a red Pleistocene soil sequence with calcium carbonate nodules greater than 1 cm in diameter. Unit B is an early Holocene soil lacking advanced carbonate and clay film development. Both soils indicate periods of land stability.
The deposits of Unit C are blue-grey clays and silts with some peat beds marked in black. Unit C muds are interpreted as subaqueous deposits and its inland extent marks a maximum transgression. Unit D consists of interbedded alluvium and soil up to 4 metres thick. Cores above the line of section represent core sites off of the line of profile at a slightly different elevation.

The deposits of Unit D, yellowish brown clay loam divided into separate horizons by soil development, overlies Unit C. Potsherds found within Unit D range from Neolithic to Hellenistic age. More than 2 m of post-Hellenistic alluvium is present in the upper section of this unit.

DEPOSITIONAL HISTORY

Unit C muds record an early to middle Holocene marine transgression which began before 3820 ± 100 B.C. since the dated peat (AP 49-5.8) was located well above the base of Unit C. The inland limit of the subaqueous Unit C deposits marks the maximum shoreline of this

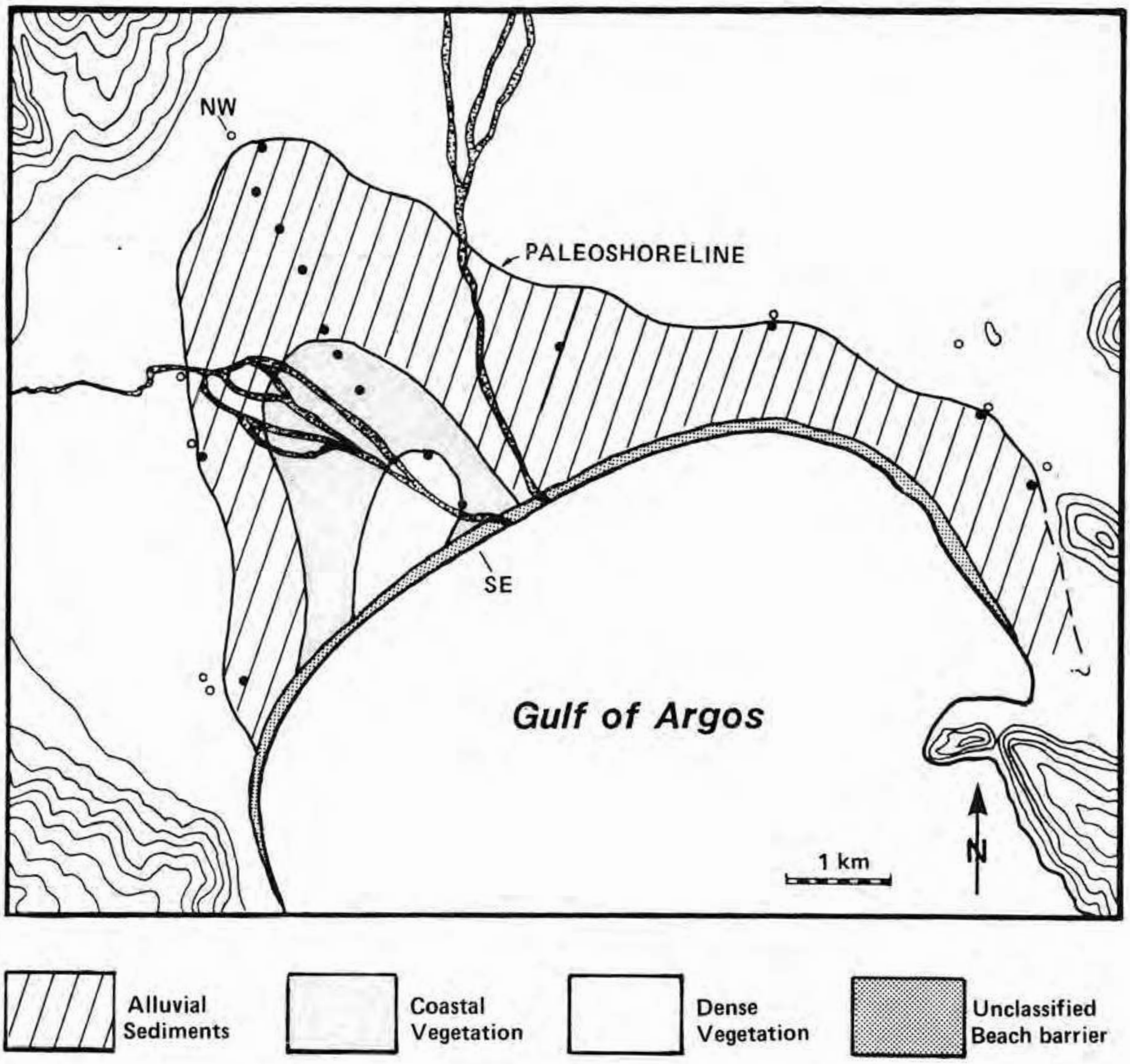


Figure 8: Projection of boundaries seen in the coastal region of the Argive plain on the computer-classified land cover map onto location map of subsurface core sites marking the presence of transgressive muds (solid circles) and their absence (open circles). The boundary between the alluvial sediment-covered coastal area and the densely vegetated floodplain seen on the satellite image correlates to the inland limit of the subsurface marine to lagoonal mud unit, marking the maximum early to middle Holocene transgressive shoreline.

transgression. The palaeoshoreline corresponding to the transgression is the boundary between cores with Unit C muds and cores where it is absent (Figure 6).

Landward of a beach barrier which developed during the transgression, peats were deposited in a lagoon. Snail shells indicate that brackish to freshwater conditions prevailed due to the discharge of river as well as seawater into the lagoon. Although most of the lagoon has been filled with sediment and is now overlain by floodplain alluvium of Unit D, in Nea Kios remnants of the wetland conditions persist. During shoreline progradation periods of land stability and soil formation were separated by periods of sediment aggradation.

We turn now to the comparison of the subsurface stratigraphy and the facies distribution with the Landsat imagery.

CONCLUSIONS

Geomorphic units identified on the Landsat-1 image and computer classification methods of remote sensing show the areal distribution of various surficial cover that are defined on the basis of vegetation, land use, soil properties, and water variations. Figure 8 is a map of the coastal zone of the Argive plain which illustrates a projection of computer-classified cover types from the satellite image onto the location map of the core sites. From the comparison of the two data sets (satellite and subsurface), we see that the sharp boundary between the agricultural-rich alluvial valley and the coastal plain seen on the satellite image as a vegetation change correlates to the inland limit of the subsurface Unit C marine to lagoonal muds. The spectral reflectance of coastal plain at the boundary to the floodplain is characterized by the non- to sparsely-vegetated alluvial sediment cover type. Since we know from the subsurface data that the Unit C muds do not extend farther inland under the sediments of the central valley, we infer that the subsurface transgressive muds affect the surface geology (i.e. change in soil, vegetation, or water properties) enough to allow the detection and the identification of a palaeoshoreline.

Within the western side of the coastal plain, the area mapped as coastal vegetation (Cover type 4) correlates with the subsurface peat deposits from the line of section. This is the probable location of a middle Holocene lagoon. At the centre of the Holocene deposits, the densely vegetated (Cover type 2) area correlates to the modern day wetlands which are remnant of an earlier lake.

Of particular interest to coastline reconstruction studies, the maximum extent of the early to middle Holocene transgression is recorded in the satellite image even though the deposits are covered by 4 metres of modern floodplain deposits. Since Landsat satellites record only the reflectance properties of the upper 0.01 mm of the surface, we can deduce that the surface variations seen as vegetation, soil, and water reflectance changes on the Landsat image are controlled by the surficial geology which can be correlated to subsurface units. Interpretations of the Landsat data as presented here, however, must be verified by fieldwork. This method of satellite data interpretation is not meant as a replacement of fieldwork but as a reconnaissance technique to minimize the amount of necessary field sampling and to maximize the area of potential study.

ACKNOWLEDGEMENTS

We wish to thank the Stanford Remote Sensing Lab and R.J.P. Lyon for supplying the Landsat-1 CCT used in this study and for the generous use of equipment, programs (written by Kai Lanz), and supplies. The results presented in this paper are part of the "Argive Plain Project", a cooperative investigation carried out by the "Deutsches Archäologischen Institut" in Athens and the Department of Geology at Stanford. We would like to thank the German School for their logistic help in the field and Tjeerd van Andel for his supervision of the project. Dr. H. Haas at the radiocarbon laboratory of the Institute for the Study of Earth and Man in Dallas provided dates for peat sample AP 49-5.8. Thanks are extended to Lisa E. Wells, Kevin O. Pope, Andy Tomlinson and others who reviewed drafts of this paper and to Cleavy McKnight for assistance in production of the image figures.

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