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GRADUATE SCHOOL

The Middle and Late Holocene Geology and Landscape Evolution of the Lower Acheron River Valley, Epirus, Greece

A THESIS
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Mark Richard Besonen

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Table of Contents

LIST OF FIGURES

PREFACE AND ACKNOWLEDGMENTS

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ABSTRACT

The lower Acheron River Valley, Epirus, Greece, hosts a rich, archaeological heritage dating back to the Lower Palaeolithic (Dakaris, 1971). Beginning with the Odyssey of Homer in the eighth century BC, numerous ancient authors make reference to the valley and describe a landscape configuration that is significantly different from that of the present. Three notable discrepancies concern:

1.) the size of the Glykys Limen (modern Phanari Bay),
2.) the nature, geometry, and evolution of the Acherousian lake, and
3.) the course of the Acheron River with respect to Kastri during the Classical Period.

Are these ancient authors incorrect in their descriptions of the valley, or can a natural sequence of geomorphic evolution account for such discrepancies? To answer this question, an examination of the changing paleogeography and paleoenvironmental configuration of the valley during the past 4000 years was undertaken.

Twenty-eight gouge auger sediment cores were taken from various locations in the valley between 1992 and 1994. Selected sediment samples underwent analyses of microfossil assemblages, organic carbon content, grain-size, magnetic susceptibility, and anhysteretic magnetization. Results from these analyses were used along with stratigraphic data and eight radiocarbon dates to reconstruct the middle and late Holocene paleogeography of the valley. The reconstructions suggest that the accounts given by ancient authors are correct, and that the discrepancies are the result of natural landscape evolution. In fact, the picture that emerges shows that recent geomorphic change in the valley has been quite significant with nearly six kilometers of shoreline progradation having occurred during the last 4,000 years.

INTRODUCTION

The earth's coastal systems have undergone profound change since the end of the Pleistocene. From that time, and through the globally-warmer climate of the early and middle Holocene, rapidly rising eustatic sea level of at least 100 meters has produced an endlessly changing series of coastal configurations. By approximately 4000 years ago, the rapid eustatic sea level rise either decreased abruptly, or terminated completely (Kraft, 1972). Since that point, both natural processes and most recently anthropogenic influences have continued to shape the world's coasts. Local coastal evolution due to these two processes may be orders of magnitude less than that produced by rapidly changing eustatic sea level, but over thousands of years it can amount to significant change.

The magnitude and effect of changing coastal geomorphology during the past 5,000 years is probably more profound along the coasts of the northeastern Mediterranean Basin than in any other part of the world. This is the case for two reasons. First, eustatic sea level has been relatively stable through this time; therefore, the simple physiography of the narrow, rocky, and mountainous coasts has acted like a funnel concentrating sedimentary deposition or erosion in limited areas. In contrast, where deposition or erosion has occurred over wide areas such as the broad U.S. Atlantic coastal plain, changes in shoreline position have been relatively less rapid during this period of stable eustatic sea level. The second reason is that archaeological remains and literary and historical references to this region from the last few millennia are abundant, and have been more thoroughly studied and examined than for any other part of the world. The existence of these "benchmarks" makes recent changes in landscape configuration and topography quite apparent.

Greece (Figure 1) represents the perfect union between these two factors, and as a consequence, modification of its coastal configuration during the middle and late Holocene is conspicuous. Pervasive alpine tectonism has molded the Greek landscape, and left it extremely rugged and mountainous. Arable land suitable for agriculture occurs almost exclusively in the form of very flat, low-lying river valley coastal plains, and

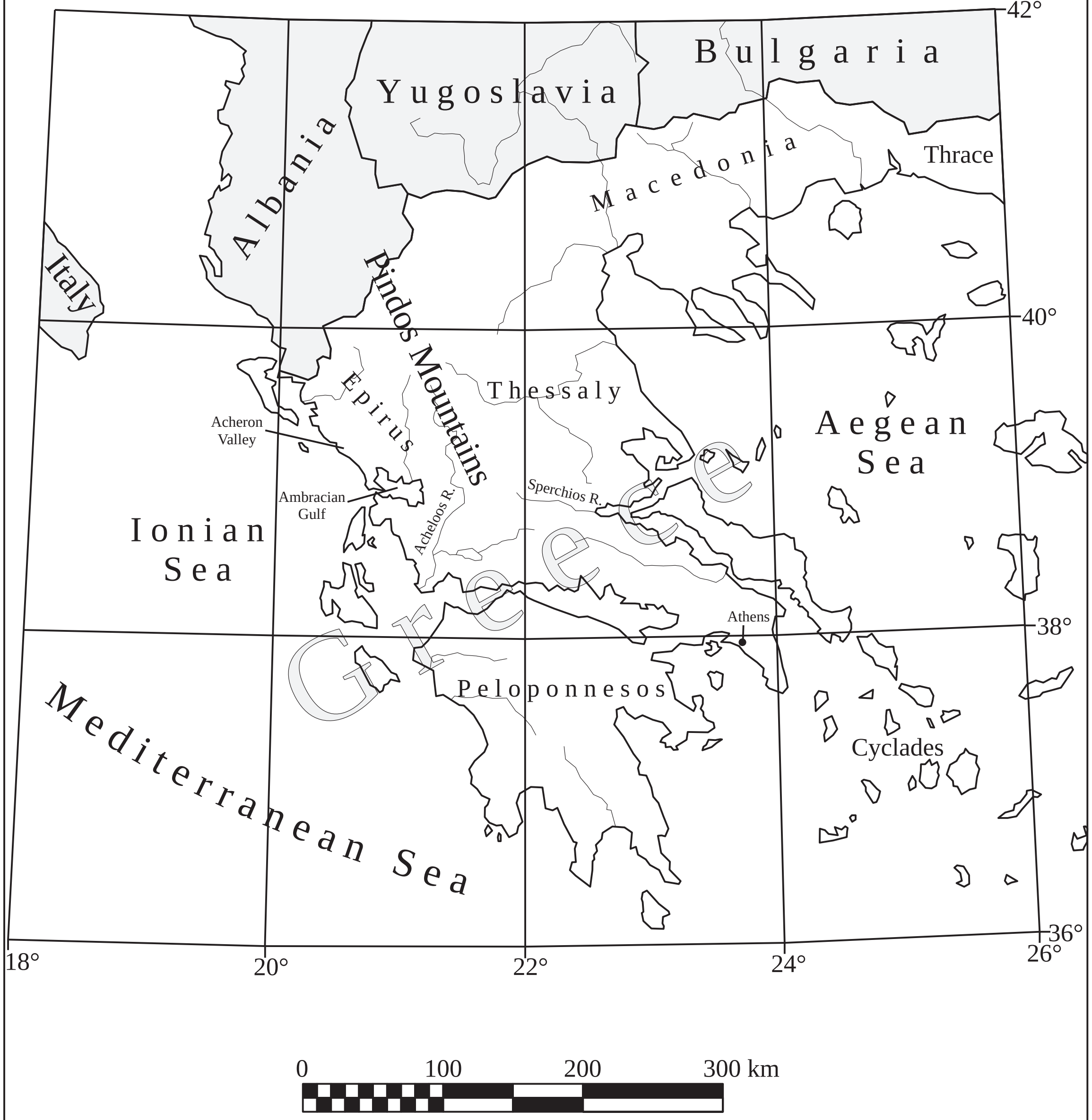


Figure 1--Area map of Greece

accounts for only 30% of the country's area (Dakaris, 1971). Human occupation at the present and in the past has naturally been concentrated on and around these coastal plains. As a result, most Greek coastal river valleys invariably host a very rich archaeological heritage, and are often mentioned in the works of ancient authors.

The disciplines of geology and archaeology find a natural interface here, both contributing to, and benefiting from one another. Literary and historical accounts along with precisely dateable artifacts and contexts provide the geologist with abundant chronologic control that is almost unparalleled for any other moment of geologic time. Archaeologists benefit by gaining a broad understanding of the physical environment in which the material remains they study were generated. Indeed, one of the more important realizations of modern archaeology is that the physical environment is dynamic. The resources, topography, and configuration of the landscape noted in a particular location today were no doubt different in the past. Judgements and interpretations about past cultures and civilizations must therefore take these dynamic elements into consideration.

The present project is offspring of a fortuitous relationship between geology and archaeology (see Tartaron (1996) for the archaeology component). Its objective has been to interpret and understand the changing geomorphology, topography, and paleoenvironments in the lower Acheron River Valley of Epirus, Greece (Figure 2) from the middle Holocene through the present. It was motivated and supported by the Nikopolis Project, a multidisciplinary archaeological survey of southern Epirus directed by Dr. James Wiseman of Boston University. The Boston University team has devoted a significant amount of time to survey in the lower Acheron Valley because of its rich archaeological heritage. This heritage is recorded not only by material remains, but by literary and historical references back to at least the eighth century BC when Homer, the ancient Greek epic poem writer, is thought to have lived. Homer and the ancient Greeks considered the Acheron to be an infernal river, and held that the valley was an entrance into the Underworld (Homer, Odyssey, X.508-515).

Various other ancient literary and historical sources also make reference to the valley (see Tartaron (1996) for complete documentation), and their accounts depict a

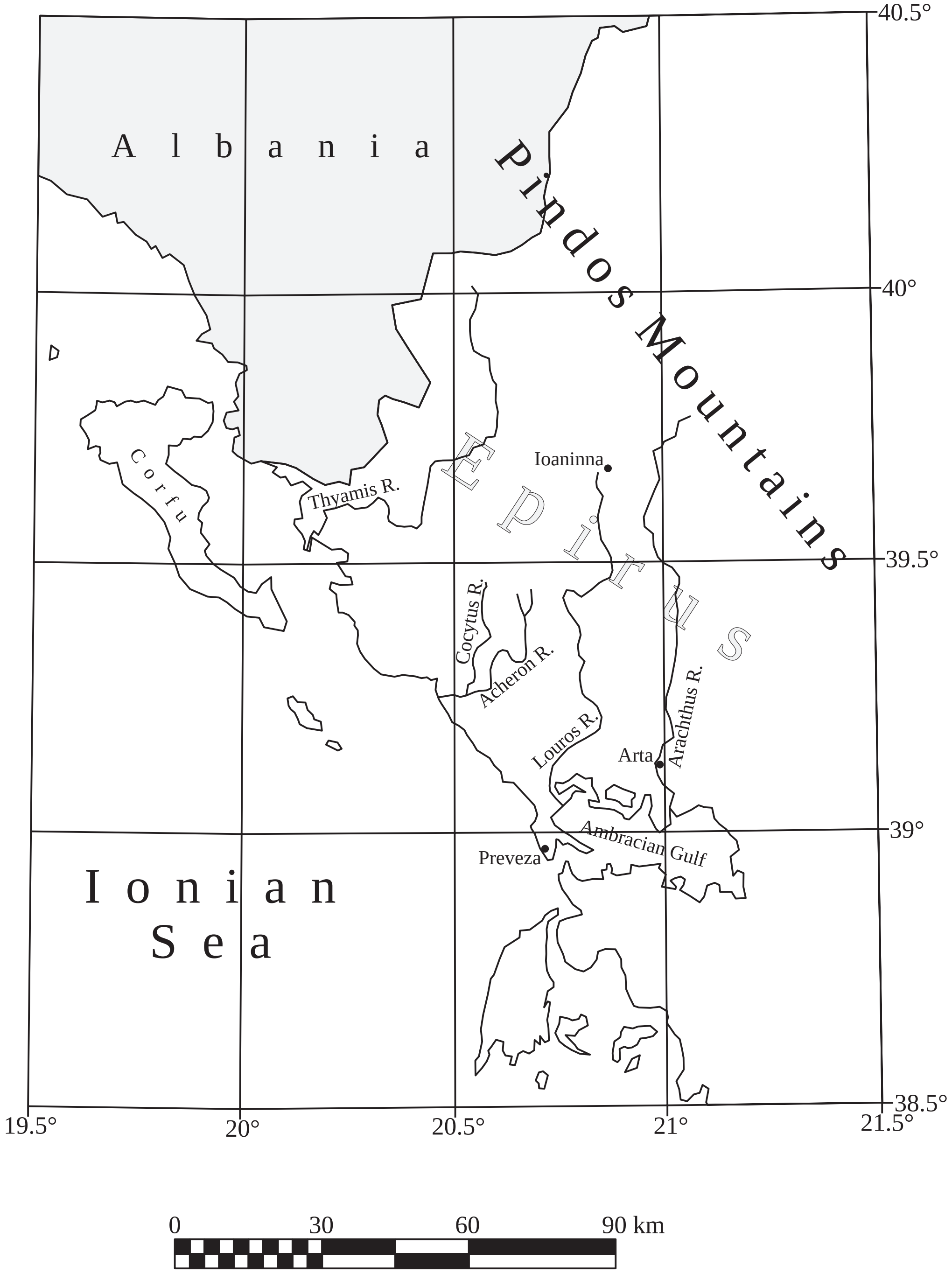


Figure 2--Area map of Epirus

landscape configuration that does not match the topography at present. This poses a problem for archaeologists who attempt to relate ruins in the valley with particular settlements mentioned in ancient accounts. Are these ancient authors mistaken in their descriptions of the valley, or can a natural sequence of landscape evolution account for such discrepancies? Three conspicuous inconsistencies involve:

1) the size of the Glykys Limen (modern Phanari Bay),
2) the nature, geometry, and evolution of the Acherousian lake, and
3) the course of the Acheron River with respect to Kastri during the Classical Period.

The explanation and resolution of these three discrepancies are goals of the present project, and are of equal interest to both the Boston University archaeological and geological teams. In the first case, the information will be extremely useful for interpretation of the valley's archaeological record, and in the second case, it will reveal details about the mechanisms and rates of recent geomorphic evolution which have operated in the valley.

PHYSIOGRAPHY, GEOLOGY, AND NEOTECTONICS OF EPIRUS AND THE LOWER ACHERON VALLEY

Physiography:

Epirus is the northwesternmost province of Greece, bounded to the north by Albania, to the east by the Pindos Mountains, to the south by the Ambracian Gulf, and to the west by the Ionian Sea (Figures 1 and 2). A series of compressional alpine tectonic events beginning in Jurassic times and continuing through today provides the pervasive underlying NW-SE structure of Greece as well as the rest of the Balkan Peninsula (Institut de Géologie et Recherches du Sous-Sol—Athènes and Institut Français du Pétrole, 1966d; hereafter abbreviated as IGRSS/IFP, 1966d). Similar mechanisms and processes have sculpted and molded the landscape of western and northern Anatolia. In his study of the alluvial morphology of several rivers in that region, Russell (1954) describes the landscape as follows:

> "Though the gross features of the topography are structural in origin, one of the most impressive characteristics of Anatolian rivers is alluvial drowning along their lower courses. Alluviation which has taken place during the last general rise of sea level accounts for flat flood plains that stand in abrupt topographic unconformity with the bedrock faces of adjacent valley walls. Toward coasts, where flood plains become deltas, isolated hills commonly jut above the alluvium which surrounds them on all sides. These are the tops of once much higher eminences which belonged to a much rougher topography that was created by denudations when sea level stood low, during glacial stages of the Pleistocene."

This passage also exactly describes the situation in the lower Acheron River Valley, as well as much of the Greek coast. It furthermore hints at the extensive and rapid landscape evolution that has occurred in these areas following the end of the Pleistocene epoch, and provides reference for an understanding of the middle and late Holocene geology in the valley.

Previous Geologic Work Concerning Epirus:

The essential stratigraphy and overall NW-SE trending structure of Greece and neighboring areas was perceived by workers such as Philippson, Renz, and Brunn from their studies at end of the last century through about the middle of the present century (IGRSS/IFP, 1966d). Beginning in the late 1950's, a more detailed and comprehensive picture of the bedrock and structural geology of Epirus was realized by a series of French geologists, in particular Jean Aubouin.

Aubouin (1959) presented the first detailed study and interpretation of the stratigraphy and tectonics of Epirus which has served as the base and framework for successive work. This was later followed by another volume concerning the region (Aubouin, 1965). The most recent major monograph concerning the geology of Epirus became available in 1966. Published jointly by the Institut Grec de Géologie et Recherches du Sous-Sol and the Institut Français de Pétrole (IGRSS/IFP, 1966d), the volume was a result of the exploration for petroleum, and built on the work by Aubouin.

Russell (1954) noted that the major features of the landscape in Anatolia were structural in origin, and the same is true of Epirus. The region consists of a series of NNW-SSE trending folds and fault blocks which form a series of parallel limestone

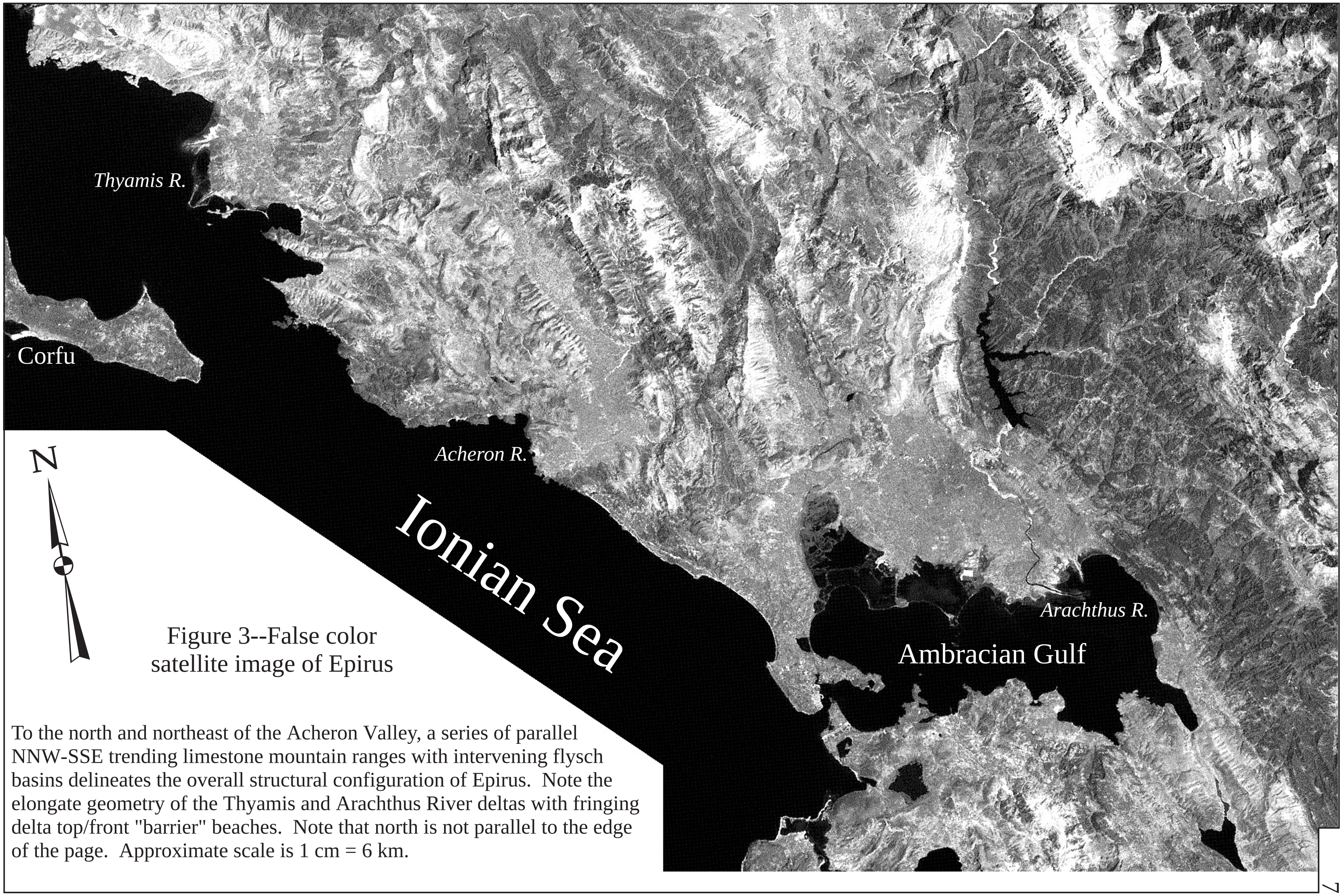


Figure 3--False color satellite image of Epirus

To the north and northeast of the Acheron Valley, a series of parallel NNW-SSE trending limestone mountain ranges with intervening flysch basins delineates the overall structural configuration of Epirus. Note the elongate geometry of the Thyamis and Arachthus River deltas with fringing delta top/front "barrier" beaches. Note that north is not parallel to the edge of the page. Approximate scale is 1 cm = 6 km.

mountain ranges with intervening flysch basins. The ranges and basins can be clearly delineated in false-color satellite images of the region (Figure 3). The folds and thrust fault blocks have been formed in a sequence of compressional orogenic events since the late Jurassic Period (IGRSS/IFP, 1966d). Some of the ranges reach over 2000 meters in elevation, but on average range from 1200-1700 meters (King et al., 1993). The marked and varied relief noted between the ranges and basins is a direct function of the structure and contrasting lithologic properties of the limestone and flysch (IGRSS/IFP, 1966d). Relief is even more spectacular along the coasts where bedrock cliffs rise directly from the sea, or very flat, coastal river alluvial plains give way in abrupt topographic discontinuity to carbonate bedrock valley walls (Figure 4).

Geology:

The simplified geology of the lower Acheron Valley shown in Figure 5 was compiled from several maps (IGRSS, 1966a, 1966b, and 1966c) produced by the Institut de Géologie et Recherches du Sous-Sol for the IGRSS/IFP (1966d) report. Recent alluvium floors the very flat valley bottom flanking the steep, carbonate bedrock valley walls. The valley walls are composed for the most part of Mesozoic and some Eocene limestones. The limestones are cherty, range from fine-grained to sublithographic, are usually fossiliferous (with the remains of calcareous algae, radiolarians, rudist clams, ammonite cephalopods, and globigerinid and other foraminifera), and in places are dolomitized and/or brecciated. Upper Eocene to Lower Miocene (Aquitanien) flysch outcrops at the base of the eastern valley wall. The flysch is composed for the most part of alternating soft micaceous sandstones and shales with intercalated thinly-bedded biogenic limestones and marls near the top. The top of this flysch unit effectively marks a large shallow thrust fault over which the more competent Mesozoic limestone has ridden to create one of the limestone ranges seen in the false color satellite image (Figure 3). Recent talus and scree slopes cover the contact and most of the flysch unit. A small strip of the Pliocene Arkhangelos Formation outcrops in the southern valley wall to the east of Pountas ridge. This is a mixed marine and continental unit which consists of conglomerates, muddy sands, and lignitic and marine shales. Finally, an inferred active,

Figure 4--Photo of concentric accretionary beach ridges surrounding Phanari Bay

(Note: This photo was taken from the bedrock highlands on the north side of the valley and the view is towards the south. The Acheron River is delineated by the faint dark band of trees visible in the background of the photo.)

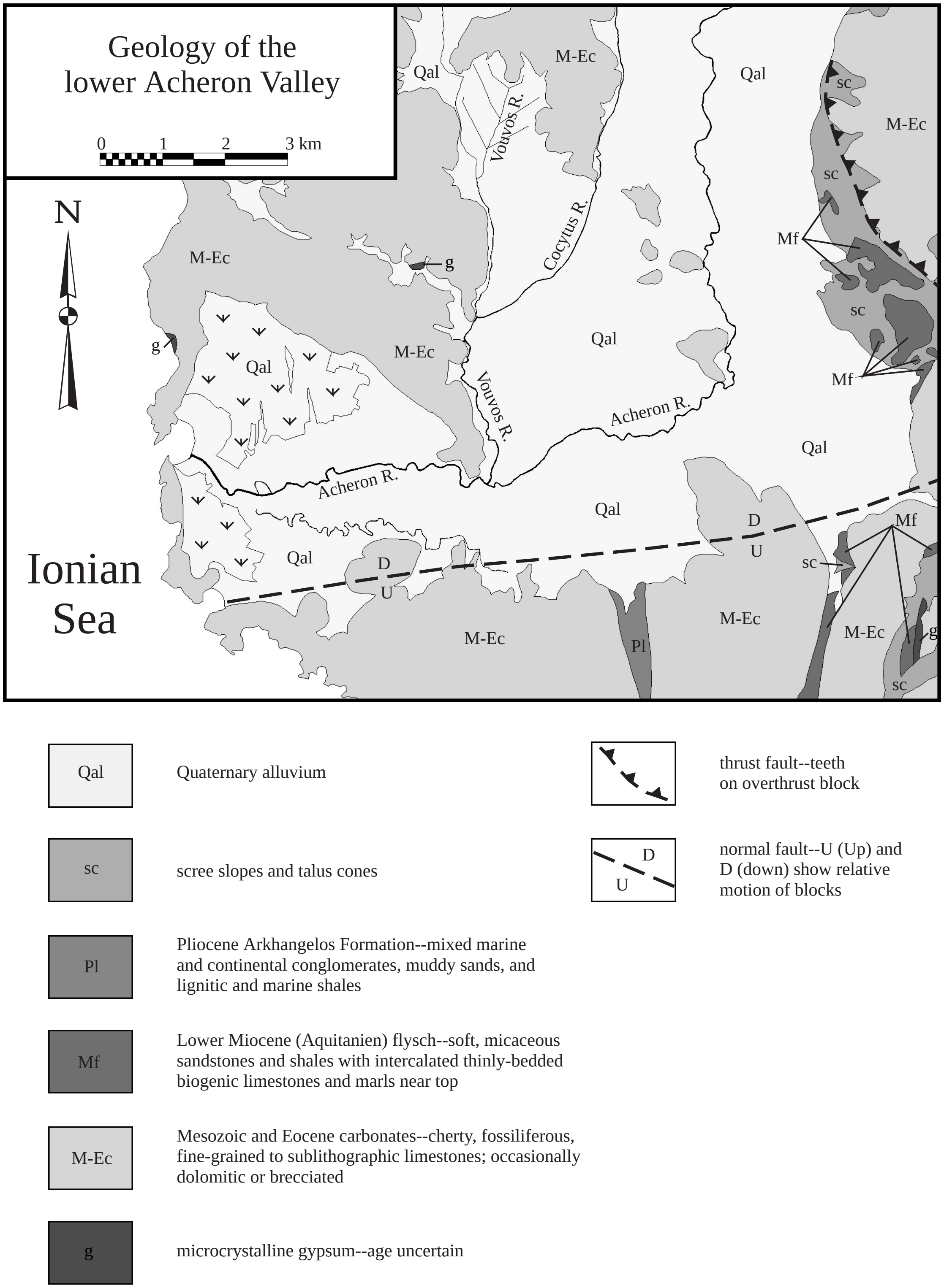


Figure 5--Simplified geology of the lower Acheron Valley

east/west-trending normal fault exists along the south valley wall (Waters, 1994), though this fault was not recognized by the 1966 IGRSS/IFP report.

Neotectonics:

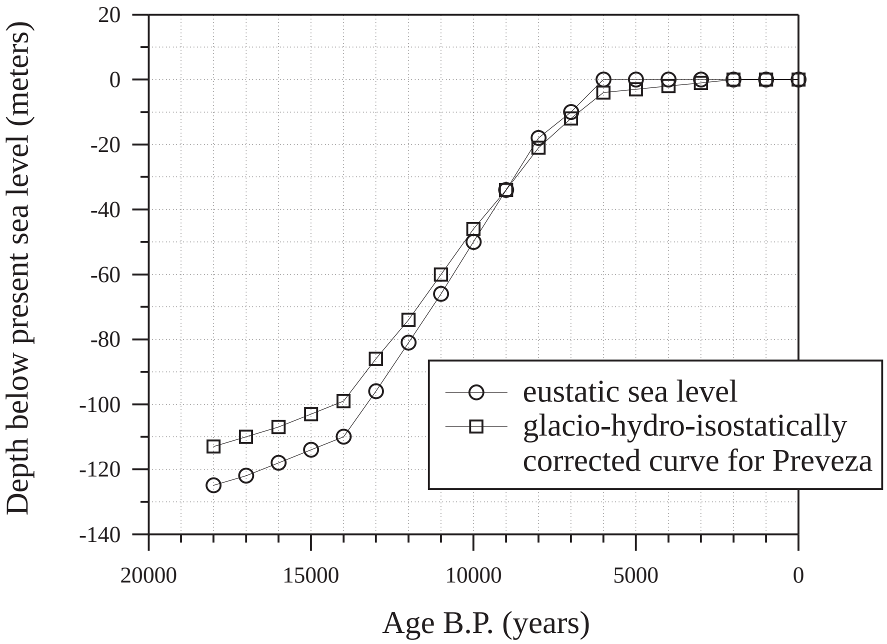
While the IGRSS/IFP geologic report (1966d) is very comprehensive through the Pliocene, an account of the Pleistocene and recent tectonic history that is most important to the present study was not realized. Fortunately, a recently published dissertation by Waters (1994) on the tectonic evolution of Epirus fills the gap. This work provides an inventory of geologic evidence such as incised river gorges, wave-cut notches, and raised shell burrows that suggest mainland Epirus and much of the coast has been undergoing uplift since the Pliocene (Waters, 1994). At the same time, it suggests that certain areas such as the Ambracian Gulf, the lower Acheron Valley, and the lower Thyamis Valley (Figures 2 and 3) are subsiding based on the very thick deposits of Quaternary sediments found at these locations (Waters, 1994). Subsidence also seems to be occurring along the northwest coast of the mainland opposite to Corfu (Figure 2) based on its steep, rocky shorelines with numerous small coves and islets, and its lack of beach platforms (Waters, 1994). Details of the neotectonic setting for each of these areas can be found in the Waters (1994) dissertation.

Waters (1994) attributes modern subsidence of the lower Acheron Valley bottom to movement on an inferred active, east-west-trending normal fault along the southern valley wall (hanging wall to the north) (Figure 5). This fault would explain the valley configuration in its lowest stretches as that of a half-graben, though Waters never explicitly describes it as such. While the alluvial valley bottom appears to be subsiding, there is some evidence to indicate uplift of the carbonate valley walls in the form of a wave-cut platform 1.7 meters above sea level on the north side of Phanari Bay (Waters, 1994).

HOLOCENE RELATIVE SEA LEVEL IN THE EPIRUS REGION

Coastal evolution is intimately related to relative sea level which is primarily determined by eustatic sea level changes, isostasy, and tectonic land movements. There is not, however, one formula or function that may be applied to localities around the globe

Figure 6--Glacio-hydro-isostatically corrected relative sea level curve for the Preveza area



to unravel relative sea level change at each location. The problem is even more severe in Greece since the region is so tectonically active—even the differences in adjacent regions may be significant. Some authors such as Flemming (1969) have attempted to apply broad rules to the problem; however, the results seem unsatisfactory. Overall consensus seems to echo the sentiment of Loy (1970) who regarded that,

> "there have been too many variations in rates of denudation, alluviation, and crustal movement in both time and place to allow the strict application of alleged world-wide sea level fluctuations to any place in Greece. Each problem must be solved, if it is to be solved, locally with local evidence."

Fortunately, a tentative glacio-hydro-isostatically corrected sea level curve for the southwestern Epirote coast is available. This relative sea level history curve for Preveza (Figure 2) illustrated in Figure 6 was proposed by Tjeerd van Andel in written communication (1996). Particularly important to note is that during the last 5,000 years, which is the focus of the present study, relative sea level rise along the southwestern Epirote coast has been less than two meters. Sedimentation at river mouths along the Epirote coast in the same time span, however, has been much in excess of that amount. A significant consequence of this relationship for this study is that, "sediment thicknesses and faunal components are more relevant to reconstructing shore positions than the local sea level curve," (van Andel, written communication, 1996).

A SUMMARY OF THE DISCREPANCY CONCERNING THE SIZE OF THE GLYKYS LIMEN (MODERN PHANARI BAY)

Ancient References:

The small marine harbor located at the mouth of the Acheron River is known today as Phanari Bay (Figure 7). Well-protected by a series of high limestone cliffs, and continuously flushed out by the high discharge of the Acheron River and its tributaries, it has characteristics that make for an ideal marine harbor. Unfortunately, it is very small measuring just 700 by 350 meters with a depth of less than 10 meters. In ancient times, the embayment was known as the Glykys Limen ("Sweet Harbor"). According to the Greek geographer and historian Strabo (7.7.5), who lived through AD 21, this was

Figure 7--Area map of the lower Acheron Valley

because the influx of fresh water from the Acheron and its tributaries caused a dilution of the marine water filling the bay.

Strabo's account is not singular—many other ancient authors also mentioned the Glykys Limen indicating that it was a well-known feature along the Epirote coastline. Descriptions by three of these authors present an ancient landscape configuration that differs greatly from the modern layout; while the modern harbor is quite small, the ancient harbor was apparently quite large. For example, the late fifth century BC Greek historian Thucydides (1.46.1-5) wrote in his history of the Peloponnesian War that the Corinthians and their allies anchored 150 of their ships in the Glykys Limen before the Battle of Syvota in 433 BC. Dio Cassius (50.12.2), another Greek historian and Roman official of the second and third centuries AD, wrote that in the summer of 31 BC, Octavius moored 250 of his ships in the harbor a few days before his confrontation with Mark Anthony and Cleopatra in the Battle of Actium. Finally, the twelfth century AD Byzantine writer Anna Komnena recorded that in AD 1084, nearly 1100 years after the Battle of Actium, the Norman Robert Guiscard and his large fleet wintered over on the Acheron delta. Modern Phanari Bay could not possibly accommodate such large naval fleets because of its small size. Are the historical accounts of these authors erroneous, or can a natural sequence of landscape evolution account for this discrepancy?

Modern Work:

In his account of his travels through the region, the British historian Hammond (1967) briefly suggested that the bay had silted up since ancient times. Dakaris (1971), an archaeologist who has done extensive work in the area, addressed the topic more thoroughly. Motivated by the accounts of Thucydides, Dio Cassius, and Anna Komnena, he supplied two further lines of limited geologic evidence that indicated the harbor was once much larger. The first line of evidence he indicated was an ancient beach ridge about 1.5 kilometers inland to the east of the village of Ammoudia (Figure 4), and the second was a "layer of sand with sea shells at a depth of 17.5 m from the present surface" that was taken near the junction of the Acheron and Cocytus Rivers (Dakaris, 1971).

Dakaris' observations were significant, but they lack chronologic control, and consequently are incapable of answering the question concerning the accuracy of the ancient literary and historical accounts. Furthermore, they provide only a snapshot of the landscape configuration at an unknown moment in time, and do not afford the archaeologist an understanding of the changing landscape and physical environment in which to make interpretations. Therefore, one of the primary objectives of the present project has been to develop a detailed history and absolute chronology for the evolution of the Glykys Limen.

A SUMMARY OF THE DISCREPANCY CONCERNING THE NATURE, GEOMETRY, AND EVOLUTION OF THE ACHEROUSIAN LAKE

Ancient References:

A second significant discrepancy between ancient accounts which mention the valley and the modern landscape configuration concerns the nature, geometry, and evolution of the no longer extant Acherousian lake. The existence of the lake is not in question because its final swampy remnants persisted until just after the First World War at which time they were drained and backfilled for agriculture (Dakaris, 1971). Much earlier, during Greek and Roman times, the lake was apparently a very conspicuous feature in the valley given that many authors made reference to it in their writings (Thucydides 1.46.3-4; Strabo 7.7.5; Pliny NH 4.1.4; Livy 8.24; Pausanias 1.17.5). By medieval times, it was referred to as the Acherousian swamp, apparently reflecting a natural infilling (Hammond, 1967; Dakaris, 1971). Though the quantity of references to the lake-swamp is significant, few provide any detailed topographical information that is useful in determining its location and nature.

Modern Work:

Several modern authors considered the existence of the lake in the valley. Leake (1835), who traveled through the region in AD 1809, left a fairly detailed description of the marshy valley bottom with its few, shallow, isolated pools during the rainy season. He concluded in his account that the marsh-lake present below Kastri (Figure 8) was the Acherousian swamp known from antiquity, seemingly not considering the possibility that

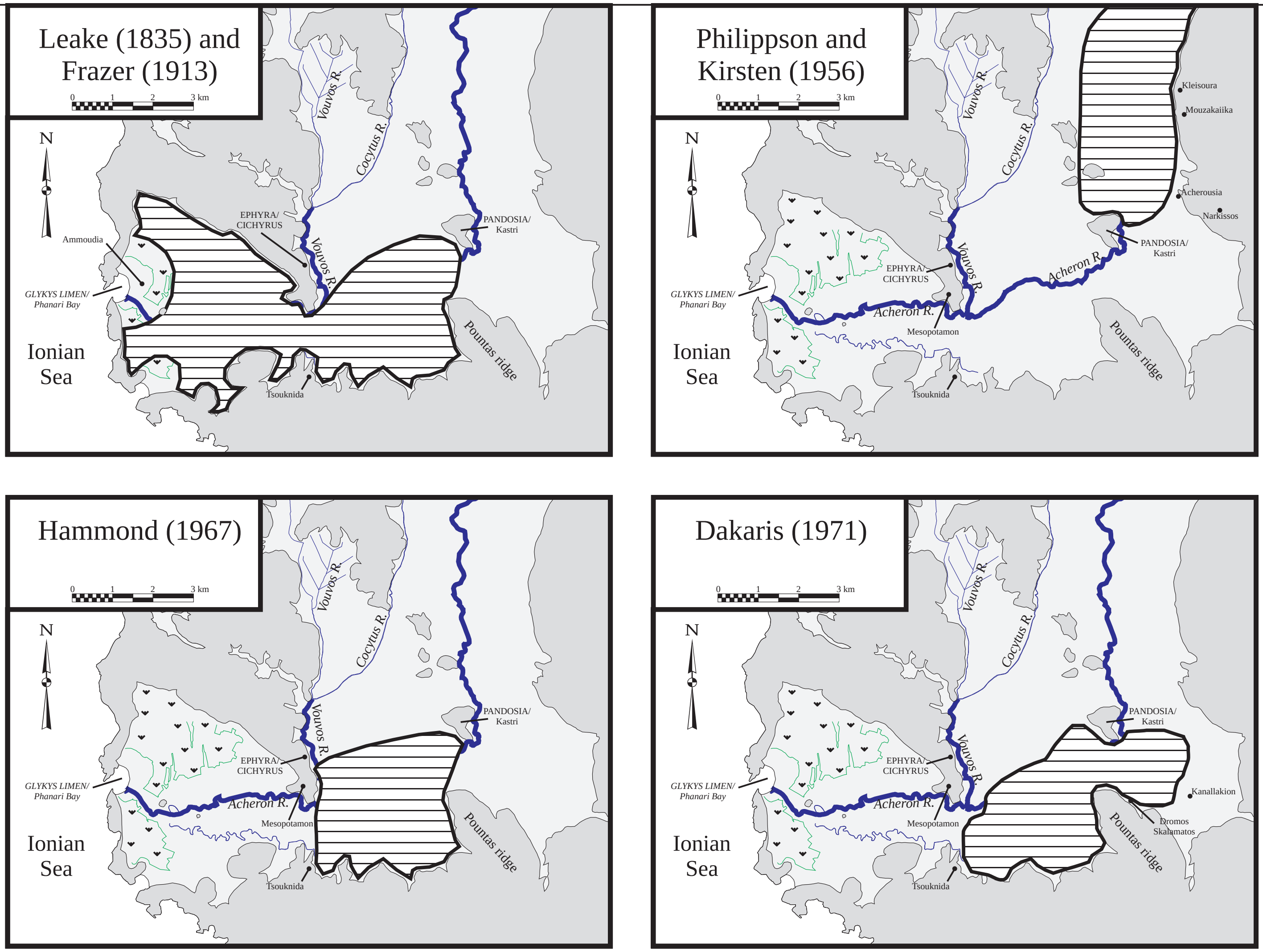


Figure 8--Suggested locations of the Acherousian lake in the lower Acheron Valley

it might have been of a different nature or proportions during ancient times (Leake, 1835). Frazer followed suit in his commentary/translation of Pausanias from 1913, and proposed that the Acherousian lake consisted of all the swampy, marshy ground between Kastri and the shoreline (Figure 8). The German geologists Philippson and Kirsten (1956) put forth another scenario in their survey of the Greek landscape, and suggested that the swampy, marshy ground which represented the lake had expanded areally, but become shallower since ancient times. Unfortunately, they did not elaborate on why they considered this to be the case. One of their map figures (redrawn in Figure 8) shows a dotted outline of what they presumably considered was the Acherousian lake (the Acheron River enters one side and exits the other). This lake stretched from east of Kastri north up the valley almost to the point where the Acheron River exits from the bedrock uplands which bound the valley to the east. Their placement of the lake is rather puzzling because all of the cited reconstructions by other authors maintain a fairly good internal consistency between each other with respect to the general location of the lake.

By the time Hammond passed through the valley in the middle of the present century, the final remnants of the lake had been filled in. Because of his interest in the history and archaeology of the region, he ventured to suggest more definitive boundaries for the Acherousian lake. Based on ancient literary and historical references, the descriptions of Leake, and some earlier work by Dakaris, the boundaries he indicated (Figure 8) were the Mesopotamon/Tsouknida valley constriction to the west, the bedrock highlands to the south, and the Pountas ridge and Kastri to the east (Hammond, 1967).

Dakaris (1971) furnished the most careful consideration of the subject based on ancient literary and historical references as well as his own observations. His reconstruction of the lake's size and location (Figure 8) was similar to that given by Hammond, but he extended the eastern boundary of the lake past the Pountas ridge and Kastri towards Kanallakion (Dakaris, 1971). The basis for this eastward extension was the chance find of 10 wooden beams during the excavation of a drainage canal east of the Pountas ridge and southwest of Kanallakion (Dakaris, 1971). Dakaris interpreted these as belonging to the keel of an ancient boat which plied the lake. Additionally, he noted that a spot on the eastern side of the Pountas ridge (Figure 7) is still referred to as 'Dromos Skalamatos' which means 'port' or 'place of embarkation'.

Dakaris, Hammond, and others based their reconstructions primarily on indirect evidence, but were also greatly influenced by the arrangement of the modern landscape in the valley. All their reconstructions overestimate the size of the lake at least as an open body of water, and do not provide any chronologic control. Philippson and Kirsten (1956) were correct in stating that the lake had become larger areally since Classical times. Unfortunately, they did not explain how they arrived at their conclusion, and the water body they illustrated is located too far up valley considering the accounts of ancient authors.

A complete and detailed chronology of the development and evolution of the lake based on geologic evidence has never been prepared. Particularly important issues to resolve include when the lake came into existence, the mechanism by which this occurred, the nature of the lake, and its geometry and dimensions through time. These questions comprise the second specific goal of the present project.

A SUMMARY OF THE DISCREPANCY CONCERNING THE COURSE OF THE ACHERON RIVER WITH RESPECT TO KASTRI DURING THE CLASSICAL PERIOD

Ancient References:

The course of the Acheron River, like that of most rivers in their lower stretches, is constantly changing. The third goal of the present project concerns determining the location of the course of the Acheron with respect to the hillock Kastri (Figure 7) during the first millennium BC. This is particularly important to archaeologists working in the valley who desire to positively identify the ruins on that hillock with those of Pandosia, a fortified urban settlement often referenced by ancient literary and historical sources (Demosthenes VII.32; Livy 8.24; Pliny NH 4.1.4; Strabo 7.7.5). The current course of the Acheron to the south of Kastri is in apparent contradiction with the ancient sources that suggest the Acheron flowed to the north of Pandosia (Demosthenes VII.32; Strabo 7.7.5). Are the ancient sources in error, or can this difference be explained by a sequence of natural landscape evolution?

In antiquity, the Acheron River served as a political boundary dividing the territory of Thesprotia to the north from Cassopaia to the south (Figure 7). Ancient sources indicate that in addition to Pandosia, another fortified urban settlement named Ephyra existed in the valley. Ephyra was situated north of the Acheron in the territory of Thesprotia, and was also near to the sea and the Acherousian lake (Pausanias 1.17.4-5; Strabo 7.7.5; Thucydides 1.46.4). Pandosia was located south of the Acheron in Cassopaia, and was further inland than Ephyra (Demosthenes VII.32; Strabo 7.7.5).

Modern Work:

Ruins of two fortified urban settlements are found in the valley today. One of these two sites exists on the ridge to the north of modern Mesopotamon, and the other site further inland on Kastri (Figure 7). From the given scenario, it might be immediately suggested that the large, ridgetop site north of Mesopotamon is that of Ephyra, and the remains on Kastri are those of ancient Pandosia. Unfortunately, certain complications have hindered these identifications in the past.

One complication was that the ridgetop site north of Mesopotamon was unknown until very recently. For example, Leake did not notice the site on his trip through the valley in AD 1809, and Hammond (1967) apparently only noticed the site because Dakaris previously indicated its presence. The greatest complication, however, arose from the fact that the present day course of the Acheron River prohibited the identification of Kastri with Pandosia if ancient topographical references were assumed to be correct (Dakaris, 1971).

Hammond (1967) suggested that the remains of Pandosia were not located in the lower Acheron Valley where the present project is based, but much further up valley at the site of Gourana. Dakaris (1971), in contrast, suggested that the ruins on Kastri were indeed those of Pandosia because the remains on the ridgetop site north of Mesopotamon had been recently positively identified as those of Ephyra. To reconcile the modern river course with the topographical references given by ancient authors, he suggested that the river had shifted it course since ancient times. "Wherever the river banks are not supported, or when the river overflows, it could result in a change in course," (Dakaris, 1971), and "the slight inclination of the Acheron plain, the swamps, and the lake, formed by the river to the south of Kastri hill, contributed to the change in the river bed, which, in ancient times, had the hill with the ruins to its south, at [sic] Cassopaia," (Dakaris, 1971).

While Dakaris' comments concerning the dynamic nature of the river course were correct, he did not provide any geologic evidence to prove that the river had indeed shifted its course from the north of Kastri to the south of it since the first millennium BC. Consequently, it had been left to faith as to whether or not this occurred, or whether the topographical references given by ancient authors were indeed correct. In order to definitively answer this question, the third objective of the current project has been to examine the changing course of the Acheron River with respect to Kastri during the past 2000 years, and based on subsurface geologic evidence either confirm or deny the shift of the river's course suggested by Dakaris.

THE USE OF MICROFOSSIL ASSEMBLAGES AND OTHER SEDIMENTOLOGICAL PARAMETERS FOR PALEOENVIRONMENTAL AND PALEOGEOGRAPHIC RECONSTRUCTIONS

Paleoenvironmental and paleogeographic reconstructions like the one undertaken in this project are nearly uniquely based on interpretations of the sedimentary deposits and sequences which were laid down in the area at the time of interest. In a marginal marine setting such as that of the lower Acheron River Valley, coastal geomorphic evolution may be rapid, and sedimentology and environments of deposition may be very complex. Significant changes in facies occur both perpendicular and parallel to the coastline, and the boundaries between adjacent environments are not usually punctuated. More complex sequences may develop in regions with a considerable tidal flux. Several complimentary tools are therefore required to make accurate determinations about the environments of deposition represented by subsurface deposits.

The Use of Ostracoda and Foraminifera in Marginal Marine Settings:

Ostracoda and foraminifera have been used with great success as indicators of paleoenvironments in many studies dealing with marginal marine environments (Tziavos, 1977; Yang, 1982; Villas, 1983). This is true because the physical characteristics of sediment such as color and grain size may not be sufficient to discriminate between deposits of fresh, brackish, and marine waters. Abundant ecological studies of living ostracods and foraminifera have shown that the distribution of a particular species is determined primarily by salinity and temperature, though other factors such as depth, water chemistry, hydrostatic pressure, turbidity and turbulence, substrate, presence/absence of shelter, food supply, currents, biologic competition, and the existence of predators and parasites may also be important (Neale, 1964; Phleger, 1960). When fossil remains of that particular species are found in sedimentary deposits, one may make the assumption given certain conditions that such sediments were deposited in paleoenvironments with the same fixed range of salinities, temperatures, and other parameters. Analysis of the distribution of differing microfossil assemblages found in the subsurface, therefore, provides an extremely powerful tool for the reconstruction of paleoenvironments and paleogeography.

Information Sources for Ostracod Ecology:

Good starting points for information about the ecological parameters that control the distribution of ostracods can be found in general summaries and syntheses provided by Benson (1961), Brasier (1980), Neale (1964 and 1988), and Pokorný (1978). Works by Carbonel (1988), Henderson (1990), Hulings and Puri (1964), Keyser (1977), Kilenyi (1969), Malkin Curtis (1960), Puri et al. (1964), Staplin (1963a), Tziavos (1977), Valentine (1976), Villas (1983), Wagner (1957), and Würdig (1983) also provide fairly direct discussions about ecological parameters that affect ostracod distribution. Information contained in the remaining ostracod-related works listed in the bibliography is less direct being contained within the results from other studies, or as ecological information for particular species.

Information Sources for Foraminiferal Ecology:

General summaries and syntheses of foraminiferal ecology are provided by Boersma (1978), Brasier (1980), Murray (1973), and Phleger (1960). Additional works with relevant discussions include Bandy (1953), Bandy and Arnal (1960), Bradshaw (1968), Ellison (1951), and Walton (1955). As with the ostracods, the remaining foraminifera-related sources listed in the bibliography also provide a wealth of ecological information, but it is tied up in the results from other studies, and ecological information for particular species.

The Problem of Contamination of Microfossil Assemblages:

One significant problem that must be considered when using ostracods, foraminifera, or other microfossils as paleoenvironmental indicators is the contamination or mixing of assemblages. Brasier (1980) and Kilenyi (1969) note mechanisms that may result in the post-mortem transport of ostracod carapaces, and Murray (1973) points out several mechanisms that may move foraminiferal tests. If such processes do cause the mixing of assemblages, inaccurate representation of the true paleoenvironment of deposition may result. Areas with low current velocities and high population densities are less susceptible to contamination (Kilenyi, 1969).

Other Sedimentological Parameters:

While the analysis of microfossil assemblages in a marginal marine setting is a critical primary tool for interpreting the probable environment of deposition for a sample, a multi-proxy approach using other sedimentological parameters provides a more robust solution. For this study, a variety of sedimentological parameters described in the Methods and Procedures section below were used with the most important being grain size, color, organic carbon content, and magnetic susceptibility. When integrated with core stratigraphy, and an understanding of the lateral arrangement of modern analog environments in light of Walther's Law of the Correlation of Facies (Middleton, 1973), a powerful method for the reconstruction of paleoenvironments and paleogeography results.

METHODS AND PROCEDURES

Field Coring Program:

A total of 28 sediment cores from various points in the lower Acheron Valley were collected during summer field seasons from 1992 to 1994 (Figure 9). Field work during the 1992 and 1993 seasons was accomplished primarily by Zhichun Jing and George (Rip) Rapp, Jr. (Archaeometry Lab, University of Minnesota—Duluth) and Richard Dunn (University of Delaware) with the aid of various members of the Boston University Nikopolis Project. Field work during the 1994 season was undertaken

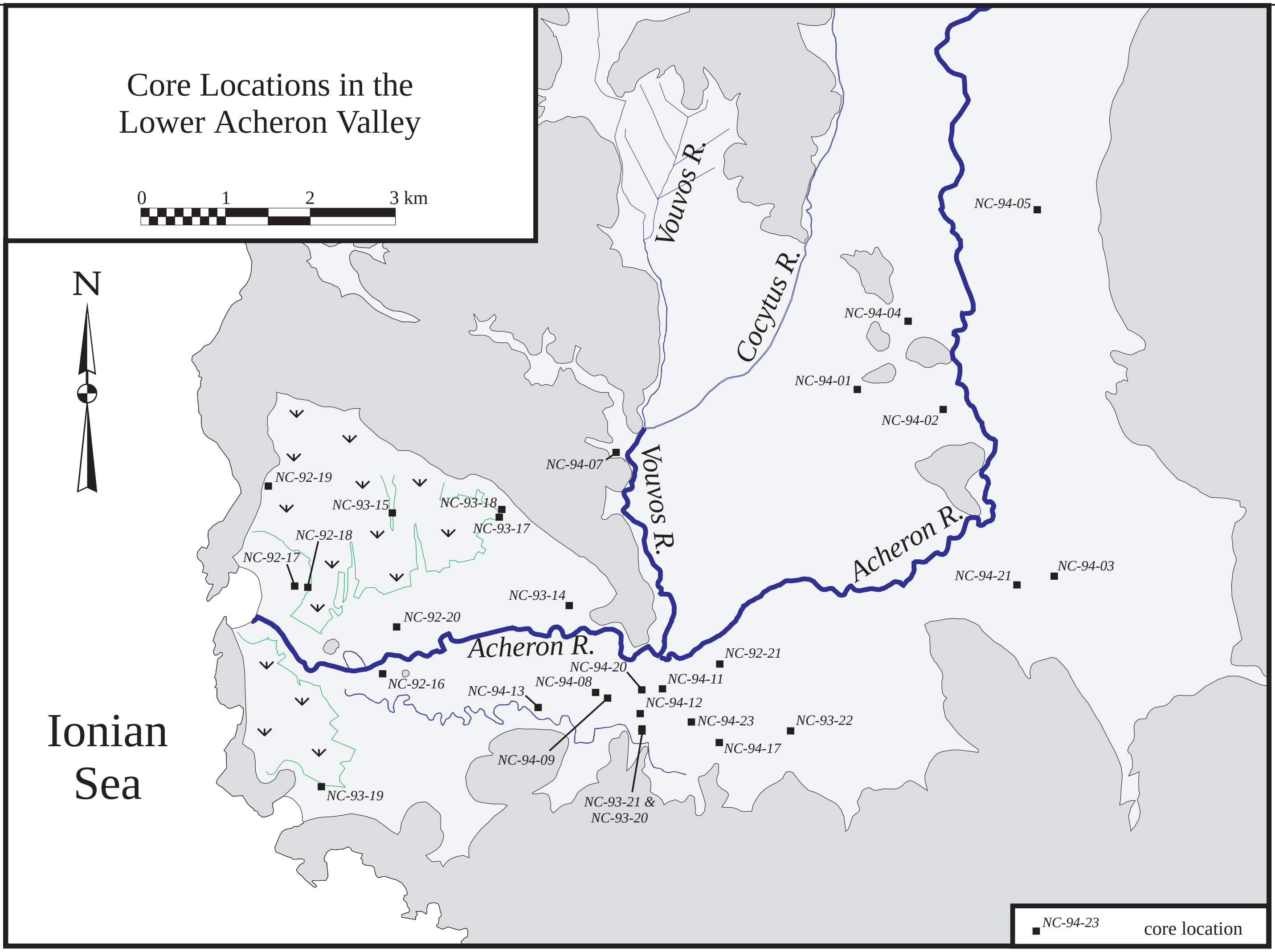


Figure 9--Core locations in the lower Acheron Valley

primarily by the author and various members of the Nikopolis Project, with the participation of Z. Jing during the first several weeks. The 13 cores collected during the 1992 and 1993 seasons were concentrated primarily in the lowest part of the valley closest to the sea. Approximately half of the cores collected during the 1994 field season came from near the Mesopotamon/Tsouknida valley constriction, and the other half from localities further up the valley.

Cores from all years are labeled using the same convention. All labels begin with "NC" (Nikopolis core), are followed by two digits which designate the field season (either "92", "93", or "94"), and then are terminated by a two digit extension that indicates the number assigned to that core during the field season. Core NC-94-23, for example, was the twenty-third core collected during the 1994 field season. Sediment cores from other localities in southern Epirus were also being collected by the Nikopolis Project geologic staff during the same field seasons, and were assigned numbers within this same system. As a result, core numbers from the Acheron Valley are not necessarily continuous.

All cores were retrieved in sections consecutively downwards by means of a one meter long, three centimeter diameter Eijkelkamp gouge auger. Because of equipment failure, cores NC-94-02 and NC-94-03 were taken with a 20 cm long, seven centimeter diameter Edelman auger bit. Depending on the consistency and induration of the sediment being cored, the use of a sledge hammer was sometimes necessary for penetration. For nearly all cores, use of the sledge hammer was necessary for penetration of strata at more than three to four meters depth. In this fashion, approximately seven to eight meters of core recovery was achieved on average, with the deepest penetration being 12.5 m (core NC-93-14). Cores shorter than the average penetration resulted because either a subsurface barrier or bedrock was encountered, or because of core hole collapse in coarse sediments. Overall, the gouge auger provides a cheap, simple, and rapid method for studying subsurface strata; however, sample size is limited, and sedimentary structures with the exception of thin layers and laminae are not preserved.

Field Core Logging and Sampling:

Core descriptions were done on site during core retrieval and important parameters are summarized graphically in Appendix A. Depth from the surface and thickness of units was recorded to the nearest five centimeters, and when possible to the nearest centimeter. Contacts between units were noted as either gradual, distinct, or very abrupt. Sediment physical properties such as color when wet (using the Munsell Soil Color Chart), approximate grain size distribution, and consistence (stickiness, plasticity, and strength) were recorded. Finally, the presence, size, and quantity of a variety of miscellaneous characteristics and features were noted. These include pedogenic structures, reduction/sesquisoxide mottles, carbonate filaments and nodules, shells and other macrofossils, organic matter and plant debris, charcoal fragments, and in one case a small pottery fragment.

Laboratory Analyses:

Sediment samples collected during the 1992 and 1993 seasons did not undergo laboratory analyses because a systematic sample representation of subsurface stratigraphy was not available. Approximately 300 sediment samples were collected during the 1994 field season, and selected samples underwent microfossil analysis, loss on ignition testing, grain-size analysis, analysis of rock magnetic properties, and radiocarbon dating. An analysis of literary and historical references to the region and early maps of the area was also undertaken.

Analysis of Microfossil Assemblages:

Study of the microfossil assemblages in 49 samples from 10 different cores collected during the 1994 season was completed. The average amount of sediment disaggregated and analyzed per sample was approximately 30 grams (Appendix B). Disaggregation of samples was accomplished by soaking in a beaker of dilute Calgon mixture for two to three days depending on the sample cohesiveness. During this soaking period, the beakers were gently shaken and stirred six to eight times to facilitate disaggregation. Following this soaking period, the contents was then wet-sieved over nested 3-inch diameter 360, 180, 90, and 63 micron sieves. The sieves were precleaned in an ultrasonic bath, and then visually inspected the prevent contamination between samples. The residues left in the sieves were dried under a heat lamp, and the 360, 180, and 90 micron fractions transferred to a black-bottomed ceramic tray where microfossils were hand-picked under a binocular scope. In most cases, the total microfossil population, including ostracods, foraminifera, gastropods, pelecypods, and charophyte oogonia was hand-picked and mounted on microfossil slides with gum tragacanth for storage and identification (Kummel and Raup, 1965).

Qualitative Assessment of Paleosalinity Based on Microfossil Assemblages:

After species counts were made, the relative percentages of the abundance of fresh and brackish to marine water organisms were calculated to provide a qualitative approximation of the salinity of the environment of deposition. In cases where microfossils were so abundant as to prohibit the collection of all remains, an attempt was made to pick organisms that represented the overall percentages encountered in the residues. When reworked microfossils derived from the fossiliferous bedrock of the valley were present, an estimate of abundance was recorded.

It should be noted that these estimation methods and calculated percentages do not furnish a statistically-valid, quantitative measurement of diversity and abundance that would be necessary for a dedicated study of microfaunal ecology. However, in conjunction with the other data generated in this project, they provide sufficient information to discriminate between different paleoenvironments of deposition especially related to salinity. Complete results from the microfossil analyses can be found in Appendix B, and summarized along core stratigraphy in Appendix A.

Loss on Ignition Analysis:

Eight cores collected during the 1994 season were analyzed along their length for organic carbon and inorganic carbon (carbonate) using the method of Dean (1974). The Dean method determines these quantities by noting the differences in the mass of a sediment sample after two high temperature burns. Samples were placed in ceramic crucibles, dried overnight at 100°C, and weighed. The samples were then burned at 550°C for one hour to incinerate organic matter, then cooled and weighed. Finally, the samples were burned a second time at 1000°C for one hour to drive the carbon dioxide out of calcium carbonate, then cooled and weighed again. By calculating the loss of mass after each of these burns with respect to the original mass of the dry sediment, the weight percent of organic and inorganic carbon contained in a sample can be calculated. Results of organic carbon content from this analysis are presented graphically along core stratigraphy in Appendix A. Both organic and inorganic carbon content results can be found in Appendix D.

Pipette Grain Size Analysis:

Though a field approximation of sediment grain size was recorded during core logging, a more exact analysis of the grain-size distribution for 23 samples was also determined by pipette according to the method of Folk (1980). Samples were selected on the basis of information collected from other analyses, in particular the microfossil and loss on ignition analyses. Approximately 30 g of sediment was disaggregated by gently crushing between fingers. The crushed samples were placed in suspension in one liter graduated cylinders with a 2.55 g/l Calgon solution as a dispersant. Twenty milliliter aliquots were removed at specified times that depended on temperature and grain-size (Folk, 1980). The aliquot parts were dried in an oven at 100°C, weighed to determine the mass of sediment they contained, and then calculations made to determine the grain size distribution (Folk, 1980). Results from this analysis can be found in Appendix C.

Rock Magnetic Analyses:

Rock magnetic analyses were performed at the University of Minnesota—Minneapolis on all sediment samples from 12 of the 15 sediment cores collected during the 1994 season. Dual-frequency magnetic susceptibility was determined on the Bartington susceptibility bridge at the Limnological Research Center, and anhysteretic remanent magnetization was determined at the Institute for Rock Magnetism. Anhysteretic remanent magnetization was imparted to samples using a Schonstedt Alternating Field Demagnetizer in a 0.1 T peak alternating field with a 0.1 mT biasing field. It was then measured on the fully-computerized 2-G Cryogenic Superconducting Rock Magnetometer.

Susceptibility is a measure of the magnetizability of a sample, and is dependent on the mineralogy and size of the magnetic fraction in the sample. It is useful for the correlation of stratigraphy, especially in longer, monotonous sections where no macro-observable variation in stratigraphy can be noticed. Susceptibility may also be used for the recognition of pedogenic alteration. Dual-frequency susceptibility is used to detect the presence of very fine-grained superparamagnetic magnetite in a sample. This may used to make inferences about anthropogenic activities because this type of magnetite is a product of activities such as fermentation and burning. Anhysteretic magnetization is used to characterize the magnetic mineralogy of a sample.

For both magnetic analyses, moist sediment samples were tightly packed into 16 mm x 16 mm x 13 mm clear plastic, magnetically inert boxes, which were then measured on a microbalance to the nearest 0.0001 grams. The exact amount of sediment in each box was determined by subtracting an average weight for each box (3.0134 grams as determined from measurements on 50 boxes [σ=0.0432]) from the total weight of the box and sediment noted above. Results from theses analyses are presented graphically in Appendix D.

Radiocarbon Analysis:

Eight samples of organic material were radiocarbon dated by the accelerator mass spectrometer (AMS) method. Four samples from the 1992 and 1993 seasons were dated by the Radiocarbon Laboratory at the University of California—Riverside. Four samples from the 1994 season were dated by Beta Analytic Laboratories Inc. of Miami, Florida. After samples were collected in the field, they spent between one and four weeks unrefrigerated before being returned to the U.S. where they were prepared and kept in a desiccator until submission to the laboratories for dating. Calibration of the results from radiocarbon years before present to calendar years was accomplished by the use of the CALIB Revision 3.0.3c computer program available from M. Stuiver and P. Reimer of the Quaternary Research Center at the University of Washington, Seattle. Uncalibrated results from the laboratories, calibrated results from the CALIB program, and details used in the CALIB program can be found in Appendix E.

Use of Literary and Historical References and Early Maps:

In conjunction with the information obtained during field work and the other laboratory analyses, an examination of literary and historical references by ancient and recent authors, as well as early maps of the area was undertaken. In particular, passages by Homer, Thucydides, Strabo, Anna Komnena, and Leake (1835) were examined. The early maps of the area are from a variety of sources beginning in AD 1545, and are reproduced in Figures 17 and 18.

RESULTS OF MICROFOSSIL ASSEMBLAGE ANALYSIS AND RELATED ECOLOGY OF THE LOWER ACHERON VALLEY

Identification of Ostracods and Foraminifera:

The microfossil assemblages contained in forty-nine sediment samples from the 1994 season, and one sample from the 1993 season from a total of ten different core locations were examined. Complete results are contained in Appendix B, and summarized along core stratigraphy in Appendix A. Identification of the ostracods down to the species level was achieved for 24 forms, down to the genus level for one form, and left undetermined for one form. Though all references listed in the bibliography were helpful to some extent, those by Ascoli (1964), Bhatia (1968), Devoto (1965), Ellis and Messina (1952-present), Puri et al. (1964), Puri et al. (1969), Sars (1925), Tassos (1975), Tziavos (1977), Villas (1983), Wagner (1957), and Yang (1982) proved exceedingly useful because they are either based in the same region, or are extremely comprehensive.

Identification of the foraminifera was less rigorous, being down to the species level for three forms, to the genus level for four forms, and to the family level for one larger well-known group. All related sources listed in the bibliography were helpful to some extent, but those by Tassos (1975), Tziavos (1977), Villas (1983), and Yang (1982) proved extraordinarily helpful given their basis in the region.

Ecology of Ostracods and Foraminifera:

Besides being particularly helpful for the identification of the ostracods and foraminifera recognized in this study, Ascoli (1964), Puri et al (1964), Sars (1925), Tassos (1975), Tziavos (1977), Villas (1983), Wagner (1957), and Yang (1982) also served as primary references for ecological and paleoenvironmental information related to those organisms. This information was amply augmented by the other references listed in the bibliography. Appendix B contains a complete summary of results from the microfossil analyses. It is composed of a mix of scanning electron microscope and normal transmitted light photographs of representative microfossils, a list of references used for identifications, a summary of the ecological information available for each microfossil based on the cited references, and tabulated results of species distribution and abundances.

Recognition of Microfossil Assemblages:

Two microfossil assemblages can be defined from the mix of ostracods and foraminifera recovered from the lower Acheron Valley. The first assemblage is indicative of shallow, fresh water environments and is composed almost entirely of fresh water ostracod species. Some of these species are also tolerant of slightly brackish conditions. The second assemblage is indicative of shallow, nearshore brackish to marine (and possibly hypersaline) habitats and is composed of a mix of ostracods and foraminifera. Microfossil identifications and paleoecological interpretations made by the author were later confirmed and corrected by Dr. Frederick Swain of the University of Minnesota—Minneapolis.

Shallow, Fresh Water Microfossil Assemblage:

The shallow, fresh water microfossil assemblage from the lower Acheron Valley consists of the following 14 species of ostracods:

Candona albicans Brady, 1864
Candona sp. aff. C. caudata Kaufmann, 1900
Candona compressa (Koch, 1837)
Candona cf. lactea Baird, 1850
Candona neglecta Sars
Candona truncata Furtos, 1933
Cyclocypris cf. laevis (O.F. Müller, 1785)
Darwinula stevensoni (Brady and Robertson, 1870)
Herpetocypris cf. reptans (Baird)
Ilyocypris gibba (Ramdohr, 1808)
Limnocythere cf. inopinata (Baird, 1843)

Limnocythere sp.
Potamocypris cf. villosa (Jurine, 1820)
Ostracod sp. A, possibly *Prionocypris zenkeri* (Chyzer, 1858)

All 16 species do not occur together in a single fresh water sediment sample, and in fact most occur in only rare quantities in a few of the samples. This distribution may reflect natural abundances, slight differences in the exact paleoenvironment of deposition, natural patchiness in distribution, or possibly the fact that the gouge auger samples only a very small areal portion of sediment. The exceptions to this rule are juvenile specimens of *Candona albicans* Brady, 1864, *C. compressa* (Koch, 1837), *C. cf. lactea* Baird, 1850, and *C. neglecta* Sars which occur in varying quantities in all of the fresh water samples. *Ilyocypris gibba* (Ramdohr, 1808) also approaches commonality in several samples. Several different types of fresh water gastropods and pelecypods were noted; however, they were not identified, but just counted. Additionally, occasional charophyte oogonia were recognized and collected. A complete list of the abundances and distribution can be found in Appendix B.

The genus *Candona* is a well-known group characteristic of fresh water environments (Sars, 1925; Benson, 1961; Staplin, 1963a). Unfortunately, the juvenile forms of many *Candona* species are not easily distinguishable from one another. For example, juveniles forms of *C. albicans* Brady, 1864 and *C. compressa* (Koch, 1837) are not easily discernible from one another under a regular binocular scope, and the same is true for the juvenile forms of *C. cf. lactea* Baird, 1850 and *C. neglecta* Sars (F. Swain, personal communication, 1996). As a result, when the abundance totals of particular species were prepared, juveniles of *C. albicans* Brady, 1864 and *C. compressa* (Koch, 1837) were grouped together, and the same was done with the immature specimens of *C. cf. lactea* Baird, 1850 and *C. neglecta* Sars. The inability to differentiate the immature forms of these species, however, does not detract from their usefulness as indicators of paleosalinity because all are characteristic of fresh water environments.

Shallow, Nearshore Brackish to Marine Water Microfossil Assemblage:

The shallow, nearshore brackish to marine water microfossil assemblage from the lower Acheron Valley consists of the following 12 ostracods:

Cushmanidea elongata (Brady)
Cyprideis torosa (Jones, 1850)
Cytheridea neapolitana Kollman, 1960
Cytheridea gr. sorbyana (Jones)
Cytheromorpha fuscata (Brady, 1869)
Leptocythere bacescoi (Rome, 1942)
Leptocythere cf. castanea (Sars, 1866)
Loxoconcha elliptica Brady, 1868
Loxoconcha cf. granulata Sars, 1866
Loxoconcha ovulata (Costa, 1853)
Paracytherois cf. acuminata Müller, 1894
Tyrrhenocythere amnicola (Sars, 1888)

and the following foraminifera:

Ammonia beccarii (Linné, 1758)
Bolivina sp.
Bulimina sp.
Cribrononion translucens (Natland, 1938)
Elphidium crispum (Linné, 1758)
Fursenkoina sp.
members of the family *Miliolidae* Ehrenberg, 1839 (several *Quinqueloculina spp.* and *Triloculina sp.*)

As with the organisms of the fresh water assemblage, not all of these brackish water species occur together in a sample. Again this inhomogeneous distribution may reflect natural abundance, subtle changes in the exact paleoenvironment of deposition, natural patchiness, or the fact that the gouge auger samples only a very limited area. In contrast, whereas the fresh water fauna were sparse or absent in appropriate samples, all shallow, near shore brackish to marine sediments showed extremely high total microfossil abundances. Certain forms were present in nearly all samples and in some cases occurred in extreme abundance. These forms include *Cyprideis torosa* (Jones, 1850), *Leptocythere* *cf. castanea* (Sars, 1866), *Loxoconcha elliptica* Brady, 1868, *Loxoconcha ovulata* (Costa, 1853), *Paracytherois cf. acuminata* Müller, 1894, *Tyrrhenocythere amnicola* (Sars, 1888), *Ammonia beccarii* (Linné, 1758), *Cribrononion translucens* (Natland, 1938), and various members of the family *Miliolidae* Ehrenberg, 1839.

Minimal Mixing and Contamination Between Modern Microfossil Assemblages:

The mixing and contamination of fresh and brackish to marine microfossil assemblages may be significant in some areas, especially in regions with large tidal fluxes (Kilenyi, 1969), but it was minimal in the sediment samples from the lower Acheron Valley. This lack of mixing is not unexpected considering the very small tidal variation of just around 20 cm along the northwest coast of Greece. Villas (1983) noted some mixing of marine microfossils in the fresh water environments of the Acheloos delta just 150 kilometers to the south of the Acheron Valley (Figure 1). She explained this as a result of "deposition during storms which move landward from the Ionian Sea and flood the essentially flat delta plain," (Villas, 1983). However, the situation in the Acheron Valley is much different—storm wave action in Phanari Bay is small due to the sheltering effect of the large carbonate cliffs which enclose the bay. The Acheloos delta plain, on the other hand, is not enclosed as such and experiences the unbuffered assault of storm waves.

Presence of Reworked Microfossils from Bedrock Valley Walls:

Though there appears to be insignificant mixing and contamination between recent fresh, brackish, and marine water deposits in the lower Acheron Valley, abundant mixing between recent assemblages and reworked ancient forms was noted. These reworked microfossils include calcareous algae, radiolarians, and various globigerinid and other foraminifera derived from the fossiliferous Mesozoic and Eocene carbonate bedrock valley walls, and carried down to the valley bottom by fluvial processes. Fortunately, these reworked ancient forms are quite easy to distinguish from recent specimens because they are highly abraded and/or encrusted and recrystallized. These reworked microfossils have no innate value for indicating the paleosalinity of the Holocene environment in which they were deposited. However, since they are carried and deposited in the fluvial system, they occur in extreme abundance in fluvial-related environments such as natural levees, floodplains, delta distributary channel and distributary mouth bars, and subaqueous levee systems. In contrast, their presence in standing bodies of water such as lakes or backswamps is minimal.

RESULTS—ENVIRONMENTS OF DEPOSITION IN THE LOWER ACHERON VALLEY AND THE CHARACTERISTICS AND CRITERIA USED TO RECOGNIZE THEIR SEDIMENTARY DEPOSITS

Modern Fluvial and Deltaic Nearshore Depositional Systems:

The modern sedimentary environments in the lower Acheron River Valley are very similar to those found at other spots along the Greek coast (Tziavos, 1977; Villas, 1983) and the Mediterranean, and may be divided into two broad depositional systems. The first system, hereafter referred to as the fluvial depositional system, consists of all the sedimentary environments landward of the shoreline. At the present, these include river channel, natural levee, crevasse splay, floodplain, and backswamp environments. Shallow fresh water lakes also existed in the valley until the first part of this century, but have been subsequently filled in for agriculture. The second depositional system recognized in the lower Acheron Valley is a deltaic nearshore association and is composed of the environments located seaward of the shoreline within the marine embayment of the Glykys Limen. These include fresh to brackish water delta top marsh, delta distributary channel, distributary channel mouth bar, subaqueous levee, lower delta front, prodelta, interdistributary bay, and accretionary beach environments. Figure 10 is a composite drawing that illustrates the lateral arrangements of the environments of the fluvial and deltaic nearshore systems.

For the present study, the most important properties used to distinguish deposits of one environment from another turned out to be grain size, color, organic carbon content, and microfossil content. The stratigraphic relationship between units keeping in mind Walther's Law (Middleton, 1973), and the subsurface geometry of deposits were also extremely important. Below follows a brief discussion of each environment with the characteristics and criteria that were used to distinguish the deposits from that environment.

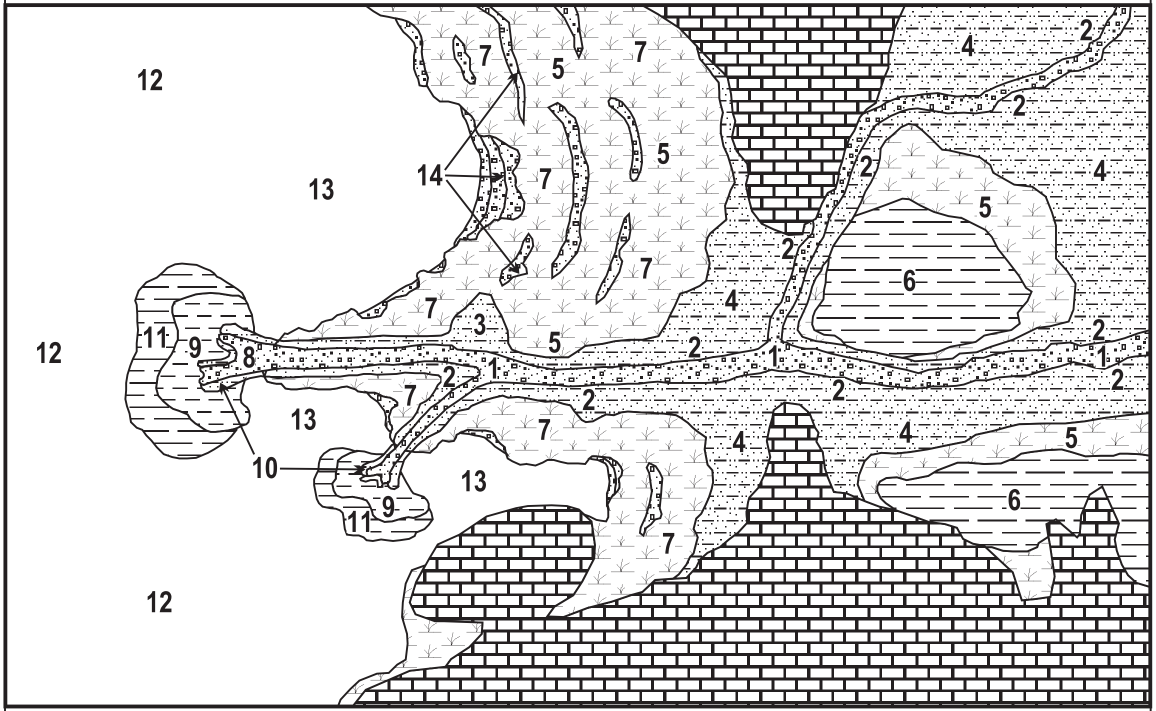


Figure 10--Environments of deposition in the lower Acheron Valley

Note: This is a composite drawing of the different environments of deposition recognized in the lower Acheron Valley (see **Results--Environments of Deposition in the Lower Acheron Valley and the Characteristics and Criteria Used to Recognize Their Sedimentary Deposits** of text), and is meant to illustrate the lateral arrangement of these environments. It is not meant as a reconstruction of the landscape at any point in time.

Fluvial Depositional System:

1.) river channel
2.) natural levee
3.) crevasse splay
4.) floodplain
5.) backswamp to fresh water marsh
6.) shallow fresh water lake

Deltaic Nearshore System:

7.) fresh to brackish water delta top marsh
8.) delta distributary channel
9.) distributary channel mouth bar
10.) subaqueous levee
11.) delta front
12.) prodelta
13.) interdistributary bay
14.) accretionary beach

River Channel:

River channel deposits are composed of the coarsest sediments found in the fluvial depositional system, and include lag deposits and bars that form directly in the river channel. Deposits are usually tan or buff in color, but may exhibit a reduced color if trapped in an environment such as an oxbow lake. In the lowest reaches of the valley, where the river channel and bar system grades into the deltaic environment, sands and gravels may also have a gray color. Reineck and Singh (1980) note that channel deposits and bars often contain accumulations of drifted organic matter. Ostracods and other microorganisms do not generally inhabit such environments, and the occasional carapaces of detrital origin that do make it to the river channel are quickly destroyed in the high energy environment, or are diluted in the abundant clastic material. Reworked microfossils from the local bedrock occur in extreme abundance in deposits of this environment since it is the main transport agent for such materials.

Subaerial Natural Levee:

Subaerial natural levees are wedge-shaped ridges of sand and muddy sand that are deposited directly adjacent to a river along its length, and thin away from the river. These deposits are created when coarse sediments carried overbank by a flooding river are dropped out of suspension. They are generally finer-grained than channel deposits, become increasingly finer outward from the river channel, and eventually grade into floodplain or backswamp. Because these deposits are exposed subaerially, they tend to be tan to orange to brown in color, and may exhibit weak pedogenic features such as sesquisoxide mottles and nodules, and carbonate filaments and nodules. Reineck and Singh (1980) note that large amounts of organic matter may be incorporated into natural levees. Occasional ostracod carapaces of detrital origin, and abundant reworked microfossils liberated from the local bedrock are found in these deposits. Natural levees have played a significant role as agents of geomorphic evolution in the lower Acheron Valley through the middle and late Holocene, and their significance will be discussed in The Late Holocene Birth and Evolution of the Acherousian Lake section below.

Crevasse Splay:

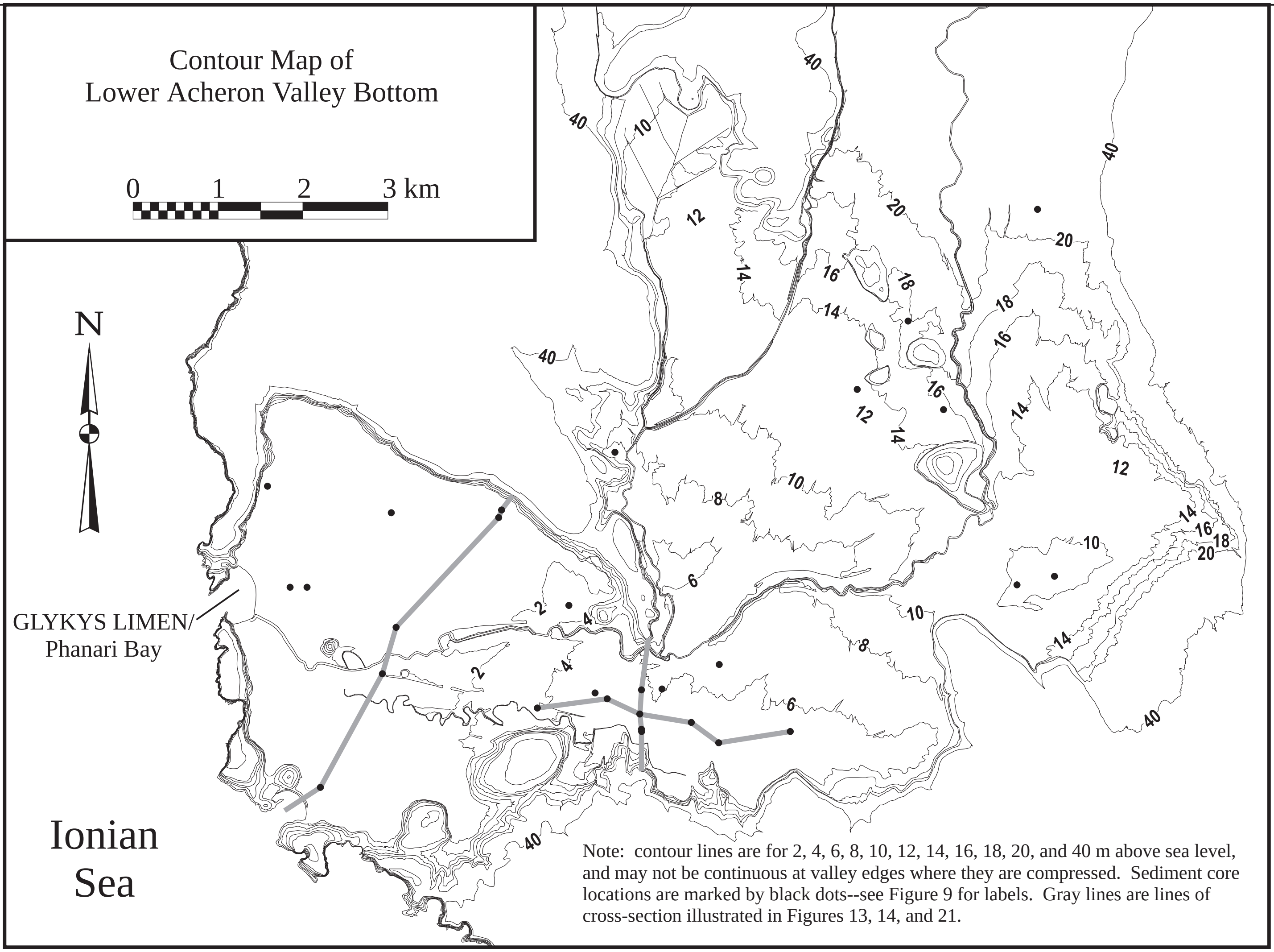
Crevasse splay deposits form during periods of exceptional flooding when channels may be cut through the natural levee system allowing water and bedload sediment to escape onto the adjacent floodplain, or into backswamp or interdistributary bay environments. They occur as lobe-shaped wedges of sand to mud-sized sediment that thin away from the river channel. A modern lobe-shaped crevasse splay deposit delineated by the two meter above sea level contour line can be seen in the floodplain to the SW of ancient Ephyra (Figure 11). Reineck and Singh (1980) note that crevasse splay deposits may occur on scales from decimeters to several hundred of meters. Though these deposits are similar in composition to natural levee deposits, they can be distinguished by their geometry, and the fact that they appear as abrupt pulses of coarser sediment within the mud and silt of floodplain, backswamps, or interdistributary bays. Such deposits contain abundant reworked microfossils from the local bedrock, and relatively small amounts of organic matter.

Floodplain:

The floodplain environment consists of the flat, low ground adjacent to a river that acts as a settling basin for fine-grained suspended sediment carried over the river's banks during flooding. Floodplain deposits consist mostly of silt and clay with occasional fine sand laminae. This environment is exposed subaerially, so its sediments tend to be tan to orange to brown in color, exhibit slight to moderate pedogenic development, and tend to be more compact and stiffer than sediments from other environments. Occasional modern ostracod carapaces of detrital origin, common fragments of terrestrial gastropod shells, and abundant reworked microfossils from the local bedrock are found in such deposits. These deposits contain moderate amounts of organic carbon.

Backswamp:

The backswamp environment represents a transitional step between floodplain and shallow lake environments. It commonly occurs in low, poorly-drained areas adjacent to the river channel or valley walls, and consists of nearly perennially saturated, swampy and marshy ground. In the Acheron Valley, it also occurs in the low swales



Note: contour lines are for 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, and 40 m above sea level, and may not be continuous at valley edges where they are compressed. Sediment core locations are marked by black dots--see Figure 9 for labels. Gray lines are lines of cross-section illustrated in Figures 13, 14, and 21.

Figure 11--Contour map of lower Acheron Valley bottom

between of the spectacular accretionary beach ridges east and northeast of Phanari Bay. Backswamp deposits are composed of dark gray to brown, organic-rich mud and clays, though sandy intervals may be present depending on the proximity of the river channel. In some cases, vegetation is so abundant that the backswamp is essentially a fresh water marsh, and deposits consist of peat and peaty mud. Such deposits contain moderately high to very high weight percentages of organic carbon. Members of the fresh water ostracod genus *Candona* occur in common to abundant quantities in backswamp deposits, while other fresh water forms occur in lesser quantities.

Shallow Fresh Water Lake:

Shallow fresh water lakes and pools are no longer present in the lower Acheron Valley, but they occupied a significant portion of the valley bottom in the past. These lakes are commonly transitional with backswamp and marsh environments. Deposits from such lakes are generally gray in color, and are fine-grained containing abundant clay. The average grain size of six pipette analyses from the inferred lake sediments in core NC-94-23 is 8.54 Φ (clay), with the samples being composed of 56% clay, 43% silt, and 1% sand (Appendix C). Such deposits have a moderate organic content, ranging from 3-8 weight percent. Microfossils present in such deposits consists of relatively sparse numbers of fresh water ostracods and gastropods. Microfossil abundance increases when the deposit is transitional with backswamp and marsh deposits, and is probably the result of the greater organic content (food supply) of shallower environments. The most significant mechanism for the creation of these shallow lakes in the lower Acheron Valley involves the impingement of a river channel and levee system against the bedrock valley walls and is described below in detail (The Late Holocene Birth and Evolution of the Acherousian Lake section). Oxbow lakes which are very common in other coastal river plain localities (Russell, 1954; Villas, 1983) are infrequent in the lower Acheron Valley at the present day. The only example that exists today is the horseshoe-shaped loop immediately north of the Acheron River approximately 1.25 km to the ESE of Phanari Bay (Figure 11).

Fresh to Brackish Water Delta Top Marsh:

The fresh to brackish water delta top marsh is a thick accumulation of reeds and marsh grasses fringing the shoreline on the delta top such as that which exists at present on top of the Acheron delta to the south and southeast of Phanari Bay. The marsh is situated at approximately sea level and receives input of water and sediment from the fluvial and marine systems. Deposits consist of peat and peaty mud with occasional sand layers, and are composed of up to 25 weight percent organic matter. The microfossil assemblages in delta top marsh deposits grade upwards from extremely abundant shallow brackish water forms (especially *Cyprideis torosa* (Jones, 1850), *Leptocythere cf. castanea* (Sars, 1866), *Loxoconcha elliptica* Brady, 1868, *Ammonia beccarii* (Linné, 1758), and *Cribrononion translucens* (Natland, 1938)) to abundant fresh water forms; this reflects its location at the transition from the fresh water fluvial system to the marine embayment.

Delta Front—Distributary Channel, Distributary Mouth Bar, and Subaqueous Levee:

The delta distributary channel, distributary mouth bar, and subaqueous levee are active delta front environments within the marine embayment where the majority of deposition and delta progradation occurs. All three environments are essentially subaqueous continuations of the subaerial fluvial channel and natural levee environments. The coarsest sediments in the system are generally sands and sandy gravels which floor the delta distributary channel. Subaqueous levees border the distributary channel and are composed mostly of sand and silt. Reineck and Singh (1980) note that subaqueous levees also commonly contain intercalations of organic debris. As currents in the distributary channel lose competence, sediment is dropped out of suspension and forms a broad sandy apron around the distributary known as the distributary mouth bar. All recognized active delta front deposits from the lower Acheron Valley are gray to dark gray in color; however, Villas (1983) reports that both gray and tan components exist from her study of the Acheloos River. Microfossils present in such deposits consists primarily of abundant numbers of brackish to marine water organisms, and abundant reworked microfossils from the local bedrock carried by the fluvial system. Deposits from these environments grade basinward into the laminated clays, muds, and fine sands of the lower delta front and prodelta, and laterally into the interdistributary bay environment.

Lower Delta Front and Prodelta:

The lower delta front and prodelta environments are located basinward of the active delta front, and act as a settling basin for suspended sediment. Deposits from both environments consist of gray to dark gray laminated clays, muds, and fine sands, but the sediments of the lower delta front are noticeably coarser since they are a distal extension of the active delta front environments. Deposits from these environments have a low to moderate organic carbon content (3-4 weight percent), and their microfossil assemblages consist strictly of abundant brackish to marine water organisms without any fresh water forms.

Interdistributary Bay:

The interdistributary bay is a shallow open body of water located to the side or partially behind the active delta front. At the present day, no interdistributary bays exist on top of the Acheron delta because Phanari Bay is almost entirely filled in, but such bays did exist in the past. Deposits from this environment are composed of gray to dark gray silts and clays that settle out of suspension, and sandy material washed in over the natural levees surrounding the fluvial distributary channels of the delta top. Crevasse splay deposits are also commonly found interbedded in deposits of interdistributary bays. Delta top marshes which surround these bays contribute to their moderate to high organic carbon content (4-8 weight percent). Deposits from this environment also contain extremely abundant brackish to marine water microfossil assemblages, as well as reworked microfossils from the local bedrock in common to abundant quantities.

Accretionary Beach:

A spectacular series of concentric accretionary beach ridges and intervening swales surrounds modern Phanari Bay (Figure 4). The Acheron delta top and front provide a constant source of sandy sediment that is reworked by normal wave activity, and then piled up high over the regular wave base by spring and storm waves. Long-shore currents that could keep the system in equilibrium by removing excess sand do not

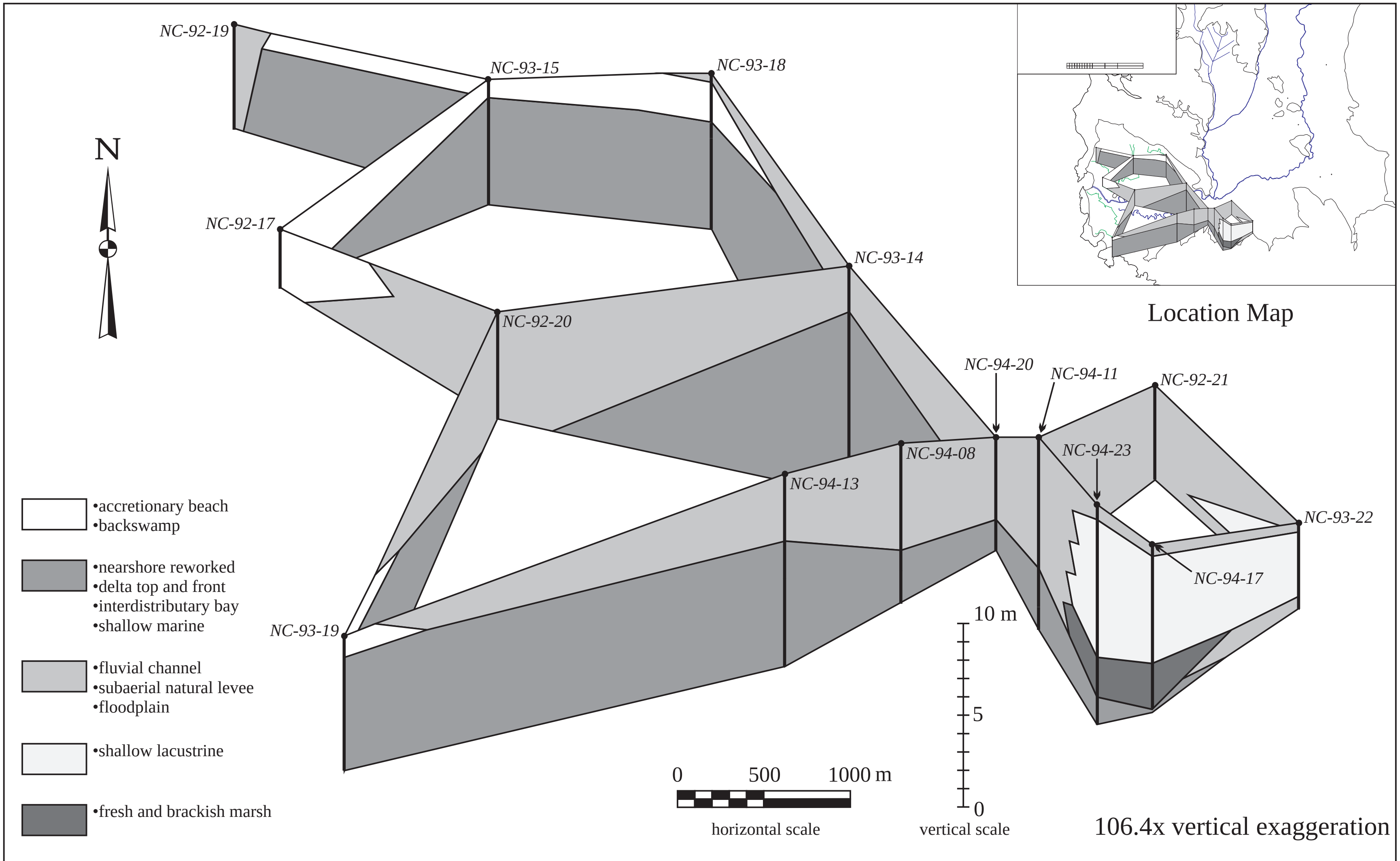


Figure 12--Fence diagram of subsurface stratigraphy in lower Acheron Valley

exist or are very weak because Phanari Bay is so well-sheltered. As a result, these ancient beach ridges have accreted one by one continuously decreasing the size of Phanari Bay. The sands which compose these ridges are generally coarse-grained with occasional small pebbles, and are tan to buff in color. Backswamp and marshy deposits accumulate in the swales between the beach ridges because of their low elevation. These beach ridges are laterally transitional with the delta top and delta front environments.

THE MIDDLE AND LATE HOLOCENE GEOMORPHIC EVOLUTION AND PALEOGEOGRAPHY OF THE GLYKYS LIMEN

Overall Regressive Nature of Stratigraphy:

Geologic evidence collected during this study has provided many details about the middle and late Holocene geomorphic evolution and paleogeography of the lower Acheron Valley. The relative sequence of events indicated by subsurface stratigraphy is supplemented by eight radiocarbon dates which provide absolute chronologic control. Overall, the sedimentary record in the valley is regressive in nature reflecting alluviation during a period of very slowly rising relative sea level (Figure 12).

Dakaris (1971) suggested that the Glykys Limen was formerly much larger and extended back to near the Mesopotamon/Tsouknida valley constriction at "a certain geological period." This was based on his observation of a fossil beach ridge 1.5 kilometers to the east of the village of Ammoudia on Phanari Bay, and the presence of fossil marine macrofauna encountered in a boring near the confluence of the Acheron and Vouvos Rivers (Figure 7). The Mesopotamon/Tsouknida valley constriction is a natural obstruction in the valley both areally and in the subsurface (Figures 13, 14, and 12), and might have logically served as a natural boundary to transgressing Holocene seas. Results from present study, however, indicate that marine influence reached even further inland than Dakaris suggested; rising Holocene seas stretched at least to the location of core NC-94-17 (Figure 9) several hundred meters east of the valley constriction around 2100 BC (Figure 15). Several radiocarbon dates provide absolute chronologic control for this and other shoreline positions during the past 4,000 years.

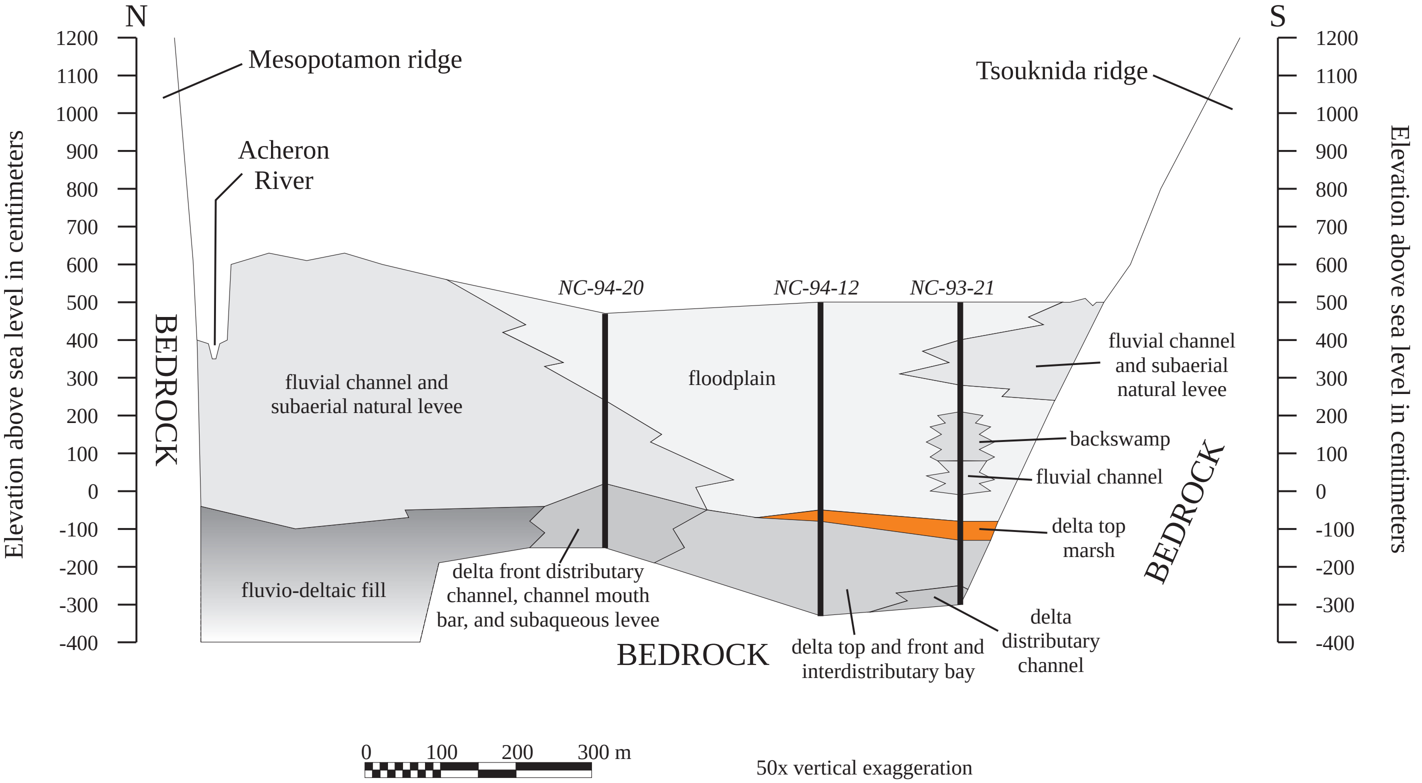


Figure 13--North/south cross-section through Mesopotamon/Tsouknida valley constriction

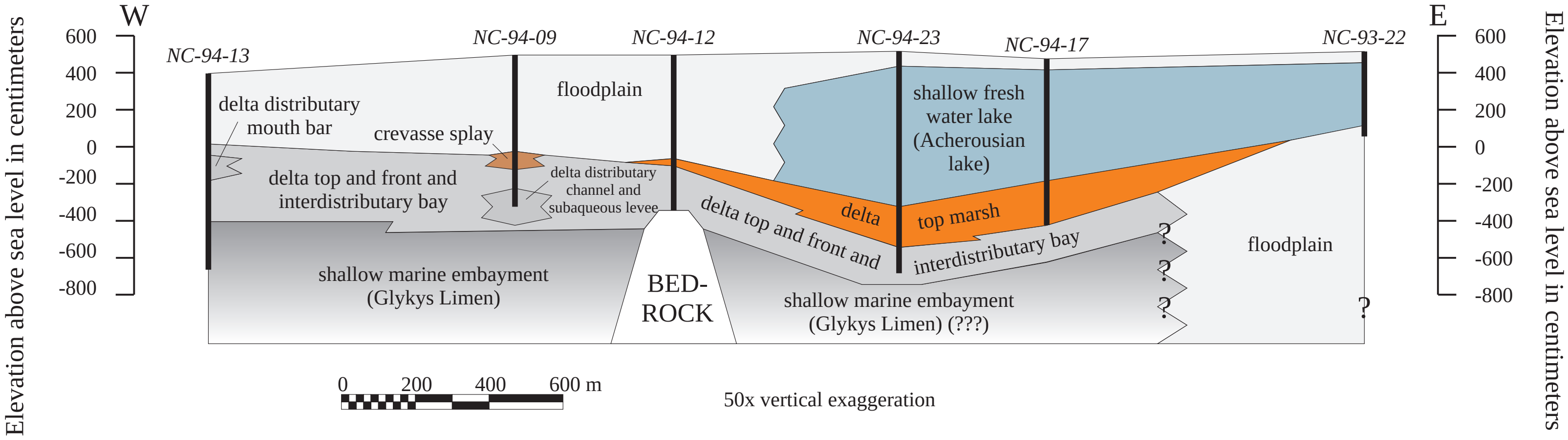
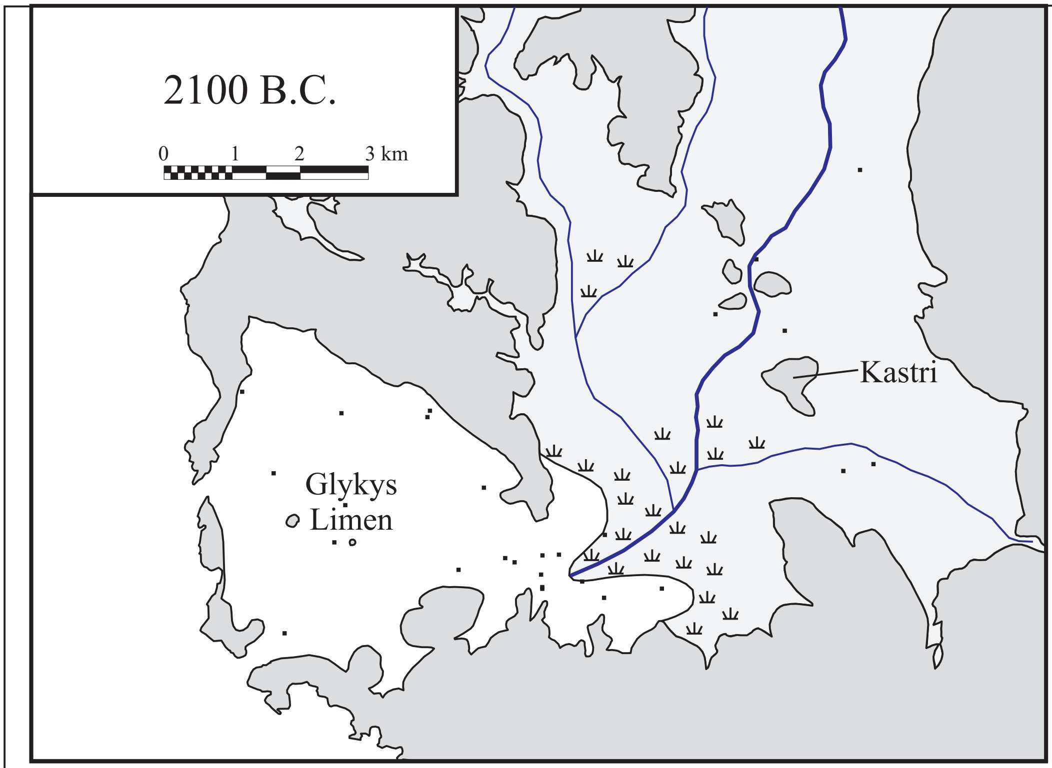


Figure 14--East/west cross-section through Mesopotamon/Tsouknida valley constriction



Note: The small black squares in these diagrams mark core locations. See Figure 9 for labels.

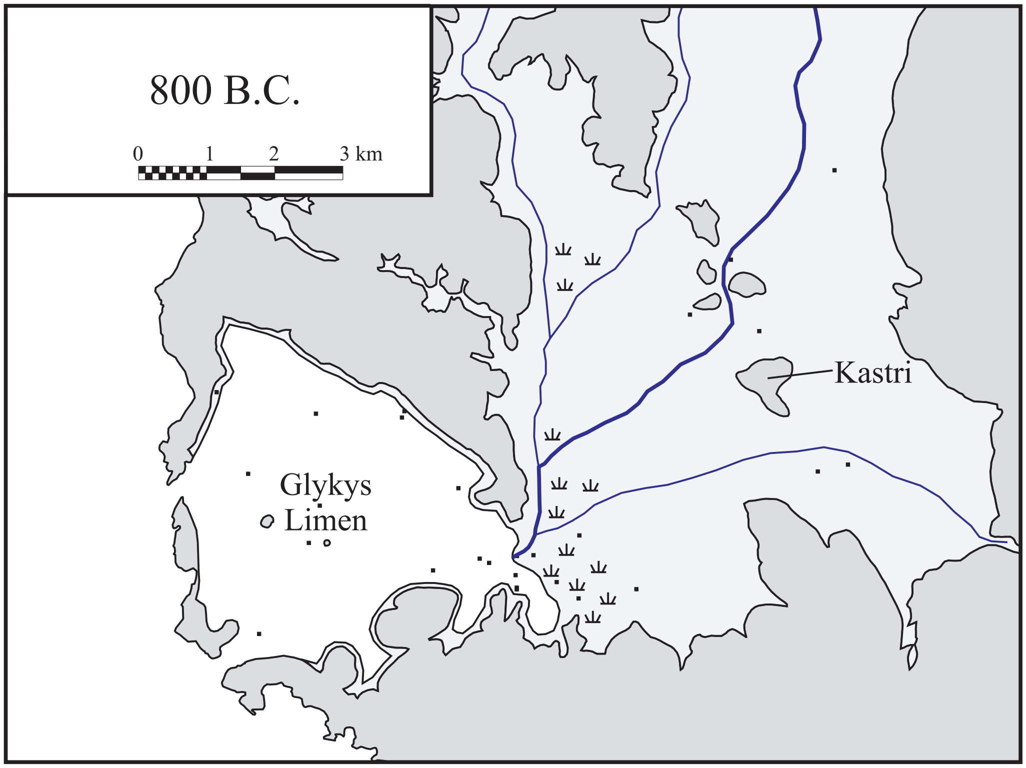


Figure 15--Paleogeographic reconstructions for 2100 BC and 800 BC

Generalized Nature of Reconstructed Shorelines:

It is important to recognize that the reconstructed shorelines generated in this project should be taken only as generalized locations of the shoreline position. Because wave and tide energy are small along the Epirote coast, and even smaller in well-protected Phanari Bay, the Acheron delta is dominated by fluvial processes (Reineck and Singh, 1980). Such fluvially-dominated deltas display an elongate geometry space-permitting. Present Phanari Bay is almost entirely filled in, and this elongate geometry in not apparent. However, it may be noted from other river deltas in Epirus such as that of the Thyamis and the Arachthus seen in the false color satellite image of the region (Figure 3). Additionally, the delta may have had multiple distributary channels. These facts preclude the possibility of being able to reconstruct the exact shoreline at any moment in time.

Glykys Limen in 2100 BC:

Cores NC-94-17 and NC-94-23 (Figures 9 and 14; Appendix A) have a similar stratigraphy and illustrate the overall regressive nature of the sediments laid down in the lower Acheron Valley during the middle and late Holocene. Both cores consist of deposits from the following environments given in normal stratigraphic order: 1.) delta top to front, 2.) brackish water delta top marsh grading upwards into fresh water marsh, 3.) shallow fresh water lake, and 4.) floodplain. A radiocarbon date on peat from the bottom of the brackish water delta top marsh of core NC-94-23 returns a calibrated 1σ range of ages from 4030 +100/-100 years before present, or 2080 +100/-100 BC. This is part of the extensive subsurface delta top marsh deposit seen in the cross-sections through the Mesopotamon/Tsouknida valley constriction (Figures 13 and 14). This indicates that the interface between the delta top/front and brackish water delta top marsh environments found today at Phanari Bay has migrated at least 5.3 kilometers seaward at the expense of the Glykys Limen since approximately 2100 BC (Figure 15).

Maximum Inland Extent of Glykys Limen:

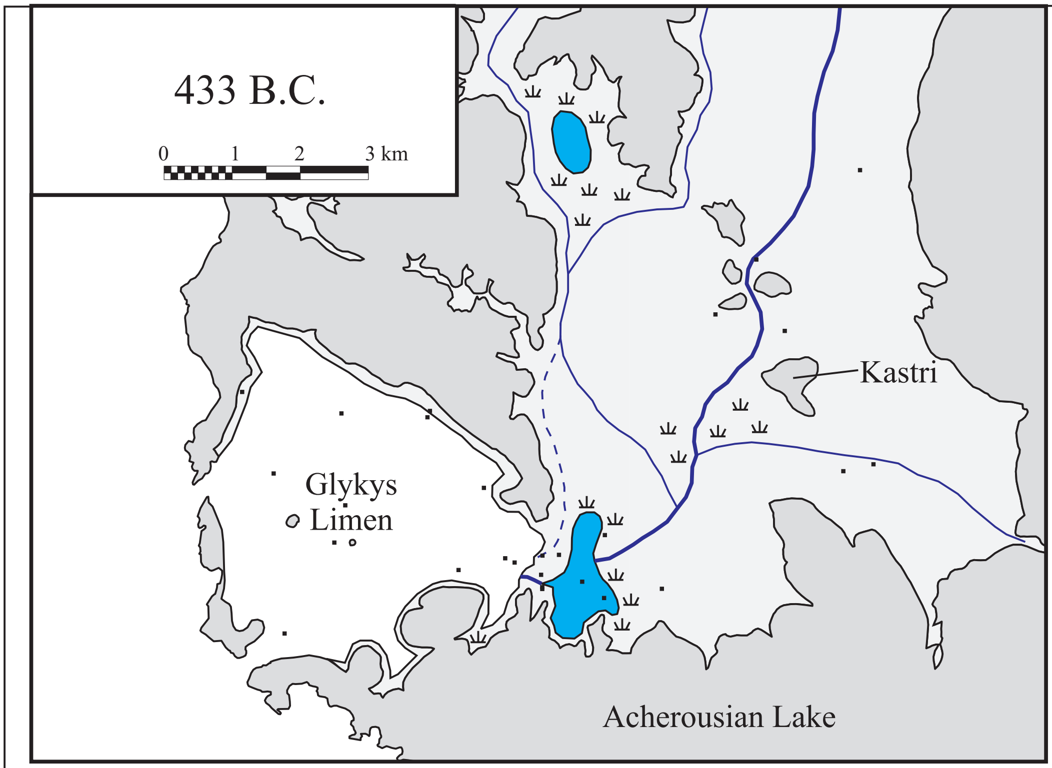
Brackish water conditions also existed at the locality of core NC-94-17 which is located further inland at approximately 5.7 km from Phanari Bay (Figure 9). A radiocarbon date was not obtained from this core, but it is reasonable to assume that the base of the delta top marsh there is approximately the same age or slightly older that of core NC-94-23. The maximum post-glacial eastward extent of the marine embayment is not known because only a few shallow cores are available east of cores NC-94-17 and NC-94-23.

Glykys Limen in 1750 BC:

Core NC-93-21 (Figures 9 and 13; Appendix A) shows a basal stratigraphy that is similar to cores NC-94-17 and NC-94-23, and provides another radiocarbon date that further helps to constrain a former shoreline position at around 1750 BC (Figure 15). Delta top and front sediments directly overlie bedrock, and are in turn succeeded by a delta top marsh environment. However, since NC-93-21 is located about 0.5 km to the west of the other two cores within the Mesopotamon/Tsouknida valley constriction where several fluvial systems coalesce, subaerial fluvial deposits dominate the stratigraphy above the delta top marsh. In fact, all cores within this area of the valley constriction (Cores NC-94-20 and NC-94-12 as well; also see Figures 13 and 12), show delta top and front deposits directly overlain by subaerial fluvial deposits. This indicates that the Acherousian lake never extended west into or through the valley constriction (see The Late Holocene Birth And Evolution Of The Acherousian Lake section below). A radiocarbon date from the delta top marsh peat of NC-93-21 returns a calibrated 1σ range of ages from 3690 +140/-60 years before present, or approximately 1740 +140/-60 BC. This age is approximately 350 years younger than the radiocarbon date from core NC-94-23, which is appropriate given that it is closer to the modern shoreline.

Glykys Limen Between 1750 BC and AD 1100:

Following the 1750 BC radiocarbon date on the location of the shoreline from core NC-93-21, the next radiocarbon date which helps to constrain shoreline position is on a marsh reed from NC-94-13 (Figures 9 and 14; Appendix A) which is dated to around AD 1100 (see Glykys Limen in AD 1100 section below). Between these dates, the position of the shoreline at 433 BC and 1 BC (Figure 16) has been reconstructed using the accounts of Homer, Thucydides, and Strabo for chronologic control. In light of the



Note: The dashed line above indicates a possible alternative course for the Vouvos River. The small black squares in these diagrams mark core locations. See Figure 9 for labels.

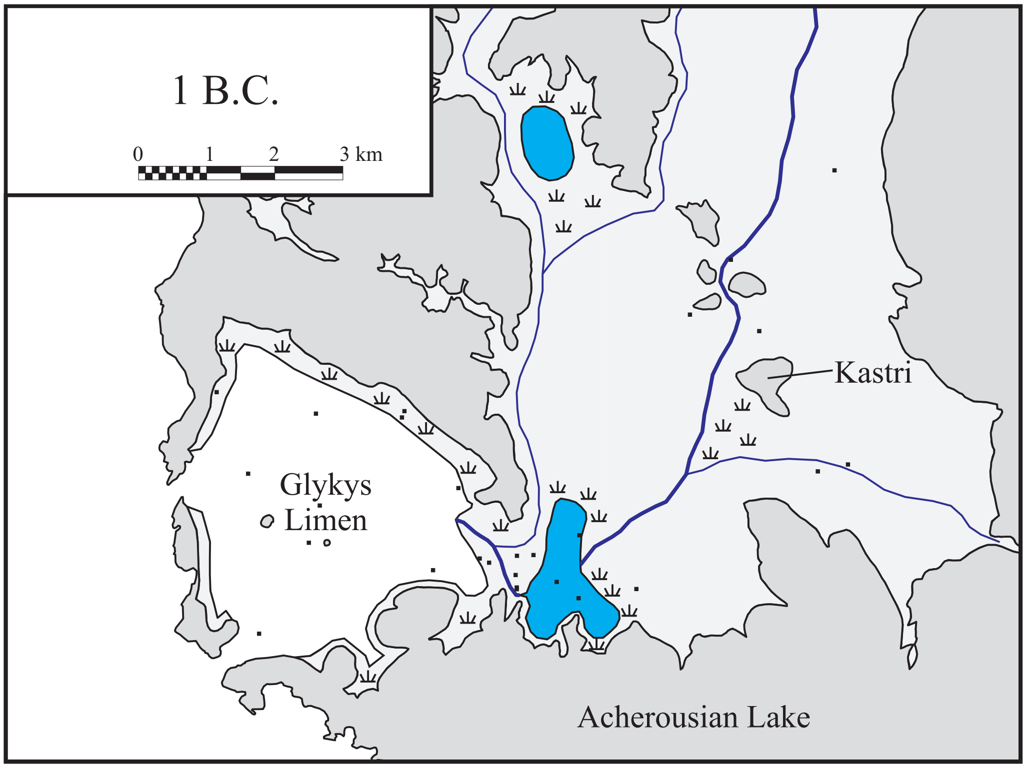


Figure 16--Paleogeographic reconstructions for 433 BC and 1 BC

geologic evidence and other radiocarbon dates, the accounts of these ancient authors present a logical and coherent sequence of events when examined in chronological order. Progradation of the shoreline during this period is intimately linked to the birth and existence of the Acherousian lake which will be discussed in detail below (see Acherousian Lake as a Sediment Trap and Moderator of Shoreline Progradation and The Late Holocene Birth And Evolution Of The Acherousian Lake sections).

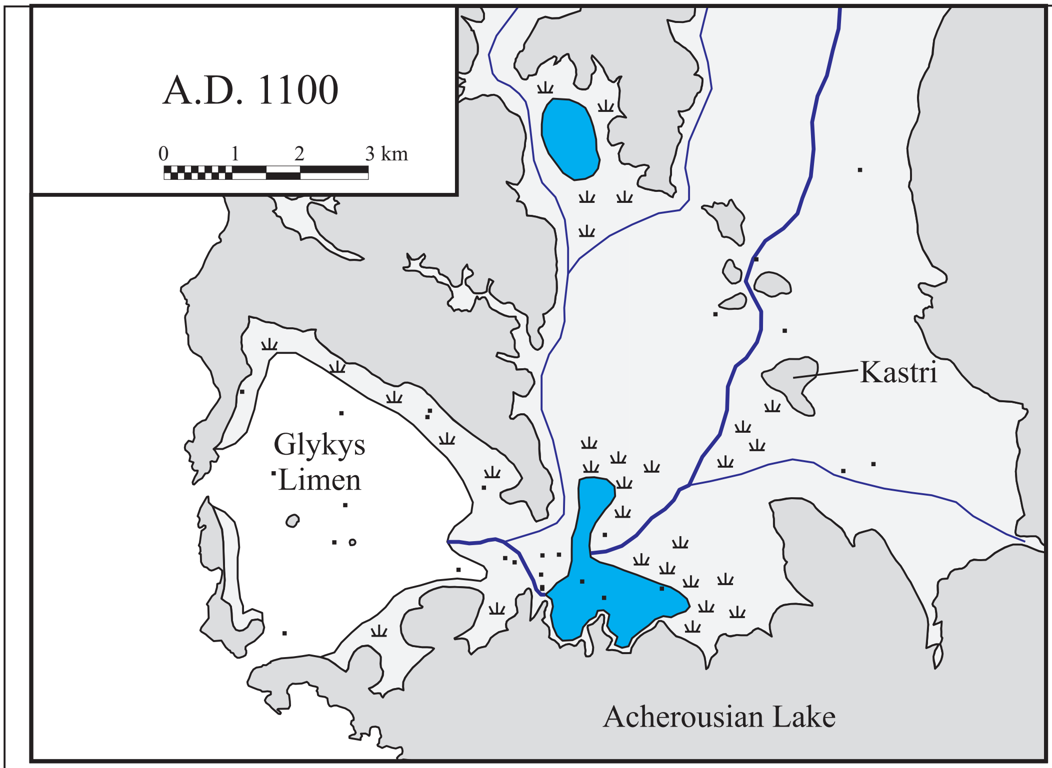
Glykys Limen in AD 1100:

West of the Mesopotamon/Tsouknida valley constriction, both geologic evidence and historical documents provide information about the changing size of the Glykys Limen. Core NC-94-13 (Figures 9 and 14; Appendix A), which is 3.5 kilometers from modern Phanari Bay, is composed from the base upwards of shallow marine prodeltaic deposits of the Glykys Limen that are overlain by delta front sediments. The delta front sediments grade upwards into deposits of a distributary mouth bar, and then an interdistributary bay. The sequence is capped by subaerial fluvial sediments. A marsh reed retrieved from the distributary mouth bar deposit was radiocarbon dated and returns a calibrated 1σ range of ages from 850 +80/-60 years before present, or approximately AD 1100 -80/+60. The vertical sequence in this core indicates that it is not directly in front of the prograding delta, but on its flank, so the actual delta front position would have been somewhat seaward of this location. A hypothetical delta front position for this time is illustrated in Figure 17.

Glykys Limen Since AD 1100 Based on Early Maps:

Constraints on delta growth since AD 1100 are not provided by radiocarbon dates because limited resources were available. However, even if resources were available, the radiocarbon calibration curve is relatively irregular during the last 500 years. Because of this, radiocarbon dating may not be used effectively during the last 500 years since material dated to this time period could in reality date to almost any time during the last 500 years.

Early maps of the area provide some generalized information about the extent of the infilling of the Glykys Limen during this period. Figures 18 and 19 show a



Note: The small black squares in these diagrams mark core locations. See Figure 9 for labels.

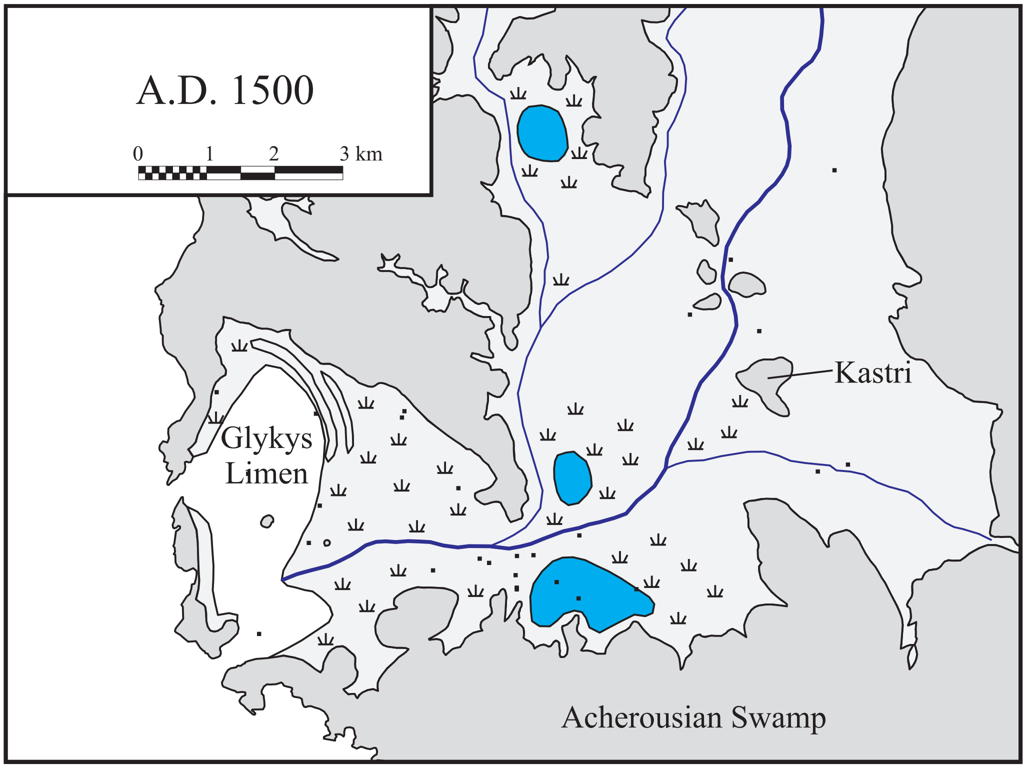


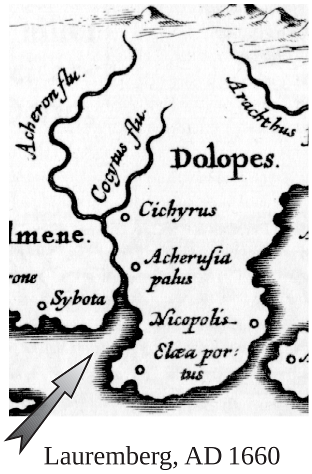
Figure 17--Paleogeographic reconstructions for AD 1100 and AD 1500

Muenster, AD 1545
(*from* Sphyroeras et al., 1985)

Gastaldi, around AD 1575
(*from* Sphyroeras et al., 1985)

De Jode, AD 1578
(*from* DeJode, 1578)

Mercator, late 16th C. AD
(*from* Sphyroeras et al., 1985)



Lauremberg, AD 1660
(*from* Lauremberg, 1660)

Visscher, AD 1682
(*from* Sphyroeras et al., 1985)

Baudrant, AD 1716
(*from* Sphyroeras et al., 1985)

D’Anville, AD 1756
(*from* Sphyroeras et al., 1985)

Figure 18--Early maps (AD 1545-1756) illustrating the lower Acheron Valley

Barbie du Bocage, AD 1791
(*from* Sphyroeras et al., 1985)

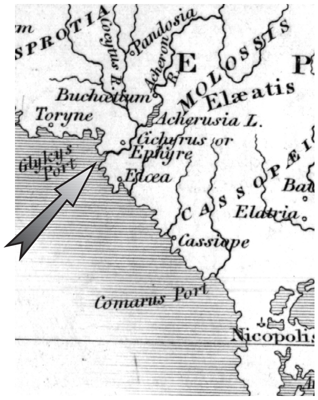
Olivier, early 19th C. AD
(*from* Sphyroeras et al., 1985)

Lapie, AD 1827
(*from* Sphyroeras et al., 1985)

Atlas of Classical Geography, AD 1871
(*from* Hughes, 1871)

Atlas of Ancient and
Classical Geography,
mid to late 19th C. AD
(*from* anonymous, 1909)

Maps and Plans
Illustrative of Thucydides,
probably late 19th C. AD
(*from* anonymous, late 19th C. AD?)



Maps and Plans
Illustrative of Thucydides,
probably late 19th C. AD
(*from* anonymous, late 19th C. AD?)

Maps and Plans
Illustrative of Thucydides,
probably late 19th C. AD
(*from* anonymous, late 19th C. AD?)

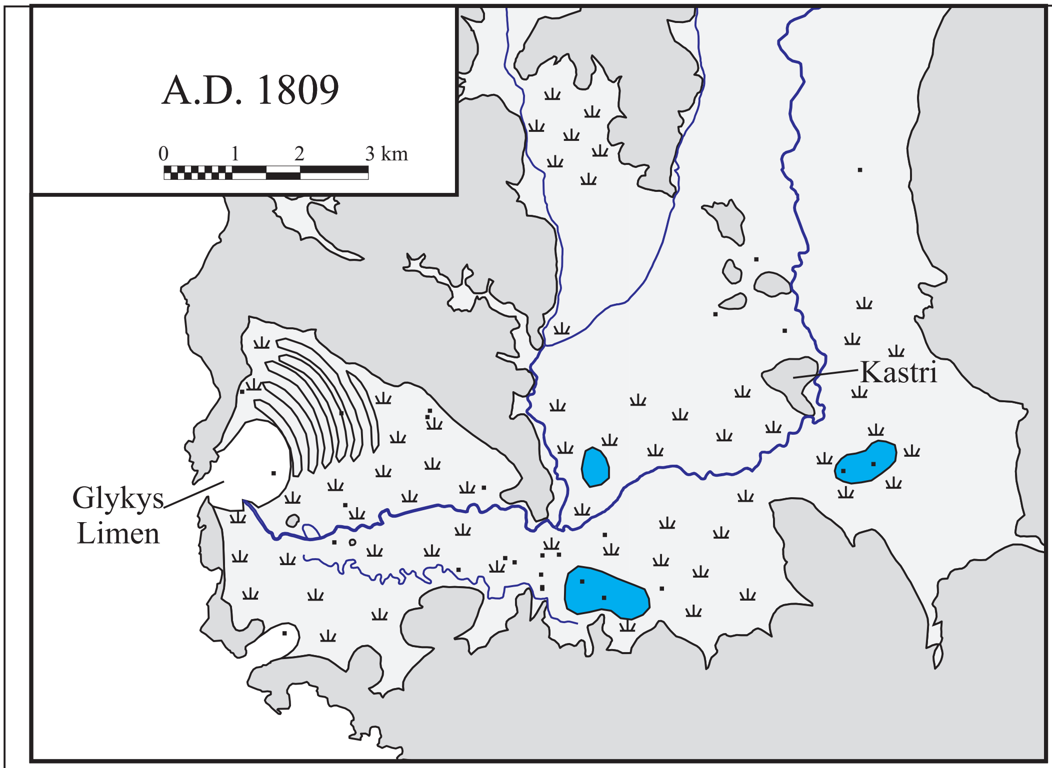
Figure 19--Early maps (AD 1791-early twentieth century)
illustrating the lower Acheron Valley

compilation of these maps with arrows indicating the Glykys Limen/Phanari Bay. These maps are not geographically perfect, and in most cases do not show great detail. However, by using the relative size of the Glykys Limen compared to the Ambracian Gulf, and the intersection of the Acheron and Cocytus Rivers as a reference point, it seems appropriate to suggest that through the seventeenth century AD, the Glykys Limen was still a relatively significant body of water. For example, works by Mercator were known for "the exact dimensions of the areas mapped, the measurement of distances, and the correct positioning of the various geographical features," (Sphyroeras et al., 1985). His map of Greece from the late sixteenth century AD shows a relatively large Glykys Limen (Figure 18). In contrast, all the maps from the late eighteenth century AD and onward clearly illustrate the harbor as much smaller (Figure 19). Figure 17 shows a reconstruction of the shoreline in this period at about AD 1500.0

The description of Leake (1835) as he passed through the region in AD 1809 provides significant information about the landscape configuration east of the Mesopotamon/Tsouknida constriction, but details about the coastline and actual delta front are scarce. The modern village of Ammoudia which surrounds present day Phanari Bay did not come into existence till after Leake's time in the early part of the twentieth century AD (T. Tartaron, oral communication, 1996). Therefore, the shoreline position in AD 1809 must have been a bit further eastward (Figure 20).

Probable Redeposition of Organic Material From Core NC-92-20:

There is one radiocarbon date from the area of the Glykys Limen that seems anomalously old given its location and the type of deposit from which it was obtained. Redeposition seems a likely candidate to explain the discrepancy. Core NC-92-20 (Figure 9; Appendix A) is situated in the middle of the area of the Glykys Limen about 1.6 kilometers from Phanari Bay. It consists of deposits that are inferred to be floodplain and natural levee deposits, which directly overlie either bedrock or gravel. A radiocarbon date of organic material retrieved 50 cm above the base of the core returns a calibrated 1σ range of ages from 2650 +70/-290 BP, or 700 +70/-290 BC. This would suggest that the



Note: The small black squares in these diagrams mark core locations. See Figure 9 for labels.

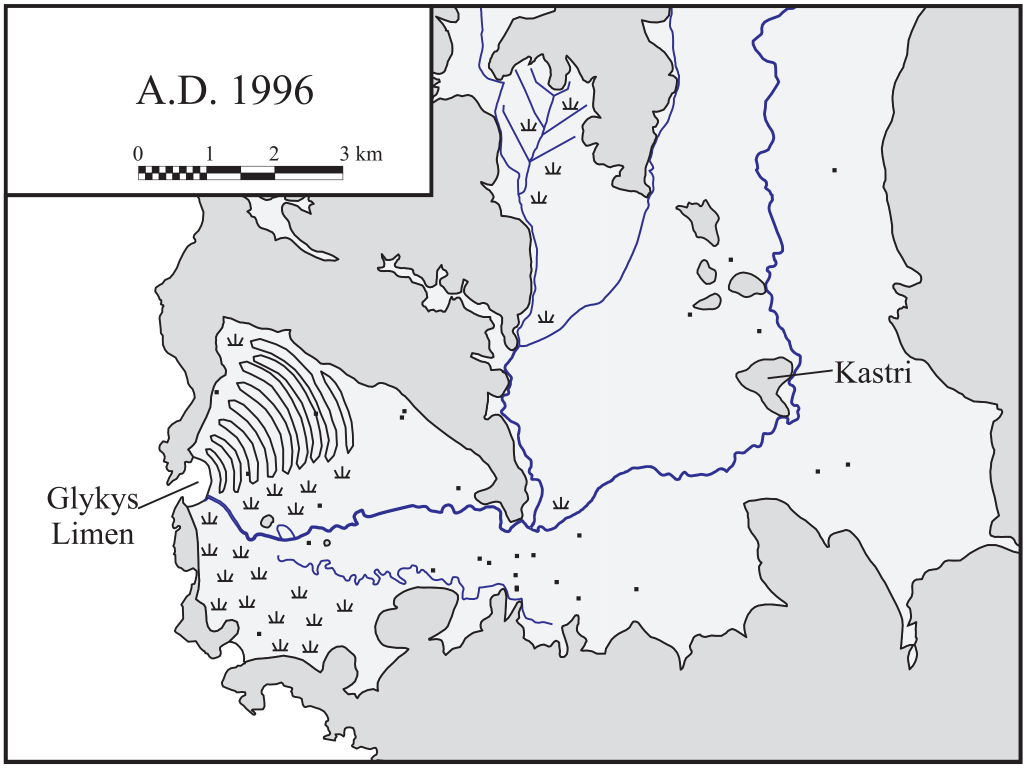


Figure 20--Paleogeographic reconstruction for AD 1809 and modern landscape

delta top is at this location as early as 700 BC, and therefore the delta front position would be further basinward of this location.

This interpretation is problematic since it is in gross contrast with the other radiocarbon dates and the strong geomorphic evidence of the accretionary beach ridges surrounding Phanari Bay (see Changing Rates of Shoreline Progradation and Importance of Accretionary Beach Ridges section below). This date from NC-92-20 is also problematic considering the accounts of ancient authors. If the Acheron delta had prograded as far as core NC-92-20 by 700 BC, the Glykys Limen would not have been able to accommodate the large naval fleets that were to anchor in it hundreds of years later. Neither would the descriptions by Thucydides and others that suggest the Acherousian lake and the Glykys Limen were fairly proximal during the Classical Period be appropriate because it will be seen below that the Acherousian lake never extended westward past the Mesopotamon/Tsouknida valley constriction.

The anomalously old radiocarbon date from core NC-92-20 is likely due to redeposition. The stratigraphy in the core is rather peculiar, and is only similar to that seen in core NC-92-16 which is less than 600 meters away. Though the deposits are subaerial, they occur up to five meters below sea level. In fact a large package of subaerial fluvial sediment is present in the valley in this area (Figures 12 and 21). Bedrock is very shallow as indicated by limestone knobs that stick up through the alluvium just 500 meters to the south, and 700 meters to the west (Figure 11). These bedrock knobs are covered with red sediment and vegetation at present, and would have been small vegetated islands before the infilling of the Glykys Limen. Consequently, it seems probable that the deposits around the bedrock knobs such as in core NC-92-20 may represent reworked older sediment and material shed off of the islands.

Changing Rates of Shoreline Progradation and Importance of Accretionary Beach Ridges:

It is interesting to note the various rates of valley infilling and shoreline progradation through time. For example, in the 3200 years from 2100 BC to AD 1100, the shoreline apparently prograded the relatively small amount of two kilometers (Figures 15, 16, and 17). However, in the 850 years from AD 1100 to the present, almost three

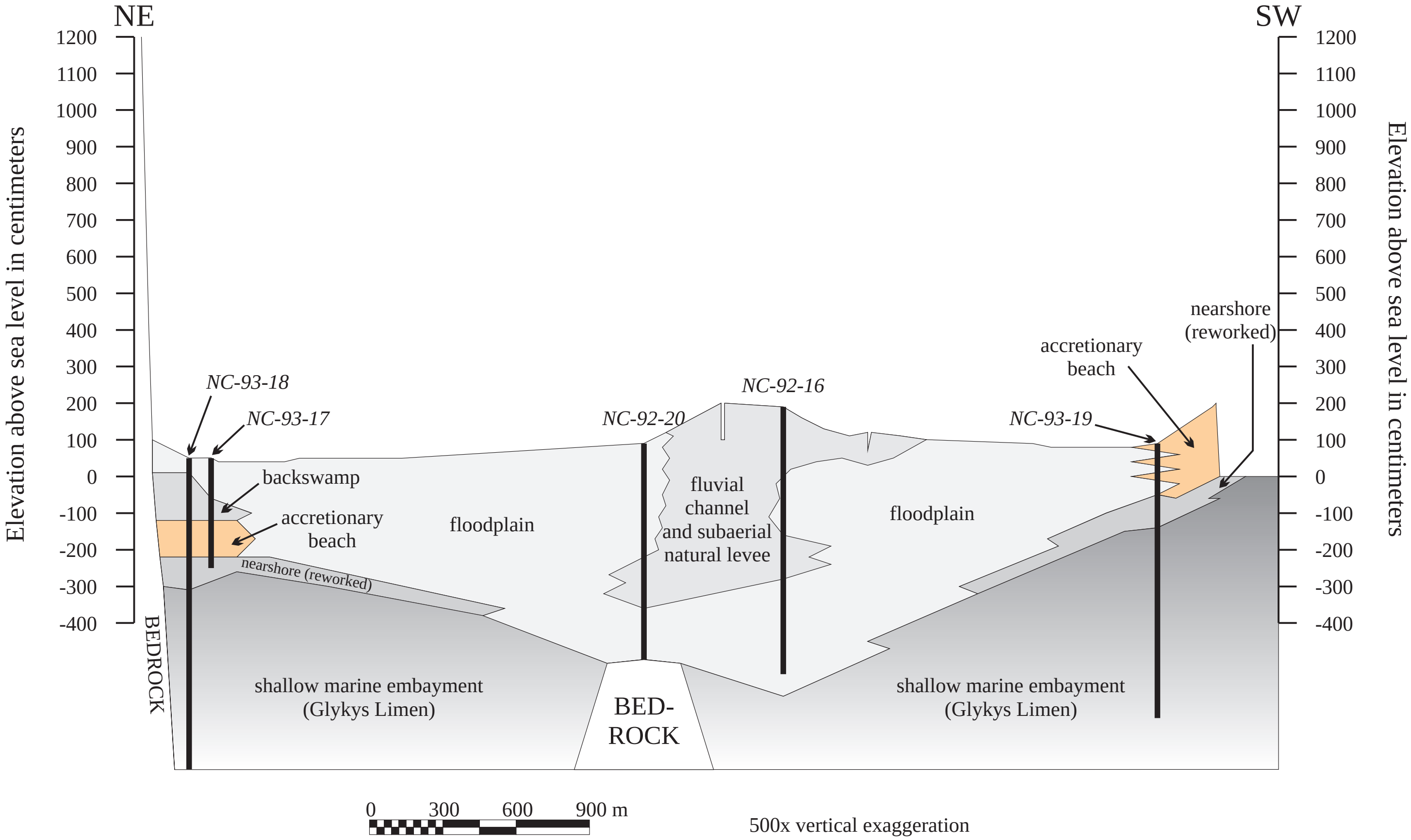


Figure 21--Northeast/southwest cross-section through valley bottom (area of former marine embayment)

and a half kilometers of shoreline progradation occurred (Figures 17 and 20). This scenario for an early relatively slow shoreline progradation, followed by the rapid infilling of the Glykys Limen is also supported by the three kilometer wide system of accretionary beach ridges and swales noted east of modern Phanari Bay (Figure 4).

Such beach ridges are usually associated with uplift, something not unexpected given the compressional tectonic environment of Epirus (Waters, 1994). However, all ridges are encountered in the same elevational band (between 3 m below sea level. and 1 m above sea level), and no progression of elevations can be noted moving inland. If such ridges were deposited slowly during the last 3000-4000 years, it should be expected that they would be encountered at progressively higher elevations inland. Alternatively, if the valley bottom is subsiding as Waters (1994) indicates, it should be expected that the beach ridges moving inland would become progressively lower.

Neither of these scenarios is the case; all the beach ridges are of approximately the same elevation on detailed 1:5000 scale topographic maps of the area. This can also be seen with less resolution in Figure 11—the area of the infilled harbor to the west of Valanadorrachi (Figure 7) is extremely flat and even. This suggests that the ridges were deposited very rapidly in the last 400 or 500 years; neither uplift nor subsidence has had sufficient time to produce a progressive, notable change in elevation of the ridges moving landward. Independent of radiocarbon dating, this fact argues that the last three kilometers of shoreline progradation have been very rapid. Tziavos (1977) found a similar situation in his examination of the Sperchios delta on the eastern coast of Greece, noting that delta growth was occurring at a continuously increasing rate.

Acherousian Lake as a Sediment Trap and Moderator of Shoreline Progradation:

The difference in the rates of shoreline progradation may be due to several factors, an important one probably being the formation of the Acherousian lake. As will be discussed below, the lake as an open body of water apparently did not come into existence until some time between 2100 and 433 BC (Figures 15 and 16), but more likely between 800 and 433 BC. Previous to the formation of the lake, the entire sediment load carried by the Acheron River was delivered to the sea where it formed a delta and allowed for the progradation of the coast. However, once the lake came into existence, it functioned as an efficient sediment trap for the Acheron River which then built a lacustrine delta into the lake (Figures 16 and 17).

With the necessary sediment source to supply a prograding coastline cut off, a relatively slow rate of shoreline progradation resulted following the inception of the lake. The lake's ability to accommodate sediment and inhibit shoreline progradation was further enhanced by two factors which are discussed in detail in the next section below (The Late Holocene Birth And Evolution Of The Acherousian Lake section)—a western boundary/spillway that was built increasingly higher, and subsidence of the lake floor. Eventually the lake filled in and the normal sediment load carried by the Acheron once again made it to the coast to supply shoreline progradation. This probably occurred after AD 1100, but before Turkish times (Figure 17) since by that point the Acherousian lake remained as nothing more than a swamp (Hammond, 1967).

Other Factors Capable of Moderating Coastal Evolution:

Though the formation of the Acherousian lake was undoubtedly an important factor in moderating shoreline evolution in the valley, several other factors must also be considered. For example, shoreline progradation in a normal basin infill sequence becomes progressively more rapid with time because deposition early on is directed towards filling in the bottom of the basin. As the basin grows continuously shallower, an increasingly larger portion of the sediment supply can be dedicated to shoreline progradation. This would result in increasing rates of shoreline progradation.

One other factor which may help explain the changing rates of shoreline progradation may simply be the amount of sediment delivered to the fluvial system. Increased sediment delivery which would result in shoreline progradation could occur because of natural or anthropogenic activities. If the rate of shoreline progradation did increase rapidly around AD 1500 as evidence seems to indicate, this is nearly contemporaneous with the start of the Little Ice Age (Grove, 1988). The cooler and wetter climate of this time would result in an increased delivery of sediment to the fluvial system. Alternatively, anthropogenic activities such as deforestation and land use for agriculture would lead to an increased delivery of sediment to river systems and consequently to the coast. In support of this, Dakaris (1971) reports that the valley became used extensively for agriculture beginning in Turkish times. Finally, from work in other areas of Greece, van Andel et al. (1990) have suggested that increased sediment delivery to a basin may also be the result of the degradation and lack of maintenance of terraces and cultivated land. During times of economic and political stress, structures designed to minimize soil loss fall into disrepair, and thus the sediment supply generated in a river basin increases. Unfortunately, based on the present set of data obtained during this project, no correlation between periods of increased or decreased valley infilling due to climatic or anthropogenic factors can be positively or negatively concluded.

THE LATE HOLOCENE BIRTH AND EVOLUTION OF THE ACHEROUSIAN LAKE

While several modern authors have ventured to treat the topic of the no longer extant Acherousian lake, a detailed chronology of its development and evolution based on geologic evidence has never been prepared. From the present study, particularly important elements such as when the lake came into existence, the mechanism by which this occurred, the nature of the lake, and its geometry and dimensions through time have become available. The absolute chronology which accompanies these details is based partly on radiocarbon dates, and partly on an analysis of literary and historical references by ancient authors.

Dakaris (1971) provided the most thorough consideration of the size and location of the lake during Classical times (Figure 8), followed by Hammond (1967) who offered a simple verbal description. Unfortunately, their reconstructions were based primarily on indirect evidence, the modern landscape configuration in the valley, and the assumption that the lake filled in gradually over time becoming shallower and areally less expansive. However, the mechanism responsible for the impoundment of the lake was dynamic, and it did not experience a normal lacustrine infill sequence and evolution. Instead, it maintained a shallow profile, but grew continuously larger spreading upvalley through time. The mechanism responsible for this is explained below in detail. Because of these factors, Dakaris, Hammond, and others overestimated the size of the lake at least as an open body of water.

Initial Formation of the Acherousian Lake and Fluvial Plug Impoundment Mechanism:

Cores NC-94-23 and NC-94-17 (Appendix A) located just to the east of the Mesopotamon/Tsouknida valley constriction (Figure 9) illustrate the overall regressive nature of the middle and late Holocene sedimentary packages in the valley. They consist from the base upwards of deposits from the following environments: 1.) delta top to front, 2.) brackish water delta top marsh grading upwards into fresh water marsh, 3.) shallow fresh water lake, and 4.) floodplain. The shallow fresh water lake deposit is from the Acherousian lake. A radiocarbon date on peat from the bottom of the fresh to brackish water delta top marsh of core NC-94-23 returns a calibrated 1σ range of ages from 4030 +100/-100 years before present, or 2080 +100/-100 BC Therefore, it can be unequivocally concluded that the Acherousian lake came into existence at some point after approximately 2100 BC.

The sequence of stratigraphy in cores NC-94-23 and NC-94-17 indicates that the marsh was essentially drowned as the lake came into existence directly on top of it. Some mechanism to the west of these core localities was therefore responsible for the impoundment of the lake. Analysis of the stratigraphy in cores NC-94-20, NC-94-12, and NC-93-21 (Appendix A) which are just 600 m to the west in the valley constriction near Mesopotamon/Tsouknida (Figure 9) provides this answer.

A cross-section through NC-94-20, NC-94-12, and NC-93-21 shows a massive fluvial plug filling the valley at this point (Figure 12 and 14). The stratigraphy in these cores consists of delta top and front sediments that are immediately overlain by fluvial channel, subaerial natural levee, and floodplain sediments. In contrast, core NC-94-23, which is just 600 m to the east, consists of the same delta top and front sediments overlain by 7.5 m of sediment from the Acherousian lake. From this relationship, it is clear that the lake was impounded to the east of the Mesopotamon/Tsouknida valley constriction because of the fluvial sediments that existed in the valley right at the constriction (Figures 12 and 14).

Channel and Levee System Migration as an Agent of Significant Geomorphic Evolution in the Past and at Present:

This fluvial plug records the migration of the channel and levee system of the Acheron River or one of its tributaries. As the channel/levee system built south-southwestward from the eastern side of the Mesopotamon ridge, it eventually impinged onto the bedrock walls bounding the valley to the south (Figures 16 and 17). As a result, a shallow, closed depression was pinched off to the east behind this channel/levee system, and water ponded up drowning the delta top marsh to form the Acherousian lake (Figure 16).

This mechanism of river channel and levee migration is an extremely important agent of geomorphic evolution in the valley. Depending on the depth of the impounded water, this basin becomes either a backswamp or shallow lake. At present, the process can be seen operating in at least three other spots in the valley. One example is the southwest-trending topographic bulge delineated by the 12 m above sea level contour line (Figure 11) to the WSW of Koroni (Figure 7). This topographic bulge represents a former channel/levee system of the Cocytus River that has impinged onto the bedrock valley wall to the west, and pinched off a closed depression to its north. Another example is the closed depression to the NW of Kanallakion (Figure 7) that is delineated by the 10 m contour line seen in Figure 11. In this instance, the channel/levee system of the Acheron River heading south from Kastri impinged onto the tip of Pountas ridge (Figure 7). This created the closed depression immediately to the east delineated by the 10 m contour as described above. The final example concerns the small depression delineated by the 6 m contour line (Figure 11) to the ESE of Ephyra (Figure 7). This depression formed upvalley of the junction of the Acheron and Vouvos Rivers as the Acheron channel/levee system impinged against the Mesopotamon/Ephyra ridge system. An incipient closed depression, also delineated by the 6 m contour line (Figure 11), will be created just south of the Acheron River if the Acheron/Vouvos junction migrates towards the bedrock valley wall to the south. In essence, the Acherousian lake may come into existence once again just as it did originally.

Russell (1954) noted a similar process in his study of the Meander River in western Anatolia. In this case, a rapidly prograding delta front/coastal plain built across the entrance to a marine embayment essentially trapping a standing pool of water within the embayment. He also noted the same process under slightly different circumstances on the Mississippi Delta. There he recognized shallow lakes (“levee-flank depressions”) which had formed on the delta top in the area behind/between the intersection of two stream channel/levee systems (Russell, 1967).

Use of Ancient Literary and Historical References to Constrain the Evolution of the Acherousian Lake:

Though the radiocarbon date of approximately 2100 BC (Appendix E) from core NC-94-23 indicates the impoundment of the Acherousian lake must have occurred after that point, a more tightly constrained chronology could be determined by another radiocarbon date at the top of the fresh water marsh deposit. Unfortunately, limited resources do not allow for this possibility. Consequently, tighter constraints for the lake's inception are based on an analysis of literary and historical references by ancient authors. Differing opinions about the accuracy and validity of topographical references made by ancient authors are certain; however, it seems appropriate that if such references are taken in chronological order and present a coherent and logical sequence of events, they may be useful. On the contrary, if they present a sequence of events that is improbable, or if various references contradict one another, one may be inclined to question their validity. Fortunately, a detailed analysis of ancient literary and historical references to the Acheron Valley in chronologic order shows that they present a logical and coherent sequence for the evolution and development of the Acherousian lake.

Literary and Historical Evidence From Homer, Thucydides, and Strabo:

The earliest reference to the valley comes from the Odyssey of Homer. Current thought suggests that the Odyssey, as well as the Iliad, may have been written about 800 BC, but describe events of around 1200 BC. In Book X (Odyssey, X.508-515) Homer writes:

> And when in your ship you have traversed Oceanos,
> Where the scrubby strand and groves of Persephone are,
> Both tall poplars and willows that lose their fruit,
> Beach your ship there by deep-whirling Oceanos;
> But go on yourself to the moldy hall of Hades.
> There into Acheron flow Puriphlegethon
> And Cocytus, which is a branch of the Styx's water,
> And a rock and a concourse of the two resounding rivers.

No mention of the lake is made, in fact Homer strictly describes a scene in which several tributaries feed into the Acheron River. The adage "lack of evidence does not constitute evidence for a lack" is applicable here, but it may be suggested that Homer did not mention the lake because it did not exist at the time he witnessed or learned of the topography in the valley. The lake then probably formed at some point between the writing of the Odyssey around 800 BC, and the time of Thucydides' account of the valley about 400 years later when the lake is mentioned for the first time.

Thucydides (1.46.4) who wrote contemporary history gave a description of what must have been a recently nascent Acherousian lake in his account of the Battle of Syvota of 433 BC:

> It is a harbour, and above it lies a city away from the sea in the Eleatic district of Thesprotia, Ephyra by name. Near it is the outlet into the sea of the Acherusian lake; and the river Acheron runs through Thesprotia and empties into the lake, to which it gives its name.

Of interest here is the fact that Thucydides strictly states "Near it is the outlet into the sea of the Acherusian lake" as if the lake empties directly into the sea. This seems to imply that the Acherousian lake and the sea (actually the Glykys Limen) are very close—the two are split by only a very narrow barrier of land on which is situated the lake spillway (Figure 16). This narrow barrier of land is the channel and levee system of the Acheron and/or one of its tributaries which caused the impoundment of the lake as explained above. Thucydides clearly identifies the Acheron River as flowing into the lake, but says nothing to the effect that it exits from the lake.

His account is distinct from all references by later authors in that it suggests the extreme proximity of the Acherousian lake and the sea. Later accounts suggest that more than just a lake spillway is present, and that the channel carrying water from the lake to the sea is significantly long enough to be identified as that of the Acheron River. For example, Strabo (7.7.5), the Roman historian and geographer who wrote during the latest part of the first century BC, wrote the following:

> Then comes Cape Cheimerium, and also Glycys Limen, into which the River Acheron empties. The Acheron flows from the Acherusian Lake and receives several rivers as tributaries, so that it sweetens the waters of the gulf.

It would seem then that the strip of land separating the lake from the sea had become sufficiently wide in the 400 years between the accounts of Thucydides and Strabo such that the channel draining the Acherousian lake could be identified as that of the Acheron River.

It can be unequivocally demonstrated that the Acherousian lake formed at some point after approximately 2100 BC based on the radiocarbon date from core NC-94-23. Furthermore, since Homer, Thucydides, and Strabo present a logical and coherent picture of the probable development of the lake in their writings, it is suggested that the lake did not form until some point between 800-433 BC.

Archaic Period Decline in Population Possibly Due to Birth of Acherousian Lake:

There is one other bit of circumstantial evidence that may support the notion that the lake did not come into existence until this late period. Malaria has always been a problem in the low-lying coastal areas of Epirus. Dakaris (1971) noted that the presence of a shallow lake in the lower Acheron Valley would lead to unhealthy living conditions and promote malaria. Unfortunately, he had no evidence for when the lake formed, and probably assumed that it had been present in the valley throughout the Holocene following the post-glacial rise of sea level. Still, he noted that the archaeological record from the valley indicated a decrease in population during the Archaic Period which runs from approximately 700-500 BC (Dakaris, 1971, Fig. B and C). He was not able to tie it in with any particular event, but suggested that it was due to malaria and the swamps.

This decrease in population during the Archaic Period might be strictly coincidental, but it may also be appropriate to attribute it to the birth of the Acherousian lake.

Size of the Acherousian Lake Through Time:

With respect to the size of the lake, because Dakaris and others did not recognize the mechanism responsible for its impoundment, they assumed that the lake followed a typical lacustrine infill sequence and became increasingly shallower and areally less expansive through time. In contrast, Philippson and Kirsten (1956) suggested that the lake had become larger since ancient times, but they did not explain why they considered this the case or provide supporting evidence for their conclusion. Results from this study suggest that the assertion by Philippson and Kirsten (1956) is correct, and detailed geologic information to prove that this is the case is available for the first time.

Early after its formation, the lake existed as a shallow body of open water surrounded by a fringe of marshy ground (Figure 16). Sediment carried by the Acheron would have quickly filled it in, but the spillway for the lake which was the channel/levee system of the Vouvos River was being built progressively higher thus accommodating continuously more sediment (Figure 22). As a result, the lake maintained a shallow profile, but grew simultaneously larger spreading upvalley (Figures 16, 17, and 20). Unfortunately, the small number of cores to the east and northeast of the Mesopotamon/Tsouknida valley constriction makes defining the northern and eastern borders of the lake somewhat arbitrary.

Estimate of Sediment Accommodation by the Acherousian Lake:

It was mentioned in the previous section that the lake served as a sediment trap, and thus moderated shoreline progradation. However, the sediment trap was dynamic—the aggrading spillway in the Mesopotamon/Tsouknida valley constriction provided that the trap grew continuously larger (Figure 22). One may estimate the thickness of sediment accommodation in the lake by summing up the contributions produced by 1.) the constantly aggrading river channel and levee spillway, and 2.) subsidence of the lake bottom and sediment compaction.

EXPLANATION: The Acherousian lake did not follow a simple evolutionary path (e.g. progressive infilling leading to a decrease in depth and surface area). Instead, several simultaneously-occurring factors controlled the evolution of the lake, and consequently the evolution of the Glykys Limen. Those factors include 1.) a progressive vertical accretion of the lake spillway through time, 2.) subsidence of the lake bottom and sediment compaction, and 3.) simultaneous infilling of the lake with sediment carried by the fluvial system. Progressive vertical accretion of the lake spillway led to a consequent progressive rise in lake level. This resulted in an increase in the areal extent of the lake through time, and the development of a transgressive sequence upvalley (floodplain succeeded by shallow marshy lake). Vertical accretion of the spillway also served to increase the capacity of the Acherousian lake as a sediment trap. This was further enhanced by subsidence of the lake bottom and sediment compaction. Despite the progressively rising water level and increasing surface area, the lake maintained a shallow profile because of simultaneous infilling with sediments carried by the Acheron River.

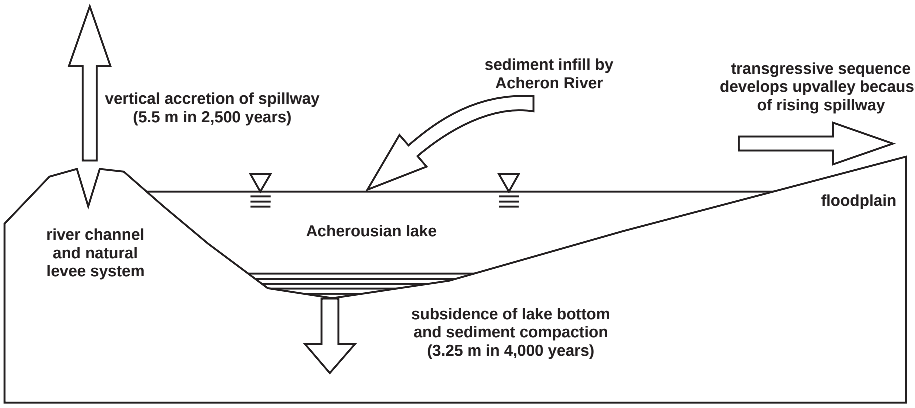
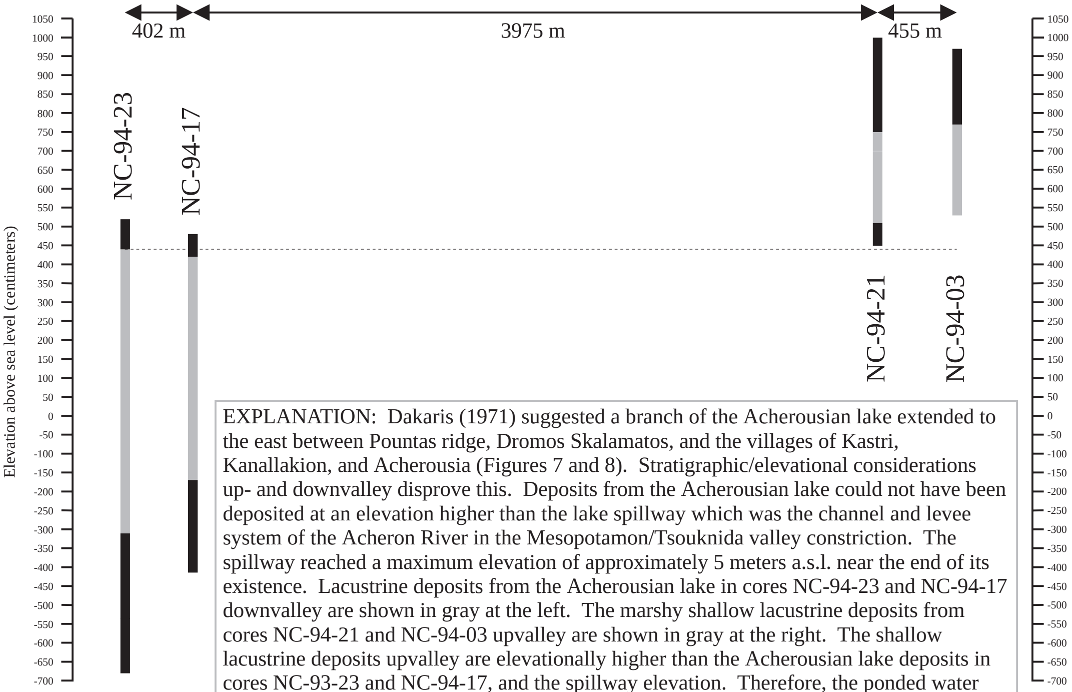


Figure 22--Factors controlling the evolution of the Acherousian lake



EXPLANATION: Dakaris (1971) suggested a branch of the Acherousian lake extended to the east between Pountas ridge, Dromos Skalamatos, and the villages of Kastri, Kanallakion, and Acherousia (Figures 7 and 8). Stratigraphic/elevational considerations up- and downvalley disprove this. Deposits from the Acherousian lake could not have been deposited at an elevation higher than the lake spillway which was the channel and levee system of the Acheron River in the Mesopotamon/Tsouknida valley constriction. The spillway reached a maximum elevation of approximately 5 meters a.s.l. near the end of its existence. Lacustrine deposits from the Acherousian lake in cores NC-94-23 and NC-94-17 downvalley are shown in gray at the left. The marshy shallow lacustrine deposits from cores NC-94-21 and NC-94-03 upvalley are shown in gray at the right. The shallow lacustrine deposits upvalley are elevationally higher than the Acherousian lake deposits in cores NC-93-23 and NC-94-17, and the spillway elevation. Therefore, the ponded water east of the Pountas ridge that Dakaris suggested was a branch of the Acherousian lake could not possibly have been confluent with the main portion of the lake. This ponded water developed very late in history of the valley, perhaps as late as the end of the sixteenth century AD when the Acheron River shifted its course to south of Kastri.

Figure 23--Deposits of the Acherousian lake versus shallow lacustrine deposits upvalley

Assuming the Acherousian lake came into existence at some point between 800 and 433 BC as outlined above, then the 5.5 m of fluvial plug material noted in core NC-94-12 which impounded the lake accumulated in approximately the last 2500 years. Subsidence of the lake bottom and sediment compaction can be estimated using core NC-94-23. The base of the brackish water delta top marsh in this core was radiocarbon dated to approximately 4000 BP. Because the tidal range in the region is minimal, it is assumed that the brackish water delta top marsh was deposited at an elevation close to mean sea level. At 4000 BP, relative mean sea level in the region was about two meters less than at present (Figure 6). The brackish water delta top marsh material that was radiocarbon dated was retrieved from 5.25 m below modern sea level. Therefore, the lake bottom has subsided approximately 3.25 m (= 5.25 m - 2 m) in the last 4000 years. Together then, the aggradation of the fluvial plug at the valley constriction (5.5 m), and subsidence of the lake bottom and sediment compaction (3.25 m) have accommodated nearly nine meters (actually 8.75 m = 5.5 m + 3.25 m) of sediment infill into the lake.

Increasing Lake Area Documented by Stratigraphic Onlap of Deposits Upvalley:

Evidence for the initial small size of the lake, followed by the expansion of marshy, swampy ground upvalley can be noted by comparing the stratigraphy in cores NC-94-23 and NC-94-17 with that of core NC-93-22 (Figures 9 and 14). Cores NC-94-23 and NC-94-17 are located just to the east of the fluvial plug in the valley constriction and contain 7.5 m and 5.9 m, respectively, of lacustrine mud and clay from the Acherousian lake (Appendix A). These lake deposits begin at 3.1 m and 1.7 m below sea level, and run to 4.4 m and 4.2 m above sea level, respectively. Core NC-93-22 is located approximately one kilometer east of NC-94-23 and NC-94-17 in the area considered by Dakaris and others to be the ancient lake. However at this locality, a much thinner sequence (3.5 m) of mixed lacustrine and marsh deposits occurs between 1.7 m and 4.2 m above sea level (Appendix A). The lake deposits in the core are underlain by a very stiff floodplain alluvium with some pedogenic development. This package of lacustrine and marshy deposits shows stratigraphic onlap upvalley, and its transgressive nature confirms the gradual increase of lake level through time (Figures 14 and 22). The lake probably never extended much further upvalley than the location of NC-93-22 because the mixed lacustrine and marsh deposit here is indicative of the lake edge and shore.

Temporal and Spatial Control on the Transgression of the Lake Upvalley:

By making broad assumptions, we can provide some temporal and spatial control for the transgression of the lake upvalley. The base of mixed lacustrine and marsh sedimentation in core NC-93-22 (Appendix A) starts at 1.2 meters above sea level. Lacustrine and marsh sedimentation could not have occurred at this point until the surface elevation of the Acherousian lake reached at least 1.2 meters above sea level due to aggradation of the spillway. When did the lake surface elevation reach 1.2 meters above sea level?

By blindly ignoring subsidence and assuming a linear rate of infilling, we can estimate this using the lacustrine deposits of core NC-94-23 (Appendix A) as a proxy "timeline" for control of events upvalley such as at the location of NC-93-22. Lacustrine sedimentation in core NC-94-23 occurs between 3.1 meters below sea level to 4.4 meters above sea level. It was concluded above that the lake came into existence at the locality of NC-94-23 definitively after 2100 BC, but probably more specifically between 800 and 433 BC. Lacustrine deposition there ended after the First World War at which time the final remnants of the swamp were backfilled. By equating 3.1 meters below sea level with approximately 800-433 BC (using mid-ground as 600 BC), and 4.4 meters above sea level with AD 1925, 1.2 meters above sea level falls around AD 850. Therefore, using core NC-94-23 and the assumptions mentioned above, it may be estimated that the expansion of the lake and marshy ground did not reach the locality of NC-93-22 till approximately AD 850.

Northern and Eastern Lake Shoreline Based on Topography:

Evidence suggests Dakaris (1971), Hammond (1967), and others greatly overestimated the size of the lake (Figure 8), especially considering their reconstructions represent the supposed lake extent during the Classical Period. The shape and location of their reconstructions also seem to contradict modern topography in some cases. For example, Dakaris suggested the lake had a NE/SW-trending shore between Mesopotamon and Kastri (Figure 7), while Hammond (1967) described an approximately E/W-trending shore. However, topographic contours lines in this area (Figure 11) strike NW/SE; therefore the shoreline would have had the NW/SE trend (Figures 16 and 17).

Improbability of Dakaris' Lake Reconstruction Based on Stratigraphy:

Dakaris' (1971) who provided the most authoritative reconstruction of the lake (Figure 8) suggested that a branch of it extended to the east between Pountas ridge, Dromos Skalamatos, and the villages of Kastri, Kanallakion, and Acherousia (Figure 7), but this is not correct. This was based on some oak balks unearthed by chance near Dromos Skalamatos which he interpreted as "oak keels indicating that there was some harbor and perhaps a shipyard at this point of the lake."

In the first place, it was demonstrated above that the transgression of the Acherousian lake upvalley did not reach the location of core NC-93-22 till around AD 850, and it did not reach much further east after that. Also, as was mentioned above, this area is a closed depression that came into existence when the Acheron channel and levee system impinged against the tip of Pountas ridge after shifting its course to the south of Kastri. Evidence discussed below suggests this shift of the river course occurred very recently, perhaps as late as the end of the sixteenth century AD (Figure 20). Thus, in ancient times the lake could not have extended as far east as Dakaris illustrated.

An examination of stratigraphic evidence confirms that that the main body of Acherousian lake to the west of Pountas ridge was not confluent with the much later water body that formed to the east of the ridge, and this is illustrated in Figure 23. Laminated muds and marshy sediments of lacustrine origin do occur in this small basin to the east of the ridge, but they form a relatively thin deposit, and elevationally they are too high to have been deposited by the Acherousian lake. Core NC-94-03 (Figure 9 and Appendix A) was retrieved from the center of this small depression. It is composed of a backswamp deposit overlain by a fresh water marsh deposit, which is in turn succeeded by floodplain deposits. Core NC-94-21 (Figure 9) was retrieved just 450 meters from the first core and exhibits nearly identical stratigraphy, except that it terminates in a floodplain deposit at its base. Even though core NC-94-03 did not penetrate lower floodplain deposit, because it is close to and shorter than the second core, it can be inferred that if it had penetrated further, the lower floodplain deposit noted in the neighboring core would also have been reached fairly quickly.

Recalling that the fluvial plug sediments in the Mesopotamon/Tsouknida valley constriction served as the spillway for the Acherousian lake, deposits from the lake must occur at or below the elevation of the spillway which reached a maximum elevation of approximately five meters above sea level (Figures 13 and 14) near the end of its existence. The lacustrine and marshy deposits in cores NC-94-03 and NC-93-21 occur in an elevational zone between 5.1 and 7.7 meters above sea level. Therefore, the standing water body that deposited these sediments must have had a significantly higher water surface elevation than the Acherousian lake (Figure 23). Consequently, it could not be confluent with the larger lake. This evidence definitively indicates that Dakaris' (1971) extension of the lake east past Kastri and Pountas ridge is incorrect.

Recent Evolution of the Acherousian Lake/Swamp:

By Turkish times, the Acherousian lake had become a swamp with a few isolated pools of water (Hammond, 1967) (Figure 17). Continued growth of the Acheron River channel and levee system split the remains of this swamp. This interpretation is supported by the broad topographic high (Figure 11) of the modern river channel and levee system to the east of Mesopotamon which is delineated by the 6 meter contour.

Leake (1835) provided an excellent summary of the marshy valley bottom from his travels through the region in the spring of AD 1809, and noted that several pools of open water existed at that point (Figure 20). After the First World War, the final marshy remnants of the former Acherousian lake were filled in (Dakaris, 1971), and the area has been used for agriculture since that point.

THE CHANGING COURSE OF THE ACHERON WITH RESPECT TO KASTRI

Instead of providing direct geologic evidence to demonstrate that the Acheron River had shifted its course to the south of Kastri since Classical times, Dakaris (1971) used reverse reasoning to suggest this was the case. His desire to identify the ruins on modern Kastri with those of ancient Pandosia forced him to reconcile the accounts of ancient authors with the modern landscape layout by suggesting that the river had shifted its course. The lack of evidence to support his assertion consequently left the proposed shift as a matter of faith. Cores NC-94-02 and NC-94-04 collected during this study provide appropriate geologic evidence to demonstrate that the shift in river course did indeed occur.

Terminus Ante Quem Date for River Channel From Classical Pottery Fragment:

Core NC-94-02 (Figure 9 and Appendix A) was retrieved north of Kastri, between it and the larger of the two Xirolophos hillocks (Figure 7). Deposits from the following environments occur in sequence from the base of the core upwards are: 1.) floodplain, 2.) backswamp, 3.) floodplain, 4.) fluvial channel, and 5.) floodplain. At the interface between the lowest floodplain unit and the backswamp, a small, rounded reddish pottery fragment was encountered. Because the fragment is abraded, it lacks diagnostic features to place it in a ceramic period. However, Melissa Moore and Stavros Zabetas, ceramic specialists working in the Boston University Nikopolis Project, have suggested that based on the texture of the ceramic, it should date to the Classical Period (personal communication, 1994). Since this pottery fragment occurs below the deposits of a fluvial channel, it provides a *terminus ante quem* date for the existence of the river channel at that location. Therefore, at some point past the beginning of the Classical Period, a fluvial channel (probably that of the Acheron) existed north of Kastri.

Modern (<500 Year BP) Radiocarbon Date on Channel Deposit:

Core NC-94-04 (Figure 9 and Appendix A) was retrieved north of Kastri between the hillock of Koronopoulos and the larger of the two Xirolophos hillocks (Figure 7). From the base upwards, deposits from the following environments occur in succession: 1.) floodplain, 2.) backswamp, 3.) fluvial channel, 4.) backswamp, and 5.) floodplain. The fluvial channel sediment is over 1.5 meters thick, and gravel clasts up to one centimeter in diameter were retrieved. This deposit is from a significant river channel like that of the Acheron, and not from a smaller stream. A radiocarbon date on a piece of wood from the base of the fluvial channel deposit returns a calibrated 1σ range of ages from 380 +90/-70 years BP, or AD 1570 +70/-90 (Appendix E). For calibrated radiocarbon dates this young, it turns out that the specimen could in reality date to almost any time during the last 500 years because the radiocarbon calibration curve is relatively irregular during this period. However, the significant conclusion of this result is that a river channel, probably that of the Acheron River, was operating to the north of Kastri within the last 500 years. When Leake passed through the region in AD 1809, he recorded that the Acheron River followed a course to the south of Kastri similar to present. Therefore, if the fluvial channel sediments in core NC-94-04 are indeed from the Acheron River, it would suggest that the course of the Acheron shifted from the north of Kastri to its south sometime between approximately AD 1500 and 1809. As a result, it seems appropriate to abandon the skepticism that has prevented the unanimous identification of the ruins on modern Kastri with those of ancient Pandosia because of the discrepancy between the accounts of ancient authors and the modern arrangement of the landscape.

It should be noted that this late shift of the river course helps control the size and chronology of the Acherousian lake. The shallow closed depression to the northwest of Kanallakion (Figure 7) that is delineated by the 10 meter contour line on Figure 11 was pinched off as the Acheron channel/levee system impinged onto the tip of Pountas ridge. Thus, Dakaris' reconstruction (Figure 8) showing the lake extending east past Kastri and Pountas ridge is not correct as explained in the Improbability of Dakaris' Lake Reconstruction Based on Stratigraphy section above.

SUMMARY AND CONCLUSION

Numerous ancient authors beginning with Homer in the eighth century BC make reference to the lower Acheron Valley in Epirus, Greece and indicate a landscape configuration that is significantly different than at present. Three notable discrepancies between the ancient landscape and modern landscape exist. The first problem concerns the size of the Glykys Limen (modern Phanari Bay) which at present is very small, but was much larger in ancient times according to the descriptions of the ancient accounts. The second significant discrepancy concerns the evolution of the no longer extant Acherousian lake which ancient sources indicate was a conspicuous feature in the valley.

The final discrepancy concerns the course of the Acheron River which today flows to the south of the hillock Kastri, but was located to the north of that site according to ancient sources. Geologic evidence from twenty-eight gouge auger sediment cores taken at various locations in the valley indicates that significant geomorphic change in the valley has occurred during the last 4,000 years. It appears that the discrepancies between the accounts of ancient authors and the modern landscape can be explained by a natural sequence of geomorphic evolution in the valley.

Significant Conclusions and Results About the Glykys Limen:

The shoreline of the Glykys Limen has prograded nearly six kilometers in the last 4000 years doing so at varying rates. In the 3200 years from 2100 BC to AD 1100, the shoreline prograded just two kilometers (Figures 15, 16, and 17). However, nearly three and a half kilometers of shoreline progradation occurred in the 900 years from AD 1100 to the present (Figures 17 and 20). The difference in the rates of shoreline progradation may be due to several factors, an important one probably being the formation of the Acherousian lake which served as an efficient sediment trap and moderated the quantity of sediment delivered to the shore of the Glykys Limen. The noted changes in rates of shoreline progradation may also be related to the normal infill sequence of a basin, or the amount of sediment delivered to the fluvial system which is dependent on natural climatic variability and anthropogenic activities among other considerations.

Significant Conclusions and Results About the Acherousian Lake:

The Acherousian lake appears to have developed relatively late in the Holocene, definitively between 2100 and 433 BC, but probably between 800 and 433 BC. It never reached the proportions suggested in reconstructions by Dakaris (1971), Hammond (1967), and others. The lake came into existence by a sedimentary process which appears to be a very effective agent of geomorphic change in the valley; because the valley is so narrow, migrating river channel and levee systems frequently impinge against the bedrock valley walls pinching off shallow closed depressions upvalley of the impingement point. Because of this, the Acherousian lake did not experience a normal lacustrine infill sequence becoming shallower and areally less-expansive through time. Instead, the river channel and levee system which served as the lake spillway aggraded continuously causing a consequent rise in lake surface elevation. Infilling by fluvial sediment, subsidence of the lake bottom, and sediment compaction were occurring simultaneously with the rising lake level. The balance between these parameters allowed the lake to maintain a shallow marshy profile, but grow continuously larger spreading upvalley through time. By Turkish times, the lacustrine delta built into the lake by the Acheron River breached the spillway thus allowing its sediment supply to return to the coast. Subsequent to this, normal lacustrine infill processes dominated the swampy, marshy remnants of the lake.

Significant Conclusions and Results About the Course of the Acheron River:

Regarding the course of the Acheron River, a pottery fragment and an AMS radiocarbon date from two significant river channels north of Kastri suggest that the river course followed a northerly route around the hillock during Classical times. The river course appears to have migrated to the south of the hill very recently, probably between AD 1500 and 1809.

Conclusions About the Accuracy of Ancient Accounts for Archaeologists and Geologists:

It appears that the discrepancies noted between the accounts of ancient authors and the modern landscape of the Acheron Valley are not due to errors committed by these authors, but due to a natural sequence of landscape evolution in the valley. While ancient accounts may not provide detailed information about the ancient landscape or topographical relationships for paleogeographic and paleoenvironmental reconstructions, their careful examination may provide information and details that are not recoverable from the geologic record. The disciplines of geology and archaeology find a natural interface here, both contributing to, and benefiting from one another. Indeed, the profound geomorphic evolution noted in the Acheron Valley during the last 4,000 years of relatively stable eustatic sea level reaffirms the need for multidiciplinary archaeological investigations that strive for a broad understanding of the dynamic physical environment in which the material remains they study were generated.

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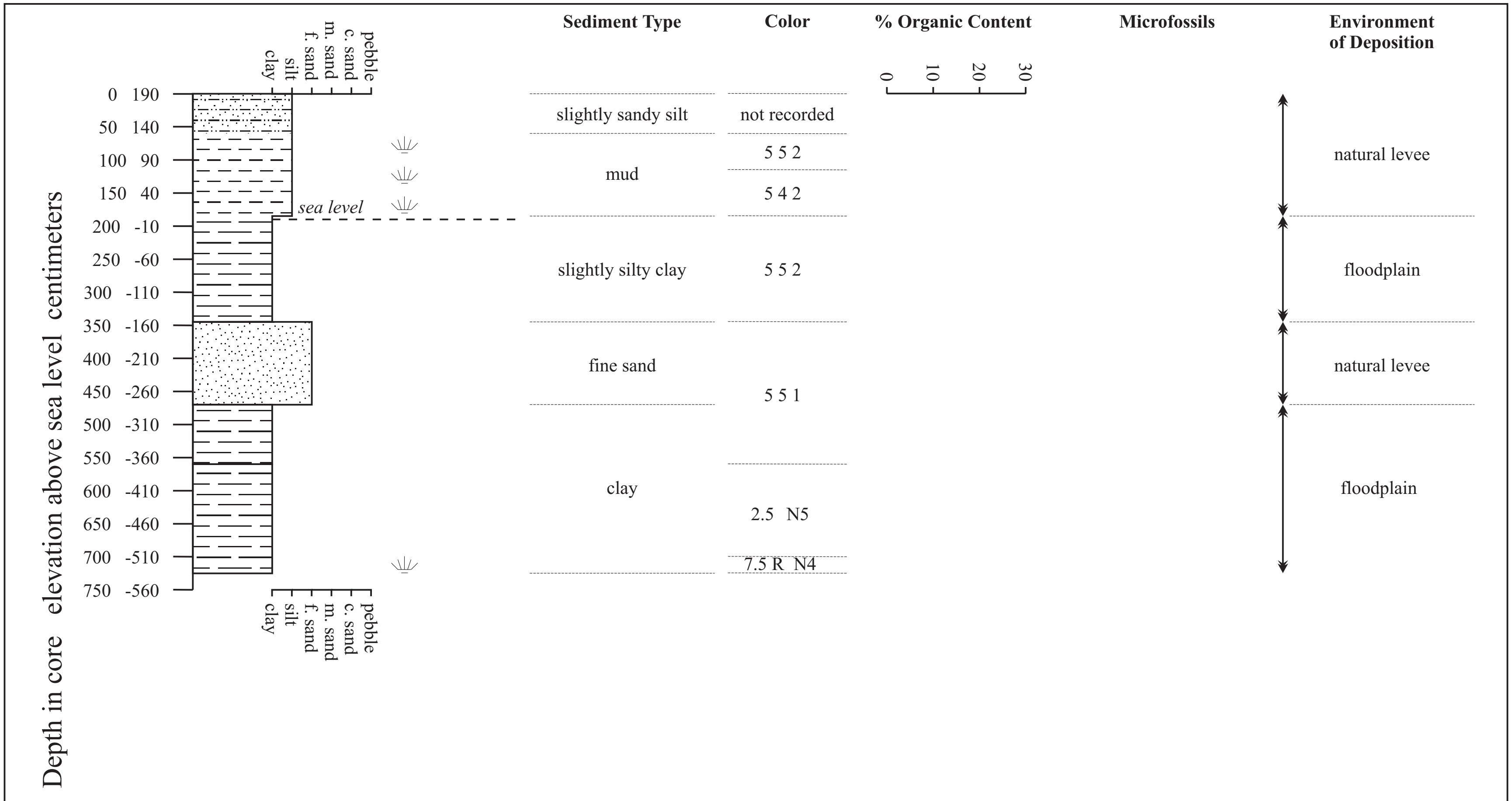
Appendix A--Core Stratigraphy (Including Organic Carbon Content, Microfossil Abundances, and Probable Environments of Deposition)

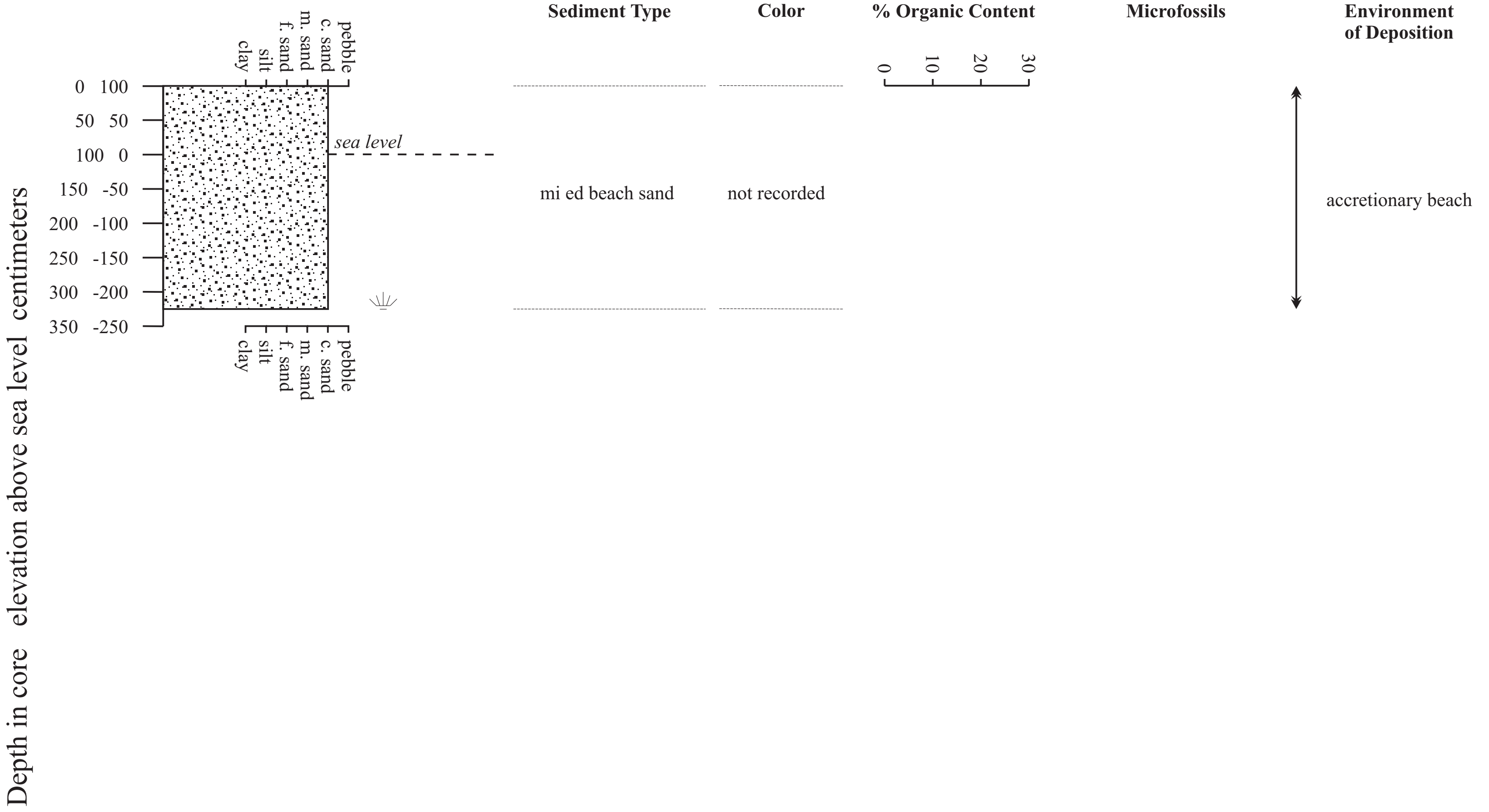
This appendix contains the sediment core stratigraphy from all field seasons. Width of the core, lithologic patterns, and a "Sediment Type" description reflect the grain size and type of sediment. Organic matter present in the stratigraphy is indicated by one of the symbols in the legend below. Locations of calibrated C-14 AMS dates are indicated by arrows. "Color" (according to the Munsell Soil Color Chart), weight percent of organic matter determined by loss on ignition analysis ("% Organic Matter"), and results of the microfossil analyses ("Microfossils") are included. An explanation of results from the microfossil analyses is found in the legend below, and in the "Qualitative Assessment of Paleosalinity Based on Microfossil Assemblages:" section of the text. The probable "Environment of Deposition" represents the author's interpretation of the stratigraphy based on all available data.

Symbol	***Explanation***
ѱ	common coarse-grained organic matter
ѱ≡	abundant coarse-grained organic matter
(ѱ)	few to trace coarse-grained organic matter
ѱ	common fine-grained organic matter
(ѱ)	abundant fine-grained organic matter
ѱ≡	few to trace fine-grained organic matter
← C-14: 4030 +100/-100 BP	calibrated C-14 AMS date in years B.P.
qty. 615: 1.3% F, 91.4% B, 7.3% R	qty. XXX = quantity/total number of freshwater, brackish to marine water, and reworked microfossils in the sample 1.3% F = percentage of freshwater forms in quantity XXX 91.4% B = percentage of brackish to marine water forms in quantity XXX 7.3% R = percentage of reworked microfauna in quantity XXX

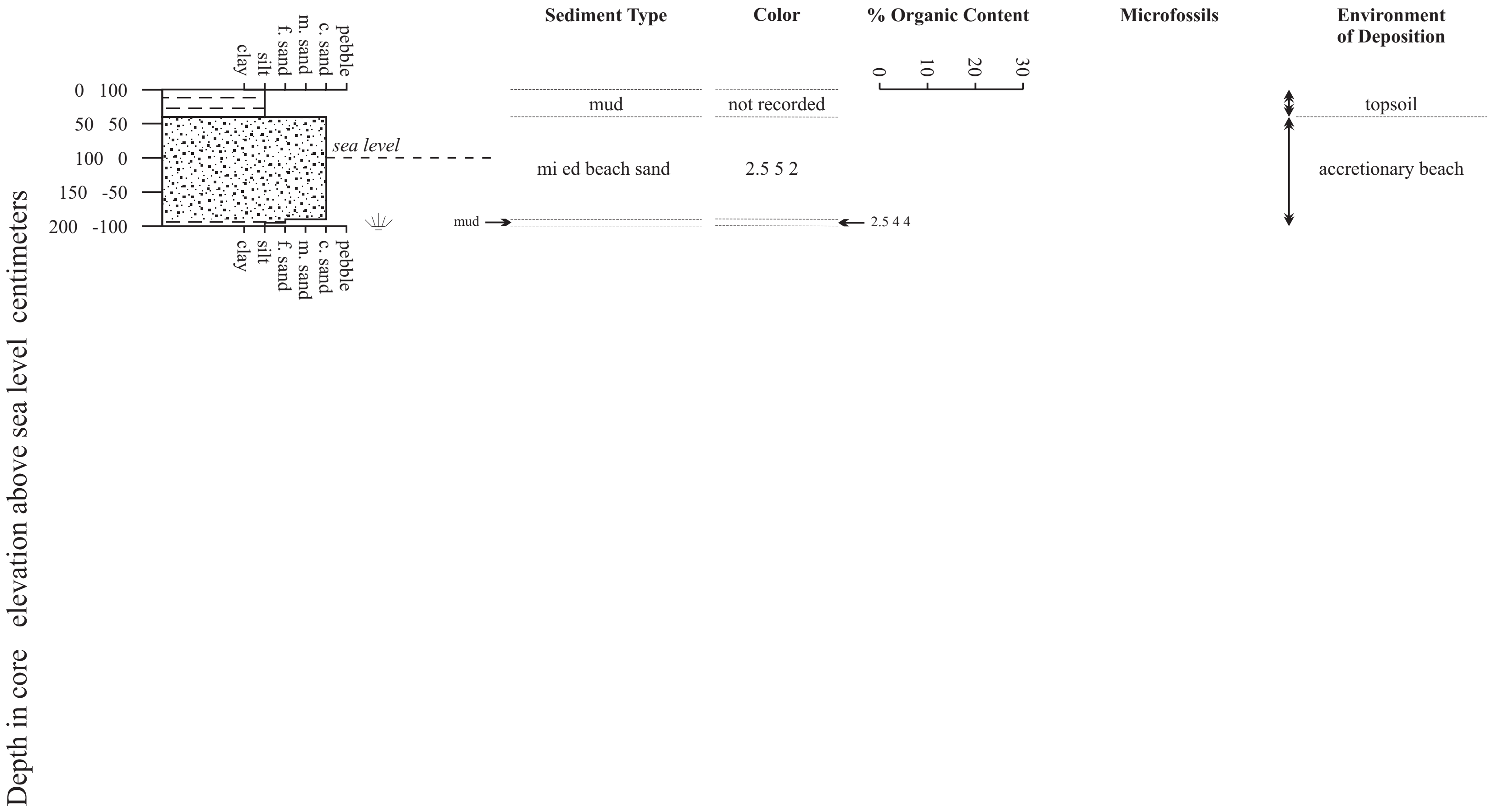
Appendix A Table of Contents


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0
10
20
30
Depth in core
elevation above sea level
centimeters
0 190
50 140
100 90
150 40
200 -10
250 -60
300 -110
350 -160
400 -210
450 -260
500 -310
550 -360
600 -410
650 -460
700 -510
750 -560
sea level
slightly sandy silt
not recorded
natural levee
5 5 2
mud
5 4 2
slightly silty clay
5 5 2
floodplain
fine sand
natural levee
5 5 1
clay
floodplain
2.5 N5
7.5 R N4
clay
silt
f. sand
m. sand
c. sand
pebble

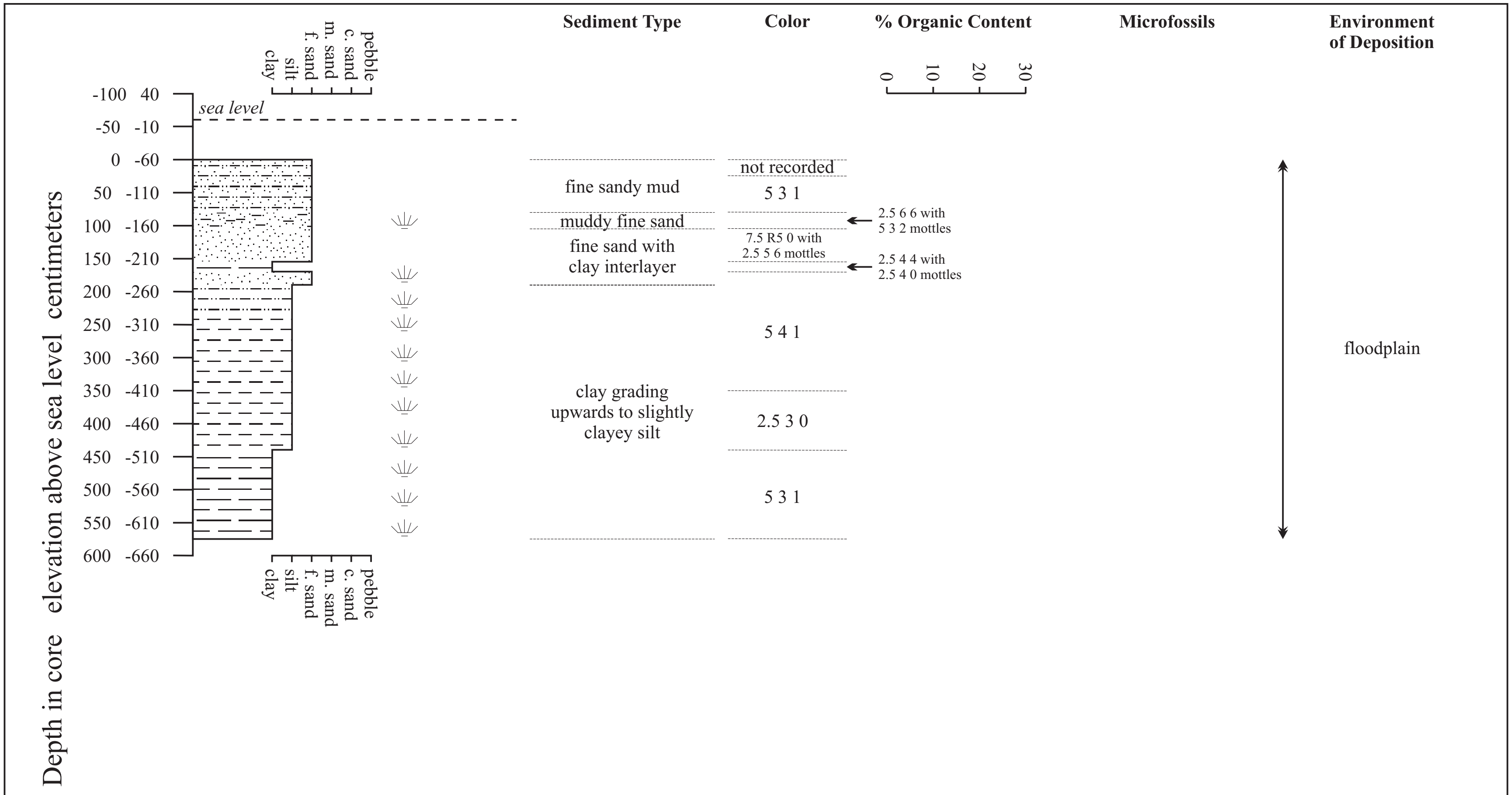
NC-92-16


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0 10 20 30
0 100
50 50
100 0
150 -50
200 -100
250 -150
300 -200
350 -250
sea level
mixed beach sand
not recorded
accretionary beach
Depth in core elevation above sea level centimeters

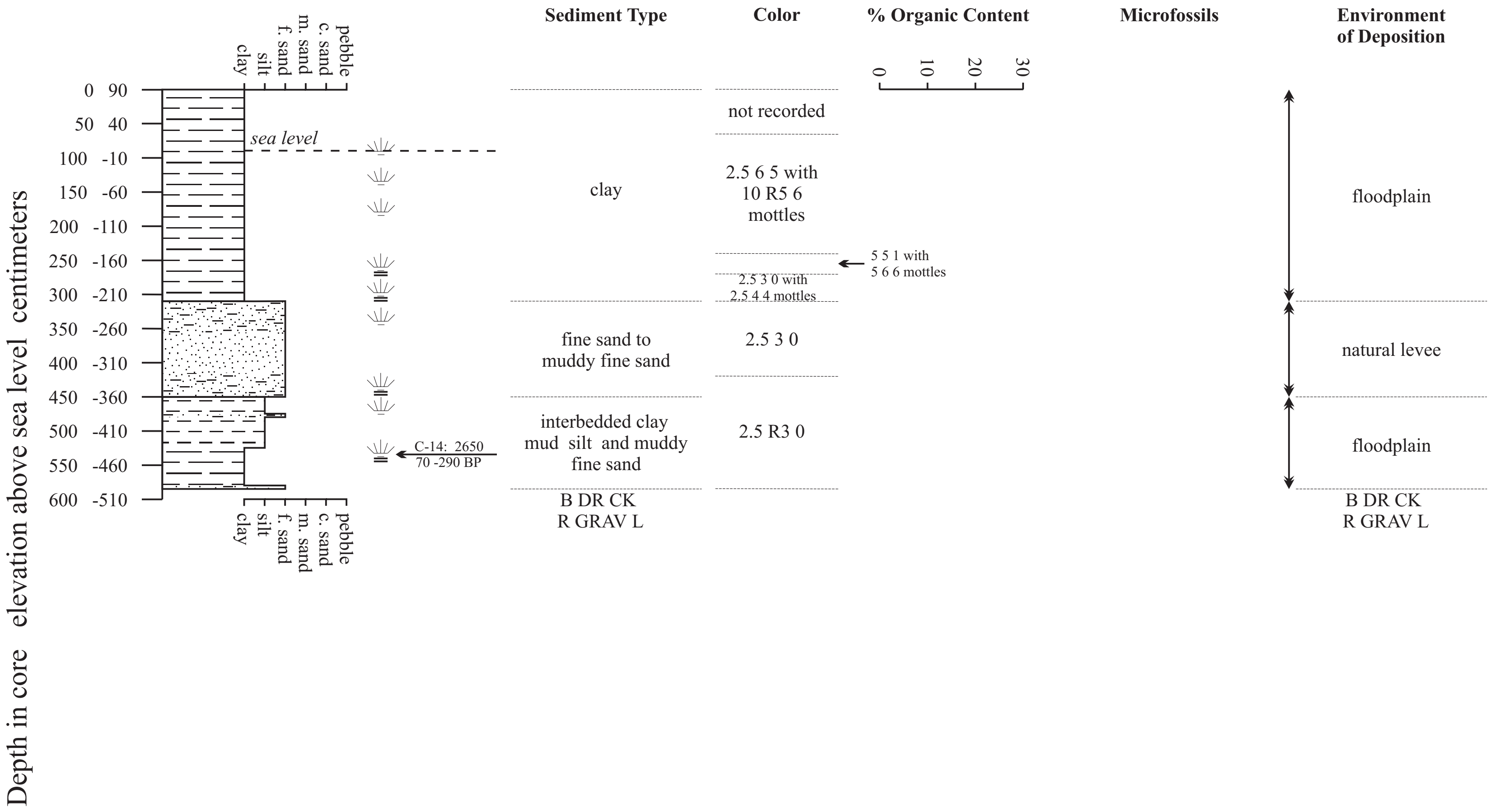
NC-92-17


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0
10
20
30
0 100
50 50
100 0
150 -50
200 -100
sea level
mud
not recorded
topsoil
mi ed beach sand
2.5 5 2
accretionary beach
mud
2.5 4 4
Depth in core elevation above sea level centimeters

NC-92-18

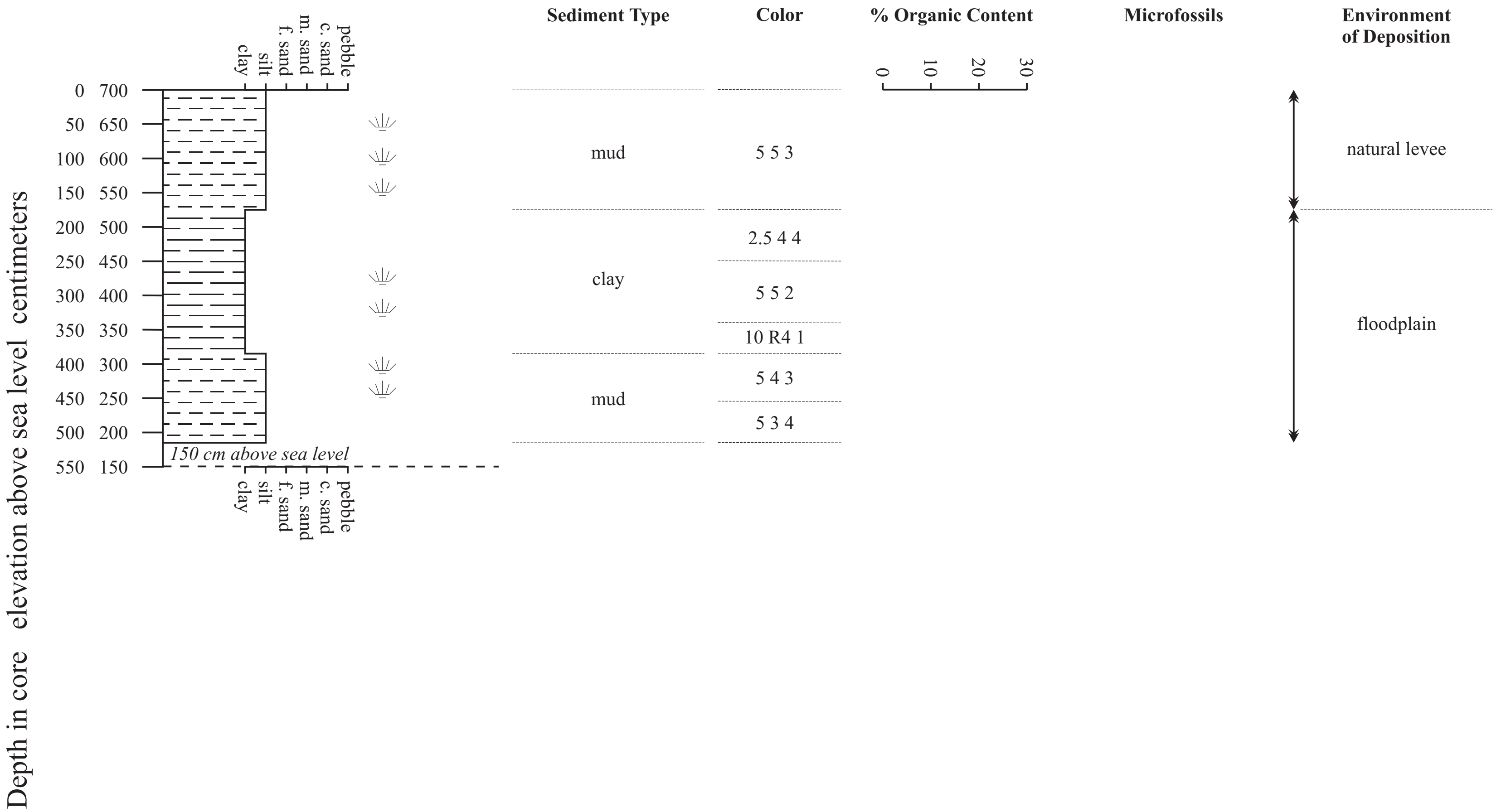

Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0
10
20
30
sea level
Depth in core
elevation above sea level
centimeters
-100 40
-50 -10
0 -60
50 -110
100 -160
150 -210
200 -260
250 -310
300 -360
350 -410
400 -460
450 -510
500 -560
550 -610
600 -660
fine sandy mud
muddy fine sand
fine sand with clay interlayer
clay grading upwards to slightly clayey silt
not recorded
5 3 1
2.5 6 6 with 5 3 2 mottles
7.5 R5 0 with 2.5 5 6 mottles
2.5 4 4 with 2.5 4 0 mottles
5 4 1
2.5 3 0
5 3 1
floodplain

NC-92-19

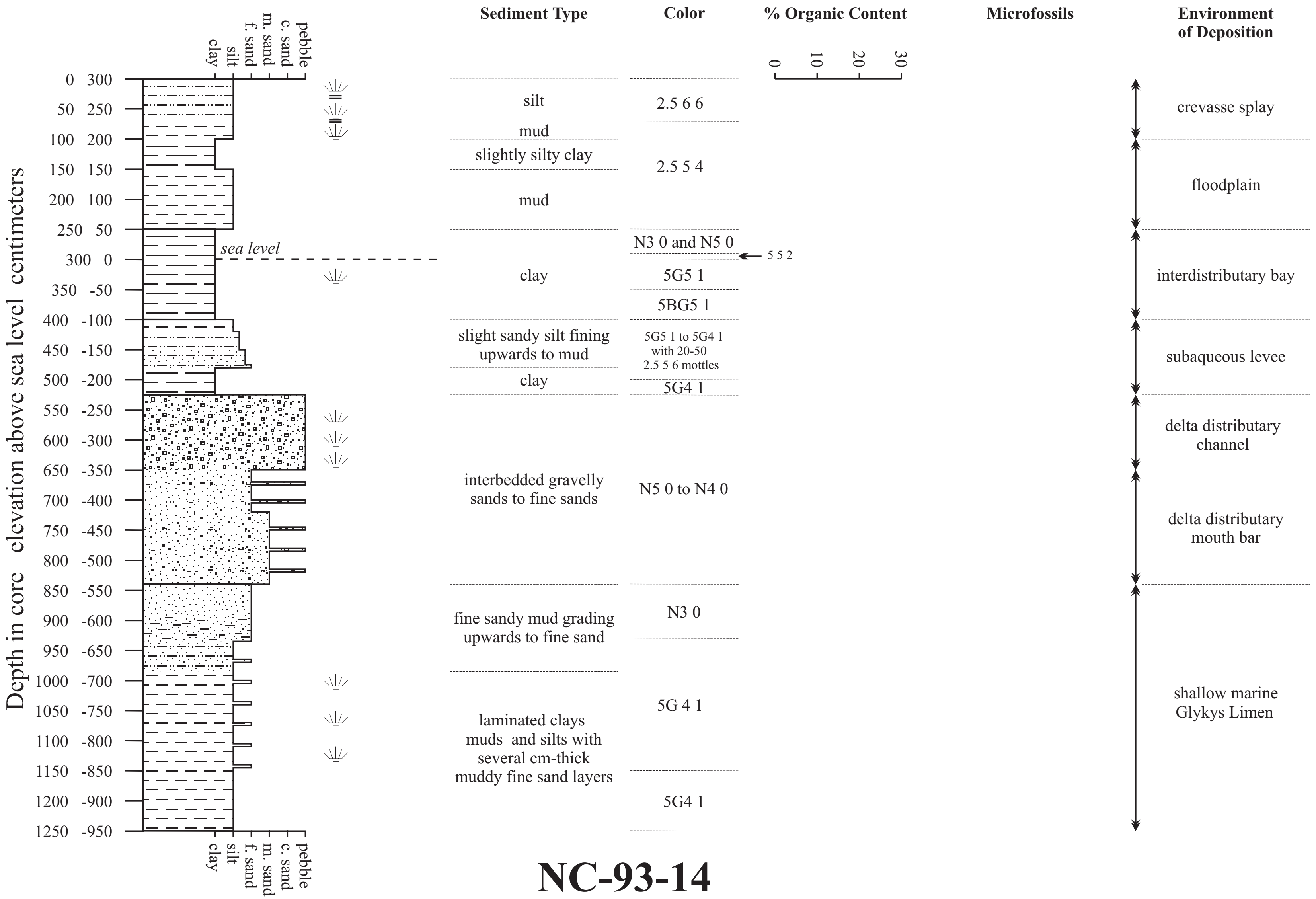


Depth in core elevation above sea level centimeters
pebble
c. sand
m. sand
f. sand
silt
clay
0 90
50 40
100 -10
150 -60
200 -110
250 -160
300 -210
350 -260
400 -310
450 -360
500 -410
550 -460
600 -510
sea level
C-14: 2650
70 -290 BP
Sediment Type
clay
fine sand to
muddy fine sand
interbedded clay
mud silt and muddy
fine sand
B DR CK
R GRAV L
Color
not recorded
2.5 6 5 with
10 R5 6
mottles
5 5 1 with
5 6 6 mottles
2.5 3 0 with
2.5 4 4 mottles
2.5 3 0
2.5 R3 0
% Organic Content
0
10
20
30
Microfossils
Environment
of Deposition
floodplain
natural levee
floodplain
B DR CK
R GRAV L

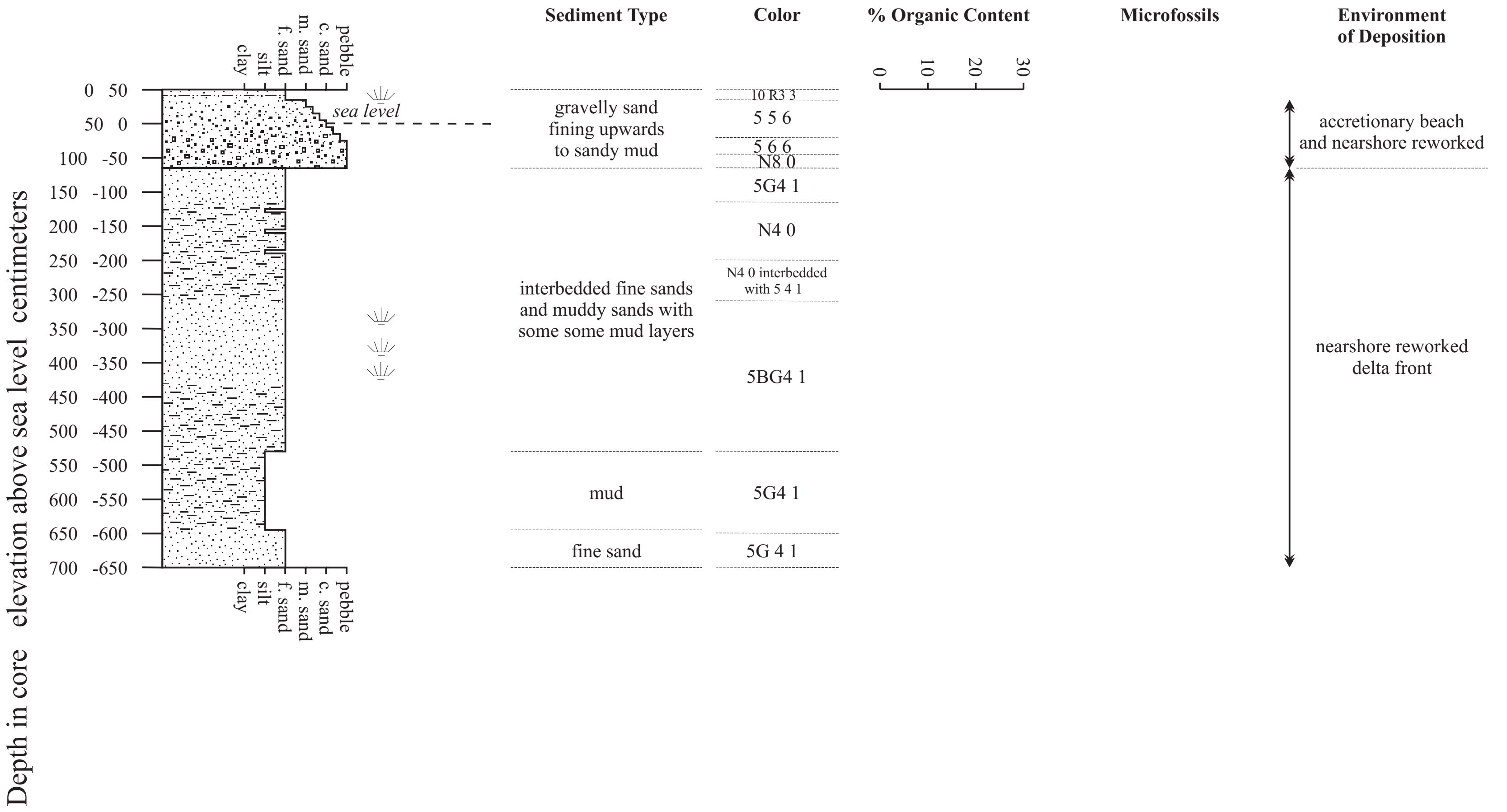
NC-92-20


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0 10 20 30
Depth in core
elevation above sea level centimeters
0 700
50 650
100 600
150 550
200 500
250 450
300 400
350 350
400 300
450 250
500 200
550 150
150 cm above sea level
mud
5 5 3
natural levee
clay
2.5 4 4
5 5 2
10 R4 1
floodplain
mud
5 4 3
5 3 4

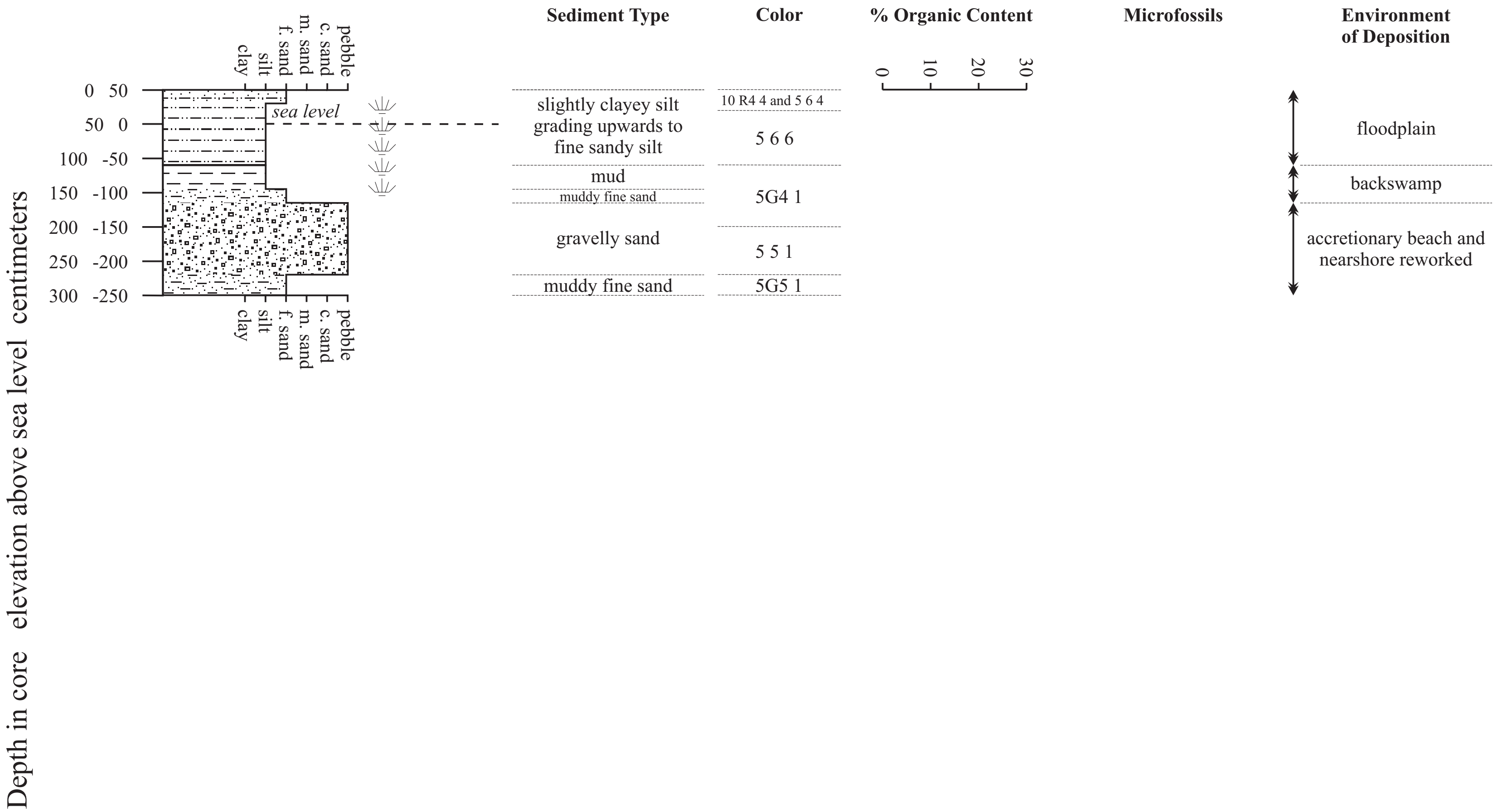
NC-92-21


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0
10
20
30
Depth in core elevation above sea level centimeters
0 300
50 250
100 200
150 150
200 100
250 50
300 0
350 -50
400 -100
450 -150
500 -200
550 -250
600 -300
650 -350
700 -400
750 -450
800 -500
850 -550
900 -600
950 -650
1000 -700
1050 -750
1100 -800
1150 -850
1200 -900
1250 -950
sea level
silt
mud
slightly silty clay
mud
clay
slight sandy silt fining upwards to mud
clay
interbedded gravelly sands to fine sands
fine sandy mud grading upwards to fine sand
laminated clays muds and silts with several cm-thick muddy fine sand layers
2.5 6 6
2.5 5 4
N3 0 and N5 0
5G5 1
5BG5 1
5G5 1 to 5G4 1 with 20-50 2.5 5 6 mottles
5G4 1
N5 0 to N4 0
N3 0
5G 4 1
5G4 1
5 5 2
crevasse splay
floodplain
interdistributary bay
subaqueous levee
delta distributary channel
delta distributary mouth bar
shallow marine Glykys Limen
pebble
c. sand
m. sand
f. sand
silt
clay

NC-93-14

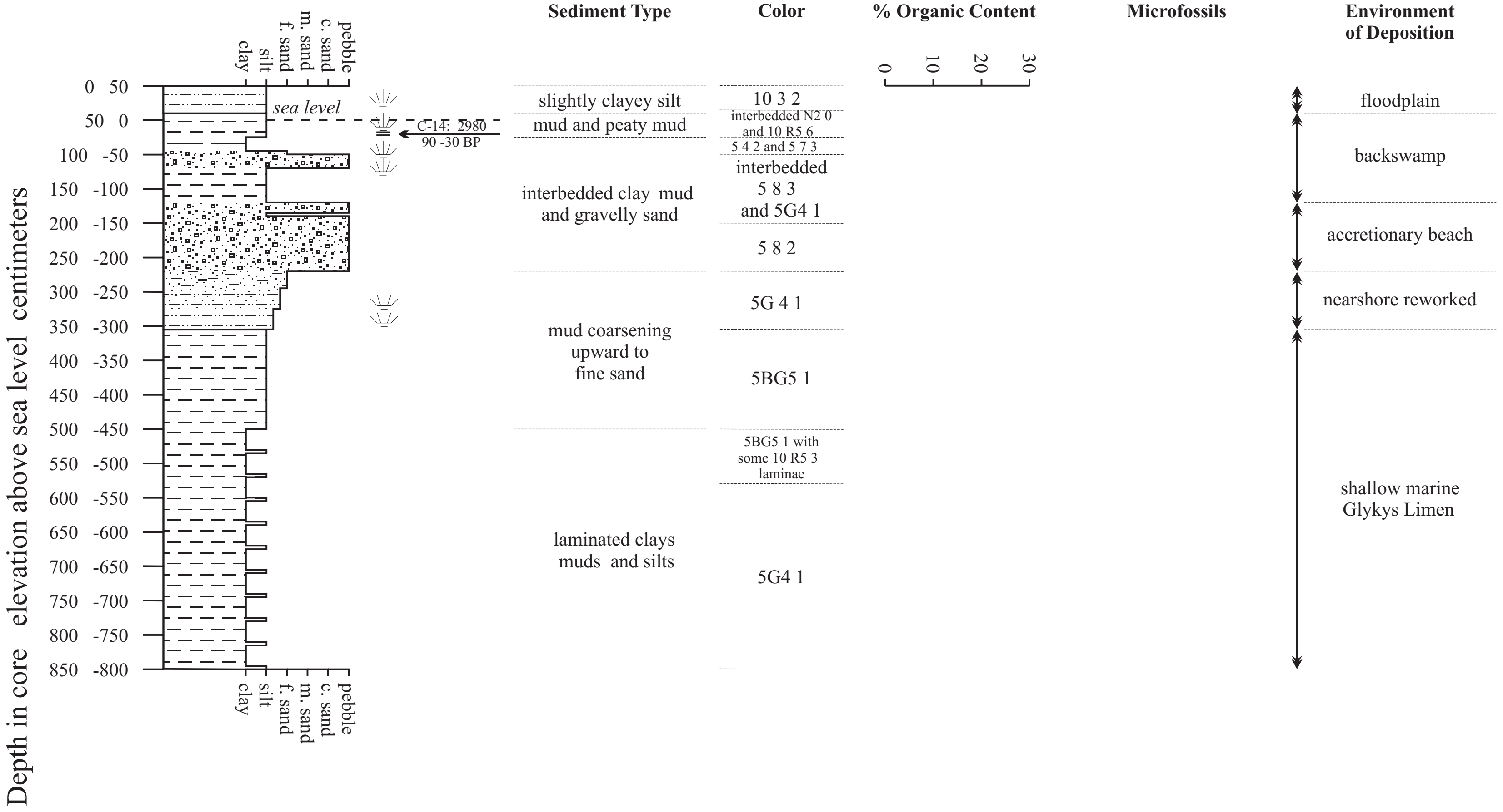

Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0 10 20 30
sea level
Depth in core
elevation above sea level
centimeters
0 50
50 0
100 -50
150 -100
200 -150
250 -200
300 -250
350 -300
400 -350
450 -400
500 -450
550 -500
600 -550
650 -600
700 -650
gravelly sand fining upwards to sandy mud
interbedded fine sands and muddy sands with some some mud layers
mud
fine sand
10 R3 3
5 5 6
5 6 6
N8 0
5G4 1
N4 0
N4 0 interbedded with 5 4 1
5BG4 1
5G4 1
5G 4 1
accretionary beach and nearshore reworked
nearshore reworked delta front

NC-93-15

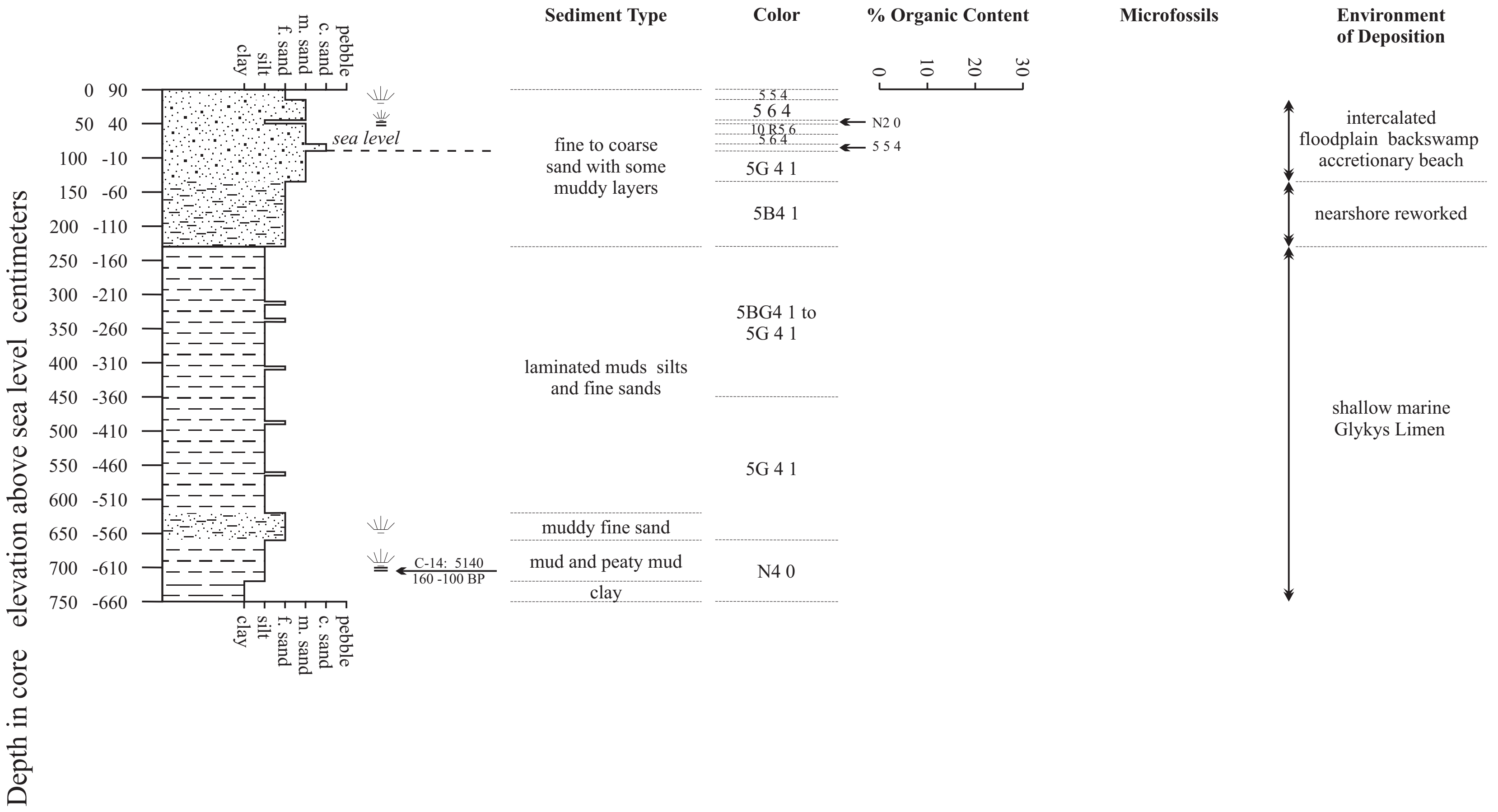


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0 10 20 30
0 50
50 0
100 -50
150 -100
200 -150
250 -200
300 -250
sea level
slightly clayey silt grading upwards to fine sandy silt
mud
muddy fine sand
gravelly sand
muddy fine sand
10 R4 4 and 5 6 4
5 6 6
5G4 1
5 5 1
5G5 1
floodplain
backswamp
accretionary beach and nearshore reworked
Depth in core elevation above sea level centimeters

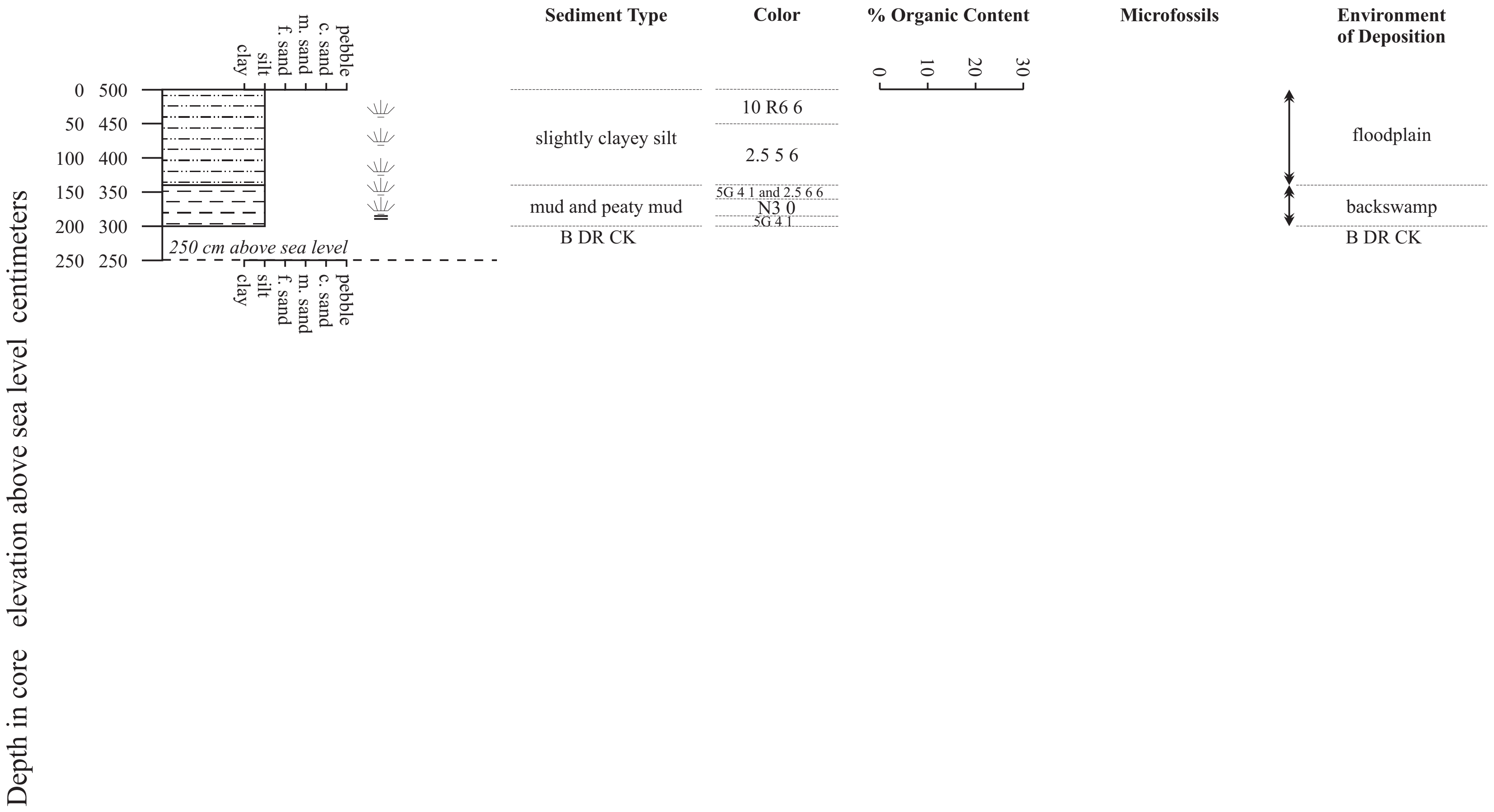
NC-93-17


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
0
10
20
30
pebble
c. sand
m. sand
f. sand
silt
clay
Depth in core elevation above sea level centimeters
0 50
50 0
100 -50
150 -100
200 -150
250 -200
300 -250
350 -300
400 -350
450 -400
500 -450
550 -500
600 -550
650 -600
700 -650
750 -700
800 -750
850 -800
sea level
C-14: 2980 90 -30 BP
slightly clayey silt
mud and peaty mud
interbedded clay mud and gravelly sand
mud coarsening upward to fine sand
laminated clays muds and silts
10 3 2
interbedded N2 0 and 10 R5 6
5 4 2 and 5 7 3
interbedded 5 8 3 and 5G4 1
5 8 2
5G 4 1
5BG5 1
5BG5 1 with some 10 R5 3 laminae
5G4 1
floodplain
backswamp
accretionary beach
nearshore reworked
shallow marine Glykys Limen

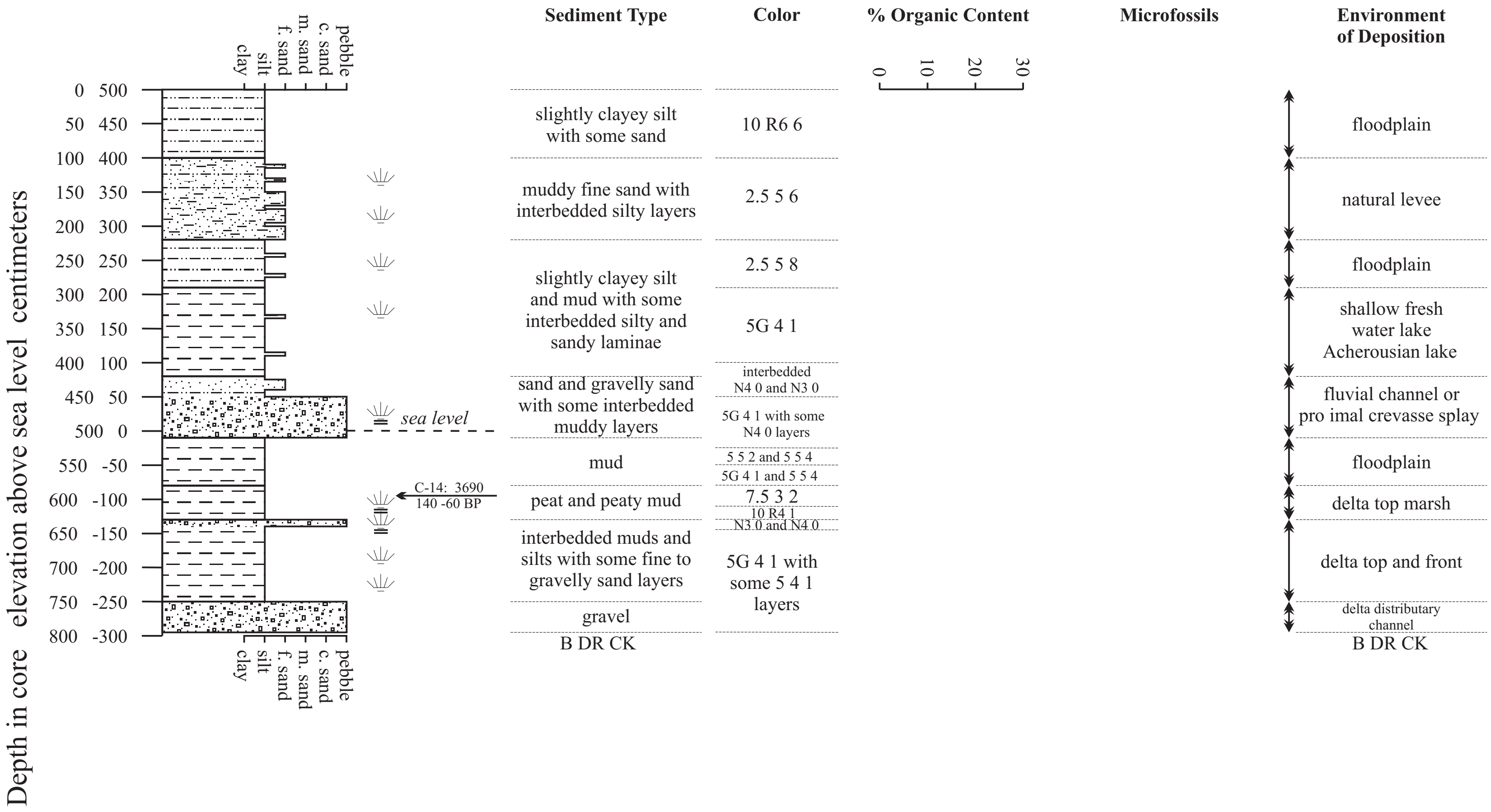
NC-93-18


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0 10 20 30
Depth in core elevation above sea level centimeters
0 90
50 40
100 -10
150 -60
200 -110
250 -160
300 -210
350 -260
400 -310
450 -360
500 -410
550 -460
600 -510
650 -560
700 -610
750 -660
sea level
C-14: 5140
160 -100 BP
fine to coarse sand with some muddy layers
laminated muds silts and fine sands
muddy fine sand
mud and peaty mud
clay
5 5 4
5 6 4
N2 0
10 R5 6
5 6 4
5 5 4
5G 4 1
5B4 1
5BG4 1 to 5G 4 1
5G 4 1
N4 0
intercalated floodplain backswamp accretionary beach
nearshore reworked
shallow marine Glykys Limen

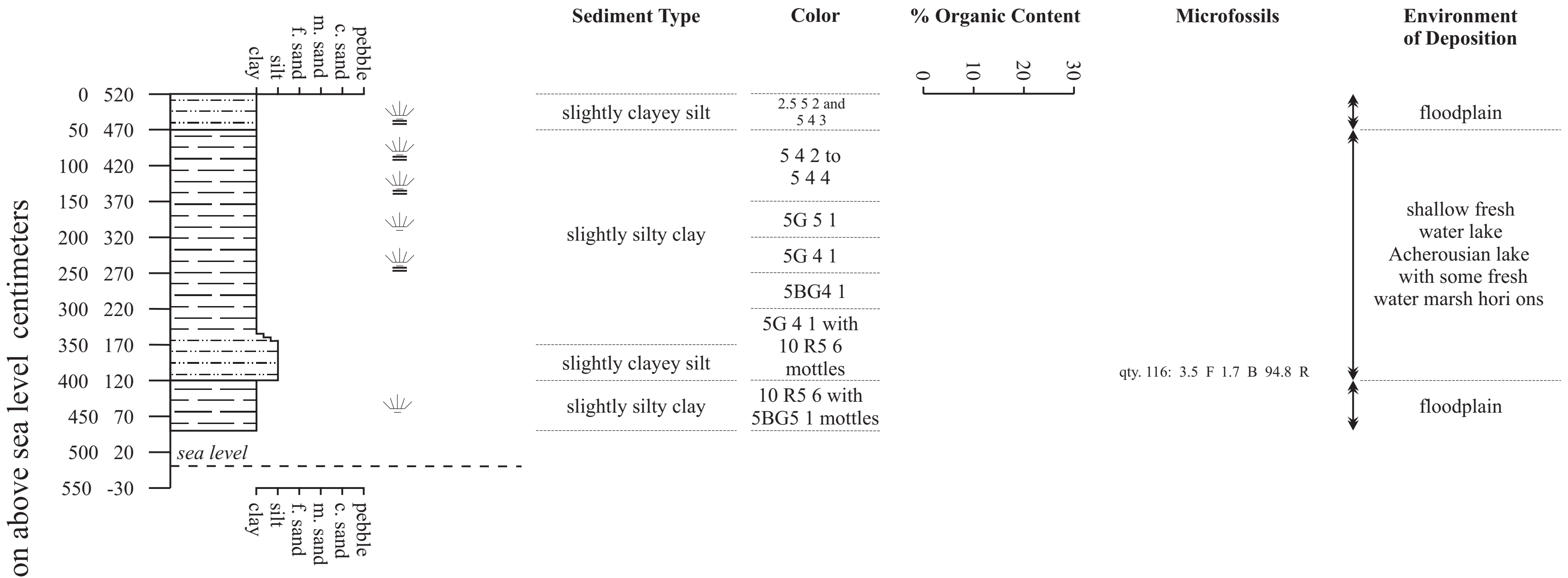
NC-93-19


Depth in core elevation above sea level centimeters
clay
silt
f. sand
m. sand
c. sand
pebble
0 500
50 450
100 400
150 350
200 300
250 250
250 cm above sea level
Sediment Type
Color
% Organic Content
0
10
20
30
Microfossils
Environment of Deposition
slightly clayey silt
mud and peaty mud
B DR CK
10 R6 6
2.5 5 6
5G 4 1 and 2.5 6 6
N3 0
5G 4 1
floodplain
backswamp
B DR CK

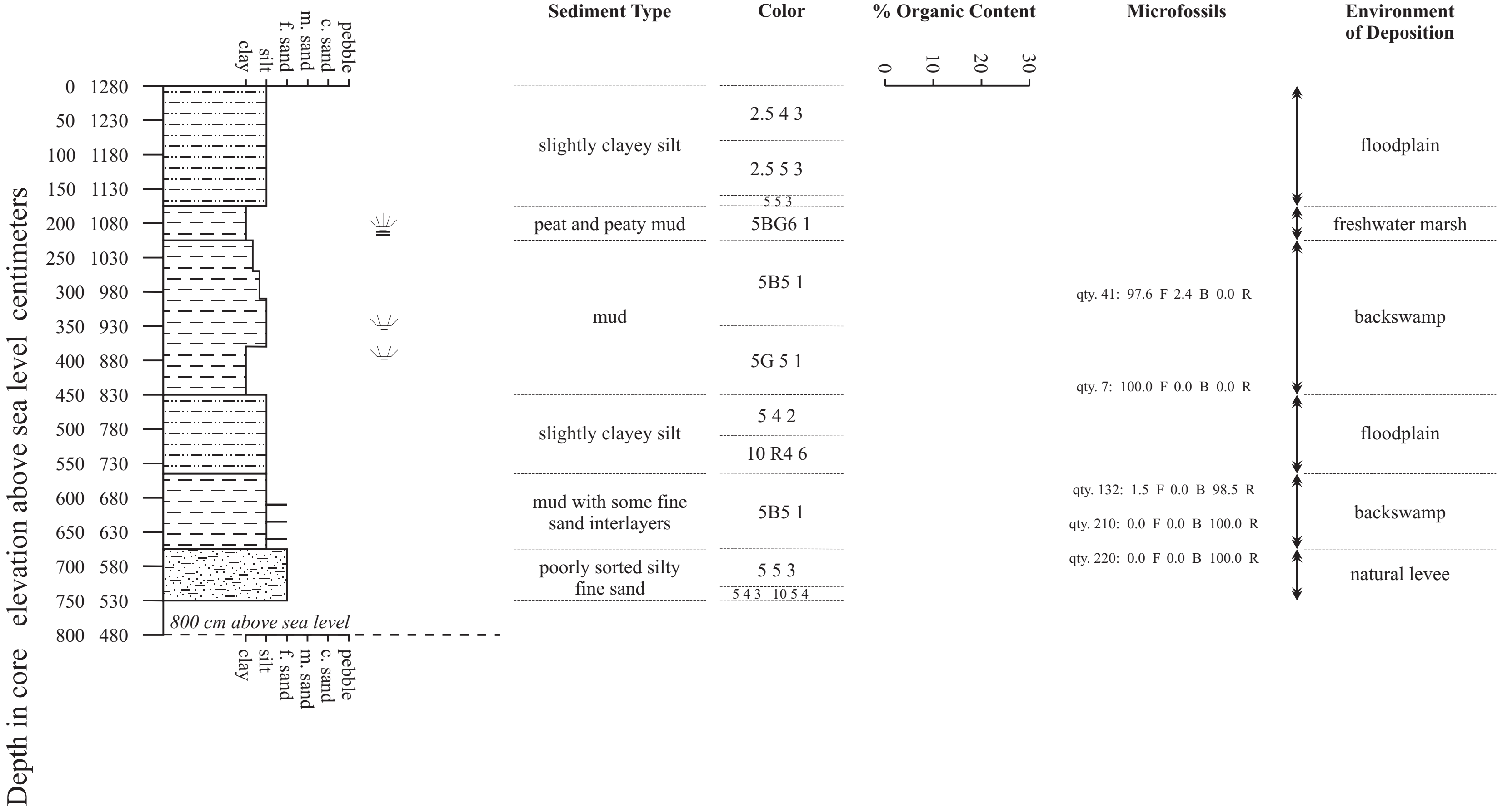
NC-93-20


Depth in core elevation above sea level centimeters
0 500
50 450
100 400
150 350
200 300
250 250
300 200
350 150
400 100
450 50
500 0
550 -50
600 -100
650 -150
700 -200
750 -250
800 -300
clay
silt
f. sand
m. sand
c. sand
pebble
sea level
C-14: 3690
140 -60 BP
Sediment Type
slightly clayey silt with some sand
muddy fine sand with interbedded silty layers
slightly clayey silt and mud with some interbedded silty and sandy laminae
sand and gravelly sand with some interbedded muddy layers
mud
peat and peaty mud
interbedded muds and silts with some fine to gravelly sand layers
gravel
B DR CK
Color
10 R6 6
2.5 5 6
2.5 5 8
5G 4 1
interbedded N4 0 and N3 0
5G 4 1 with some N4 0 layers
5 5 2 and 5 5 4
5G 4 1 and 5 5 4
7.5 3 2
10 R4 1
N3 0 and N4 0
5G 4 1 with some 5 4 1 layers
% Organic Content
0
10
20
30
Microfossils
Environment of Deposition
floodplain
natural levee
floodplain
shallow fresh water lake Acherousian lake
fluvial channel or pro imal crevasse splay
floodplain
delta top marsh
delta top and front
delta distributary channel
B DR CK

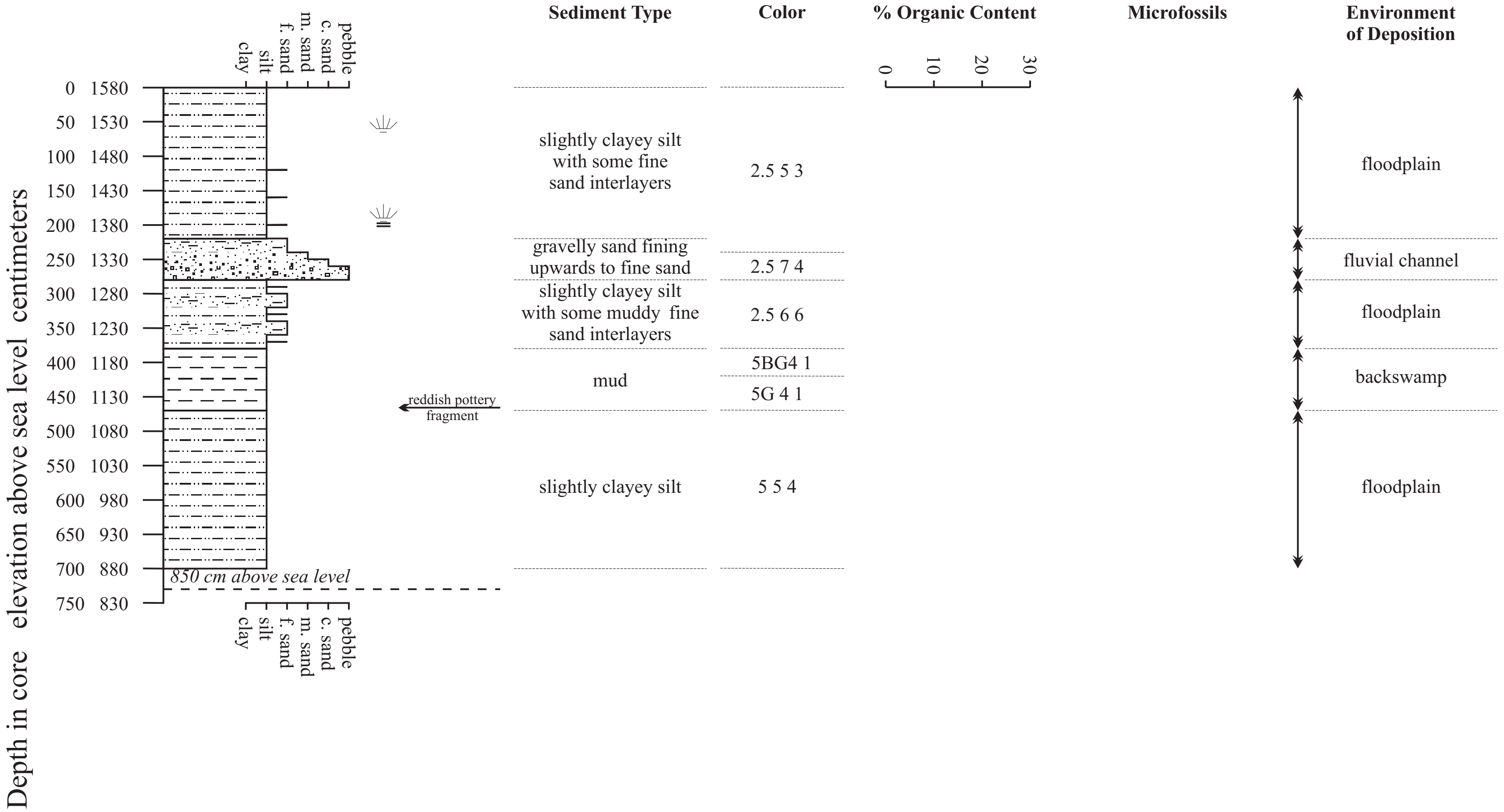
NC-93-21


Depth in core elevation above sea level centimeters
0 520
50 470
100 420
150 370
200 320
250 270
300 220
350 170
400 120
450 70
500 20
550 -30
sea level
clay
silt
f. sand
m. sand
c. sand
pebble
Sediment Type
Color
% Organic Content
0
10
20
30
Microfossils
Environment of Deposition
slightly clayey silt
2.5 5 2 and 5 4 3
floodplain
5 4 2 to 5 4 4
5G 5 1
5G 4 1
5BG4 1
5G 4 1 with 10 R5 6 mottles
slightly silty clay
shallow fresh water lake Acherousian lake with some fresh water marsh hori ons
slightly clayey silt
qty. 116: 3.5 F 1.7 B 94.8 R
slightly silty clay
10 R5 6 with 5BG5 1 mottles
floodplain

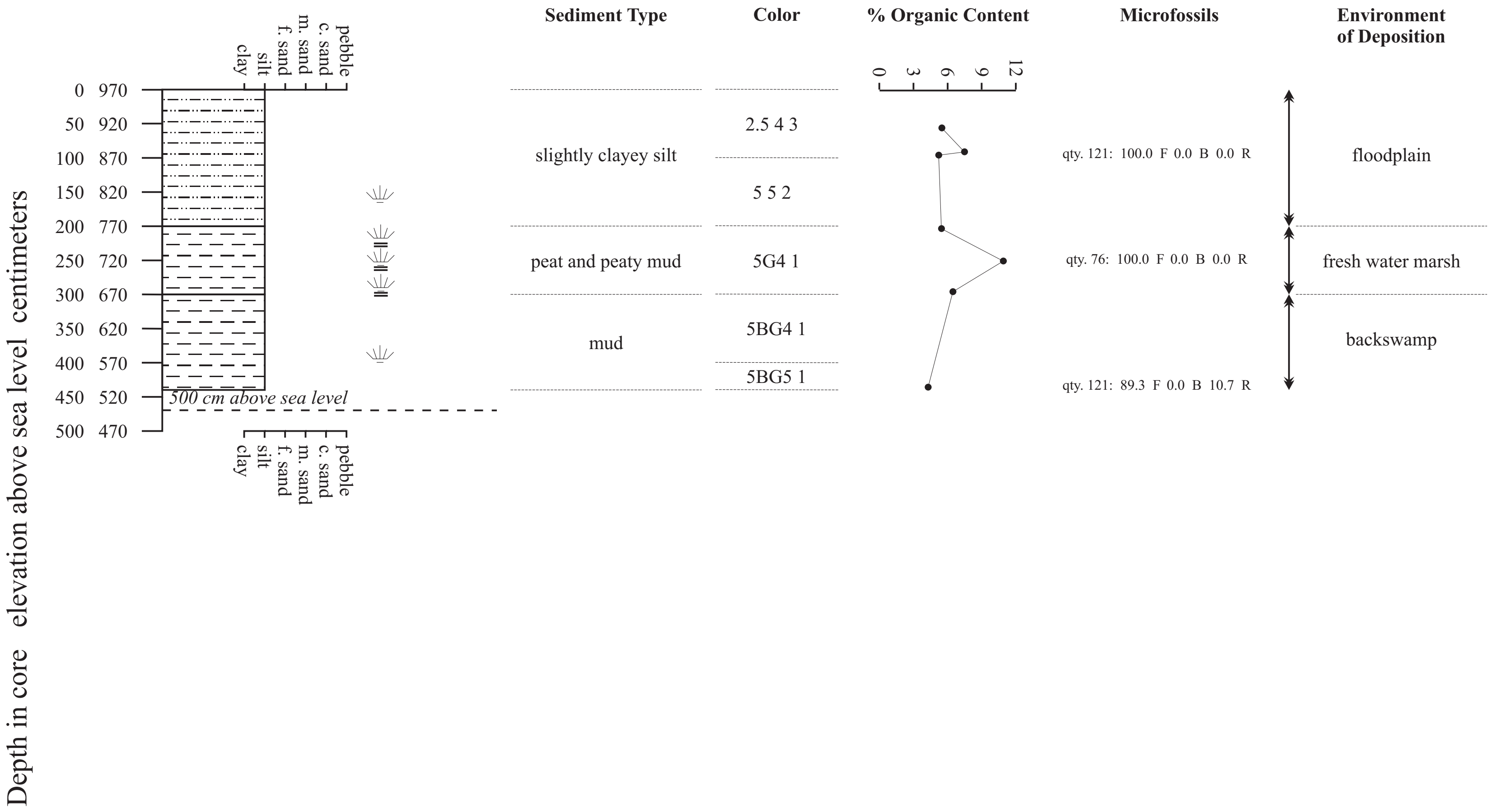
NC-93-22


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
Depth in core elevation above sea level centimeters
clay
silt
f. sand
m. sand
c. sand
pebble
0 1280
50 1230
100 1180
150 1130
200 1080
250 1030
300 980
350 930
400 880
450 830
500 780
550 730
600 680
650 630
700 580
750 530
800 480
800 cm above sea level
0
10
20
30
slightly clayey silt
2.5 4 3
2.5 5 3
5 5 3
floodplain
peat and peaty mud
5BG6 1
freshwater marsh
mud
5B5 1
5G 5 1
qty. 41: 97.6 F 2.4 B 0.0 R
qty. 7: 100.0 F 0.0 B 0.0 R
backswamp
slightly clayey silt
5 4 2
10 R4 6
floodplain
mud with some fine sand interlayers
5B5 1
qty. 132: 1.5 F 0.0 B 98.5 R
qty. 210: 0.0 F 0.0 B 100.0 R
backswamp
poorly sorted silty fine sand
5 5 3
5 4 3 10 5 4
qty. 220: 0.0 F 0.0 B 100.0 R
natural levee

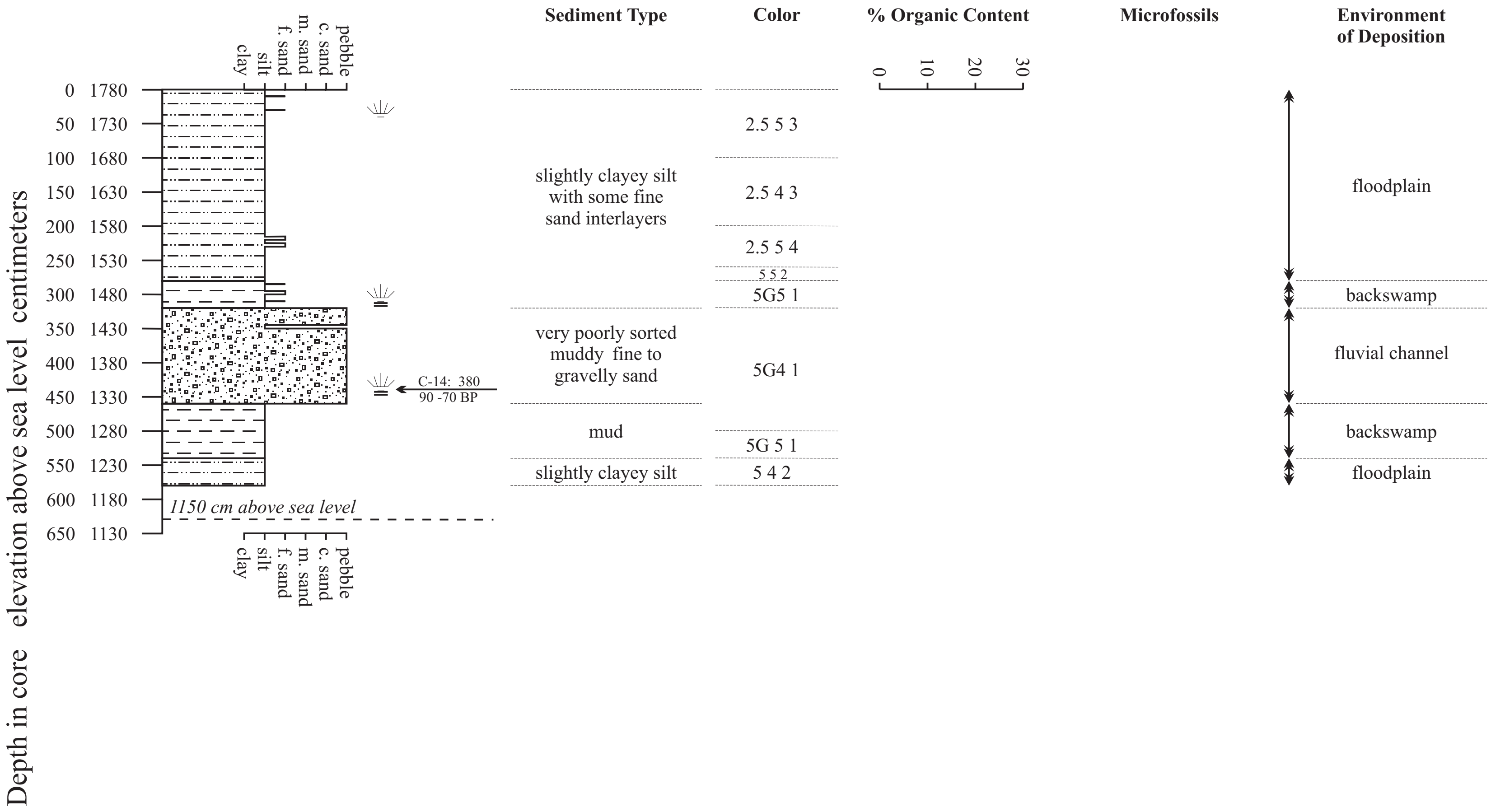
NC-94-01


Depth in core elevation above sea level centimeters
pebble
c. sand
m. sand
f. sand
silt
clay
0 1580
50 1530
100 1480
150 1430
200 1380
250 1330
300 1280
350 1230
400 1180
450 1130
500 1080
550 1030
600 980
650 930
700 880
750 830
850 cm above sea level
reddish pottery fragment
Sediment Type
slightly clayey silt with some fine sand interlayers
gravelly sand fining upwards to fine sand
slightly clayey silt with some muddy fine sand interlayers
mud
slightly clayey silt
Color
2.5 5 3
2.5 7 4
2.5 6 6
5BG4 1
5G 4 1
5 5 4
% Organic Content
0
10
20
30
Microfossils
Environment of Deposition
floodplain
fluvial channel
floodplain
backswamp
floodplain

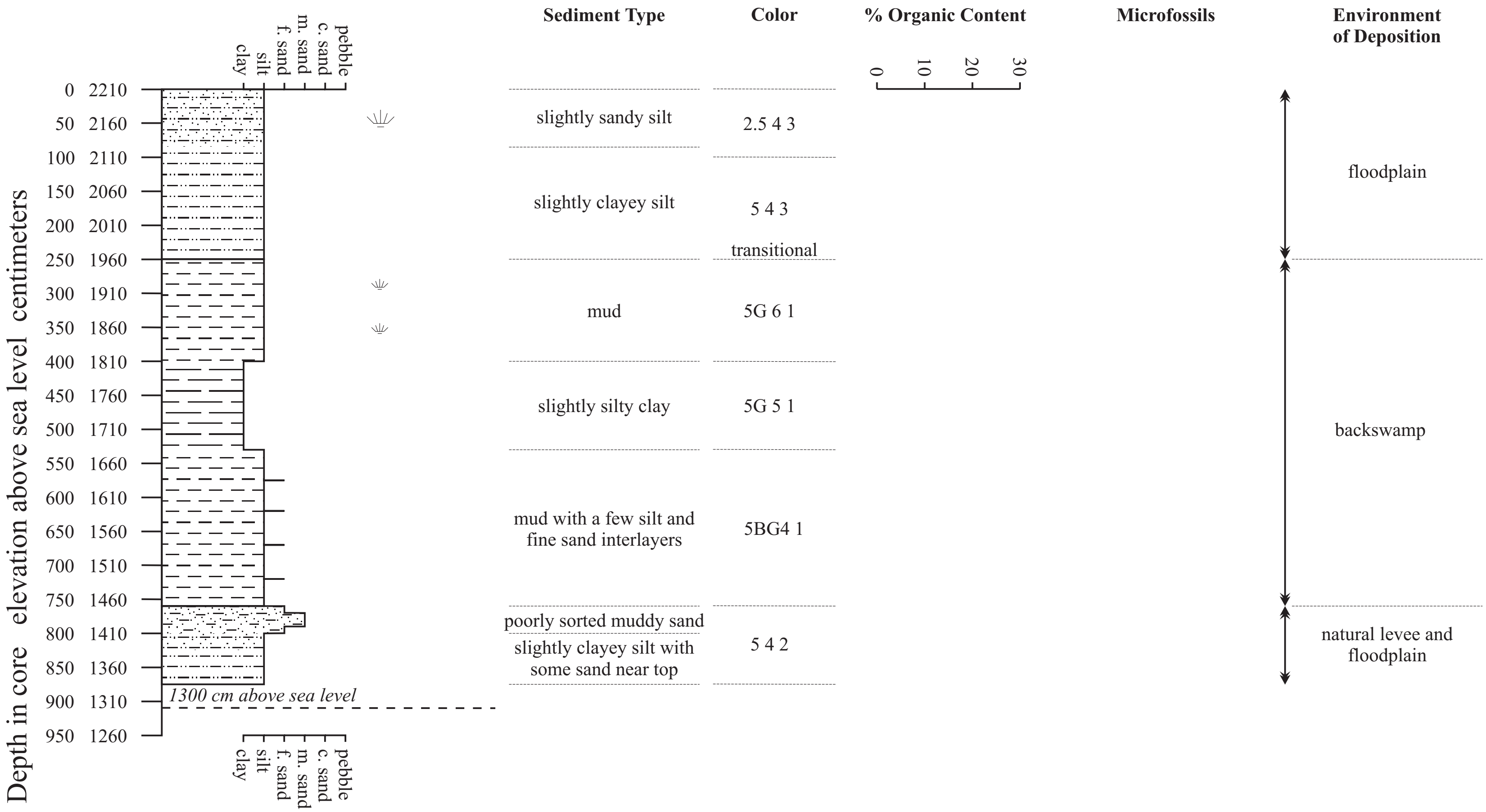
NC-94-02


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0 3 6 9 12
0 970
50 920
100 870
150 820
200 770
250 720
300 670
350 620
400 570
450 520
500 470
500 cm above sea level
slightly clayey silt
peat and peaty mud
mud
2.5 4 3
5 5 2
5G4 1
5BG4 1
5BG5 1
qty. 121: 100.0 F 0.0 B 0.0 R
qty. 76: 100.0 F 0.0 B 0.0 R
qty. 121: 89.3 F 0.0 B 10.7 R
floodplain
fresh water marsh
backswamp
Depth in core elevation above sea level centimeters

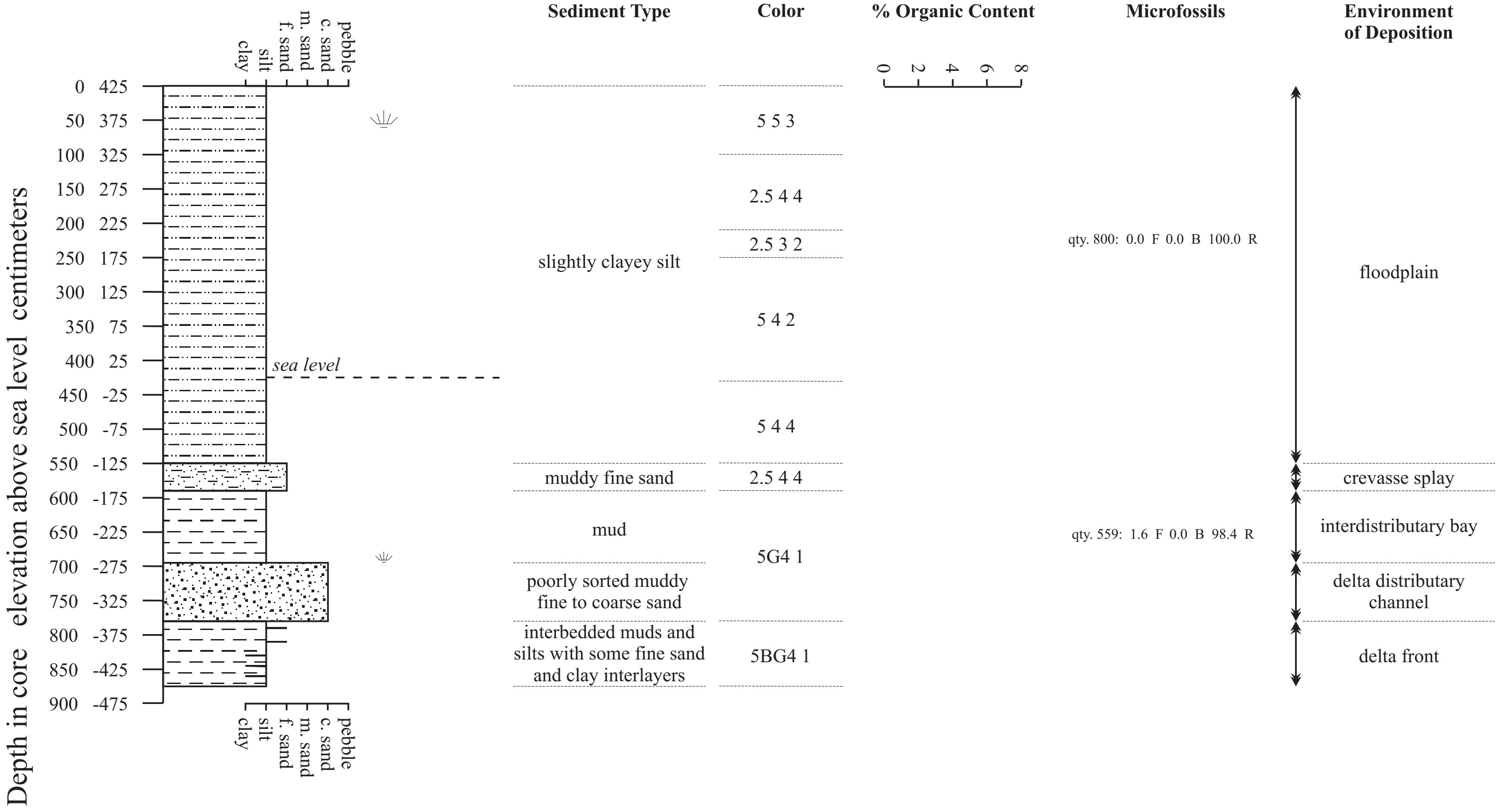
NC-94-03


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0
10
20
30
Depth in core
elevation above sea level
centimeters
0 1780
50 1730
100 1680
150 1630
200 1580
250 1530
300 1480
350 1430
400 1380
450 1330
500 1280
550 1230
600 1180
650 1130
1150 cm above sea level
C-14: 380
90 -70 BP
slightly clayey silt with some fine sand interlayers
very poorly sorted muddy fine to gravelly sand
mud
slightly clayey silt
2.5 5 3
2.5 4 3
2.5 5 4
5 5 2
5G5 1
5G4 1
5G 5 1
5 4 2
floodplain
backswamp
fluvial channel
backswamp
floodplain

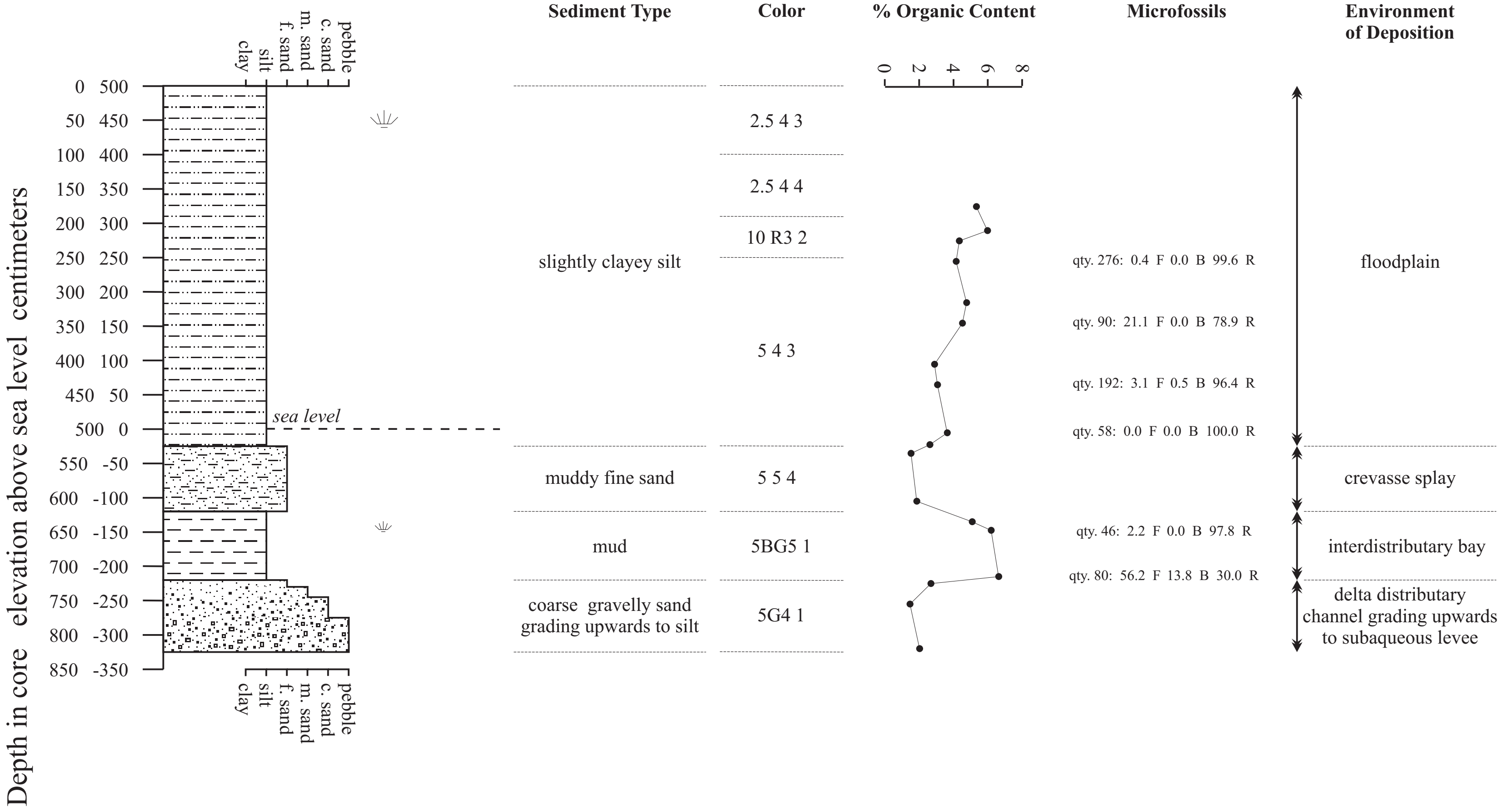
NC-94-04


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
clay
silt
f. sand
m. sand
c. sand
pebble
0
10
20
30
Depth in core
elevation above sea level centimeters
0 2210
50 2160
100 2110
150 2060
200 2010
250 1960
300 1910
350 1860
400 1810
450 1760
500 1710
550 1660
600 1610
650 1560
700 1510
750 1460
800 1410
850 1360
900 1310
950 1260
1300 cm above sea level
slightly sandy silt
2.5 4 3
slightly clayey silt
5 4 3
transitional
mud
5G 6 1
slightly silty clay
5G 5 1
mud with a few silt and fine sand interlayers
5BG4 1
poorly sorted muddy sand
slightly clayey silt with some sand near top
5 4 2
floodplain
backswamp
natural levee and floodplain

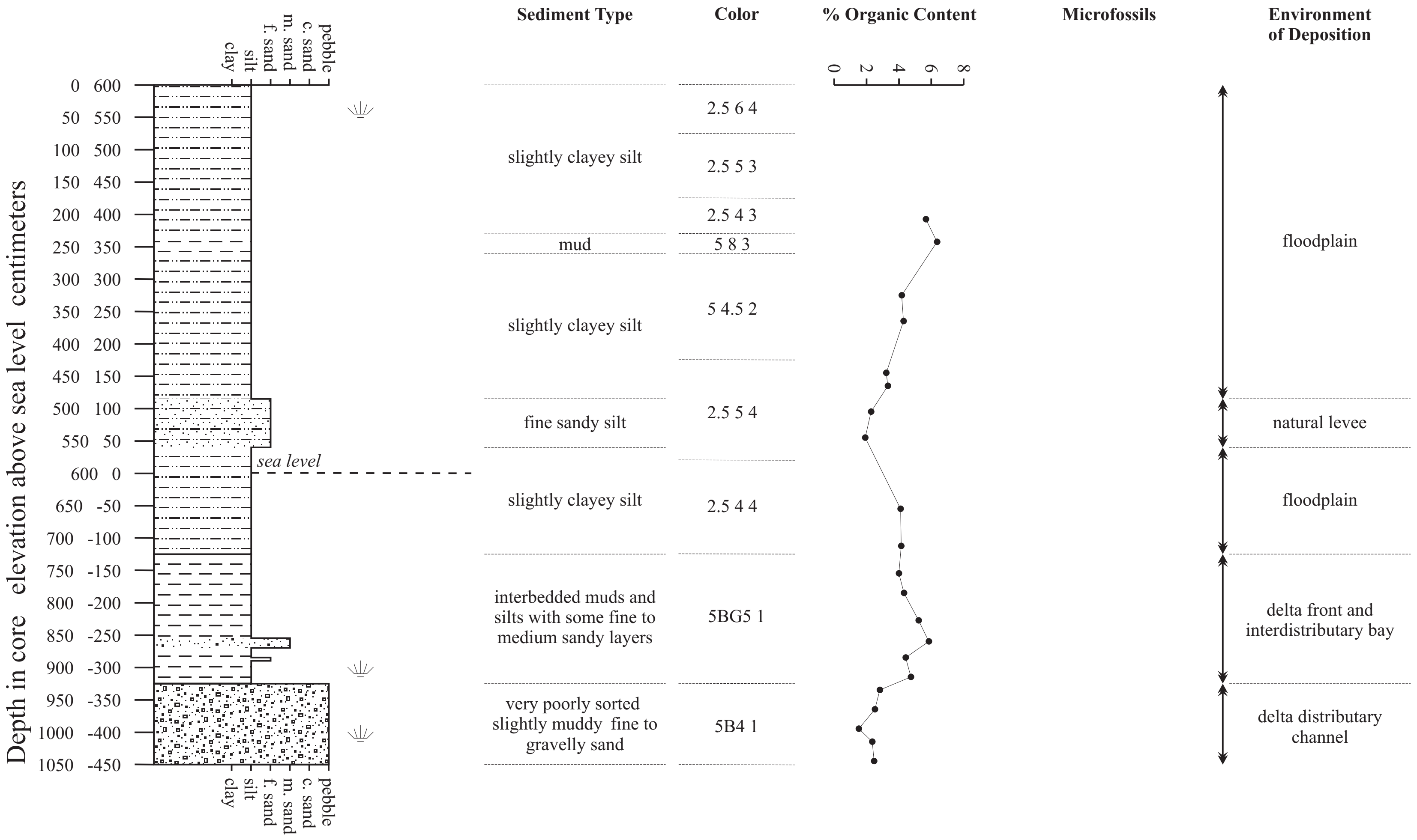
NC-94-05


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0 2 4 6 8
Depth in core
elevation above sea level
centimeters
0 425
50 375
100 325
150 275
200 225
250 175
300 125
350 75
400 25
450 -25
500 -75
550 -125
600 -175
650 -225
700 -275
750 -325
800 -375
850 -425
900 -475
sea level
slightly clayey silt
muddy fine sand
mud
poorly sorted muddy fine to coarse sand
interbedded muds and silts with some fine sand and clay interlayers
5 5 3
2.5 4 4
2.5 3 2
5 4 2
5 4 4
2.5 4 4
5G4 1
5BG4 1
qty. 800: 0.0 F 0.0 B 100.0 R
qty. 559: 1.6 F 0.0 B 98.4 R
floodplain
crevasse splay
interdistributary bay
delta distributary channel
delta front

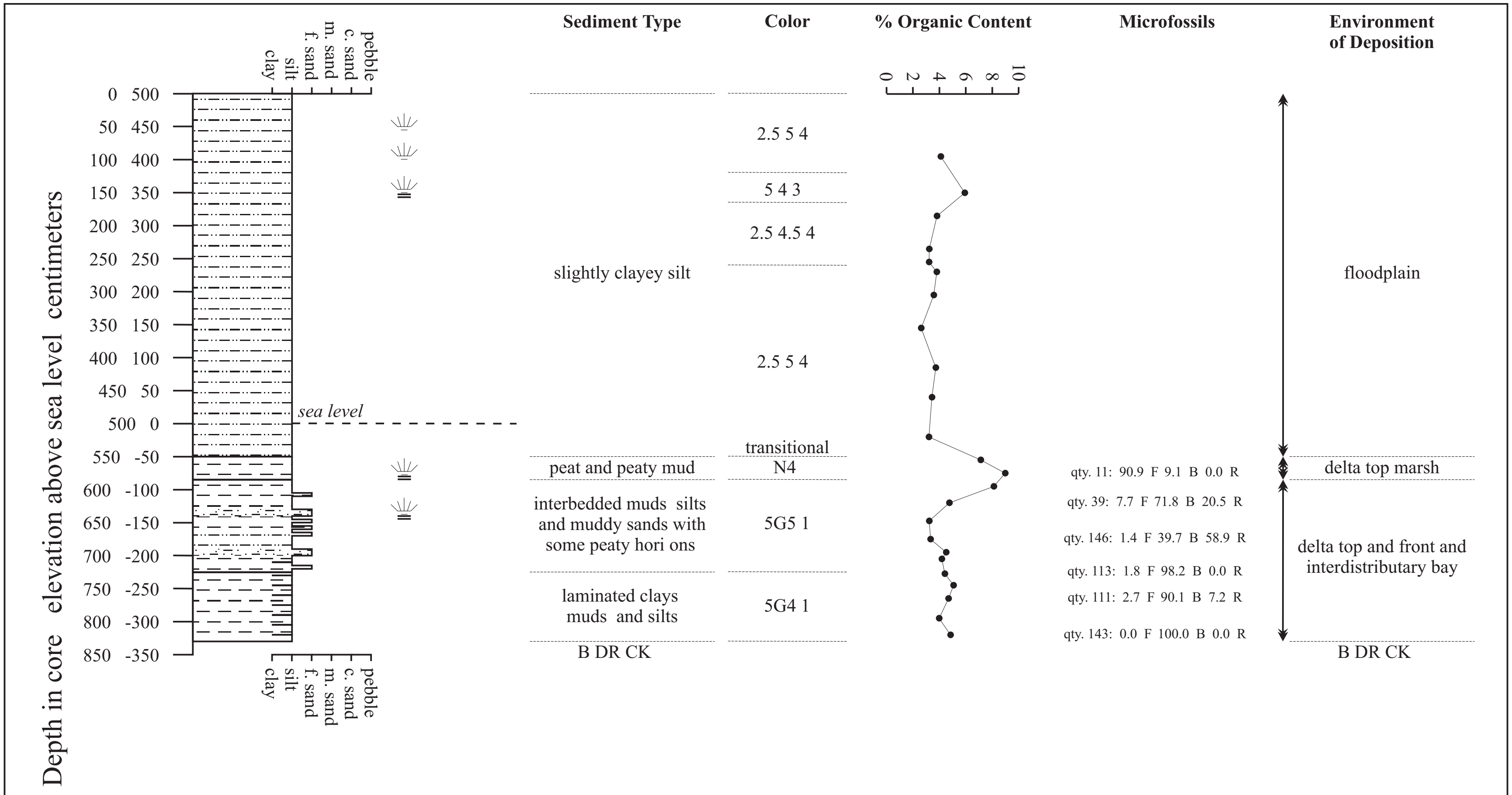
NC-94-08


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0 2 4 6 8
Depth in core elevation above sea level centimeters
0 500
50 450
100 400
150 350
200 300
250 250
300 200
350 150
400 100
450 50
500 0
550 -50
600 -100
650 -150
700 -200
750 -250
800 -300
850 -350
sea level
2.5 4 3
2.5 4 4
10 R3 2
5 4 3
5 5 4
5BG5 1
5G4 1
slightly clayey silt
muddy fine sand
mud
coarse gravelly sand grading upwards to silt
qty. 276: 0.4 F 0.0 B 99.6 R
qty. 90: 21.1 F 0.0 B 78.9 R
qty. 192: 3.1 F 0.5 B 96.4 R
qty. 58: 0.0 F 0.0 B 100.0 R
qty. 46: 2.2 F 0.0 B 97.8 R
qty. 80: 56.2 F 13.8 B 30.0 R
floodplain
crevasse splay
interdistributary bay
delta distributary channel grading upwards to subaqueous levee
pebble
c. sand
m. sand
f. sand
silt
clay

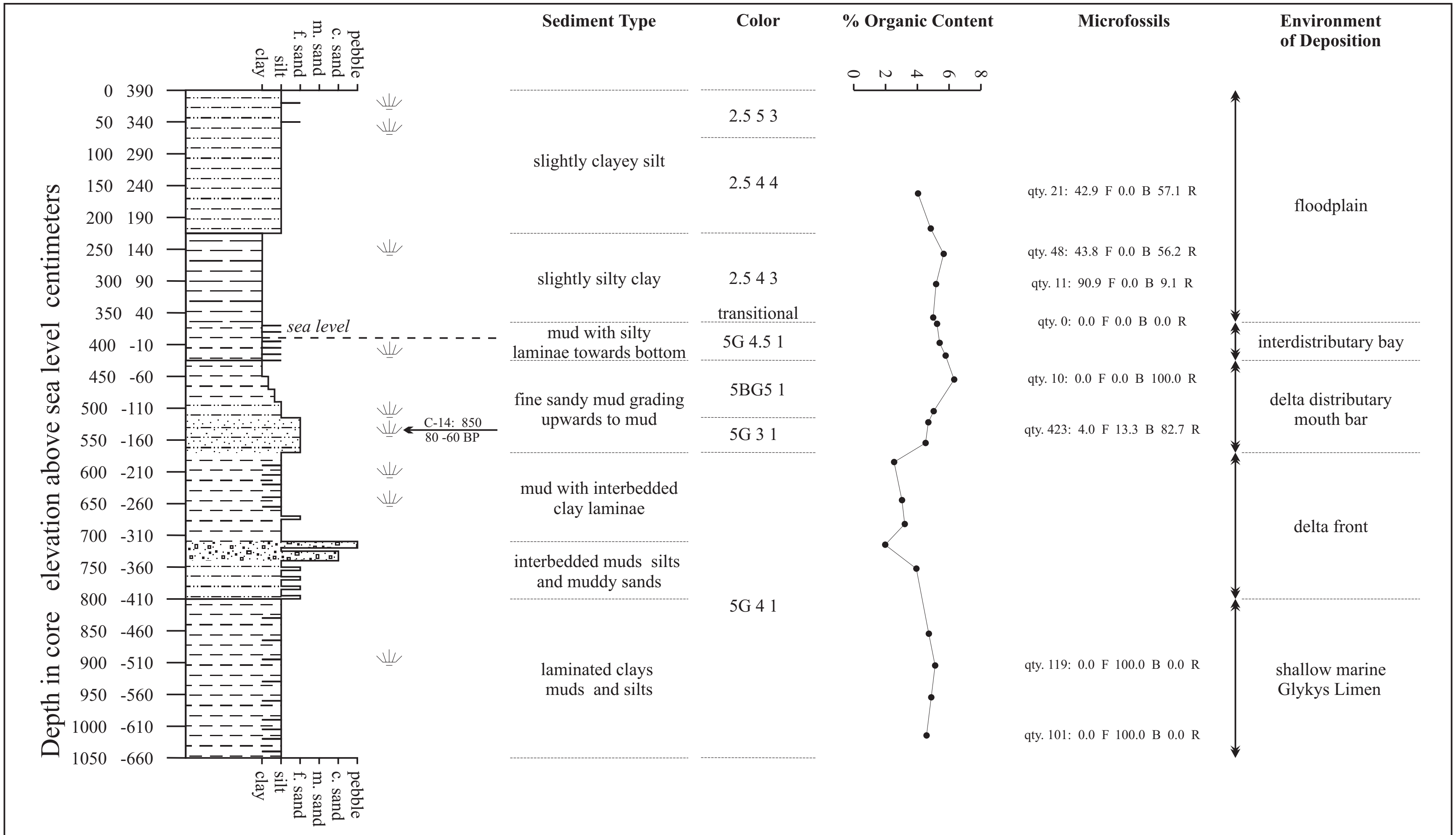
NC-94-09


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0 2 4 6 8
Depth in core elevation above sea level centimeters
0 600
50 550
100 500
150 450
200 400
250 350
300 300
350 250
400 200
450 150
500 100
550 50
600 0
650 -50
700 -100
750 -150
800 -200
850 -250
900 -300
950 -350
1000 -400
1050 -450
sea level
slightly clayey silt
mud
slightly clayey silt
fine sandy silt
slightly clayey silt
interbedded muds and silts with some fine to medium sandy layers
very poorly sorted slightly muddy fine to gravelly sand
2.5 6 4
2.5 5 3
2.5 4 3
5 8 3
5 4.5 2
2.5 5 4
2.5 4 4
5BG5 1
5B4 1
floodplain
natural levee
floodplain
delta front and interdistributary bay
delta distributary channel

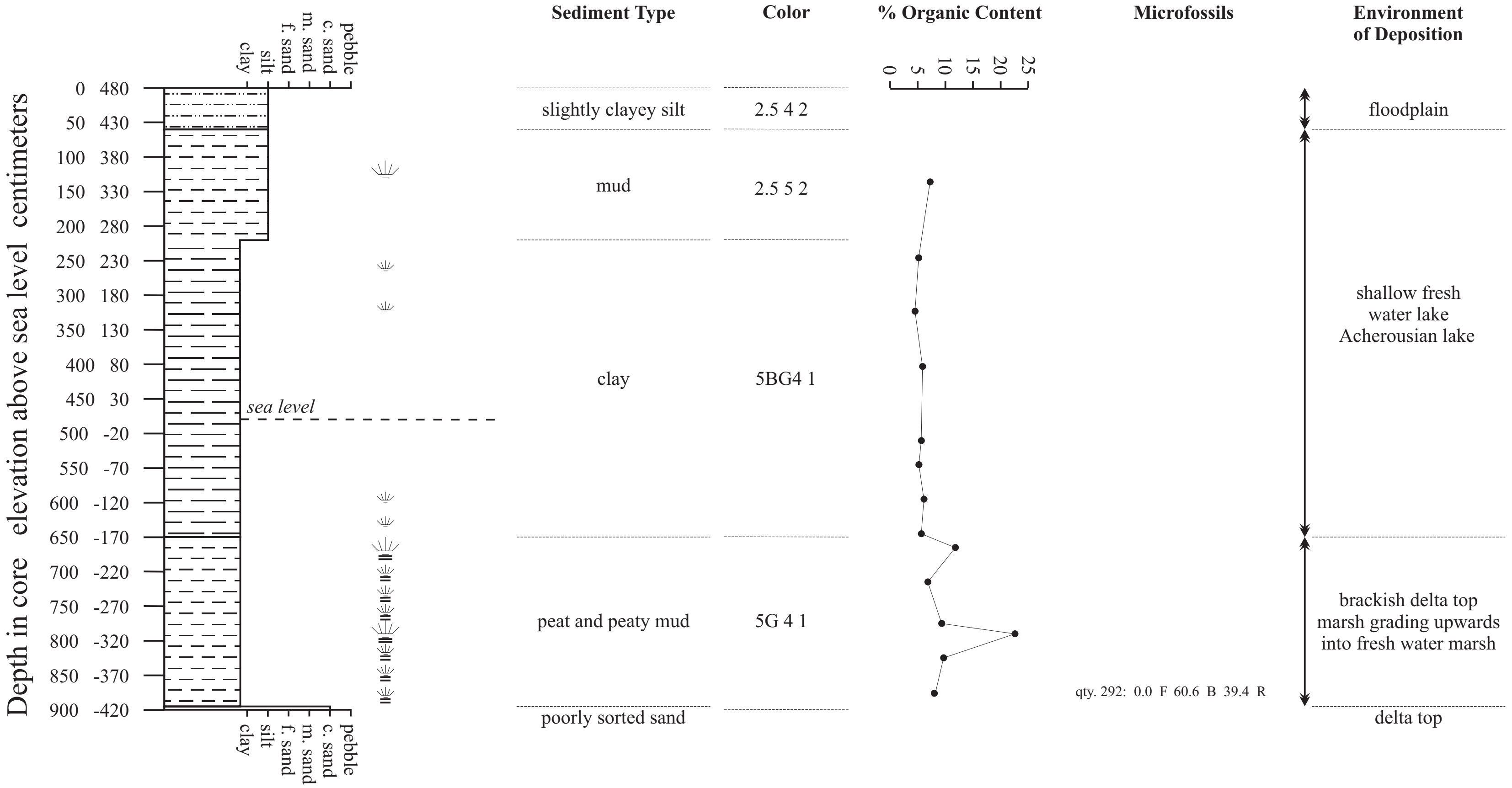
NC-94-11


Depth in core elevation above sea level centimeters
0 500
50 450
100 400
150 350
200 300
250 250
300 200
350 150
400 100
450 50
500 0
550 -50
600 -100
650 -150
700 -200
750 -250
800 -300
850 -350
clay
silt
f. sand
m. sand
c. sand
pebble
sea level
Sediment Type
slightly clayey silt
peat and peaty mud
interbedded muds silts and muddy sands with some peaty horizons
laminated clays muds and silts
BEDROCK
Color
2.5 5 4
5 4 3
2.5 4.5 4
2.5 5 4
transitional
N4
5G5 1
5G4 1
% Organic Content
0
2
4
6
8
10
Microfossils
qty. 11: 90.9 F 9.1 B 0.0 R
qty. 39: 7.7 F 71.8 B 20.5 R
qty. 146: 1.4 F 39.7 B 58.9 R
qty. 113: 1.8 F 98.2 B 0.0 R
qty. 111: 2.7 F 90.1 B 7.2 R
qty. 143: 0.0 F 100.0 B 0.0 R
Environment of Deposition
floodplain
delta top marsh
delta top and front and interdistributary bay
BEDROCK

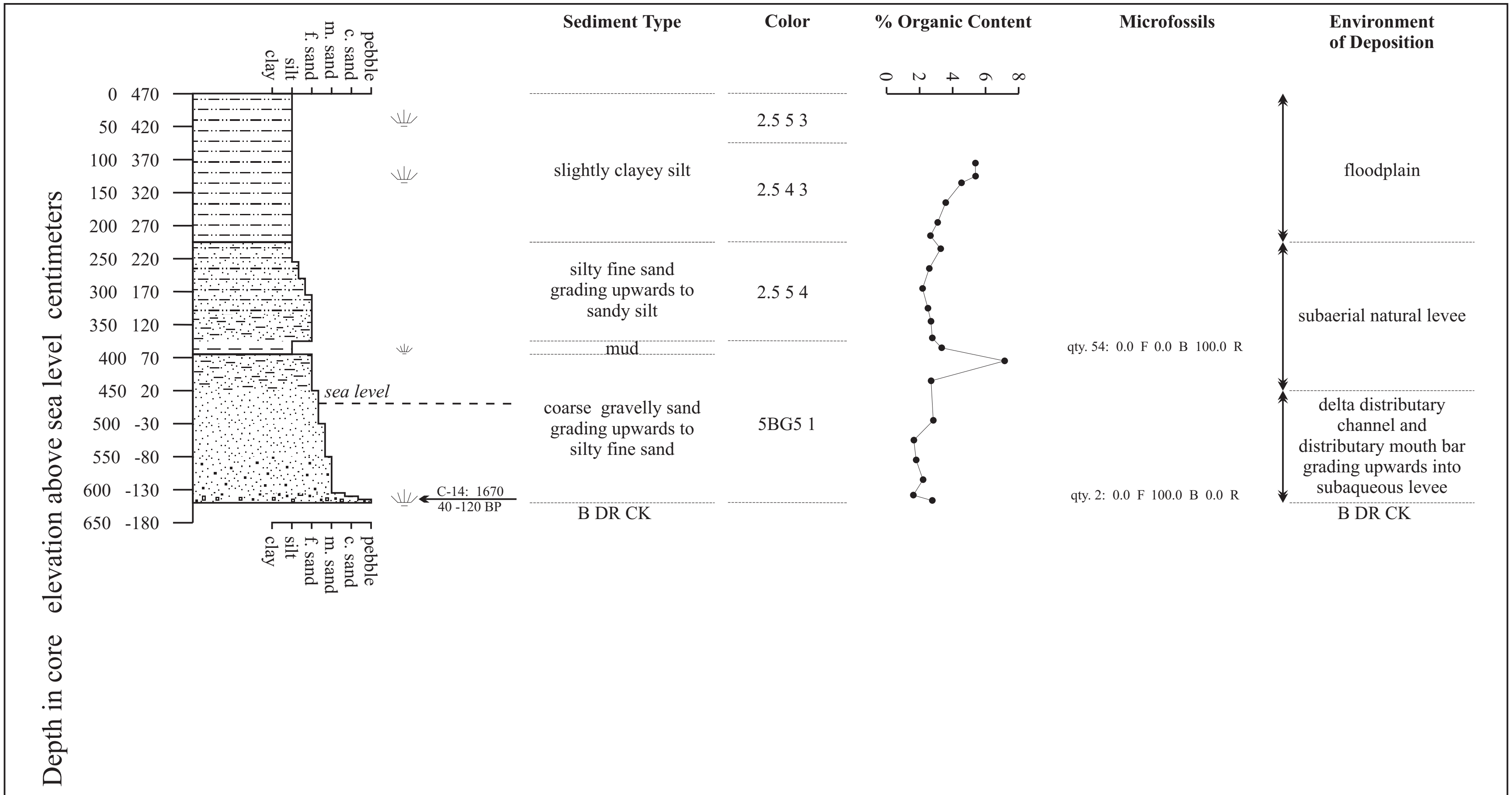
NC-94-12


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0 2 4 6 8
Depth in core elevation above sea level centimeters
0 390
50 340
100 290
150 240
200 190
250 140
300 90
350 40
400 -10
450 -60
500 -110
550 -160
600 -210
650 -260
700 -310
750 -360
800 -410
850 -460
900 -510
950 -560
1000 -610
1050 -660
sea level
C-14: 850
80 -60 BP
slightly clayey silt
slightly silty clay
mud with silty laminae towards bottom
fine sandy mud grading upwards to mud
mud with interbedded clay laminae
interbedded muds silts and muddy sands
laminated clays muds and silts
2.5 5 3
2.5 4 4
2.5 4 3
transitional
5G 4.5 1
5BG5 1
5G 3 1
5G 4 1
qty. 21: 42.9 F 0.0 B 57.1 R
qty. 48: 43.8 F 0.0 B 56.2 R
qty. 11: 90.9 F 0.0 B 9.1 R
qty. 0: 0.0 F 0.0 B 0.0 R
qty. 10: 0.0 F 0.0 B 100.0 R
qty. 423: 4.0 F 13.3 B 82.7 R
qty. 119: 0.0 F 100.0 B 0.0 R
qty. 101: 0.0 F 100.0 B 0.0 R
floodplain
interdistributary bay
delta distributary mouth bar
delta front
shallow marine Glykys Limen
clay
silt
f. sand
m. sand
c. sand
pebble

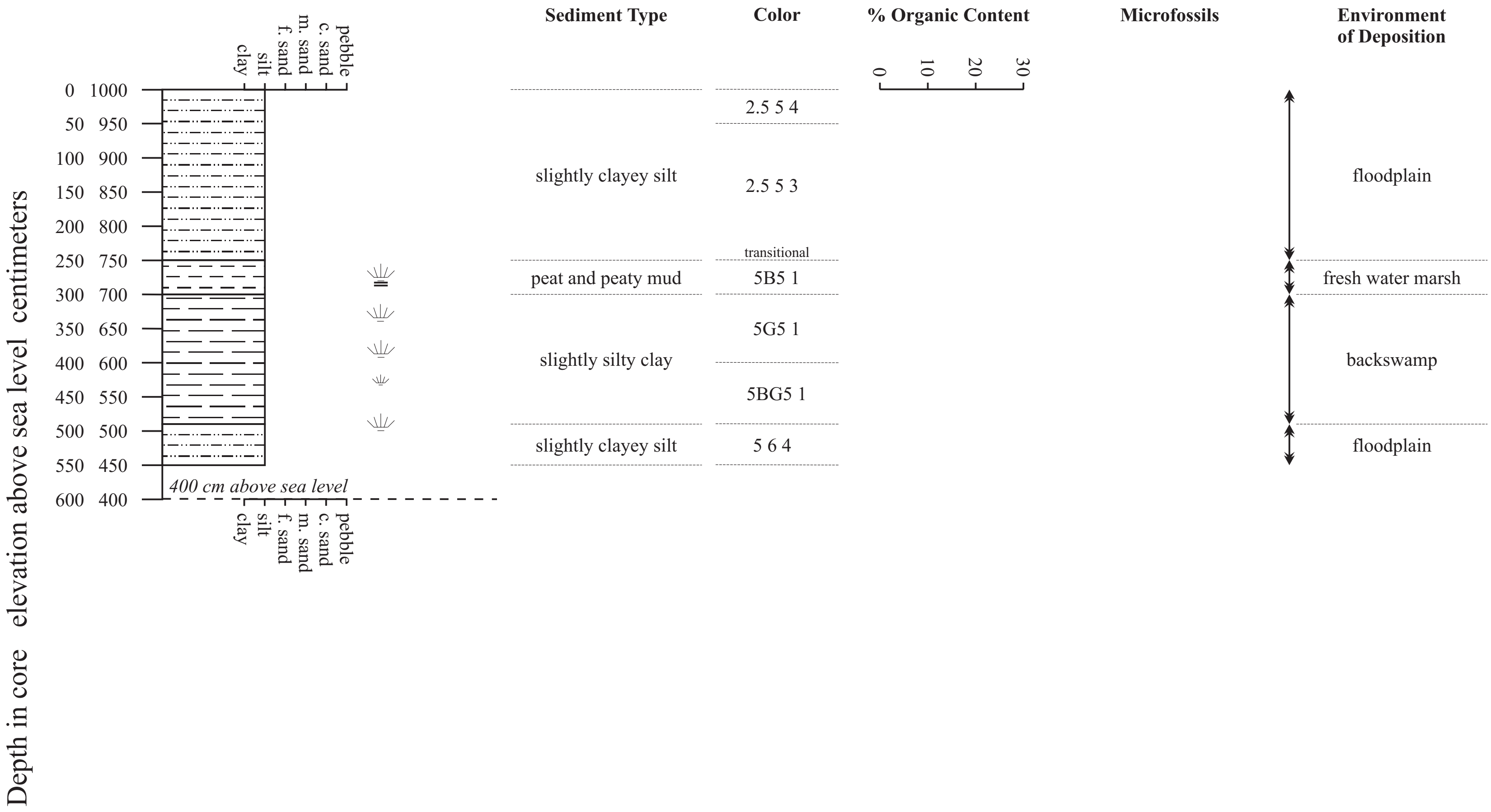
NC-94-13


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
0 5 10 15 20 25
pebble
c. sand
m. sand
f. sand
silt
clay
Depth in core centimeters
elevation above sea level centimeters
0 480
50 430
100 380
150 330
200 280
250 230
300 180
350 130
400 80
450 30
500 -20
550 -70
600 -120
650 -170
700 -220
750 -270
800 -320
850 -370
900 -420
sea level
slightly clayey silt
2.5 4 2
floodplain
mud
2.5 5 2
clay
5BG4 1
shallow fresh water lake Acherousian lake
peat and peaty mud
5G 4 1
brackish delta top marsh grading upwards into fresh water marsh
qty. 292: 0.0 F 60.6 B 39.4 R
poorly sorted sand
delta top

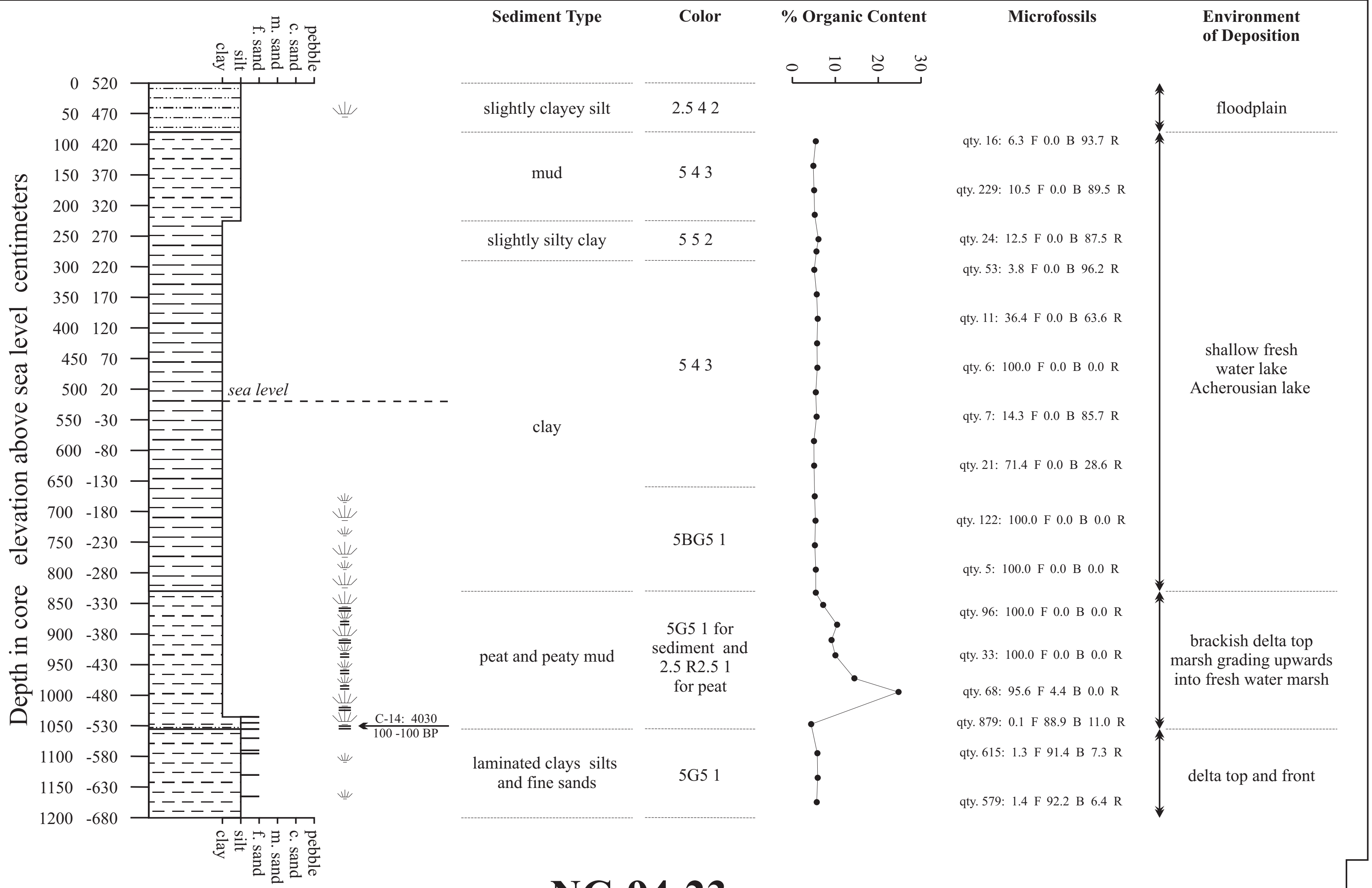
NC-94-17


Depth in core elevation above sea level centimeters
pebble
c. sand
m. sand
f. sand
silt
clay
0 470
50 420
100 370
150 320
200 270
250 220
300 170
350 120
400 70
450 20
500 -30
550 -80
600 -130
650 -180
sea level
C-14: 1670
40 -120 BP
Sediment Type
slightly clayey silt
silty fine sand
grading upwards to
sandy silt
mud
coarse gravelly sand
grading upwards to
silty fine sand
B DR CK
Color
2.5 5 3
2.5 4 3
2.5 5 4
5BG5 1
% Organic Content
0
2
4
6
8
Microfossils
qty. 54: 0.0 F 0.0 B 100.0 R
qty. 2: 0.0 F 100.0 B 0.0 R
Environment
of Deposition
floodplain
subaerial natural levee
delta distributary
channel and
distributary mouth bar
grading upwards into
subaqueous levee
B DR CK

NC-94-20


Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0
10
20
30
Depth in core elevation above sea level centimeters
0 1000
50 950
100 900
150 850
200 800
250 750
300 700
350 650
400 600
450 550
500 500
550 450
600 400
400 cm above sea level
slightly clayey silt
2.5 5 4
2.5 5 3
transitional
peat and peaty mud
5B5 1
slightly silty clay
5G5 1
5BG5 1
slightly clayey silt
5 6 4
floodplain
fresh water marsh
backswamp
floodplain

NC-94-21



Sediment Type
Color
% Organic Content
Microfossils
Environment of Deposition
pebble
c. sand
m. sand
f. sand
silt
clay
0
10
20
30
Depth in core
elevation above sea level centimeters
0 520
50 470
100 420
150 370
200 320
250 270
300 220
350 170
400 120
450 70
500 20
550 -30
600 -80
650 -130
700 -180
750 -230
800 -280
850 -330
900 -380
950 -430
1000 -480
1050 -530
1100 -580
1150 -630
1200 -680
sea level
C-14: 4030
100 -100 BP
slightly clayey silt
2.5 4 2
floodplain
mud
5 4 3
slightly silty clay
5 5 2
clay
5 4 3
5BG5 1
shallow fresh water lake Acherousian lake
peat and peaty mud
5G5 1 for sediment and 2.5 R2.5 1 for peat
brackish delta top marsh grading upwards into fresh water marsh
laminated clays silts and fine sands
5G5 1
delta top and front
qty. 16: 6.3 F 0.0 B 93.7 R
qty. 229: 10.5 F 0.0 B 89.5 R
qty. 24: 12.5 F 0.0 B 87.5 R
qty. 53: 3.8 F 0.0 B 96.2 R
qty. 11: 36.4 F 0.0 B 63.6 R
qty. 6: 100.0 F 0.0 B 0.0 R
qty. 7: 14.3 F 0.0 B 85.7 R
qty. 21: 71.4 F 0.0 B 28.6 R
qty. 122: 100.0 F 0.0 B 0.0 R
qty. 5: 100.0 F 0.0 B 0.0 R
qty. 96: 100.0 F 0.0 B 0.0 R
qty. 33: 100.0 F 0.0 B 0.0 R
qty. 68: 95.6 F 4.4 B 0.0 R
qty. 879: 0.1 F 88.9 B 11.0 R
qty. 615: 1.3 F 91.4 B 7.3 R
qty. 579: 1.4 F 92.2 B 6.4 R

NC-94-23

Appendix B--Microfossils of the Lower Acheron Valley: Identifications, Plates, Associated Ecology, and Distribution and Abundance Tables

Pages 126 through 142 of this appendix contain scanning electron microscope (SEM) images and transmitted light photographs of the microfossils identified from the lower Acheron River Valley. The SEM images were taken by the author at the University of Massachusetts Amherst Central Microscopy Facility. The transmitted light photographs were taken by the author using a petrologic microscope at the University of Minnesota--Duluth.

The microfossils are organized in alphabetical order within three working groups: fresh water ostracods, brackish to marine ostracods, and foraminifera. Accompanying each image is a list of references used to identify the microfossil. Ecological information for the organisms is summarized below the references. Most of the references contain species-level information, but if only genus-level information was available, this is indicated by a "(generic)" tag. If a reference provides a systematic description of an organism, the page number is indicated. All SEM images have a bar scale that represents 100 mm. Transmitted light photos do not contain a scale, but in many cases, the specimens photographed in transmitted light are the same specimens that were used for the SEM images.

Pages 143 through 146 of this appendix include tables that record the distribution and abundance of the microfossils in the samples studied. The weight of wet sediment that was disaggregated for each sample is recorded. For the ostracods, the counts represent tallies on individual left or right valves. If fully articulated carapaces were encountered, this is recorded by appending a "dot" and number representing the articulated carapaces to the total valve count. For example, "13•4" records that 13 individual valves were encountered--there were 4 fully articulated carapaces (e.g. 8 valves = 4 pairs of valves) and 5 disarticulated valves. Counts of other microfossils such as pelecypods, gastropods, and reworked microfossils which are not represented by plates are also included. Page 146 contains a table of simple total and percentage statistics for fresh water forms, brackish to marine forms, and reworked microfossils. It is this data that is included in Appendix A alongside the core stratigraphy.

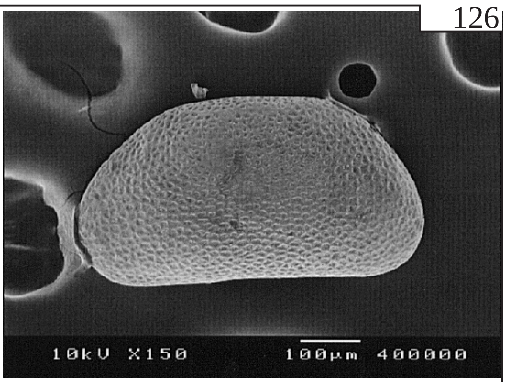
Appendix B Table of Contents

1.) *Candona albicans* Brady, 1864--(juvenile)

Sars, 1925, p. 82-83, pl. 39, fig. 1
Staplin, 1963a, p. 763 and 765, pl. 93, figs. 21-22
Bhatia, 1968, p. 471-472, pl. 2, fig. 4
Puri et al., 1969 (generic)
Villas, 1983, p. 56, pl. 4, figs. 1 and 4
Henderson, 1990, p. 68, fig. 24

Ecology: inhabits permanent or temporary shallow, fresh water, pools, ditches, ponds, and marshes; usually with muddy substrates

1.)

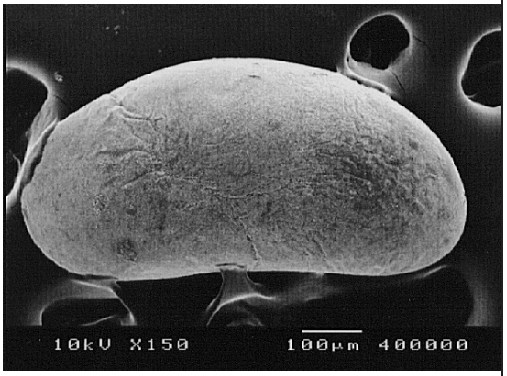


2.) *Candona sp. aff. C. caudata* Kaufmann, 1900

Sars, 1925, p. 76-77, pl. 35
Benson and MacDonald, 1963, p. 12-13, pl. 1, figs. 1, 3, and 4
Staplin, 1963a, p. 767-768, pl. 91, figs. 10-11
Devoto, 1965, p. 338, fig. 37
Puri et al., 1969 (generic)

Ecology: generally inhabits shallow, fresh water ditches, ponds, lakes, and canals with grass, weeds, and algae; often with a muddy substrate; often occurs in association with charophytes

2.)



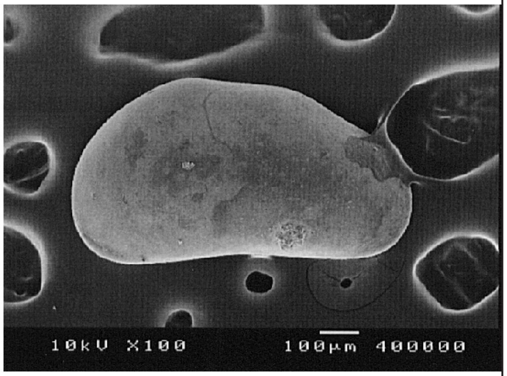
3.) *Candona compressa* (Koch, 1837)

Fig. 3b transmitted light

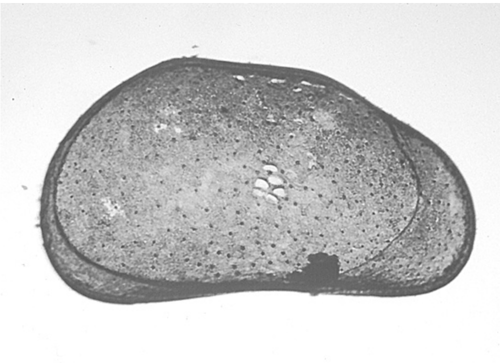
Sars, 1925, p. 83-85, pl. 39, fig. 2
Wagner, 1957, p. 20-21, pl. 2
Devoto, 1965, p. 338-339, fig. 38
Bhatia, 1968, p. 472, pl. 2, fig. 3
Puri et al., 1969 (generic)
Henderson, 1990, p. 76, fig. 28

Ecology: inhabits fresh to slightly oligohaline waters with muddy or sandy substrates

3a.)



3b.)



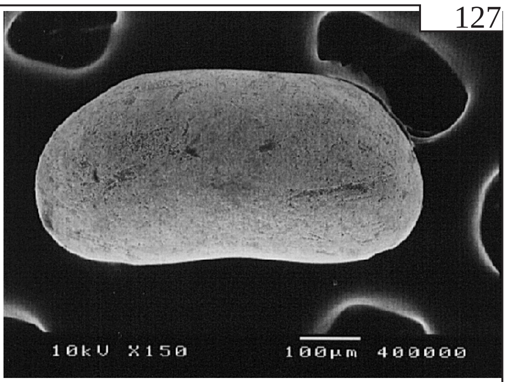
4.) *Candona cf. lactea* Baird, 1850

Fig. 4b transmitted light; Fig. 4c scar pattern close-up transmitted light

Staplin, 1963a, p. 775-776, pl. 91, fig. 1
Bhatia, 1968, p. 472, pl. 2, fig. 5, pl. 5, figs. 1-2
Puri et al., 1969 (generic)
Henderson, 1990, p. 86

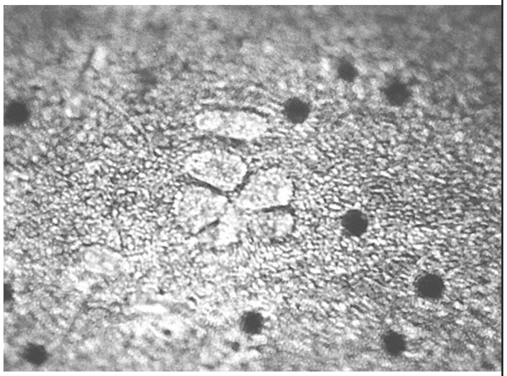
Ecology: inhabits permanent or summer-drying fresh water habitats; cold stenothermal

4a.)



4b.)

4c.)



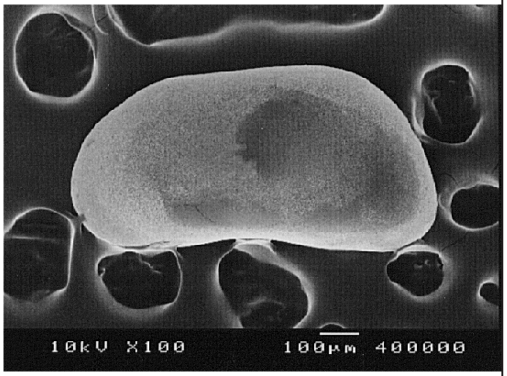
5.) *Candona neglecta* Sars

Fig. 5b transmitted light

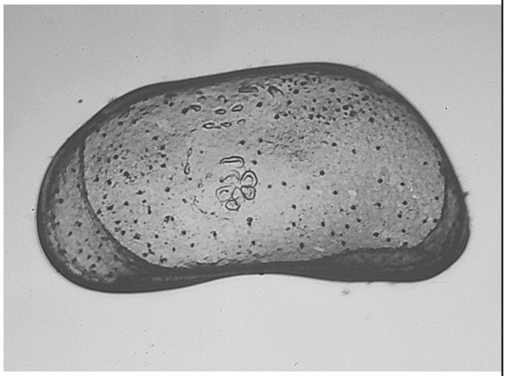
Sars, 1925, p. 73-75, pl. 34, fig. 1
Wagner, 1957, p. 21-22, pl. 3
Wagner, 1964
Devoto, 1965, p. 340
Bhatia, 1968, p. 474, pl. 3, fig. 1, pl. 5, figs. 5 and 7
Masoli, 1968/69, p. 11-12, pl. 1, pl. 4, figs. 38-40
Puri et al., 1969 (generic)
Villas, 1983, p. 56, pl. 4, figs. 2, 5, and 16
Henderson, 1990, p. 90, fig. 35

Ecology: inhabits fresh to slightly oligohaline ponds, lakes, marshes, ditches, and creeks with grass and weeds; generally with muddy substrates; possibly cold stenothermal

5a.)



5b.)

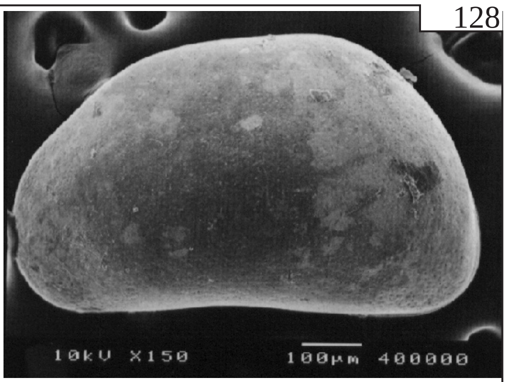


6.) *Candona cf. truncata* Furtos, 1933

Staplin, 1963a, p. 787-788, p. 94, figs. 13-16, 18, and 19
Puri et al., 1969 (generic)

Ecology: inhabits permanent or temporary shallow and marshy fresh water ponds, swamps, and lakes

6.)

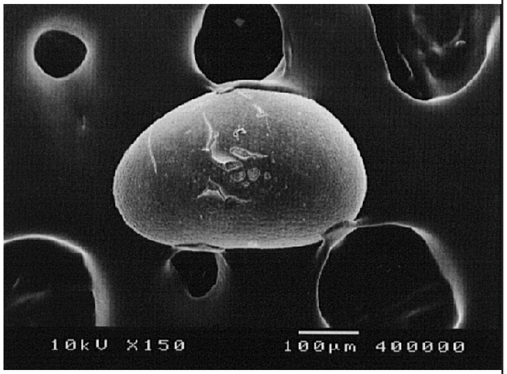


7.) *Cyclocypris cf. laevis* (O.F. Müller, 1785)

Sars, 1925, p. 93-94, pl. 43, fig. 2
Wagner, 1957, p. 22-24, pl. 4
Staplin, 1963b, p. 1182, pl. 159, figs. 27-29
Devoto, 1965, p. 342-343, fig. 46
Henderson, 1990, p. 118, fig. 48

Ecology: inhabits shallow, fresh to oligohaline, ditches, pools, ponds, and lakes with grassy bottoms and rich, marshy vegetation; often occurs in association with species of *Ilyocypris*, *Potamocypris*, and *Limnocythere*

7.)

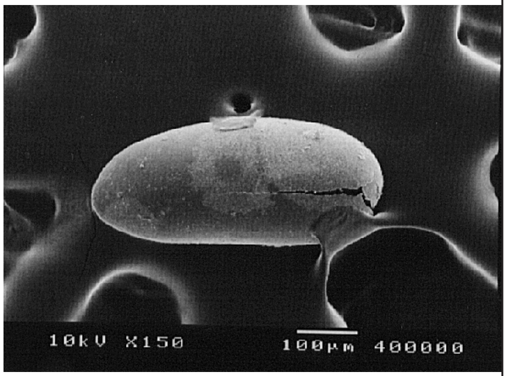


8.) *Darwinula stevensoni* (Brady and Robertson, 1870)

Sars, 1925, p. 145-146, pl. 67
Wagner, 1957, p. 334-335, pl. 11
Swain and Gilby, 1964, p. 368-369, pl. 1, fig. 3
Wagner, 1964
Devoto, 1965, p. 346, fig. 52
Bhatia, 1968, p. 470, pl. 3, fig. 5, pl. 5, fig. 13
Keyser, 1977
Villas, 1983, p. 56, pl. 6
Guillaume et al., 1985, p. 374, pl. 115, fig. 7
Neale, 1988
Henderson, 1990, p. 46-47, fig. 16

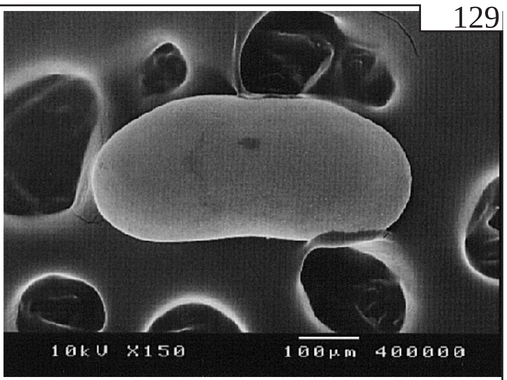
Ecology: inhabits shallow (0-10 m depth), fresh to oligohaline waters with generally organic-rich, muddy and sandy substrates

8.)



9.) *Herpetocypris cf. reptans* (Baird)--(juvenile)

9.)

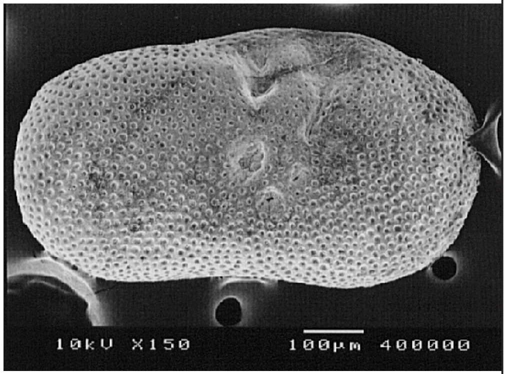


Sars, 1925, p. 128-129, pl. 59
Dobbin, 1941, p. 227, pl. 5, fig. 1; referred to as *Herpetocypris repetans* (Baird, 1935)
Devoto, 1965, p. 335, fig. 32; referred to as *Erpetocypris reptans* (Baird, 1835)
Puri et al., 1969 (generic)
Guillaume et al., 1985, p. 374, pl. 115, figs. 5-6
Henderson, 1990, p. 174, fig. 75

Ecology: inhabits permanent, shallow, fresh water ditches, ponds, and pools to large lakes with muddy substrates; eurythermal

10.) *Ilyocypris gibba* (Ramdohr, 1808)

10.)

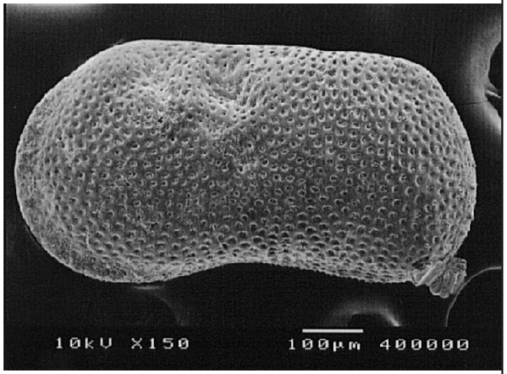


Sars, 1925, p. 106-107, pl. 49; referred to as *Ilyocypris biplicata* (Koch)
Wagner, 1957, p. 32-33, pl. 10
Staplin, 1963b, p. 1187-1190, pl. 160, figs. 36-37 and 39, and also *Ilyocypris bradyi* Sars, 1890, p. 1186-1187, pl. 160, figs. 34-35
Devoto, 1965, p. 345, fig. 50
Bhatia, 1968, p. 474 and 476, pl. 4, fig. 1, pl. 5, figs. 21-22; referred to as *Ilyocypris bradyi* Sars
Masoli, 1968/69, p. 14-15, pl. 5, figs. 57-59
Puri et al., 1969 (generic)
Carbonel et al., 1975
Tassos, 1975, pl. 3, fig. 2
Tziavos, 1977, pl. 5, figs. 1a-e; referred to as *Ilyocypris sp.*
Villas, 1983, p. 56, pl. 4, figs. 3 and 6
Guillaume et al., 1985, p. 340, pl. 98, figs. 1-2
Neale, 1988 (generic)
Henderson, 1990, p. 56, fig. 20

Ecology: inhabits shallow, fresh to oligohaline/brackish ponds, ditches, lakes, streams, and other waters with marshy vegetation and algae and muddy substrates; may prefer running water

11.) *Limnocythere cf. inopinata* (Baird, 1843)

11.)



Sars, 1925, p. 151-152, pl. 69, fig. 2
Dobbin, 1941, p. 186, pl. 1, fig. 6
Wagner, 1957, p. 37-38, pl. 13
Wagner, 1964
Carbonel et al., 1975
Guillaume et al., 1985, p. 376, pl. 116, figs. 7-8
Neale, 1988
Henderson, 1990, p. 34, fig. 11

Ecology: generally inhabits shallow, fresh to oligohaline, ponds, swamps, lakes, streams, and rivers; also encountered in the upper tidal reaches of rivers; euryhaline

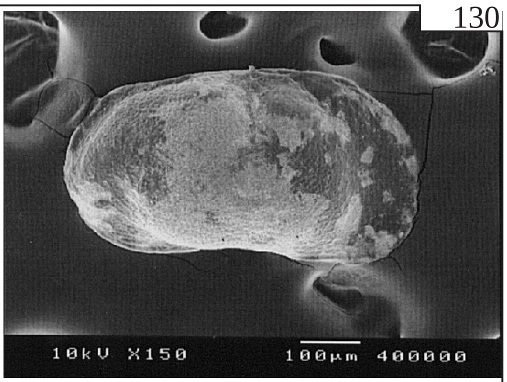
12.) *Limnocythere sp.*

Fig. 12c transmitted light

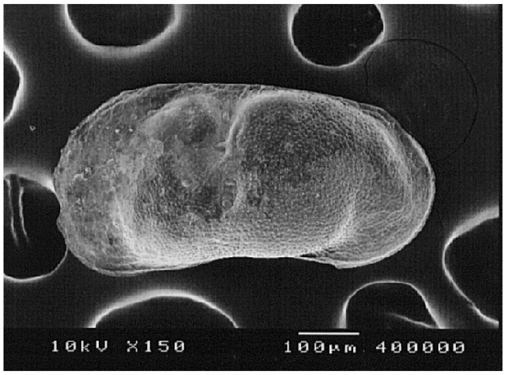
Staplin, 1963b (generic)
Devoto, 1965, p. 349, fig. 55; referred to as *Paralimnocythere rostrata* (Straub, 1952); NOTE: though the organism recovered from the Acheron Valley is identical to that illustrated by Devoto, its identification as *P. rostrata* is probably incorrect as *P. rostrata* is only known from the Middle and Upper Miocene of Germany, and the genus *Paralimnocythere* has recently undergone major revisions (personal communication with H.I. Griffiths, 1996)

Ecology: generally inhabits fresh water lakes with muddy substrates; occasionally encountered in aquatic vegetation or running water

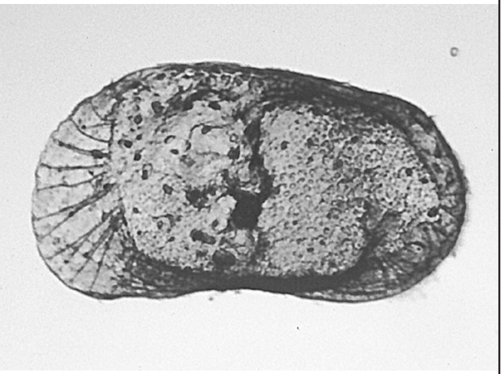
12a.)



12b.)



12c.)



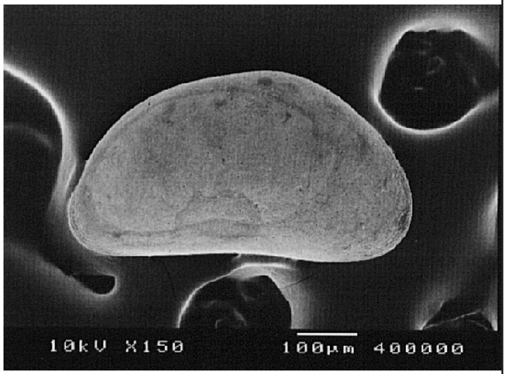
13.) *Potamocypris cf. villosa* (Jurine, 1820)

Fig. 13b transmitted light

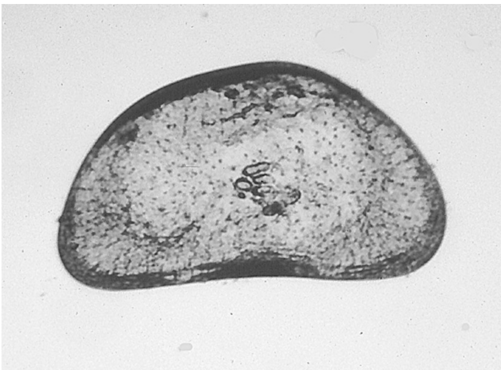
Sars, 1925, p. 142-144, pl. 66; referred to as *Cypridopsella villosa* (Jurine)
Staplin, 1963b (generic)
Puri et al., 1969 (generic)
Neale, 1988 (generic)
Henderson, 1990, p. 200, fig. 87

Ecology: inhabits shallow, fresh water ponds and swamps with grassy and muddy bottoms; often occurs close to inflowing streams; also encountered in slow-flowing streams and springs; occasionally recorded from brackish pools

13a.)



13b.)



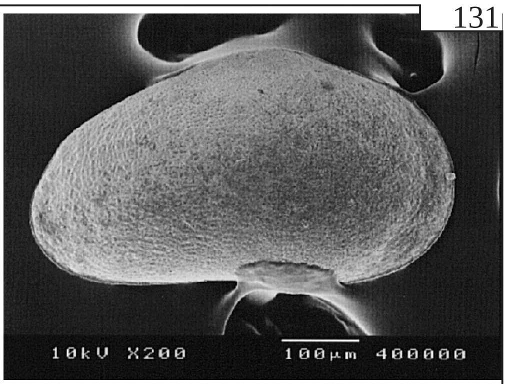
14.) *Ostracod sp. A*, possibly *Prionocypris zenkeri* (Chyzer, 1858)

Fig. 14b scar pattern close-up transmitted light

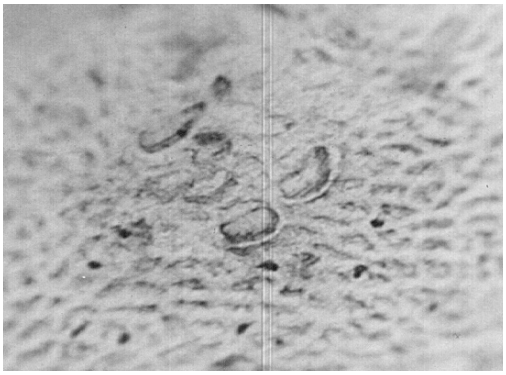
Devoto, 1965, p. 330-331, fig. 24
Henderson, 1990, p. 160, fig. 68; referred to as *Eucypris zenkeri* (Chyzer, 1858) which Henderson says is synonymous with *Prionocypris serrata* Norman; Kaufmann, 1900

Ecology: inhabits permanent and temporary shallow, fresh water, pools, ditches, ponds, and marshes; usually with muddy substrates

14a.)



14b.)

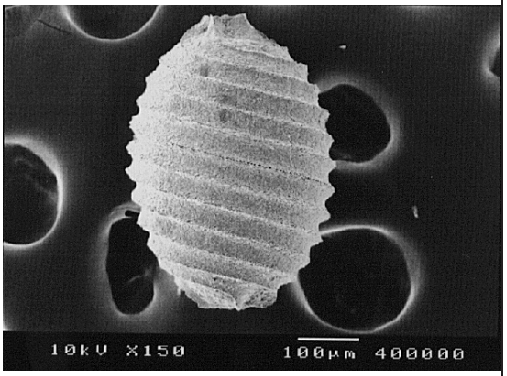


15.) *Charophyta*

Staplin, 1963a
Yang, 1982, pl. 4, figs. 17 and 19
Villas, 1983, pl. 3, figs. 24-25

Ecology: often occurs in association with *Candona caudata* Kaufmann, 1900 which inhabits shallow, fresh water ditches, ponds, lakes, and canals with grass, weeds, and algae, and often with a muddy substrate

15.)

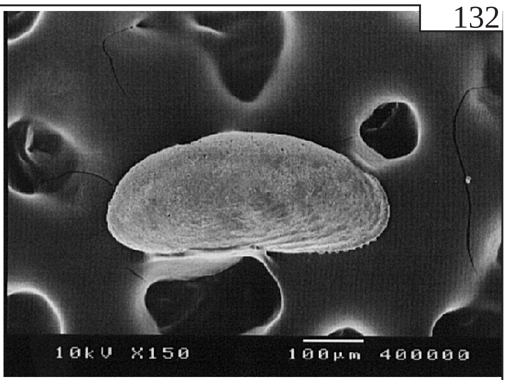


16.) *Cushmanidea elongata* (Brady)

Ascoli, 1964, pl. 1, fig. 2, pl. 2, fig. 1
Hulings and Puri, 1964, fig. 14
Puri et al., 1964, p. 135
Whatley and Wall, 1967
Williams, 1967
Masoli, 1968/1969, p. 34-35, pl. 2, fig. 17, pl. 9, figs. 123-125
Puri et al., 1969
Carbonel et al., 1975
Tassos, 1975, pl. 3, fig. 13
Villas, 1983, p. 59 and 64

Ecology: generally occurs in abundance in lower salinity, littoral to inner shelf environments from 0-50 m depth, but also encountered in water up to approximately 100 m depth; euryhaline; characteristic of shallow water nearshore to neritic environments; substrate is variable ranging from sand to mud

16.)

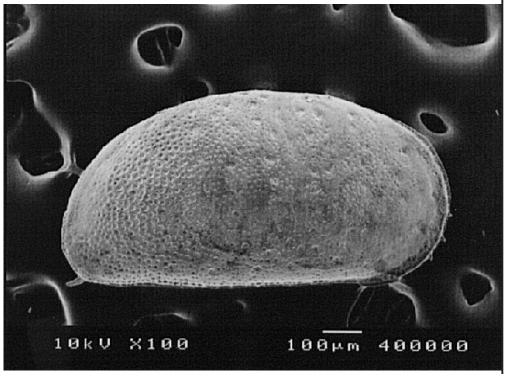


17.) *Cyprideis torosa* (Jones, 1850)

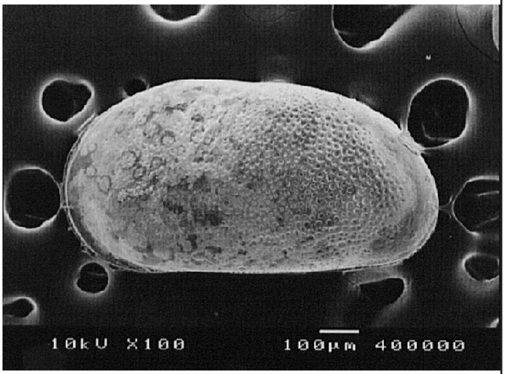
Fig. 17c transmitted light; Fig. 17d scar pattern close-up transmitted light
Sars, 1925, p. 155-156, pl. 71; referred to as *Cyprideis littoralis* Brady
Elofson, 1941, p. 33-34; referred to as *Cyprideis litoralis* (Brady), 1868
Wagner, 1957, p. 39-41, pl. 14
Wagner, 1964
Ascoli, 1964
Masoli, 1968/69, p. 33-34, pl. 9, figs. 120-122
Puri et al., 1969
King and Kornicker, 1970, p. 28-29, pl. 2, fig. 3, pl. 3, fig. 1, pl. 13, figs. 1-6, referred to as *Cyprideis torosa* (Jones), 1857
Kilenyi and Whittaker, 1974, p. 21-32, pls. 2:5:22, 2:5:24, 2:5:26, 2:5:28, 2:5:30, 2:5:32
Carbonel et al., 1975
Tassos, 1975
Vesper, 1975
Tziavos, 1977, pl. 5, figs. 3a-e
Yang, 1982, p. 104-105, pl. 8, figs. 1-5 and 8
Villas, 1983, p. 57, pl. 4, figs. 13 and 17
Guillaume et al., 1985, p. 342, pl. 99, figs. 1-2
Lachenal and Bodergat, 1988
Neale, 1988
Zangger and Malz, 1989, pl. 3, figs. 11-12
Witte, 1993, p. 13, pl. 5, figs. 1-6

Ecology: inhabits brackish (mesohaline) water, marginal marine environments in abundance; cosmopolitan distribution; encountered in lagoons, bays, estuaries, river mouths, tidal flats, and nearly all other littoral and brackish water environments; extremely eurythermal and euryhaline; has also been encountered in slightly hypersaline and limnetic environments

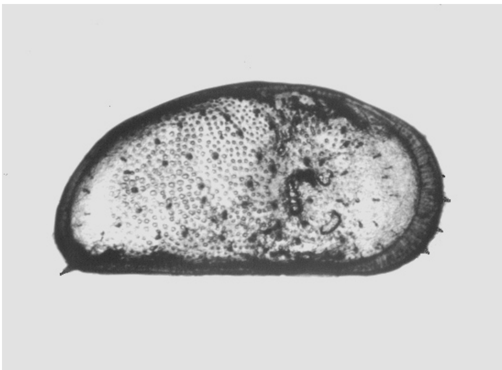
17a.)



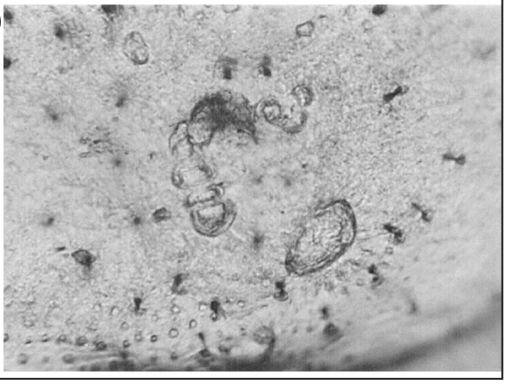
17b.)



17c.)



17d.)

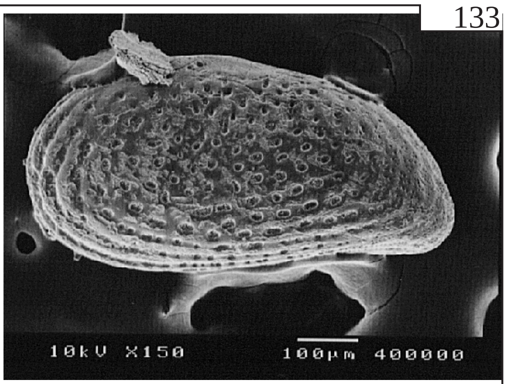


18.) *Cytheridea neapolitana* Kollman, 1960

Ascoli, 1964, pl. 1, fig. 7, pl. 2, fig. 2
Puri et al., 1964, p. 114
Masoli, 1968/69, p. 32-33, pl. 9, figs. 117-119
Puri et al., 1969
Tassos, 1975, pl. 3, fig. 9
Uffenorde, 1975, p. 159, fig. 9
Tziavos, 1977, pl. 4, figs. 2a-c (generic)
Yang, 1982, p. 103-104, pl. 7, figs. 1, 12, and 14
Lachenal and Bodergat, 1988
Zangger and Malz, 1989, pl. 2, fig. 9

Ecology: inhabits shallow marine nearshore and inner sublittoral environments up to about 50 m depth, but also occurs in water up to 100 m depth; characteristic of shallow water and nearshore environments such as bays; substrate is variable and may be unvegetated, or host calcareous and regular algae

18.)

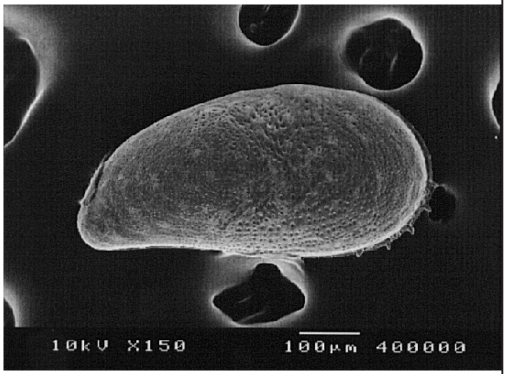


19.) *Cytheridea gr. sorbyana* (Jones)

Tassos, 1975, pl. 3, fig. 12 (generic)

Ecology: inhabits shallow marine nearshore environments such as bays

19.)



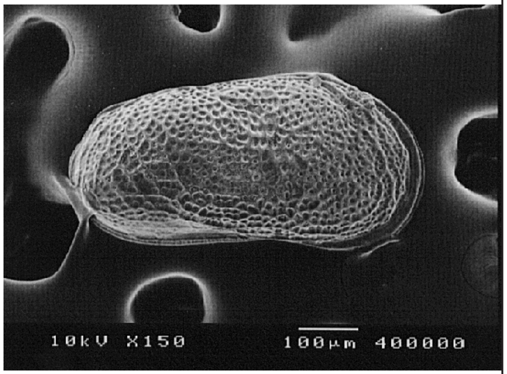
20.) *Cytheromorpha fuscata* (Brady, 1869)

Fig. 20a male; Fig. 20b female

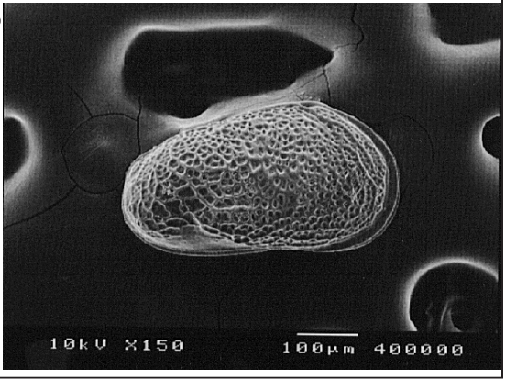
Sars, 1925, p. 177-178, pl. 81
Elofson, 1941, p. 52-53
Wagner, 1957, p. 49-50, pl. 19
Wagner, 1964
Williams, 1967
Masoli, 1968/69, p. 57-58, pl. 2, fig. 18, pl. 13, figs. 200-202
Puri et al., 1969
Boomer and Horne, 1991, p. 49-56, pls. 18:50, 18:52, 18:54, 18:56

Ecology: inhabits shallow (0-25 m depth), exclusively brackish water habitats such as river mouths, estuaries, and beaches; essentially absent in water of 18-30‰ salinity, and never found in water with salinity greater than 30‰; eurythermal; not linked to a particular substrate; often encountered among algae and plants

20a.)



20b.)

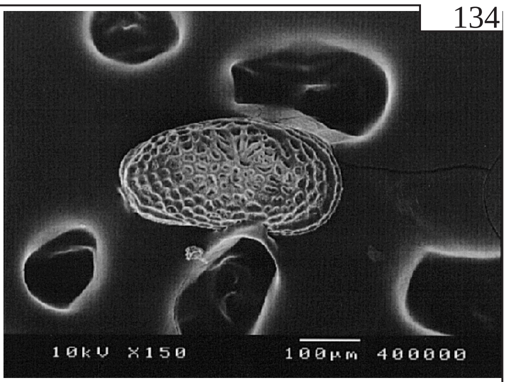


21.) *Leptocythere bacescoi* (Rome, 1942)

Malkin Curtis, 1960
Puri et al., 1964, p. 114
Masoli, 1968/69, p. 16-17, pl. 5, figs. 69-70
Puri et al., 1969
Uffenorde, 1975, p. 161, fig. 12
Yang, 1982, p. 112-113, pl. 7, figs. 5-6 and 10
Villas, 1983, p. 64, pl. 5, figs. 2 and 5

Ecology: inhabits littoral marine and shallow shelf environments up to approximately 100 m depth; characteristic of nearshore environments such as bays or open lagoons

21.)

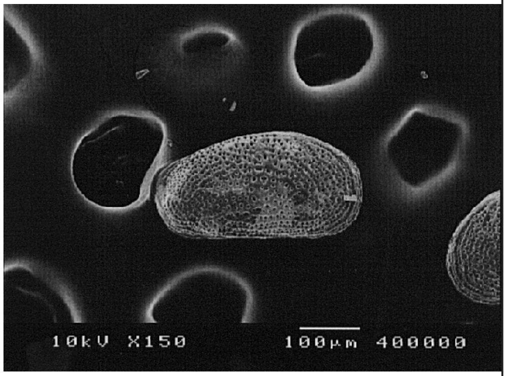


22.) *Leptocythere cf. castanea* (Sars, 1866)

Sars, 1925, p. 174-175, pl. 80, fig. 1
Elofson, 1941, p. 50-51
Wagner, 1957, p. 53-54, pl. 21
Wagner, 1964
Whatley and Wall, 1967
Williams, 1967
Puri et al., 1969
Carbonel et al., 1975
Swain and Kraft, 1975, pl. 4, fig. 7, pl. 5, fig. 1
Guillaume et al., 1985, p. 358, pl. 107, figs. 4-5

Ecology: inhabits shallow, brackish water environments such as river mouths, estuaries, lagoons, the intertidal zone, beaches, and bays down to approximately 25 m depth; occasionally found up to 70 m depth; strongly eurythermal and euryhaline; substrate is variable including sand, silt, mud, and organic detritus

22.)



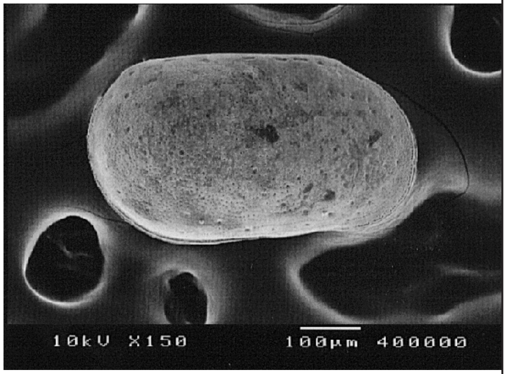
23.) *Loxoconcha elliptica* Brady, 1868

Fig. 23a male; Fig. 23b male transmitted light; Fig. 23c female; Fig. 23d female transmitted light; Fig. 23e scar pattern close-up transmitted light

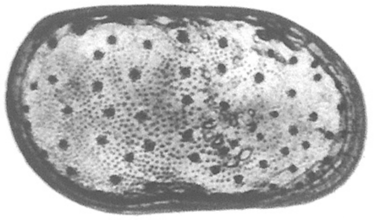
Elofson, 1941, p. 99-100
Wagner, 1957, p. 66-67, pl. 28
Wagner, 1964
Puri et al., 1969
Villas, 1983, p. 57, pl. 5, fig. 15
Carbonel et al., 1975; referred to as *Loxoconcha elliptica* (Brady, 1968)
Athersuch and Whittaker, 1976, p. 99-106, pl. 3:100, 3:102, 3:104, 3:106
Neale, 1988
Pascual and Carbonel, 1992, pl. 1, figs. 1-10

Ecology: inhabits shallow brackish water littoral environments such as estuaries, river mouths, lagoons, and the intertidal zone to several meters depth; brackish waters are generally mesohaline, but occasionally oligohaline and polyhaline; extremely eurythermal and euryhaline; often encountered among plants and near estuarine marshes

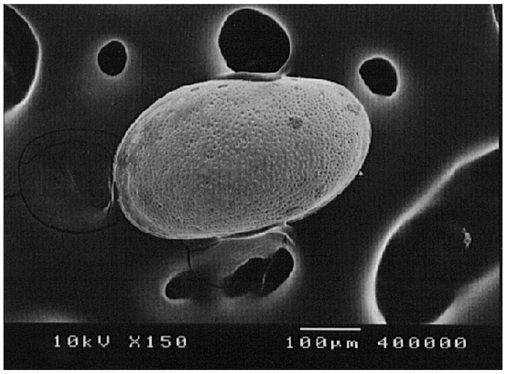
23a.)



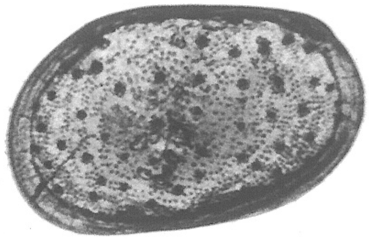
23b.)



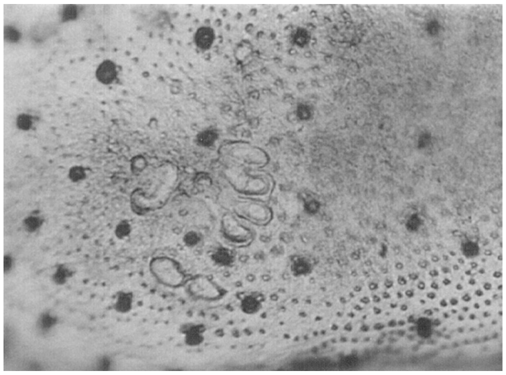
23c.)



23d.)



23e.)



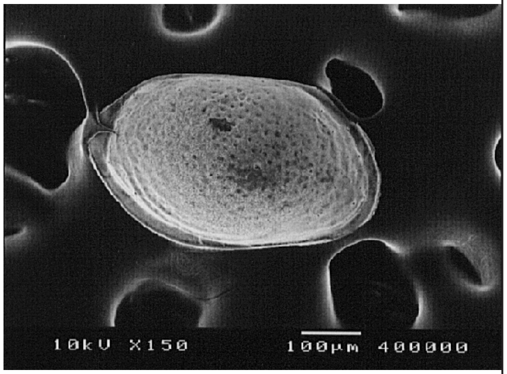
24.) *Loxoconcha cf. granulata* Sars, 1866

Fig. 24b scar pattern close-up transmitted light

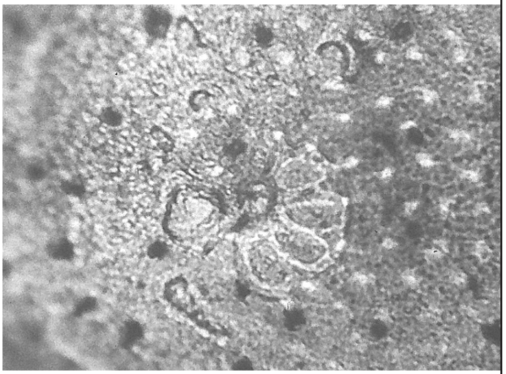
Sars, 1925, p. 219-220, pl. 102, fig. 1
Elofson, 1941, p. 101
Williams, 1967
Yang, 1982, p. 119-120, pl. 8, fig. 7; referred to as *L. sp. aff. L. bonaducei* Cimpo, 1970, but it seems comparable to the specimens recovered from the Acheron Valley
Guillaume et al., 1985, p. 352, pl. 104, figs. 1-2
Guillaume et al., 1985, p. 346, pl. 101, figs. 6-7; referred to as *Hirschmannia tamarindus* (Jones, 1856), but it seems comparable to the specimens recovered from the Acheron Valley
Neale, 1988 (generic)

Ecology: inhabits marine waters between 8-205 m depth, but usually between 20-80 m depth; highly eurythermal; may inhabit waters with a salinity of only 10-20‰; substrate variable ranging from mud to silty sand to sand

24a.)



24b.)



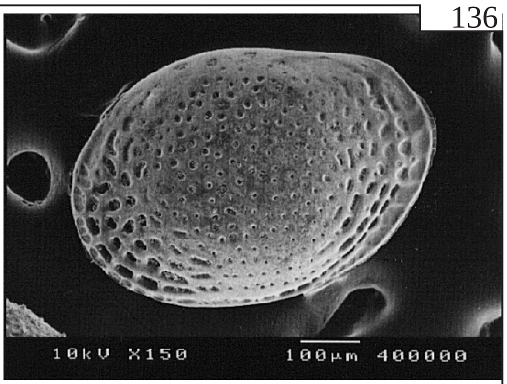
25.) *Loxoconcha ovulata* (Costa, 1853)

Fig. 25a female(?); Fig. 25b female(?) transmitted light; Fig. 25c male(?)

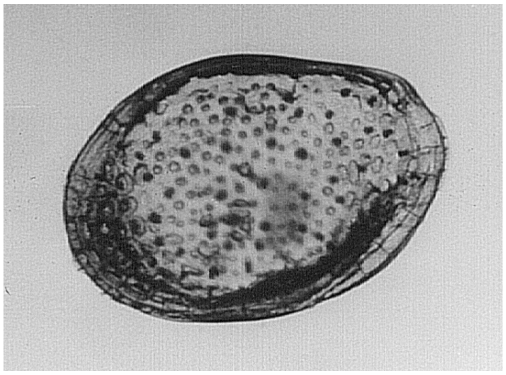
Ascoli, 1964, pl. 1, fig. 8, pl. 2, fig. 12
Masoli, 1968/1969, p. 55-56, pl. 3, fig. 34, pl. 12, figs 191-193; referred to as *Loxoconcha tumida* Brady
Puri et al., 1969
Tassos, 1975, pl. 4, figs. 26-30; referred to as *L. sp. 1* and *L. sp. 2*
Tziavos, 1977, pl. 5, figs. 5a-d; referred to as *Loxoconcha sp. 2*
Athersuch, 1979, p. 141-150, pls. 6:142, 6:144, 6:148, 6:150
Neale, 1988 (generic)
Zangger and Malz, 1989, pl. 1, fig. 10

Ecology: inhabits littoral, brackish (mesohaline) to marine water shallow shelf environments such as bays to approximately 75 m depth; occasionally found to 150 m depth; euryhaline; indicative of nearshore environments; substrate usually sandy mud, but may be variable

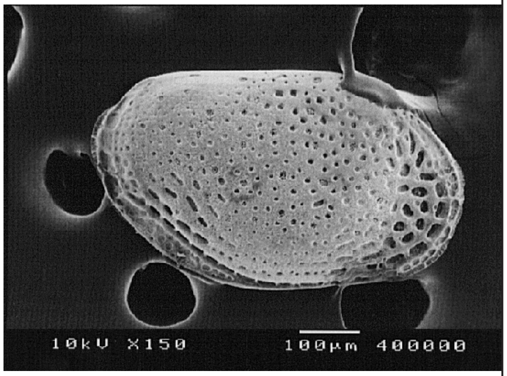
25a.)



25b.)



25c.)

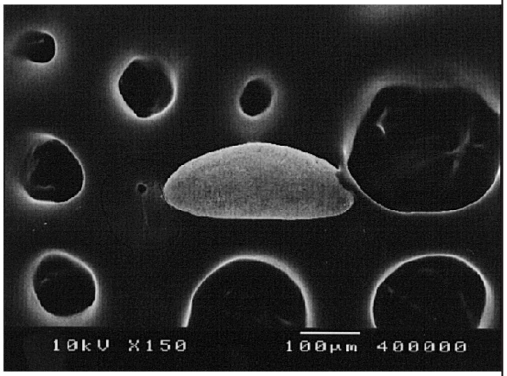


26.) *Paracytherois cf. acuminata* Müller, 1894

Sars, 1925, p. 248-249, pl. 113 (generic)
Ellis and Messina, 1952-present; systematic description of *Paracytherois acuminata* Müller, 1894
Moore, 1961, p. Q315, fig. 244, no. 7 (generic)

Ecology: associated with calcareous algae and Posidonia in the Bay of Naples, and in shallow waters of the Norwegian coast

26.)



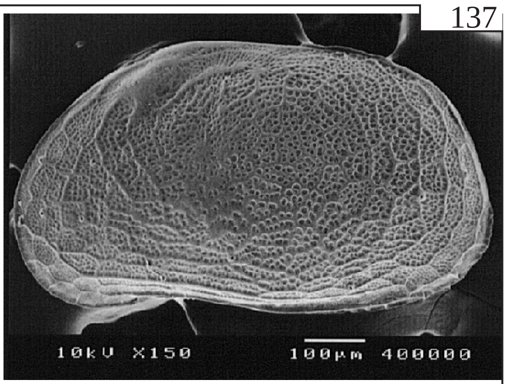
27.) *Tyrrhenocythere amnicola* (Sars, 1888)

Fig. 27a male(?); Fig. 27b female(?); Fig. 27c juvenile male(?); Fig. 27d male(?); Fig. 27e male(?) transmitted light; Fig. 27f scar pattern close-up transmitted light

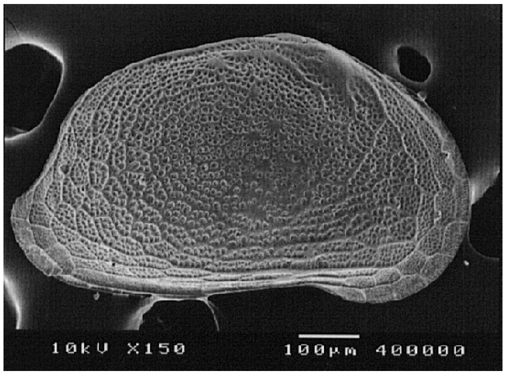
Moore, 1961, p. Q306, fig. 229, nos. 3a-c
Ruggieri, 1955; referred to as *Tyrrhenocythere pignattii* n. sp.
Devoto, 1965; referred to as *Tyrrhenocythere sicula* (Brady)
Maness and Kaesler, 1985, p. 69-72, pls. 12:70 and 12:72

Ecology: inhabits brackish water bays, lagoons, and shallow nearshore environments of the Mediterranean region

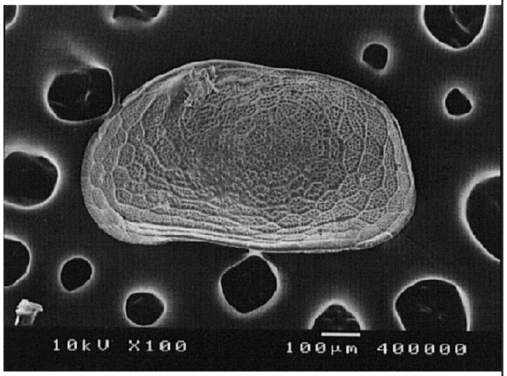
27a.)



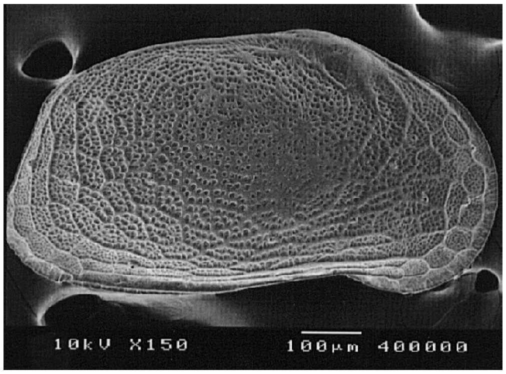
27b.)



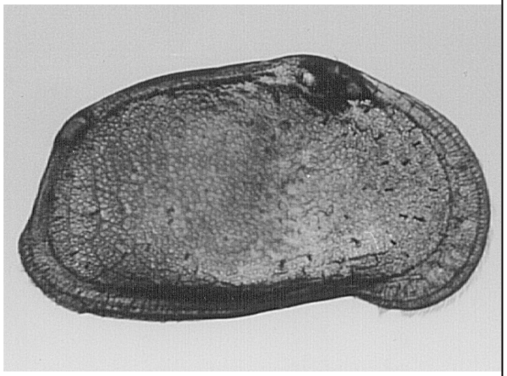
27c.)



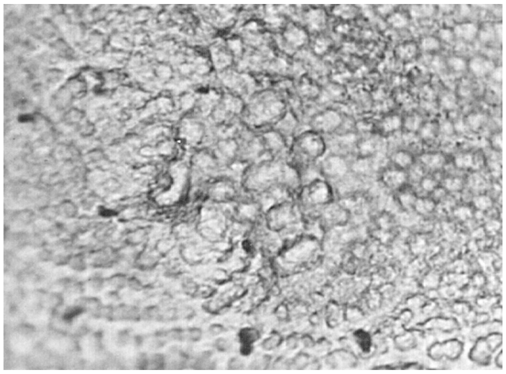
27d.)



27e.)



27f.)



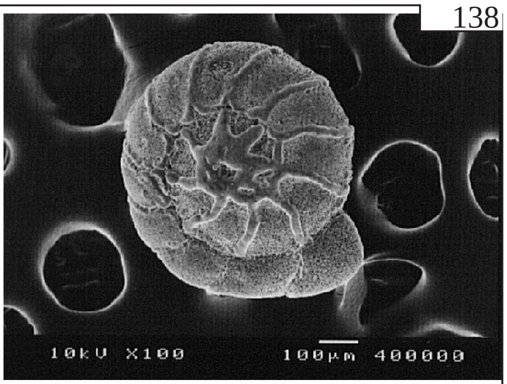
28.) *Ammonia beccarii* (Linné, 1758)

Fig. 28d and 28e umbilical view

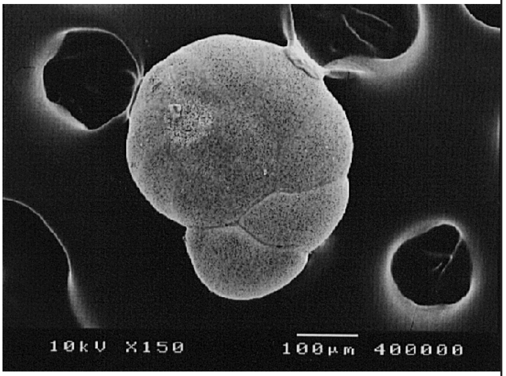
Phleger and Parker, 1951, p. 23, pl. 12, figs. 6-7; referred to as *"Rotalia" beccarii* (Linné) var. parkinsoniana (d'Orbigny) and *"Rotalia" beccarii* (Linné) var. tepida Cushman
Walton, 1955, p. 1014, pl. 103, figs. 12-13; referred to as *"Rotalia" cf. "R." beccarii* (Linné)
Todd and Bronniman, 1957, p. 38, pl. 10, figs. 1-3 and 5-1 1; referred to as *Streblus beccarii* (Linné) vars.
Lankford, 1959, pl. 3, figs. 10 and 13; referred to as *Streblus beccarii* (Linné) variant
Phleger, 1960, p. 47 and 52, pl. 1, figs. 18-19, pl. 7, fig. 28, pl. 9, figs. 5 and 23; referred to as *Streblus beccarii* (Linné)
Galloway, 1961, p. 281 (generic information), pl. 25,fig. 1; referred to as *Rotalia beccarii* (Linné)
Ascoli, 1964
Moore, 1964, p. C607, fig. 479, nos. 2-3
Phleger, 1970
Murray, 1971
Brooks, 1973, pl. 10, figs. 5 and 10
Chang and Kaesler, 1974
Schnitker, 1974, pl. 1, figs. 1-9
Tassos, 1975, pl. 2, figs. 26-27
Haake, 1977, p. 62 and 65, pl. 1, figs. 1-2
Tziavos, 1977, pl. 4, figs. 2a-c and 3a-b
Scott et al., 1979, p. 257, pl. 16, figs. 3-4
Albani and Serandrei Barbero, 1982
Yang, 1982, p. 166-168, pl. 4, figs. 14-16
Villas, 1983, p. 57-58 and 62, pl. 3, figs. 1-3
Albani et al., 1984
Loeblich and Tappan, 1988, p. 664-665, pl. 767, figs. 1-10

Ecology: inhabits shallow, nearshore brackish water and marginal marine environments in abundance; cosmopolitan; encountered in lagoons, bays, estuaries, river mouths, tidal flats, marshes, and nearly all other littoral and brackish water environments; extremely eurythermal and euryhaline; characteristic of nearshore shallow water depositional environments

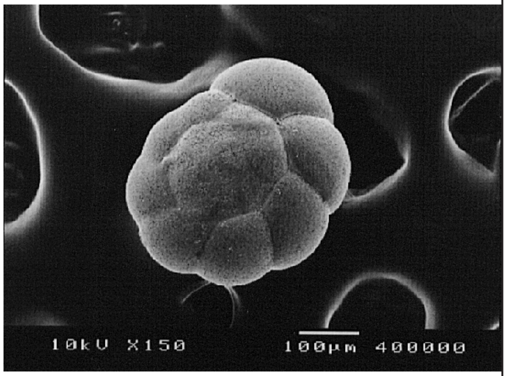
28a.)



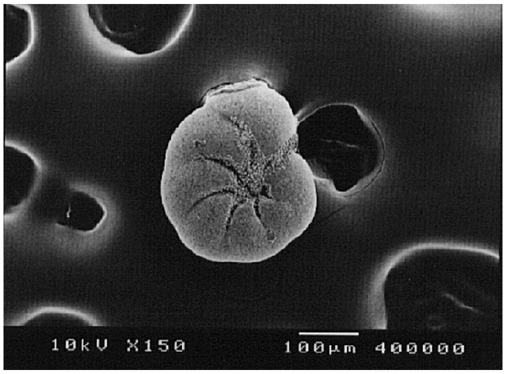
28b.)



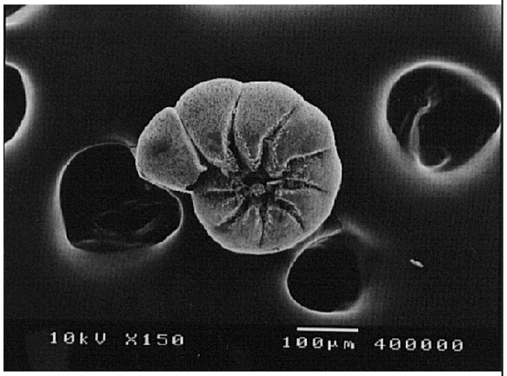
28c.)



28d.)



28e.)

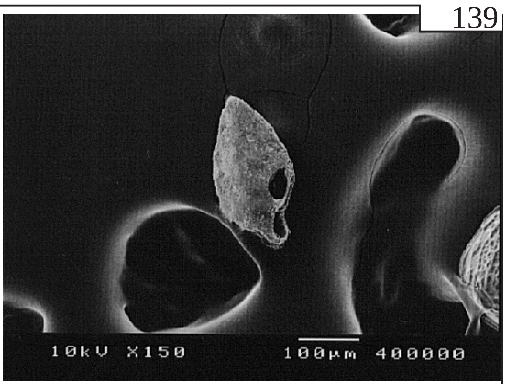


29.) *Bolivina sp.*

Phleger and Parker, 1951 (generic)
Todd and Bronniman, 1957 (generic)
Uchio, 1960 (generic)
Galloway, 1961 (1933), p. 351 (generic)
Moore, 1964, p. C549 (generic)
Haake, 1977 (generic)
Loeblich and Tappan, 1988, p. 498 (generic)

Ecology: genus is indicative of deeper marine water; most abundant in depths ranging from shallow marine to approximately 800 m; genus has cosmopolitan distribution

29.)

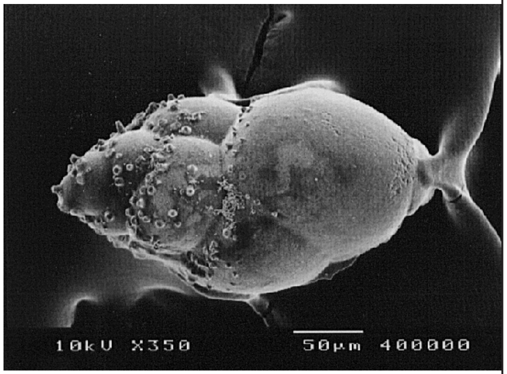


30.) *Bulimina sp.*

Phleger and Parker, 1951 (generic)
Galloway, 1961 (1933), p. 362 and 364 (generic)
Moore, 1964, p. C559 (generic)
Haake, 1977 (generic)
Tziavos, 1977, pl. 1, figs. 8a-b (generic)
Yang, 1982, pl. 3 (generic)
Villas, 1983, pl. 2, fig. 17 (generic)
Loeblich and Tappan, 1988, p. 521

Ecology: genus is indicative of deeper marine water, but its habitats range from shallow and warm to deep and cold; genus has cosmopolitan distribution

30.)

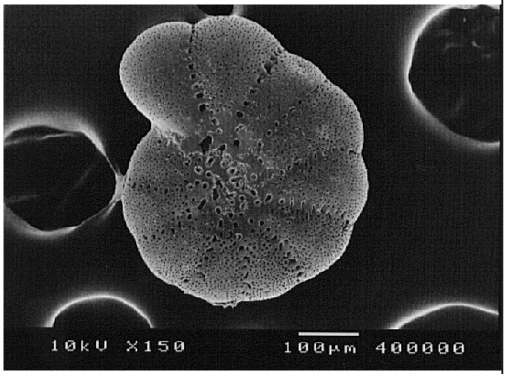


31.) *Cribrononion translucens* (Natland, 1938)

Walton, 1955, p. 1007, pl. 101, fig. 7; referred to as *Elphidium translucens* Natland
Todd and Bronniman, 1957, p. 39, pl. 7, fig. 6; referred to as *Elphidium translucens* Natland
Uchio, 1960, p. 62, pl. 4, figs. 23-24; referred to as *Elphidium spinatum var. translucens* Natland
Moore, 1964, p. C637-C638; for genus *Cribrononion* Thalman, 1947 (generic)
Phleger, 1970; referred to as *"Elphidium" cf. "E." translucens*
Brooks, 1973, pl. 10, fig. 13; note that this is for the related species *Cribroelphidium poeyanum* (d'Orbigny) (generic)
Haake, 1977, p. 66, pl. 2, fig. 3; referred to as *Elphidium translucens* Natland
Scott et al., 1979, p. 257, pl. 15, figs. 8-9
Albani and Serandrei Barbero, 1982, p. 240, pl. 1, figs. 7-10
Villas, 1983, pl. 3 (generic)
Albani et al., 1984
Loeblich and Tappan, 1988, p. 673-674; for genus *Cribrononion* Thalmann, 1947 (generic)

Ecology: inhabits shallow (less than approximately 8 m depth), nearshore, brackish to marine water environments such as estuaries, tidal flats, bays, lagoons, low marshes, and other intertidal environments; euryhaline

31.)

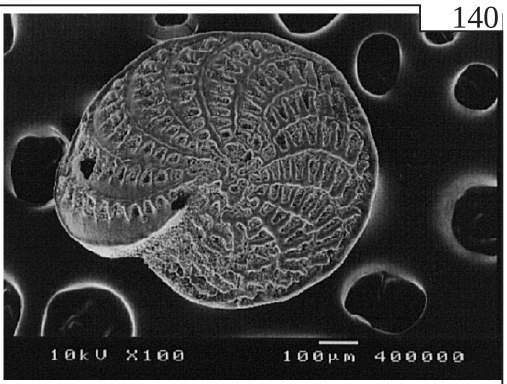


32.) *Elphidium crispum* (Linné, 1785)

Walton, 1955, p. 1007, pl. 101, fig. 11
Phleger, 1960, p. 47 and 52
Galloway, 1961 (1933), p. 269-270, pl. 24, fig. 3
Ascoli, 1964
Moore, 1964, p. C631-C635; for genus *Elphidium* de Monfort, 1808 (generic)
Tassos, 1975, pl. 1, fig. 19 (generic)
Tziavos, 1977, pl. 3, figs. 4a-b; referred to as *Elphidium macellum* (Fichtel and Moll)
Yang, 1982, p. 171-172, pl. 3, figs. 12-13
Villas, 1983, p. 60 and 65, pl. 3, figs. 10-11
Loeblich and Tappan, 1988, p. 674-675, pl. 786, figs. 8-9, pl. 787, figs. 1-5; *E. crispum* illustrated with genus-level information for *Elphidium* de Monfort, 1808

Ecology: inhabits brackish to marine water, nearshore environments such as lagoons, bays, the intertidal zone, and the shallow shelf; cosmopolitan distribution; euryhaline; often associated with *Ammonia* and the *Miliolidae* in the nearshore turbulent zone; also the most characteristic genus in lagoons along with *Ammonia* and *Ammotium*

32.)

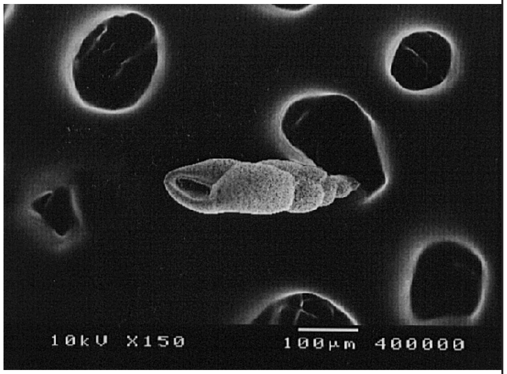


33.) *Fursenkoina sp.*

Moore, 1964, p. C731-C732; for genus *Fursenkoina* Loeblich and Tappan, 1961 (generic)
Yang, 1982, pl. 3 (generic)
Loeblich and Tappan, 1988, p. 530; for genus *Fursenkoina* Loeblich and Tappan, 1961 (generic)

Ecology: inhabits nearshore, turbulent zone to inner shelf environments from approximately 15-50 m depth; cosmopolitan

33.)



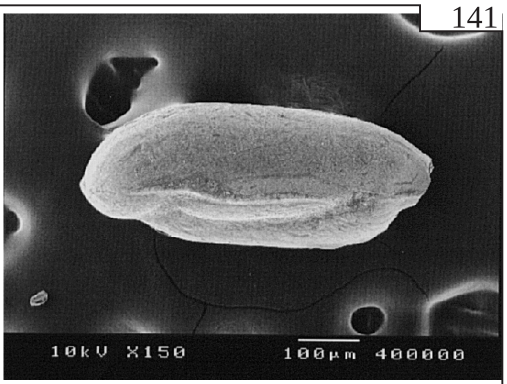
34.) various Family *Miliolidae* Ehrenberg, 1839

Figs. 34a-34i various *Quinqueloculina spp.*; Figs. 34j-34l various *Triloculina spp.*

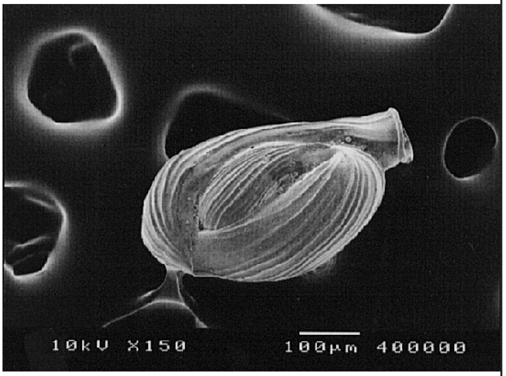
Phleger and Parker, 1951
Lankford, 1959
Bandy and Arnal, 1960
Phleger, 1960
Galloway, 1961, p. 103-108; referred to as family *Miliolidae* d’Orbigny, 1839
Moore, 1964, p. C458; for family *Miliolidae* Ehrenberg, 1839
Phleger, 1970,
Murray, 1971
Brooks, 1973
Cherif, 1973a and 1973b
Tassos, 1975, pl. 1
Tziavos, 1977, pls. 1-2
Scott et al., 1979, p. 258, pl. 15, fig. 6
Yang, 1982, pl. 1
Villas, 1983, pls. 1-2
Loeblich and Tappan, 1988, p. 352; for family *Miliolidae* Ehrenberg, 1839

Ecology: inhabits nearshore and inner shelf environments such as the intertidal and turbulent zones, lagoons, bays, marshes (esp. hypersaline), and shallow open ocean; cosmopolitan; abundant *Miliolidae* (*Triloculina spp.* and *Quinqueloculina spp.*) in association with *Elphidium spp.*, *Ammonia beccarii* (Linné), and *Quinqueloculina seminulum* (Linné, 1758) are usually excellent indicators of nearshore conditions and characteristic of water depth less than approximately 70-100 m world-wide; in particular, *Ammonia*, *Elphidium*, and various *Miliolidae* are the dominant taxa in the nearshore turbulent zone (0-20 m depth)

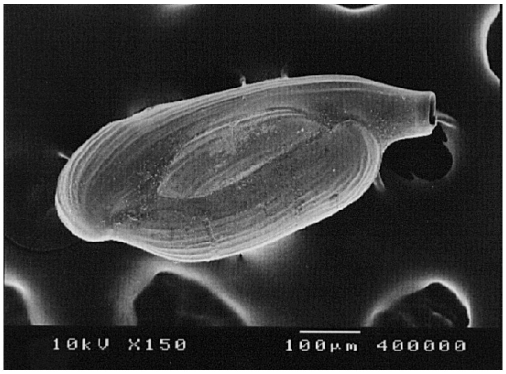
34a.)



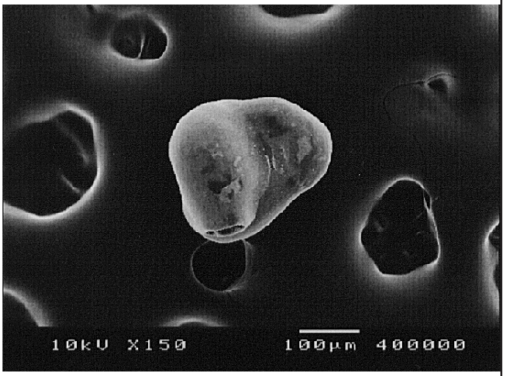
34b.)



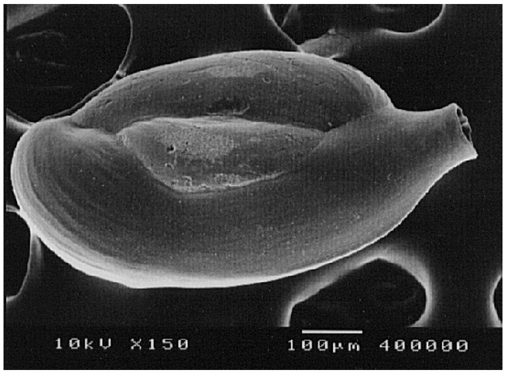
34c.)



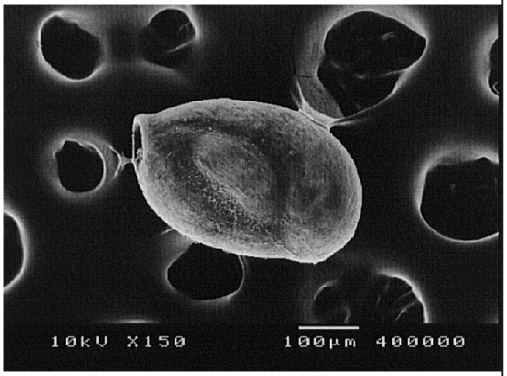
34d.)



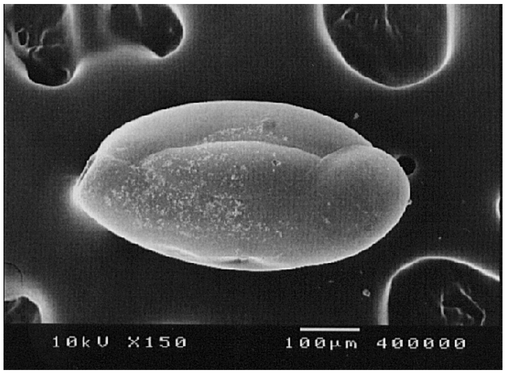
34e.)



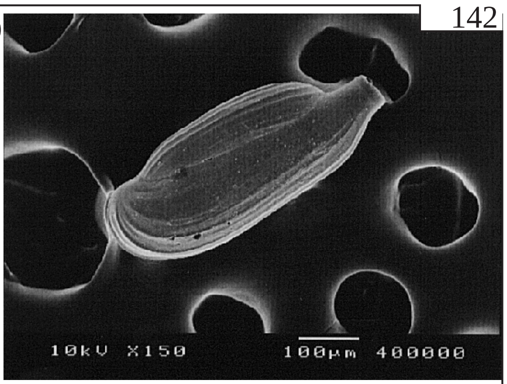
34f.)



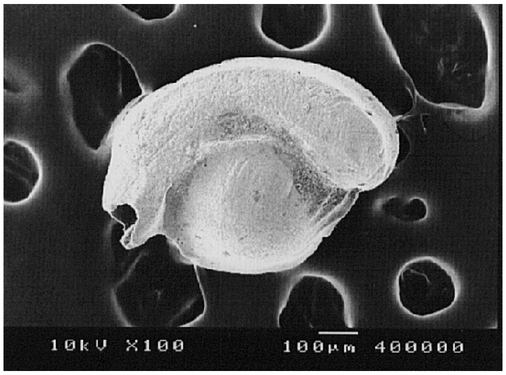
34g.)



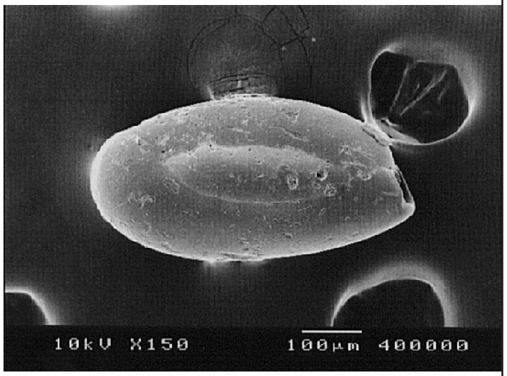
34h.)



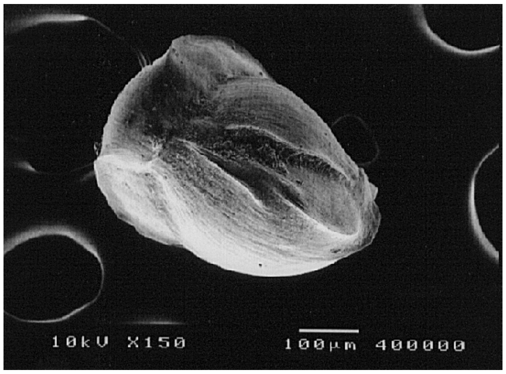
34i.)



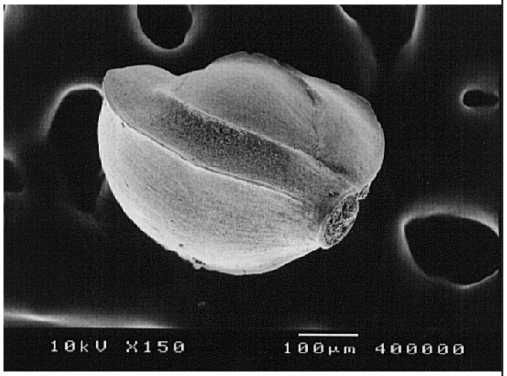
34j.)



34k.)



34l.)



Fresh Water Ostracods and Other Organisms

	grams of wet sediment disaggregated	Candona albicans Brady, 1864	Candona sp. aff. C. Caudata Kaufmann, 1900	Candona compressa (Koch, 1837)	Candona cf. lactea Baird, 1850	Candona neglecta Sars	Candona cf. truncata Furtos, 1933	C. lactea or C. neglecta juveniles--mixed	C. albicans or C. compressa juveniles--mixed	Cyclocypris cf. laevis (O.F. Müller, 1785)	Darwinula stevensoni (Brady and Robertson, 1870)	Herpetocypris cf. reptans (Baird)	Ilyocypris gibba (Ramdohr, 1808)	Limnocythere cf. inopinata (Baird, 1843)	Limnocythere sp.	Potamocypris cf. villosa (Jurine, 1820)	Ostracod sp. A	Charophyta	fresh water gastropods--mixed	fresh water pelecypods--mixed
SAMPLE CORE AND DEPTH																				
NC-93-22 (380-400 cm)	52.18 g				1			1	1				1						5	
NC-94-01 (295-315 cm)	41.30 g				6	4		15	10				1		3	1			2	1
NC-94-01 (430-450 cm)	37.34 g				2			5•1												
NC-94-01 (580-600 cm)	31.95 g				2•1															
NC-94-01 (630-650 cm)	61.96 g																			
NC-94-01 (675-700 cm)	38.61 g																			
NC-94-03 (90-100 cm)	32.49 g			2	1	9		49	47			4			9				23	10
NC-94-03 (245-255 cm)	54.30 g					18		43	14			1							8	9
NC-94-03 (430-440 cm)	37.78 g				15	1		91	1											
NC-94-08 (220-230 cm)	31.40 g																			
NC-94-08 (650-660 cm)	37.23 g							1	5				3							
NC-94-09 (250-260 cm)	39.30 g							1												
NC-94-09 (340-350 cm)	48.32 g				2			17										3	1	
NC-94-09 (430-440 cm)	42.75 g							4					1			1				
NC-94-09 (500-510 cm)	43.94 g																		2	
NC-94-09 (645-650 cm)	24.77 g											1								
NC-94-09 (710-720 cm)	35.56 g			1					3			2	30				9			
NC-94-12 (570-580 cm)	38.94 g											9•2					1	1	2	
NC-94-12 (615-625 cm)	40.65 g											2•1					1		1	
NC-94-12 (670-680 cm)	33.65 g	2•1																		
NC-94-12 (725-730 cm)	32.38 g							2•1												
NC-94-12 (760-770 cm)	32.10 g								1			2								
NC-94-12 (815-825 cm)	42.82 g																			
NC-94-13 (160-165 cm)	32.10 g				1			8												
NC-94-13 (255-260 cm)	22.30 g				6			10				5								
NC-94-13 (300-310 cm)	23.85 g				4			6												
NC-94-13 (365-370 cm)	15.10 g																			
NC-94-13 (450-460 cm)	23.40 g																			
NC-94-13 (535-540 cm)	34.47 g								6				8		2		1			
NC-94-13 (900-910 cm)	16.21 g																			
NC-94-13 (1010-1020 cm)	12.54 g																			
NC-94-17 (870-880 cm)	34.37 g																	1		
NC-94-20 (380-390 cm)	32.03 g																			
NC-94-20 (605-620)																				
NC-94-23 (90-100 cm)	21.30 g										1							3	2	
NC-94-23 (170-180 cm)	32.65 g				8	1		14					1					10		
NC-94-23 (250-260 cm)	21.28 g					2		1											1	
NC-94-23 (300-310 cm)	28.33 g							2												
NC-94-23 (380-390 cm)	21.07 g							4										1	1	
NC-94-23 (460-470 cm)	15.67 g							6												
NC-94-23 (540-550 cm)	24.80 g				1															
NC-94-23 (620-630 cm)	20.95 g				2			12	1									2		
NC-94-23 (710-720 cm)	23.63 g					4		76	33•1	4		1	3		1					
NC-94-23 (790-800 cm)	20.57 g							1	1			3								
NC-94-23 (860-870 cm)	32.17 g			4•2					80•1		1	11•1								
NC-94-23 (930-940 cm)	29.19 g		2•1		2			4	15•1			9			1					
NC-94-23 (990-1000 cm)	40.39 g		6	1				51•3	5•1	1		1							2	
NC-94-23 (1045-1050 cm)	33.76 g				1															
NC-94-23 (1090-1100 cm)	36.26 g	2						1	2				1	2•1						
NC-94-23 (1170-1180 cm)	33.59 g							2	1			3	2							

Brackish to Marine Ostracods

	grams of wet sediment disaggregated	Cushmanidea elongata (Brady)	Cyprideis torosa (Jones, 1850)	Cytheridea neapolitana Kollman, 1960	Cytheridea gr. sorbyana (Jones)	Cytheromorpha fuscata (Brady, 1869)	Leptocythere bacescoi (Rome, 1942)	Leptocythere cf. castanea (Sars, 1866)	Loxoconcha elliptica Brady, 1868	Loxoconcha cf. granulata Sars, 1866	Loxoconcha ovulata (Costa, 1853)	Paracytherois cf. acuminata Müller, 1894	Tyrrhenocythere amnicola (Sars, 1888)
SAMPLE CORE AND DEPTH													
NC-93-22 (380-400 cm)	52.18 g												2
NC-94-01 (295-315 cm)	41.30 g												1
NC-94-01 (430-450 cm)	37.34 g												
NC-94-01 (580-600 cm)	31.95 g												
NC-94-01 (630-650 cm)	61.96 g												
NC-94-01 (675-700 cm)	38.61 g												
NC-94-03 (90-100 cm)	32.49 g												
NC-94-03 (245-255 cm)	54.30 g												
NC-94-03 (430-440 cm)	37.78 g												
NC-94-08 (220-230 cm)	31.40 g												
NC-94-08 (650-660 cm)	37.23 g												
NC-94-09 (250-260 cm)	39.30 g												
NC-94-09 (340-350 cm)	48.32 g												
NC-94-09 (430-440 cm)	42.75 g												1
NC-94-09 (500-510 cm)	43.94 g												
NC-94-09 (645-650 cm)	24.77 g												
NC-94-09 (710-720 cm)	35.56 g		10•1										
NC-94-12 (570-580 cm)	38.94 g		1										
NC-94-12 (615-625 cm)	40.65 g		27										
NC-94-12 (670-680 cm)	33.65 g		19•1					2•1					1
NC-94-12 (725-730 cm)	32.38 g		5										
NC-94-12 (760-770 cm)	32.10 g		4			2•1	2•1			3•1			
NC-94-12 (815-825 cm)	42.82 g		11•2				2•1				19•5		
NC-94-13 (160-165 cm)	32.10 g												
NC-94-13 (255-260 cm)	22.30 g												
NC-94-13 (300-310 cm)	23.85 g												
NC-94-13 (365-370 cm)	15.10 g												
NC-94-13 (450-460 cm)	23.40 g												
NC-94-13 (535-540 cm)	34.47 g		7										49•3
NC-94-13 (900-910 cm)	16.21 g	5	14•1		2•1				2•1		3•1		
NC-94-13 (1010-1020 cm)	12.54 g		1	1	1				4•2		4		
NC-94-17 (870-880 cm)	34.37 g		158•39			3•1			3•1				
NC-94-20 (380-390 cm)	32.03 g												
NC-94-20 (605-620)													2•1
NC-94-23 (90-100 cm)	21.30 g												
NC-94-23 (170-180 cm)	32.65 g												
NC-94-23 (250-260 cm)	21.28 g												
NC-94-23 (300-310 cm)	28.33 g												
NC-94-23 (380-390 cm)	21.07 g												
NC-94-23 (460-470 cm)	15.67 g												
NC-94-23 (540-550 cm)	24.80 g												
NC-94-23 (620-630 cm)	20.95 g												
NC-94-23 (710-720 cm)	23.63 g												
NC-94-23 (790-800 cm)	20.57 g												
NC-94-23 (860-870 cm)	32.17 g												
NC-94-23 (930-940 cm)	29.19 g												
NC-94-23 (990-1000 cm)	40.39 g		1										
NC-94-23 (1045-1050 cm)	33.76 g		217•3				1	43•15	114•2			17•5	1
NC-94-23 (1090-1100 cm)	36.26 g		66				4•1	18•3	4		6•2		9
NC-94-23 (1170-1180 cm)	33.59 g		78•4	1		2	4	13•4	5		3	4	12

Brackish to Marine Foraminifera and Other Organisms, and Reworked Microfossils

	grams of wet sediment disaggregated	Ammonia beccarii (Linné, 1758)	Bolivina sp.	Bulimina sp.	Cribrononion translucens (Natland, 1938)	Elphidium crispum (Linné, 1785)	Fursenkoina sp.	Globigerinid-type sp.	Quinqueloculina spp. (Miliolidae)--mixed	Triloculina spp. (Miliolidae)--mixed	brackish to marine pelecypods	brackish to marine gastropods		reworked microfossils
SAMPLE CORE AND DEPTH														
NC-93-22 (380-400 cm)	52.18 g													110
NC-94-01 (295-315 cm)	41.30 g													
NC-94-01 (430-450 cm)	37.34 g													
NC-94-01 (580-600 cm)	31.95 g													130
NC-94-01 (630-650 cm)	61.96 g													210
NC-94-01 (675-700 cm)	38.61 g													220
NC-94-03 (90-100 cm)	32.49 g													
NC-94-03 (245-255 cm)	54.30 g													
NC-94-03 (430-440 cm)	37.78 g													13
NC-94-08 (220-230 cm)	31.40 g													800
NC-94-08 (650-660 cm)	37.23 g													550
NC-94-09 (250-260 cm)	39.30 g													275
NC-94-09 (340-350 cm)	48.32 g													71
NC-94-09 (430-440 cm)	42.75 g													185
NC-94-09 (500-510 cm)	43.94 g													58
NC-94-09 (645-650 cm)	24.77 g													45
NC-94-09 (710-720 cm)	35.56 g	1												24
NC-94-12 (570-580 cm)	38.94 g													
NC-94-12 (615-625 cm)	40.65 g	1												8
NC-94-12 (670-680 cm)	33.65 g	36												86
NC-94-12 (725-730 cm)	32.38 g	105			1									
NC-94-12 (760-770 cm)	32.10 g	85			1	1			2					8
NC-94-12 (815-825 cm)	42.82 g	74		1	7	6			19	4				
NC-94-13 (160-165 cm)	32.10 g													12
NC-94-13 (255-260 cm)	22.30 g													27
NC-94-13 (300-310 cm)	23.85 g													1
NC-94-13 (365-370 cm)	15.10 g													
NC-94-13 (450-460 cm)	23.40 g													10
NC-94-13 (535-540 cm)	34.47 g													350
NC-94-13 (900-910 cm)	16.21 g	55			11	12			11	4		2		
NC-94-13 (1010-1020 cm)	12.54 g	40			10	7			30	3		1		
NC-94-17 (870-880 cm)	34.37 g	7			6									115
NC-94-20 (380-390 cm)	32.03 g													54
NC-94-20 (605-620)														
NC-94-23 (90-100 cm)	21.30 g													15
NC-94-23 (170-180 cm)	32.65 g													205
NC-94-23 (250-260 cm)	21.28 g													21
NC-94-23 (300-310 cm)	28.33 g													51
NC-94-23 (380-390 cm)	21.07 g													7
NC-94-23 (460-470 cm)	15.67 g													
NC-94-23 (540-550 cm)	24.80 g													6
NC-94-23 (620-630 cm)	20.95 g													6
NC-94-23 (710-720 cm)	23.63 g													
NC-94-23 (790-800 cm)	20.57 g													
NC-94-23 (860-870 cm)	32.17 g													
NC-94-23 (930-940 cm)	29.19 g													
NC-94-23 (990-1000 cm)	40.39 g	2												
NC-94-23 (1045-1050 cm)	33.76 g	313			72	2	1					8		97
NC-94-23 (1090-1100 cm)	36.26 g	317	2	1	25	2		1	100	7	4	1		45
NC-94-23 (1170-1180 cm)	33.59 g	287	2		21	4			89	9	3	4		37

Totals and Percentage Statistics of Fresh Water Forms, Brackish to Marine Forms, and Reworked Microfossils

	grams of wet sediment disaggregated	total number of fresh water ostracods	total number of brackish to marine ostracods	total number of brackish to marine forams	total number of reworked microfossils		total microfossils of all types	% fresh water forms	% brackish to marine forms	% reworked microfossils
SAMPLE CORE AND DEPTH										
NC-93-22 (380-400 cm)	52.18 g	4	2	0	110		116	3.45	1.72	94.83
NC-94-01 (295-315 cm)	41.30 g	40	1	0	0		41	97.56	2.44	0.00
NC-94-01 (430-450 cm)	37.34 g	7	0	0	0		7	100.00	0.00	0.00
NC-94-01 (580-600 cm)	31.95 g	2	0	0	130		132	1.52	0.00	98.48
NC-94-01 (630-650 cm)	61.96 g	0	0	0	210		210	0.00	0.00	100.00
NC-94-01 (675-700 cm)	38.61 g	0	0	0	220		220	0.00	0.00	100.00
NC-94-03 (90-100 cm)	32.49 g	121	0	0	0		121	100.00	0.00	0.00
NC-94-03 (245-255 cm)	54.30 g	76	0	0	0		76	100.00	0.00	0.00
NC-94-03 (430-440 cm)	37.78 g	108	0	0	13		121	89.26	0.00	10.74
NC-94-08 (220-230 cm)	31.40 g	0	0	0	800		800	0.00	0.00	100.00
NC-94-08 (650-660 cm)	37.23 g	9	0	0	550		559	1.61	0.00	98.39
NC-94-09 (250-260 cm)	39.30 g	1	0	0	275		276	0.36	0.00	99.64
NC-94-09 (340-350 cm)	48.32 g	19	0	0	71		90	21.11	0.00	78.89
NC-94-09 (430-440 cm)	42.75 g	6	1	0	185		192	3.13	0.52	96.35
NC-94-09 (500-510 cm)	43.94 g	0	0	0	58		58	0.00	0.00	100.00
NC-94-09 (645-650 cm)	24.77 g	1	0	0	45		46	2.17	0.00	97.83
NC-94-09 (710-720 cm)	35.56 g	45	10	1	24		80	56.25	13.75	30.00
NC-94-12 (570-580 cm)	38.94 g	10	1	0	0		11	90.91	9.09	0.00
NC-94-12 (615-625 cm)	40.65 g	3	27	1	8		39	7.69	71.79	20.51
NC-94-12 (670-680 cm)	33.65 g	2	22	36	86		146	1.37	39.73	58.90
NC-94-12 (725-730 cm)	32.38 g	2	5	106	0		113	1.77	98.23	0.00
NC-94-12 (760-770 cm)	32.10 g	3	11	89	8		111	2.70	90.09	7.21
NC-94-12 (815-825 cm)	42.82 g	0	32	111	0		143	0.00	100.00	0.00
NC-94-13 (160-165 cm)	32.10 g	9	0	0	12		21	42.86	0.00	57.14
NC-94-13 (255-260 cm)	22.30 g	21	0	0	27		48	43.75	0.00	56.25
NC-94-13 (300-310 cm)	23.85 g	10	0	0	1		11	90.91	0.00	9.09
NC-94-13 (365-370 cm)	15.10 g	0	0	0	0		0	0.00	0.00	0.00
NC-94-13 (450-460 cm)	23.40 g	0	0	0	10		10	0.00	0.00	100.00
NC-94-13 (535-540 cm)	34.47 g	17	56	0	350		423	4.02	13.24	82.74
NC-94-13 (900-910 cm)	16.21 g	0	26	93	0		119	0.00	100.00	0.00
NC-94-13 (1010-1020 cm)	12.54 g	0	11	90	0		101	0.00	100.00	0.00
NC-94-17 (870-880 cm)	34.37 g	0	164	13	115		292	0.00	60.62	39.38
NC-94-20 (380-390 cm)	32.03 g	0	0	0	54		54	0.00	0.00	100.00
NC-94-20 (605-620)		0	2	0	0		2	0.00	100.00	0.00
NC-94-23 (90-100 cm)	21.30 g	1	0	0	15		16	6.25	0.00	93.75
NC-94-23 (170-180 cm)	32.65 g	24	0	0	205		229	10.48	0.00	89.52
NC-94-23 (250-260 cm)	21.28 g	3	0	0	21		24	12.50	0.00	87.50
NC-94-23 (300-310 cm)	28.33 g	2	0	0	51		53	3.77	0.00	96.23
NC-94-23 (380-390 cm)	21.07 g	4	0	0	7		11	36.36	0.00	63.64
NC-94-23 (460-470 cm)	15.67 g	6	0	0	0		6	100.00	0.00	0.00
NC-94-23 (540-550 cm)	24.80 g	1	0	0	6		7	14.29	0.00	85.71
NC-94-23 (620-630 cm)	20.95 g	15	0	0	6		21	71.43	0.00	28.57
NC-94-23 (710-720 cm)	23.63 g	122	0	0	0		122	100.00	0.00	0.00
NC-94-23 (790-800 cm)	20.57 g	5	0	0	0		5	100.00	0.00	0.00
NC-94-23 (860-870 cm)	32.17 g	96	0	0	0		96	100.00	0.00	0.00
NC-94-23 (930-940 cm)	29.19 g	33	0	0	0		33	100.00	0.00	0.00
NC-94-23 (990-1000 cm)	40.39 g	65	1	2	0		68	95.59	4.41	0.00
NC-94-23 (1045-1050 cm)	33.76 g	1	393	388	97		879	0.11	88.85	11.04
NC-94-23 (1090-1100 cm)	36.26 g	8	107	455	45		615	1.30	91.38	7.32
NC-94-23 (1170-1180 cm)	33.59 g	8	122	412	37		579	1.38	92.23	6.39

Appendix C--Results of Pipette Grain Size Analysis

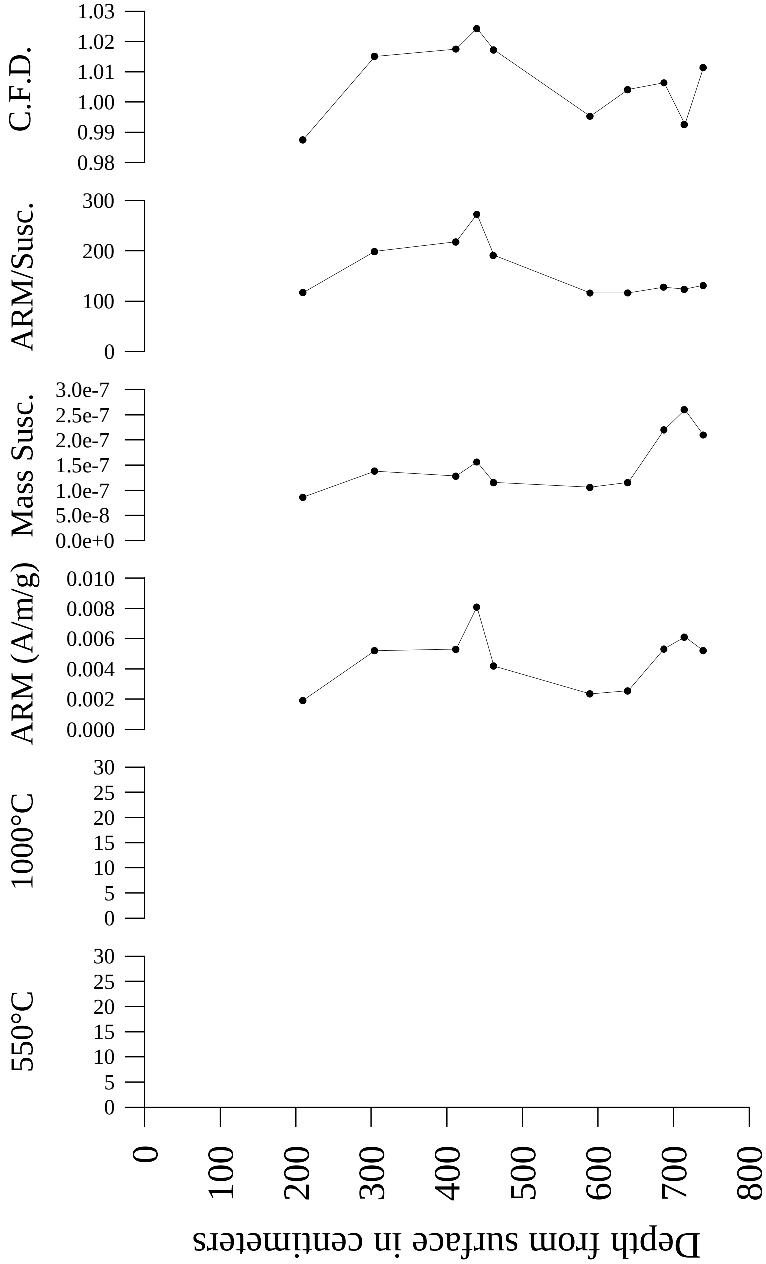
Sample	**Environment of Deposition**	**Mean Grain Size**	**Standard Deviation**	**Skewness**	**Kurtosis**
NC-94-09 (170-180 cm)	floodplain	7.53	1.82	-0.29	-1.28
NC-94-09 (310-320 cm)	floodplain	7.81	1.78	-0.67	-0.74
NC-94-09 (400-410 cm)	floodplain	6.47	2.32	0.1	-1.55
NC-94-09 (520-525 cm)	floodplain	5.81	2.14	0.59	-1.03
NC-94-09 (630-640 cm)	interdistributary bay	8.4	1.44	-1.36	1.46
NC-94-12 (145-155 cm)	floodplain	7.54	2.09	-0.52	-1.23
NC-94-12 (250-260 cm)	floodplain	7.04	1.96	-0.01	-1.41
NC-94-12 (350-360 cm)	floodplain	6.51	2.09	0.26	-1.37
NC-94-12 (455-465 cm)	floodplain	7.51	1.86	-0.37	-1.22
NC-94-12 (570-580 cm)	delta top marsh	8.22	1.64	-1.25	0.8
NC-94-12 (740-750 cm)	delta front to interdistributary bay	7.78	1.77	-0.57	-0.96
NC-94-13 (580-590 cm)	delta front	6.38	1.97	0.41	-1.16
NC-94-13 (750-755 cm)	delta front	6.65	2.5	-0.13	-1.68
NC-94-13 (950-960 cm)	shallow marine	5.77	2.03	1.06	-0.7
NC-94-23 (130-140 cm)	shallow lake	8.62	1.29	-1.58	2.12
NC-94-23 (230-240 cm)	shallow lake	8.41	1.48	-1.36	1.16
NC-94-23 (340-350 cm)	shallow lake	8.62	1.25	-1.52	1.99
NC-94-23 (580-590 cm)	shallow lake	8.71	1.17	-1.54	2.17
NC-94-23 (670-680 cm)	shallow lake	8.73	1.12	-1.45	1.6
NC-94-23 (815-820 cm)	shallow lake	8.16	1.55	-1.08	0.65
NC-94-23 (900-920 cm)	delta top marsh	8.52	1.43	-1.68	2.49
NC-94-23 (1050-1060 cm)	delta top and front	6.46	2.29	0.17	-1.57
NC-94-23 (1130-1140 cm)	delta top and front	8.09	1.6	-0.75	-0.7

Appendix D--Results of Loss on Ignition and Magnetic Analyses

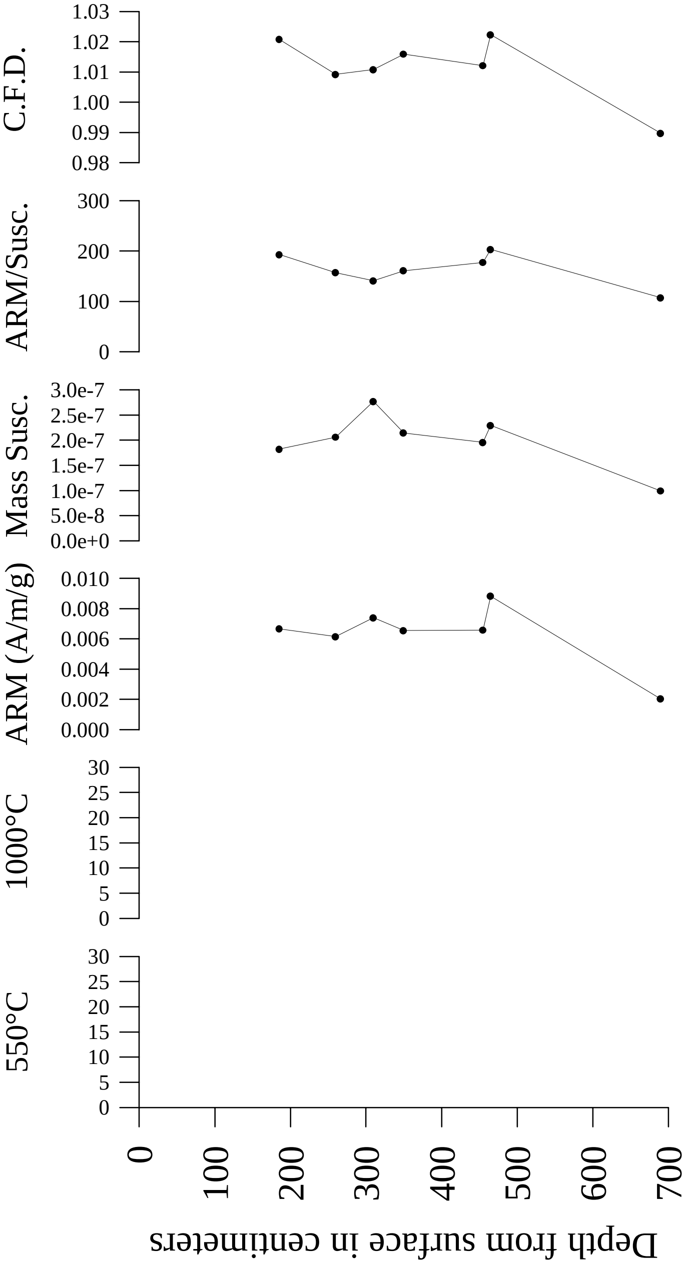
This appendix contains the results of loss on ignition and magnetic tests performed on twelve sediment cores obtained during the 1994 field season. Each core shows six parameters plotted against the sample depth in the core (e.g. "Depth from surface in centimeters"). Loss on ignition analysis was not performed on all cores, so in some cases plots for these parameters are blank. The six plotted parameters are:

1.) 550°C [percent weight loss after a 550°C burn--e.g. organic carbon content]
2.) 1000°C [percent weight loss after a 1000°C burn--e.g. carbon from carbonate]
3.) ATM (A/m/g) [anhysteretic magnetization]
4.) Mass Susc. [mass susceptibility]
5.) ARM/Susc. [ratio of anhysteretic magnetization (A/m) to volume susceptibility]
6.) C.F.D. [ratio of low frequency volume susceptibility to high frequency volume susceptibility]

Appendix D Table of Contents


550°C
1000°C
ARM (A/m/g)
Mass Susc.
ARM/Susc.
C.F.D.
0
5
10
15
20
25
30
0.000
0.002
0.004
0.006
0.008
0.010
0.0e+0
5.0e-8
1.0e-7
1.5e-7
2.0e-7
2.5e-7
3.0e-7
0
100
200
300
0.98
0.99
1.00
1.01
1.02
1.03
0
100
200
300
400
500
600
700
800
Depth from surface in centimeters

NC-94-01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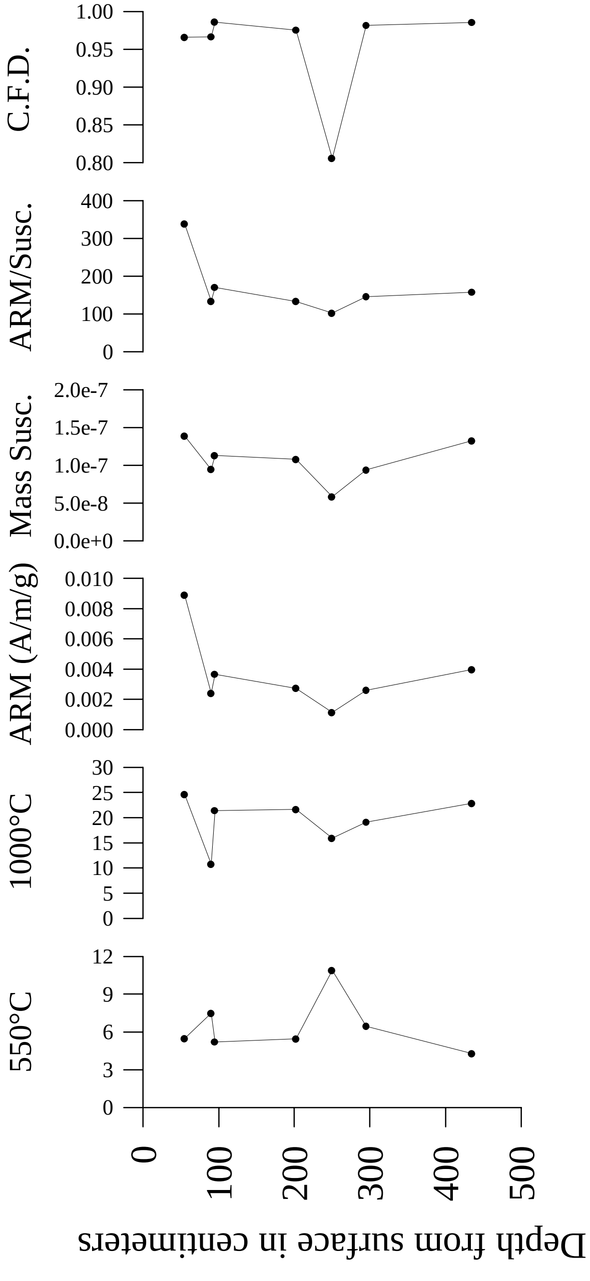
1.02
1.01
1.00
0.99
0.98
ARM/Susc.
300
200
100
0
Mass Susc.
3.0e-7
2.5e-7
2.0e-7
1.5e-7
1.0e-7
5.0e-8
0.0e+0
ARM (A/m/g)
0.010
0.008
0.006
0.004
0.002
0.000
1000°C
30
25
20
15
10
5
0
550°C
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
Depth from surface in centimeters

NC-94-02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200
100
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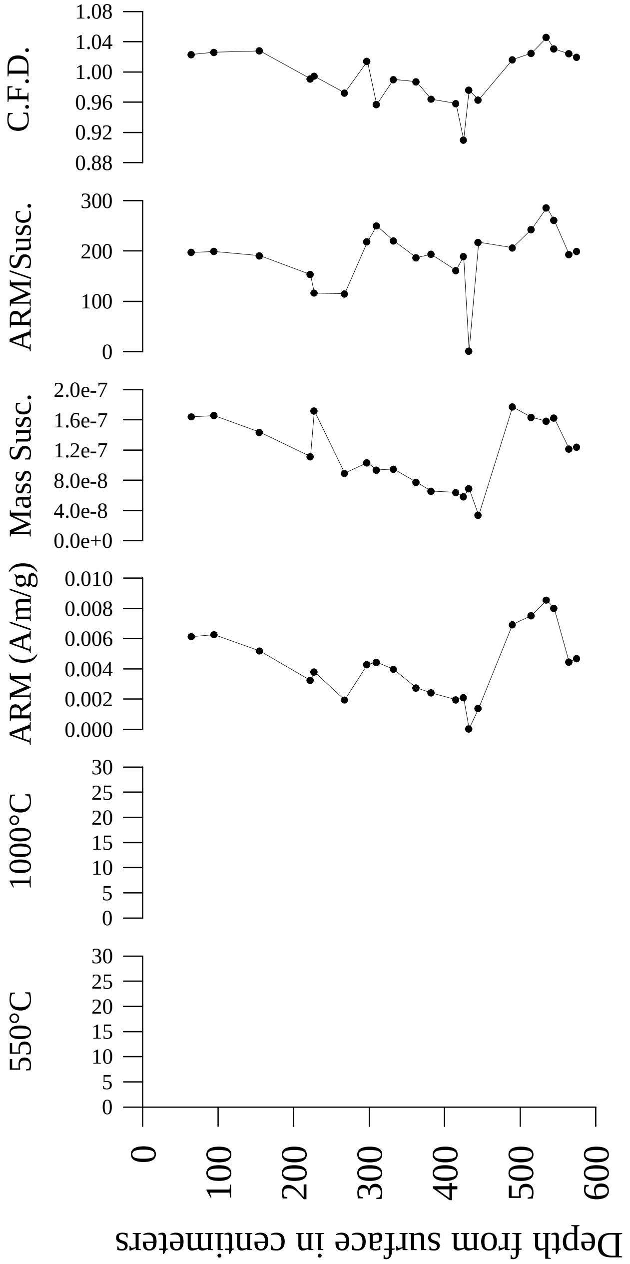
1.5e-7
1.0e-7
5.0e-8
0.0e+0
ARM (A/m/g)
0.010
0.008
0.006
0.004
0.002
0.000
1000°C
30
25
20
15
10
5
0
550°C
12
9
6
3
0
0
100
200
300
400
500
Depth from surface in centimeters

NC-94-03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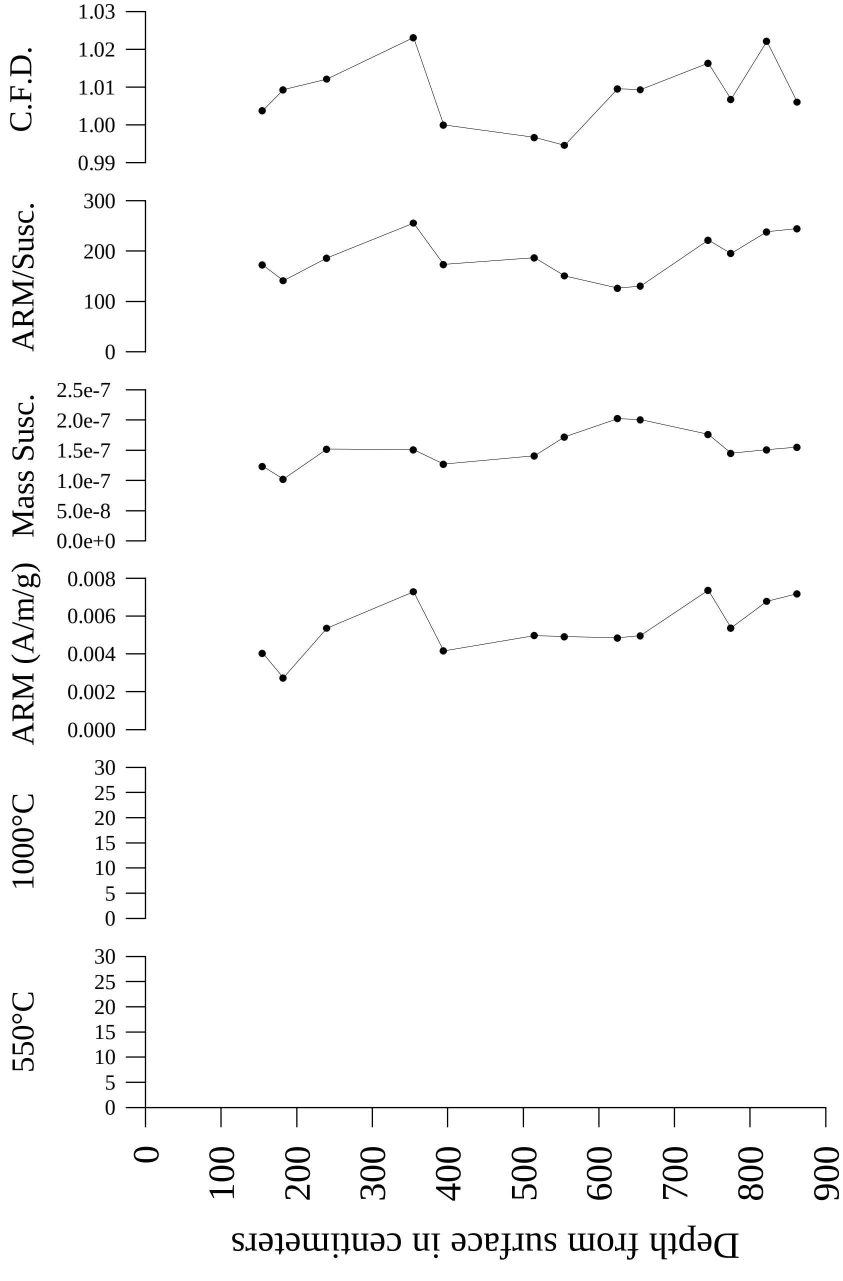
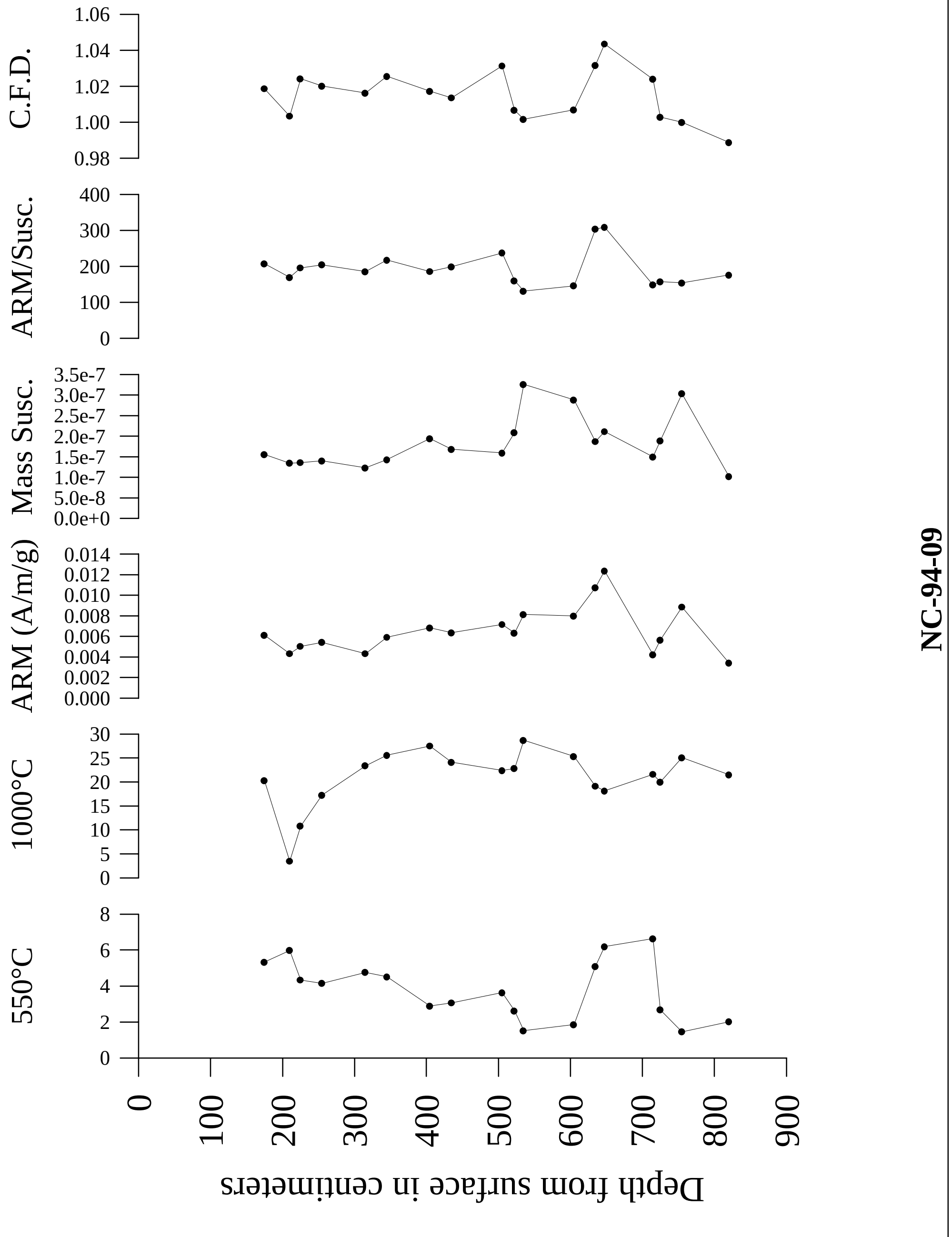
0.96
0.92
0.88
ARM/Susc.
300
200
100
0
Mass Susc.
2.0e-7
1.6e-7
1.2e-7
8.0e-8
4.0e-8
0.0e+0
ARM (A/m/g)
0.010
0.008
0.006
0.004
0.002
0.000
1000°C
30
25
20
15
10
5
0
550°C
30
25
20
15
10
5
0
0
100
200
300
400
500
600
Depth from surface in centimeters

NC-94-04


550°C
0
5
10
15
20
25
30
1000°C
0
5
10
15
20
25
30
ARM (A/m/g)
0.000
0.002
0.004
0.006
0.008
Mass Susc.
0.0e+0
5.0e-8
1.0e-7
1.5e-7
2.0e-7
2.5e-7
ARM/Susc.
0
100
200
300
C.F.D.
0.99
1.00
1.01
1.02
1.03
0
100
200
300
400
500
600
700
800
900
Depth from surface in centimeters

NC-94-05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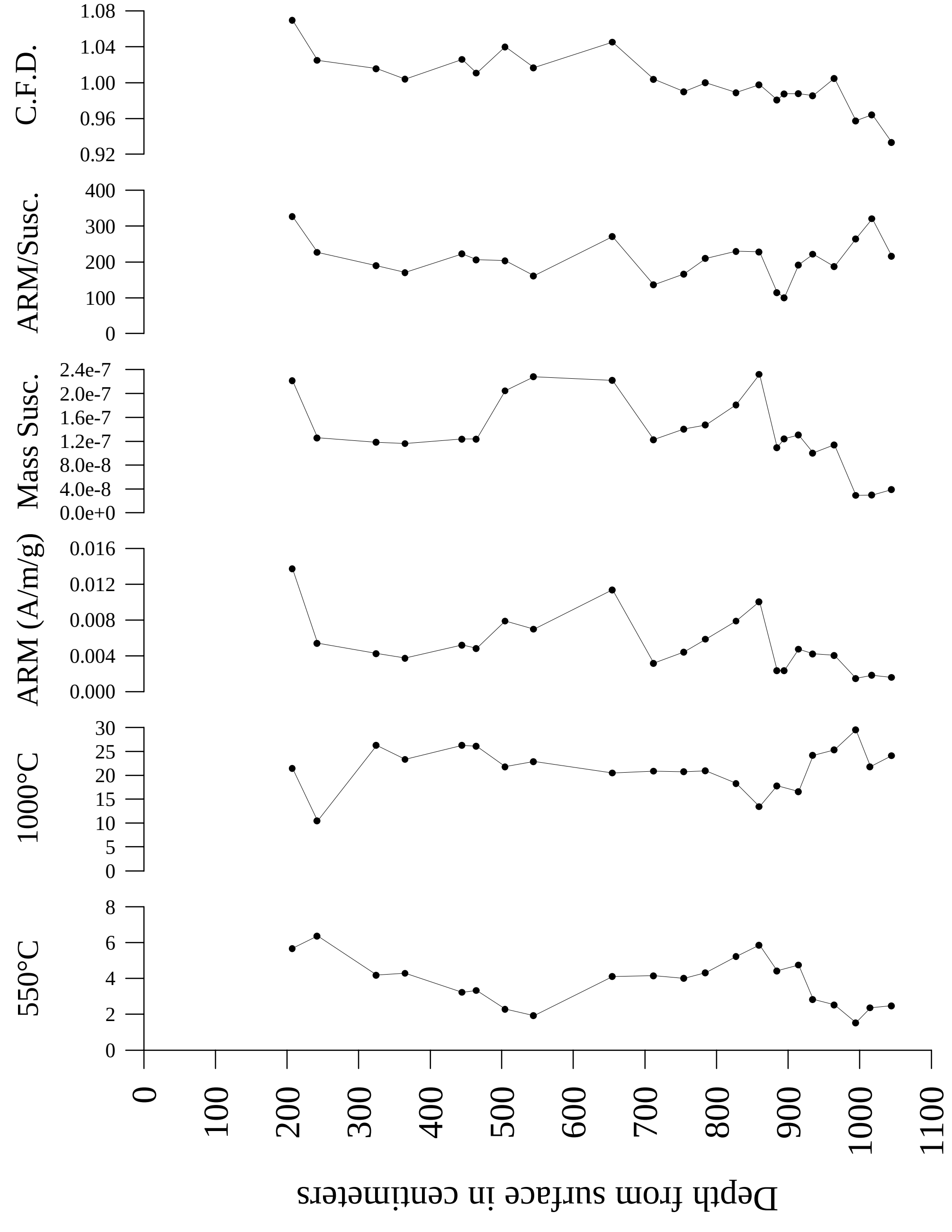
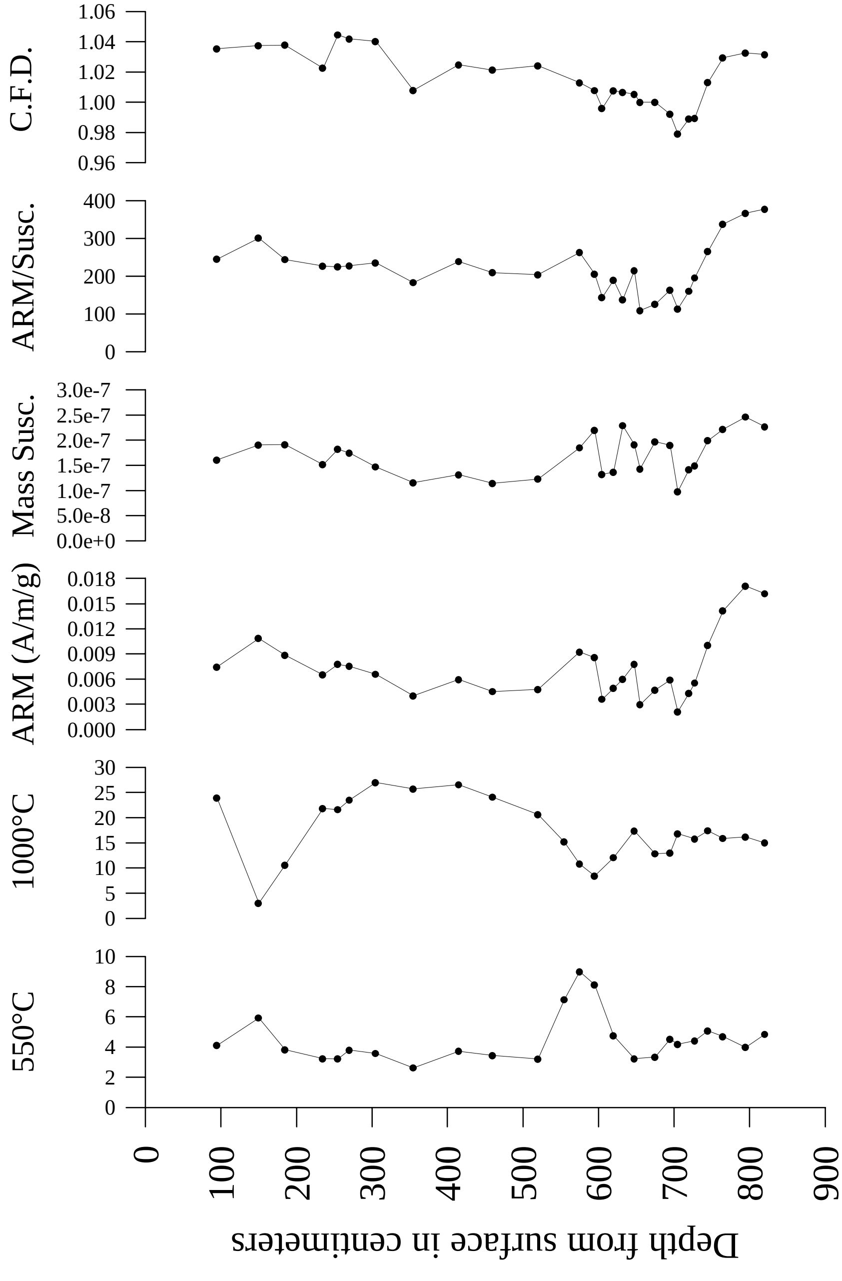
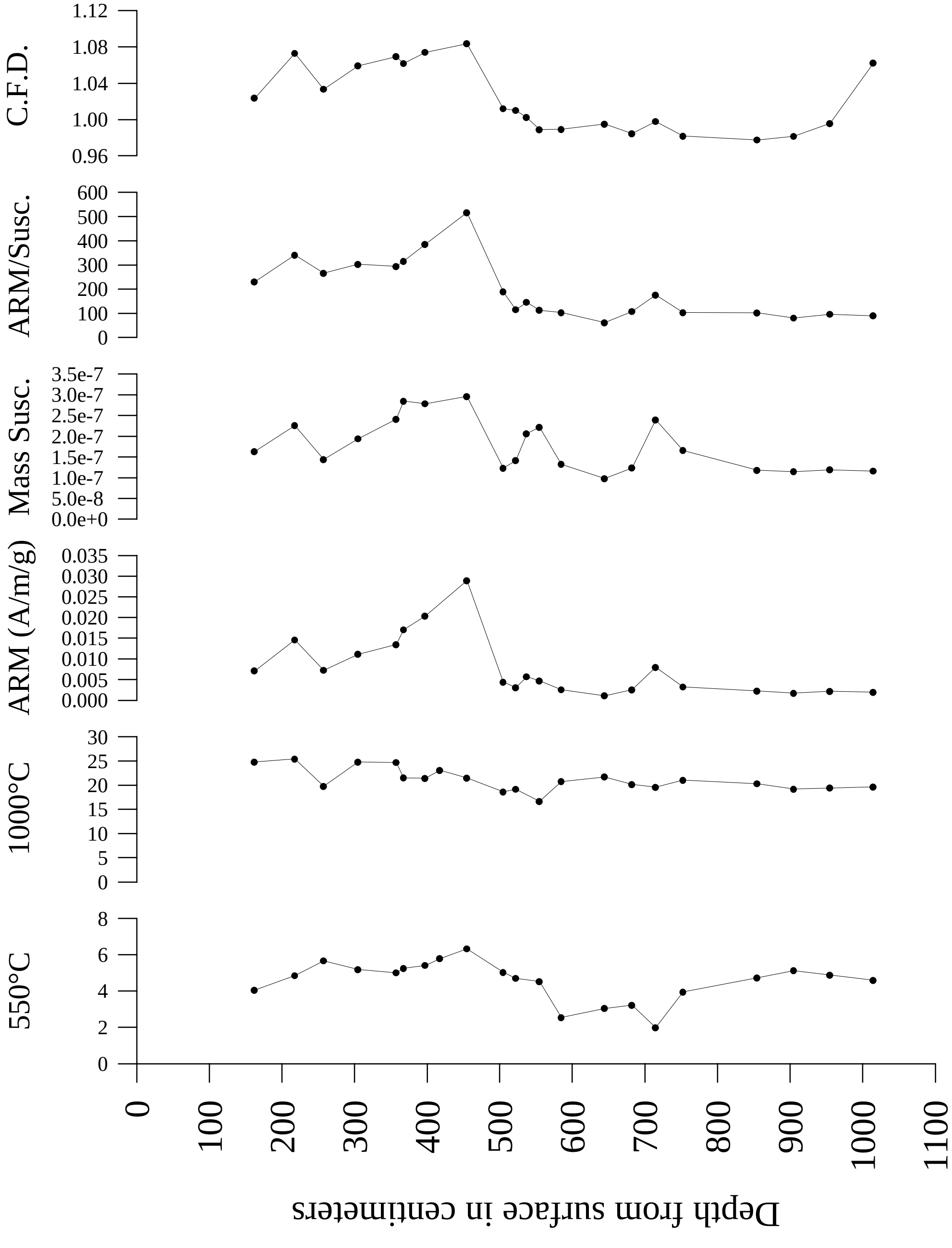
1.04
1.02
1.00
0.98
ARM/Susc.
400
300
200
100
0
Mass Susc.
3.5e-7
3.0e-7
2.5e-7
2.0e-7
1.5e-7
1.0e-7
5.0e-8
0.0e+0
ARM (A/m/g)
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
1000°C
30
25
20
15
10
5
0
550°C
8
6
4
2
0
0
100
200
300
400
500
600
700
800
900
Depth from surface in centimeters
NC-94-09


C.F.D.
1.08
1.04
1.00
0.96
0.92
ARM/Susc.
400
300
200
100
0
Mass Susc.
2.4e-7
2.0e-7
1.6e-7
1.2e-7
8.0e-8
4.0e-8
0.0e+0
ARM (A/m/g)
0.016
0.012
0.008
0.004
0.000
1000°C
30
25
20
15
10
5
0
550°C
8
6
4
2
0
0
100
200
300
400
500
600
700
800
900
1000
1100
Depth from surface in centimeters

NC-94-11


C.F.D.
1.06
1.04
1.02
1.00
0.98
0.96
ARM/Susc.
400
300
200
100
0
Mass Susc.
3.0e-7
2.5e-7
2.0e-7
1.5e-7
1.0e-7
5.0e-8
0.0e+0
ARM (A/m/g)
0.018
0.015
0.012
0.009
0.006
0.003
0.000
1000°C
30
25
20
15
10
5
0
550°C
10
8
6
4
2
0
0
100
200
300
400
500
600
700
800
900
Depth from surface in centimeters

NC-94-12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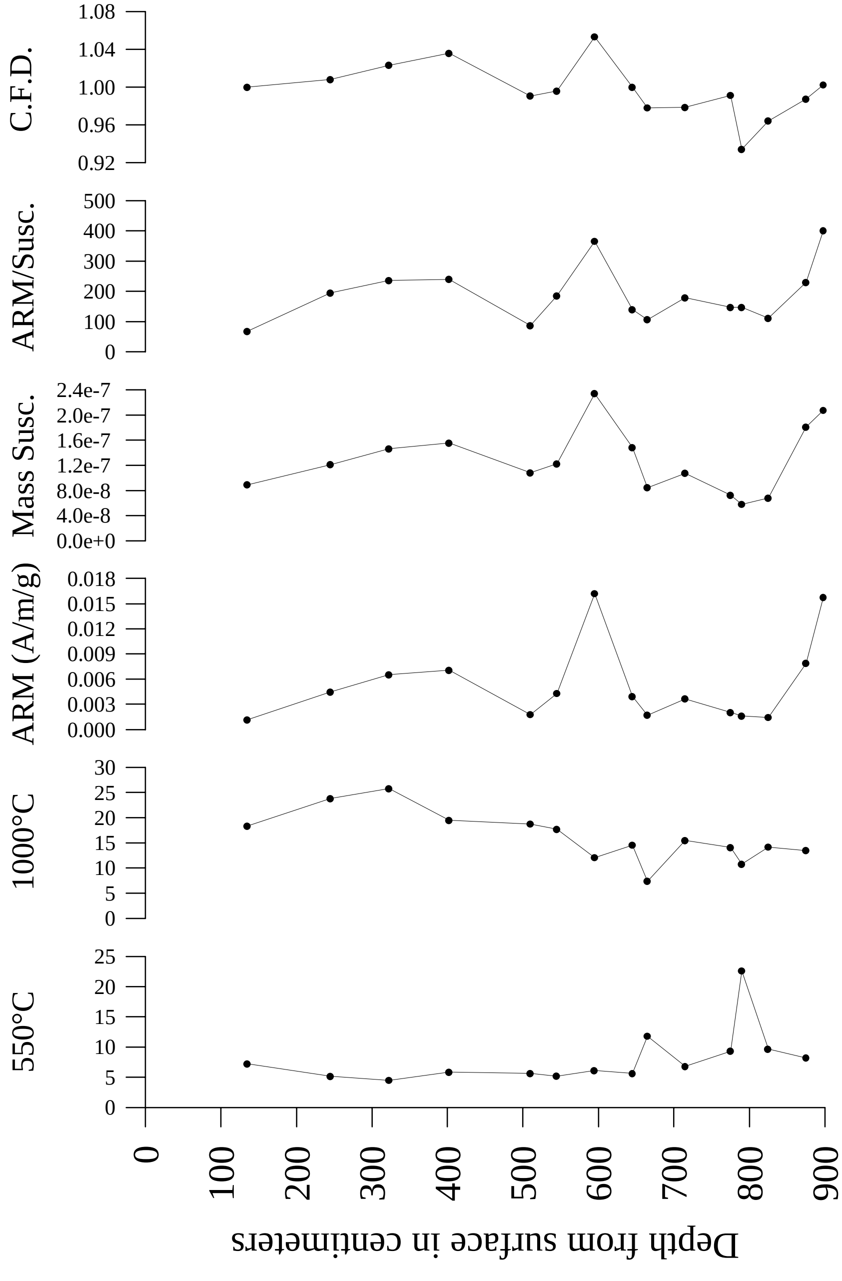
0.96
ARM/Susc.
600
500
400
300
200
100
0
Mass Susc.
3.5e-7
3.0e-7
2.5e-7
2.0e-7
1.5e-7
1.0e-7
5.0e-8
0.0e+0
ARM (A/m/g)
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
1000°C
30
25
20
15
10
5
0
550°C
8
6
4
2
0
0
100
200
300
400
500
600
700
800
900
1000
1100
Depth from surface in centimeters

NC-94-13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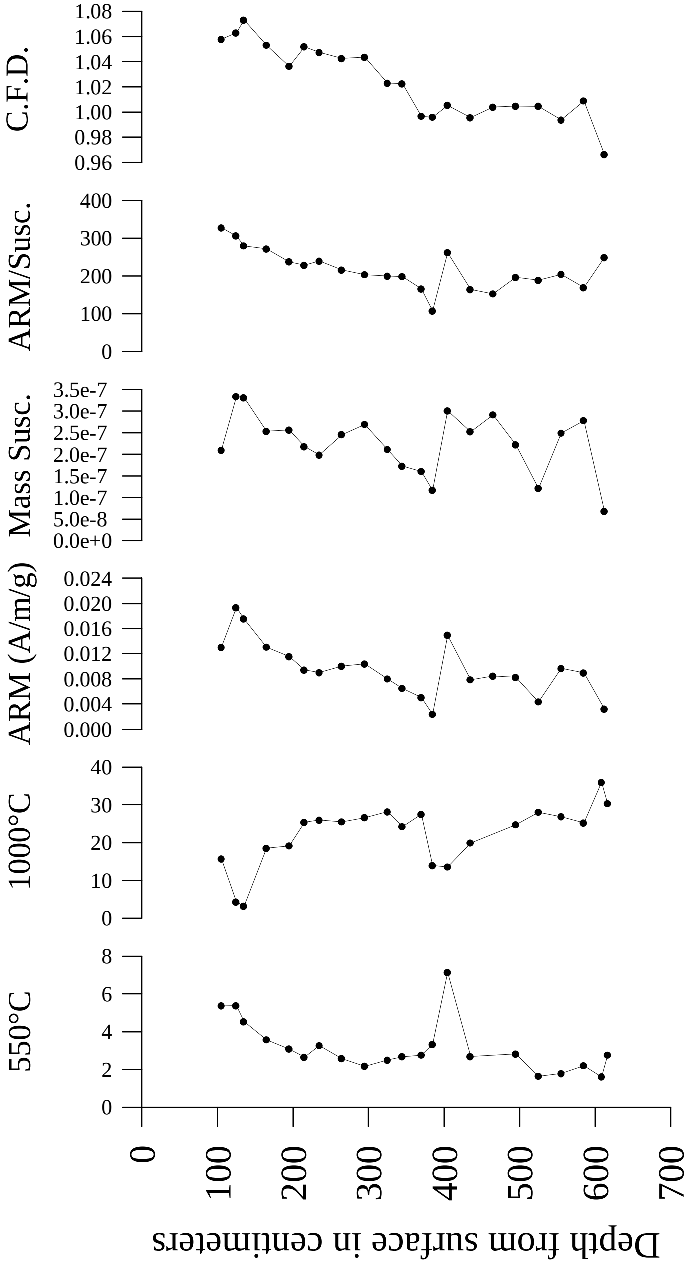
1.04
1.00
0.96
0.92
ARM/Susc.
500
400
300
200
100
0
Mass Susc.
2.4e-7
2.0e-7
1.6e-7
1.2e-7
8.0e-8
4.0e-8
0.0e+0
ARM (A/m/g)
0.018
0.015
0.012
0.009
0.006
0.003
0.000
1000°C
30
25
20
15
10
5
0
550°C
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
900
Depth from surface in centimeters

NC-94-17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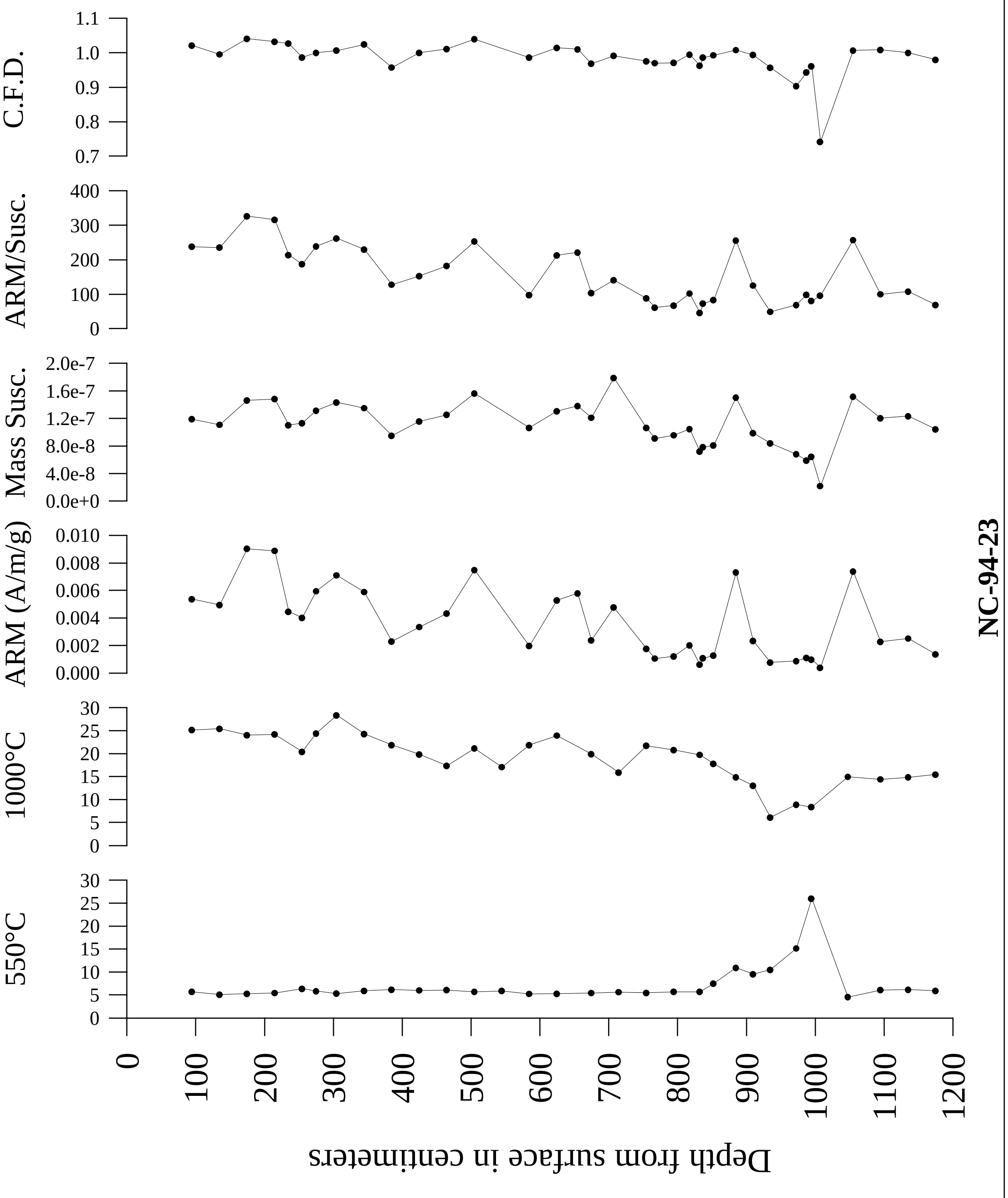
1.06
1.04
1.02
1.00
0.98
0.96
ARM/Susc.
400
300
200
100
0
Mass Susc.
3.5e-7
3.0e-7
2.5e-7
2.0e-7
1.5e-7
1.0e-7
5.0e-8
0.0e+0
ARM (A/m/g)
0.024
0.020
0.016
0.012
0.008
0.004
0.000
1000°C
40
30
20
10
0
550°C
8
6
4
2
0
0
100
200
300
400
500
600
700
Depth from surface in centimeters

NC-94-20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ARM/Susc.
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300
200
100
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Mass Susc.
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1.6e-7
1.2e-7
8.0e-8
4.0e-8
0.0e+0
ARM (A/m/g)
0.010
0.008
0.006
0.004
0.002
0.000
1000°C
30
25
20
15
10
5
0
550°C
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Depth from surface in centimeters
NC-94-23

Appendix E--Uncalibrated and Calibrated Results of ^{14}C AMS Analyses

Sample	**Lab I.D. Number**	**Sample Material**	**^{13}C/^{12}C Ratio**	**Age in ^{14}C Y.B.P.**	**Calibrated Calendar Y.B.P.**
NC-92-20 (530-540 cm)	UCR-3217	charcoal, root fragments	n/a	2470±60	2650 +70/-290
NC-93-18 (70-75 cm)	UCR-2695	peat with organic material	-27.18 ‰	2890±40	2980 +90/-30
NC-93-19 (700-720 cm)	UCR-2696	peat with wood fragments	-20.36 ‰	4520±60	5140 +160/-100
NC-93-21 (580-610 cm)	UCR-2697	peat with organic material	-28.24 ‰	3460±60	3690 +140/-60
NC-94-04 (295-300 cm)	Beta-80531	wood	-26.0 ‰	340±50	380 +90/-70
NC-94-13 (535-540 cm)	Beta-80532	plant material	-23.3 ‰	950±50	850 +80/-60
NC-94-20 (605-620 cm)	Beta-80533	wood	-39.9 ‰	1740±60	1670 +40/-120
NC-94-23 (1035-1055 cm)	Beta-80534	plant material	-27.0 ‰	3700±60	4030 +/-100

Calibration from ^{14}C years before present (conventional ^{14}C age) to calendar years was performed using the CALIB Revision 3.0.3c computer program available from M. Stuiver and P. Reimer of the Quaternary Research Center at the University of Washington, Seattle. All options were set at their default values. The data set used to make the calibrations was the INT93CAL bidecadal dedrochonologic calibration curve. A decadal calibration is also available, but is meant for use with high precision dates ($\sigma \leq$ 40 years).