1992

An Investigation of the Late Pleistocene Paleochannel Systems in the Continental Shelf, South of Chesapeake Bay Mouth

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Recommended Citation

Chen, Ziqiang, "An Investigation of the Late Pleistocene Paleochannel Systems in the Continental Shelf, South of Chesapeake Bay Mouth" (1992). *Dissertations, Theses, and Masters Projects.* Paper 1539617641.
https://dx.doi.org/doi:10.25773/v5-699h-9526

AN INVESTIGATION OF THE LATE PLEISTOCENE PALEOCHANNEL SYSTEMS IN THE CONTINENTAL SHELF, SOUTH OF CHESAPEAKE BAY MOUTH

A THESIS

PRESENTED TO

The Faculty of the School of Marine Science
The College of William and Mary

In Partial Fulfillment
Of the Requirements for the Degree of
Master of Arts

BY

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Spring, 1992

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the requirements for the degree of

Master of Arts

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DEDICATION

To

Nian'nian and Yan'zi.

涸轍之鮒，相濡
以沫，不如相忘于大海。

—— 莊周訓

ACKNOWLEDGEMENTS

I am very grateful to my committee members: Woody Hobbs, Carl Berquist, Bob Diaz, Suzette Kimball and Don Wright for all their guidance, support and encouragement during my VIMS years. I greatly appreciate the help of Suzette Kimball and Woody Hobbs for their step-by-step instructions, suggestions, and enormous efforts made for me through the entire research duration. I devote my heartest thanks to my major advisor Woody Hobbs, this thesis would have not been carried out without his countless guidance, help, understanding, and warmth. Special thanks are extended to Don Wright who provided many comments and suggestions as well as encouragement, and to Bob Diaz who provided fossil identifications and assisted in statistic operation, and to Linda Schaffner for her generosity and help in x-ray stratigraphic analysis. I am indebted to John F. Wehmiller of University of Delaware who performed the amino acid racemization analysis and offered many invaluable suggestions and discussions in my amino acid geochronal study. Leonard Jones of U.S. Army Corps of Engineering in Norfolk provided very helpful information and allowed vibracore samplings. Thanks and best wishes also go to Dr. Grace Brush of the Johns Hopkins University for her kindness and encouragement.

Special appreciation goes to Cythia Harris for her immeasurable help. I extend my thanks to Lao Du, Shen Jian and all my friends who provided me with support through the dark time.

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ABSTRACT

Analyses of an extensive network of high-resolution seismic records and borehole samples including sedimentological and aminostratigraphical data outline three generations of drainage valleys beneath the continental shelf south of the Chesapeake Bay's mouth.

Based on the geomorphic distributions, internal structures, and amino acid geochronology of the fill sequences, the three systems have been identified to be compatible in age with the well-defined Cape Charles, Eastville, and Exmore ancient valley systems beneath the Chesapeake Bay.

Analysis of fourteen aminostratigraphic samples from the paleochannel fills, overlying barrier-spit complex, and basal strata yielded A/I values ranging from 0.01 to 0.55 (basal strata), corresponding to oxygen isotope Stages 1 to 12. The A/I values for the fill sequences of the three paleochannel systems are 0.01, 0.10 - 0.15, and 0.15 - 0.21, apparently corresponding to the Stages 2, 6, and 8, or to ages of 30 +/- 10 kyr, 150 +/-20 kyr, and 260 +/-20 kyr BP respectively.

The two lower paleochannel systems are late Pleistocene, fluvial dominated deposits, with the characteristics of relatively strong and irregular seismic reflections, physically consisting of coarse sand and fine gravel; the upper paleochannel system, in contrast, shows relatively weak and smaller-scaled reflections, with finer and lithologically complicated muddy sand-silt-peat deposits which indicate a nearshore marine (at a baymouth) and /or a restricted river-estuary to open-bay environment.

The sedimentological and sedimentary analyses of the boreholes (grain-size analysis, X-ray stratigraphy, paleotonlogical analysis, Q-mode factor analysis, etc) further support our determinations for the paleochannel systems.

AN INVESTIGATION OF
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IN THE CONTINENTAL SHELF, SOUTH OF CHESAPEAKE BAY MOUTH

OVERVIEW

In recent years, investigators have been working to unravel the history of the Quaternary paleochannel systems in the Chesapeake Bay and adjecent areas by interpreting high-resolution seismic reflection records, geological mapping, and analyzing borehole data and beach sediments (Shideler et al., 1984; Mixon, 1985; Williams, 1987; Colman and Hobbs, 1987, 1988; Colman et al., 1988, 1990; Colman and Mixon, 1988; and Hobbs, 1990).

These studies, combined with the researches in the Quatenary evolution of the inner shelf of Virginia (Shideler et al., 1972; Swift et al., 1975; Cronin et al., 1981; Balknap et al., 1981; Wehmiller et al., 1982 and 1988; Niedoroda et al., 1985; Peebles, 1984; Shideler et al., 1984; Finkelstein and Kearney, 1988; Hobbs, 1990) and on the origin and the dynamic features of the sand and shoal complex in the lower Chesapeake Bay (Kimball et al., 1989; Kimball and Dame, 1989; and Dame, 1990), have greatly extended our knowledge on these subjects, especially on sea-level fluctuations and the coastal sedimentation history. The evidence provided in these studies suggests that at least three major paleochannels exist beneath the Bay which were the late Pleistocene fluvial channel systems in the bay, and may represent three major events of sea level low stand during Pleistocene time.

In a recent study, Colman et al. (1990) offered an excellent review on the historical development of our knowladge about the paleochannel systems beneath the Chesapeake Bay and the Delmarva Peninsula, as well as about the associated geological problems in this region. They outlined the regional geographic and temporal pattern of the paleochannels, discussed the origin and the preservation of the paleochannels within the bay, as well as the long-term evolution of the bay.

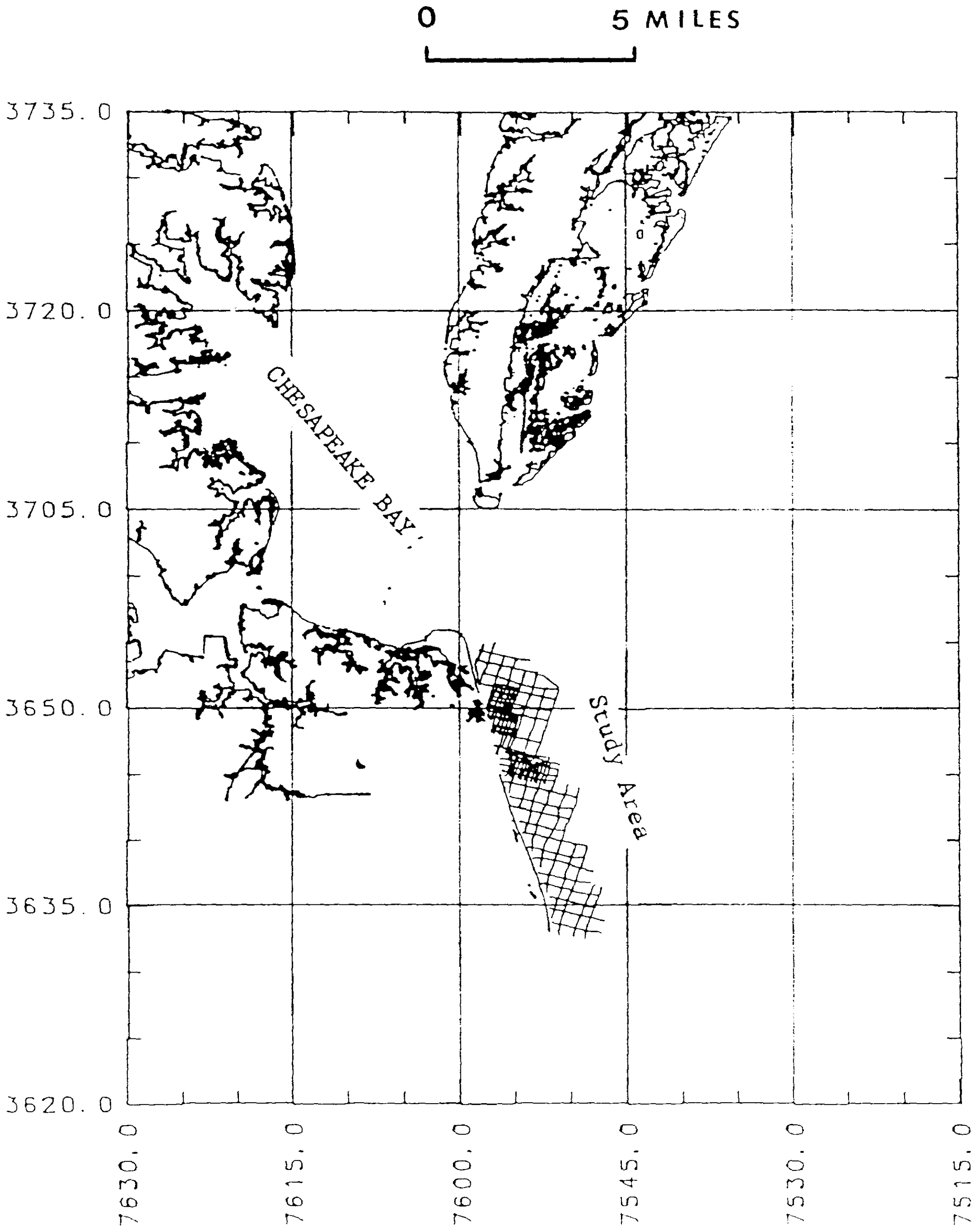
The three major paleo-channel systems are informally refered to as the Cape Charles, Eastville, and Exmore channels in young-to-old age order. The Cape Charles Channel is estimated to be related in age to the time of Imbrie's oxygen-isotope stage 2, at about 18 ka, the late Wisconsin glacial maximum. This has been supported by geomorphic and stratigraphic evidence (Colman and Hobbs, 1987; Colman et al., 1988).

The age estimates for the two older paleochannel systems have been the subject of considerable discussion and intensive argument (Cronin et al., 1981; Wehmiller and Balknap, 1982; Szabo, 1985; Wehmiller et al., 1988; Colman et al., 1988; and Mixon, 1982). Although so, the generally proposed ages for the two paleochannels beneath the bay are considered to be 150 +/- 20 ka and 260 +/-20 ka BP, or correspondant to the Stage 6 and Stage 8.

However, the existing geochronologic and stratigraphic knowledge exclusively derived from the bay and/or from the Delmarva region can not be applied directly to this study area without careful examination (Figure 1, this study area).

The geographic distributions of the paleochannel systems in the study area need to be investigated. Furthermore, the age assigments for the paleochannel systems in the study area need to be estimated which then would allow a better reconstruction of the evolution of the paleochannel systems in the region. Systematic study of the seismic stratigraphy and the sedimentological features are essential for estimating the paleoenvironments and the relative ages of the stratigraphic units within the paleochannel systems. The determinations of the absolute ages of the fillings and/or the fossil records are significant approaches for depicting the geohistory of the sedimentation, and may also provide some information about the rate and the scale of the sea-level changes in the Middle Atlantic Bight region.

Fig. 1. Study Area and Seismic Track Network



REGIONAL GEOLOGY

1. Brief Geo-history of the Chesapeake Bay Region

Prior to Permian time, approximately 225 million years ago, the North America Continent was centered around what is now Hudson Bay. Its southern shorelines were through the present day Great Lakes and southern Ontario; the region that was to become the Chesapeake Bay lay thousands of kilometers offshore (Hallam, 1974).

By the end of the Permian time, the three continents of North America, Africa, and Europe had drifted together. The sediments caught among the colliding plates were folded; the subsequent faulting and metamorphism exerted their utmost on the previous sediments, as a result the rocks of the piedmont Province were emplaced.

During the Triassic time the united continent, the Pangea, began to drift apart. At the continental edges, huge faults and rifts were very active, creating enormous valleys or 'red-bed' basins. Sediments worn from the mountains were deposied into the foreland basins. Sandy and silty fluvial deposits spread over the Appalachian regions, formed the Potomac Group of Cretaceous age.

With the widening of the huge 'cracks' between continents, the Tethys Sea invaded the opening(s), and the Atlantic Ocean began to form. The coastal-plain sediments since have been deposited upon the crystalline basement. Meanwhile, uplifting took place in the continents, and produced series of the non-marine sedimentary sequences. By the time of the Middle Cretaceous, the sea inundated the mid-Atlantic region; the marine sediments were subsequently graded upward through the Oligocene stratifications (approximately 24 or 25 million years ago).

Since the early Miocene strata are missing regionally, an episode of the sea withdrawal lasting until the middle Miocene (15 to 16.6 ma.) is inferred. The sea returned with the result that marine sediments of the Chesapeake Group, which includes Calvert, Choptank, St. Marys, Eastover and Yorktown formations of mid-Miocene to Pliocene age were deposited. This is thought to have continued until 1.6 ma ago, the very beginning of Quaternary period.

With the development of the mid-Atlantic geosyncline (Drake et al., 1968) the faulting and uplifting took place first in northern Maryland, then spread southward until the early Pleistocene. During the mid-Miocene-Pliocene time, the framework of the Chesapeake Bay formed.

On the newly formed coastal plain along the mid-Atlantic coast, the Delaware, Susquehanna, and Potomac Rivers meandered, cut and filled, and dropped sand and gravel on the courses of their adjustments to the Pliocene ocean basin.

2. Quaternary Sea-level Fluctuations

Changes of sea level due to various effects have long been authenticated. In general, it is believed that sea level was almost the same as the present sea level during the later Pliocene (Vail et al., 1977). In the early Pleistocene, approximately 1.6 ma ago, a very high sea-level stand about 30 meters above the present occurred. Sea level highs are thought to be the same or slightly above the present one in the mid-Atlantic region during the following 500,000 years (Belknap and Wehmiller, 1980). However, other researchers from different areas conclude that sea level had never been appreciably above its present height during the Quaternary.

Fairbridge (1968) outlined a model wherein sea level descended from Early Pleistocene elevations in a series of glacioeustatic oscillations superimposed on a longer term fall. However, more recent researches have firmly indicated that Fairbridge's sea-level curves are merely representative and differ regionally (Bowen, 1978; Fairbanks, 1989).

Shackelton and Opdyke (1973), using oxygen-isotope analyses of deep sea cores, defined oxygen isotopic stages which reflect the sea-level fluctuations (actually represent alternation of glacial and interglacial episodes) by determining the $^{18}O/^{16}O$ ratios in foraminifera tests. This was further confirmed by the paleoecology of reef complexes which were carefully compared with models based on modern coral associations (Chappell, 1974).

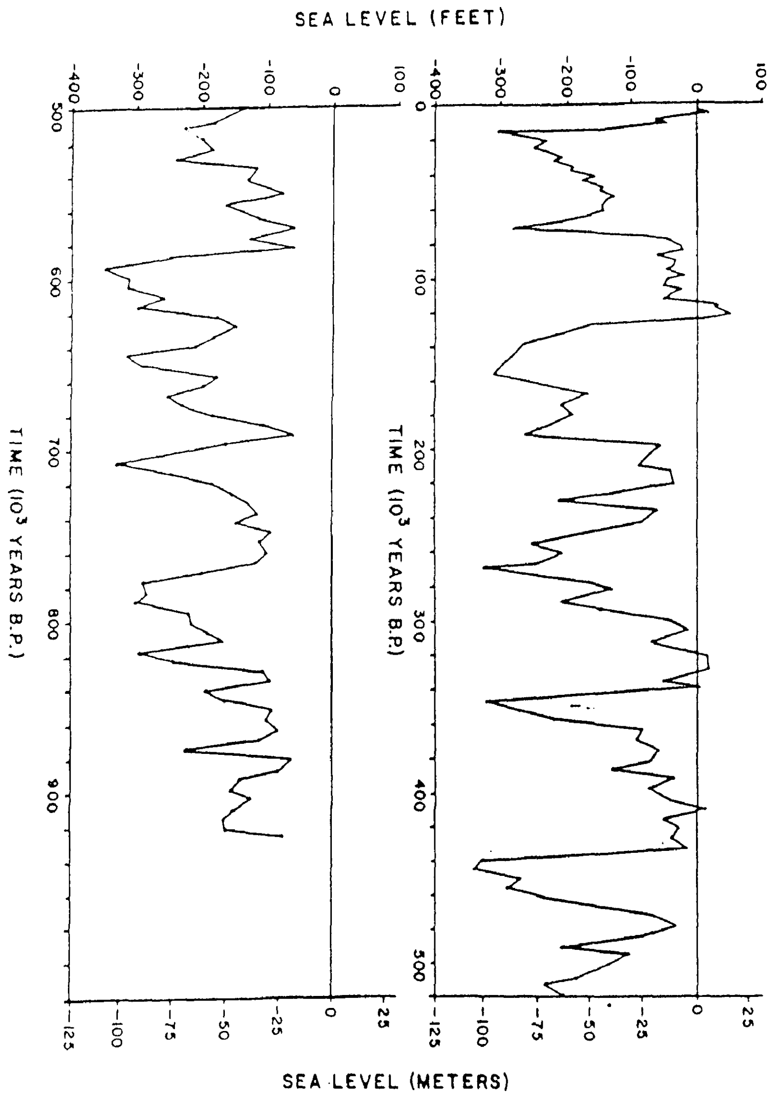
Other studies have utilized radiocarbon and uranium-series dating to estimate the oscillations' ages. Chappell and Shackleton (1986) defined the maxima of sea level for the past 240,000 years in the terrace reefs in New Guinea; Cronin et al.(1981) used uranium-series dates from corals along the United State Atlantic Coastal Plain in documenting five relatively high sea-level stands for the past 200,000 years with reference to the paleoclimate data in the region. Faribanks (1989) detailed a sea level curve for the past 17,000 yrs in Barbados by using coral Acropora palmata which is believed to be sensitive to the water depth. More recently, Bard et al.(1990) calibrated the traditional ^{14}C timescale of the sea-level changes for the past 30,000 yrs in Barbados offshore from the same locality where Faribanks worked. By using their newly established technique of Thermal-ionization Mass Spectrometry (TIMS) for U-Th dating, they concluded that before 9,000 years BP, the ^{14}C ages are systematically younger than the U-Th ages, and that the last deglaciation started 3,000 yrs earlier than previously thought. Bard et al. (1990) later extended their research to the past 130,000 yrs BP and confirmed that there were two surges in melt water at about 11,000 and 14,000 yrs BP during the last deglaciation.

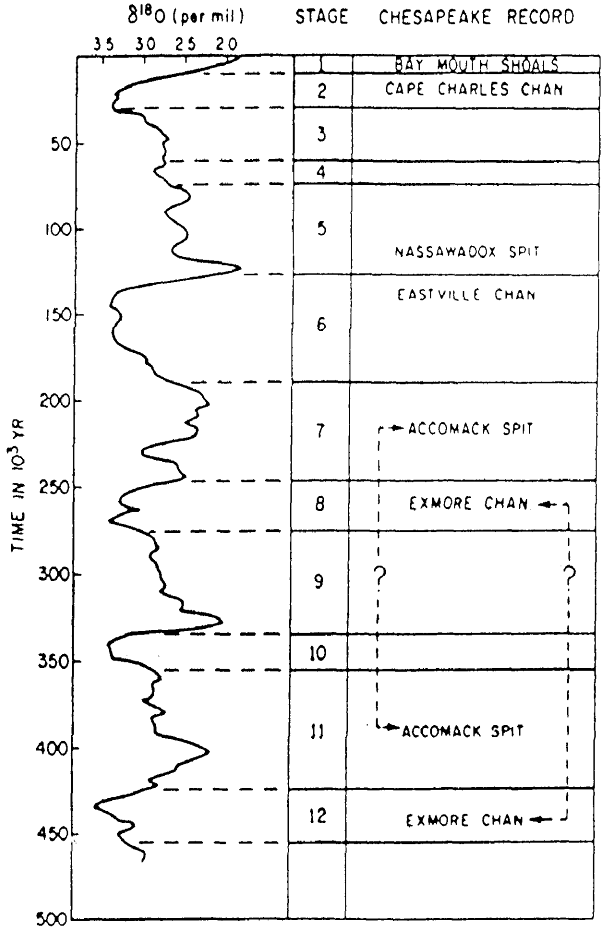
The Holocene (C-14 stage one, began 12,800 years BP (Bowen, 1978)) sea-level oscillations have been well documented. At approximately 18,000 to 20,000 yrs ago the sea level is believed to be about 100 meters below the present level, the shoreline of the Atlantic Ocean was approximately 100 kilometers east of Chesapeake Bay's mouth along the break in slope of the continental shelf. Much of the shelf was semi-arid land or swamp over which the fluvial systems drained, traversing and filling the bay area. Sand and graval sediments were spread all over the region. In the first 10,000 to 8,000 years of the deglaciation, the sea level rose approximately 80 meters, or one meter per century (Shackleton and Opdyke, 1973): Chesapeake Bay would have started to flood and young paleochannel system formed during the last major glaciation would have begun to be filled with sediments.

During the next 6,000 to 7,000 years the rate of sea-level rise slowed, sea level rose approximately 10 to 15 meters, or 15 to 20 centimeters per century. During the last 6,000 years the sea-level rise curves are considered to be smooth and continuous in the entire U.S. Atlantic costal plain (de Plassche, 1990), total 3 meters of sea level rise are thought to have been achieved.

One of the major heritages of the Quaternary sea-level fluctuations in this region is the coastal lithological stratifications which are marked by the several paleochannel systems and the barrier-spit system: the former are clearly related to major low stands of sea level; the latter represent the major sea-level maxima. During the major low stands of sea level, fluvial processes and widespread erosion were the predominant mode of morphologic development on the coastal plain. During the subsequent sea-level rise, the ocean transgressed landward. The previous fluvial sediments were redistributed into /or covered by the estuarine, nearshore, and other marine environmental deposits.

The general trend for the Quaternary sea-level changes are widely recognized (Fig.2). However, the changes vary regionally, most likely due to local tectonic activities, isostatic and hydrostatic adjustments, sediment loading, land erosion, and anthropogenic effects (such as groundwater withdrawl).





Correlation of the paleochannels and transgressive depsits in the Chesapeake Bay area with the marine oxygen-isotope record.

Figure 2. Quaternary Sea-level Flucuations

(l: from Zellmer, 1979; r: Colman & Mixon, 1988)

3. Quaternary Stratigraphy

The interface between continents and oceans, the coastline, has been considered as a linkage between the stratigraphic framework of the global sea-level curves and the local sedimentary sequences. The analysis of the sedimentary sequences has been a major approach to reveal the complex geologic history of the marine regressions and transgressions. The carvings of paleochannels and the infillings of estuarine-nearshore sedimentary sequences in Chesapeake Bay and in the inner Virginia shelf have been well documented in some areas through interpreting seismic-reflection records, geological mapping and studies of borehole data and beach sediments (Sideler and Swift, 1972; Meisburger, 1972; Oaks et al., 1974; Swift et al., 1976; Swift et al., 1975.; Cronin et al., 1981; Niedoroda et al., 1985; Peebles, 1984; Shideler et al., 1984; Colman and Hobbs, 1987; Williams, 1987; Finkelstein and Kearney, 1988; Colman et al., 1988; Colman and Mixon, 1988; Dame, 1990). These studies, among others, have described the regional stratigraphy, and indicated, as well, the primary and distinctive seismic stratigraphic units of sedimentary sequences in the region.

(1) Regional Stratigraphy:

The late Pliocene and Quaternary stratigraphy in this region has been summarized by Oaks et al.(1974), Johnson (1976), and Peebles (1984). Table 1 shows the correlation of the stratigraphic names used in the study area (modified from Peebles, 1984):

TABLE 1

Oaks and Coch (1973)	Peebles (1986)*	Johnson (1976)
Sand Bridge Formation	Tabb Formation, Lynnhaven Member	Tabb Formation, Lynnhaven Member
	Tabb Formation, Sedgefield Member	Tabb Formation, Sedgefield Member
Londonbridge Formation		
Kempsville Formation		
Norfolk Formation: Upper member - silty sand, fine sand, medium sand, sand, and silt facies		
Great Bridge Formation - Upper Member and part of the Lower Member		
Norfolk Formation: Upper member - clayey sand, silty sand, and coarse sand facies	Shirley Formation	Norfolk Formation
Windsor Formation	Windsor Formation	Windsor Formation
Great Bridge Formation - a portion of the Lower Member	Chowan River Formation	(not in study area)
Yorktown Formation	Yorktown Formation	Yorktown Formation

Correlation of previously published stratigraphic names with those used (" * ") in this study.

Yorktown Formation consists of a sandy silt facies which locally is bio-fragmental sand with unbroken fossil shells usually, a crossbedded shell hash facies with high carbonate content, and a glauconitic silty fine sand facies which consists of extensively burrowed, gray sandy silt with laminae of shell fragments and fine to medium quartz sand. Ferricrete is commonly found at the contact between the Yorktown sediments and younger deposite (Peebles, 1984). The age of this formation is generally believed to be early to late Pliocene.

Chowan River Formation occurs as subsurface sediments in the study region (Peebles, 1984). This late Pliocene marine formation consists of interbedded silty fine sand, silty clay, and bio-fragmental sand. Fossils include a diverse, shallow-water faunal assemblage which differs from that in the marine Yorktown Formation. The base of the formation is characterized by a discontinuous pebbly to bouldery sand. Groundwater migration has caused a distinctive leaching feature in the formation. The basal unit grades upward into the upper unit of fine to medium sand, clay silt and biofragmental sand. This formation is of late Pliocene age (Peebles, 1984).

Windsor Formation: The basal and lower portion of the formation consists of fine to medium sand interbedded with plant detritus, wood fragments and/or silty clay containing fine sand laminae. Pine cones and oyster shells were observed in the channel-filling deposits and basal lag deposits (Peebles, 1984); Sediments of the formation are more deeply weathered and much more compact than those of younger formations. Its age is believed to be early Pleistocene (Peebles, 1984).

Shirley Formation consists of a stratigraphic sequence which exhibits both vertical and lateral variation in lithology, fossil content and thickness. Local valley-fill deposits and estuarine peat/organic-rich deposits are the two extremes. Generally, the valley fill deposits grade upward into a discontinuous sheet of cobbly to bouldery coarse sand which defines the base of the formation. Cronin and others (1981 and 1984) determined tha U-series age of the formation as 187 +/- 20 ka indicating a middle Pleistocene age.

Tabb Formation is divided into Sedgefield Member and Lynnhaven Member which were named and mapped by Johnson (1976) on the York-James Peninsula. Sediments of these members underlie broad inner continental shelf of many terrances throughout the Deep Creek swale, the Oceana ridge, and the subsurface of the Dismal Swamp (Johnson, 1976).

I. Sedgefield Member: The sediments of the Sedgefield constitute most of the above mentioned areas. Its base is characterized by fill sediments with organic-rich silty clay and peat contain tree trunks in living position as well as roots, tree branches and stems. In its upper portion the organic rich clay contains wood fragments. A coarse sheet of pebbly to cobbly, fine to coarse sand forms a sharp contact between Sedgefield

Member sediments and those of the Shirley Formation, the Chowan River Formation and the Yorktown Formation. Sediments overlying the coarse base of the Sedgefield sediments vary with respect to geographic location. However, the sediments grade upward into a fine to medium sand, and into a fine-sandy, clayed silt. In places, the fining-upward sequence is covered by a series of arcuate sandy ridges which are less than 1.5 meter in relief. The coarse basal deposits sometimes grade into a fine to medium quartz sand with heavy minerals.

II. Lynnhaven Member: the basal valley-fill deposits grade upward into gray silty clay. The sediments of the member rest unconformably on the sedimentary sequences of the Sedgefield Member, Shirley Formation and/or Yorktown Formation. The Lynnhaven basal lag deposits grade upward into finer grained sediments. However, the upward-fining sequences are relatively thin compared to the Sedgefield and the Shirley deposits (Peebles, 1984).

(2) Seismic Stratigraphic Units

With the development of seismic-reflection techniques, some regional seismic stratigraphic units in the Bay and the study area have been suggested (Shideler et al., 1972; Williams, 1982 and 1987; Colman and Hobbs, 1987 and 1988). More recently, Hobbs (1990) and Dame (1990) confirmed the relationships among the primary stratigraphic units.

UNIT A: The deepest and oldest sedimentary unit identified in the study area (Shideler et al., 1972) exhibits only faint and discontinuous traces on seismic profiles (even on the deep-penetrating "boomer" profiles) (Williams, 1987). This formation appears throughout much of Virginia's coastal plain and most of the inner shelf (Oaks et al., 1974). Off Virginia Beach the depth of its upper surface is approximately 40 meters below mean sea level (MSL). Its stratigraphic depth and acoustic features suggest that the surface probably represents an unconformity, an erosion surface in the Virginia coastal plain (Williams, 1987; Hobbs, personal communications, 1991).

UNIT B: The next younger sedimentary sequence, is characterized by lenticular to planar stratification and prominent fluvial channels with considerable relief (Shideler et al., 1972; Williams, 1987). Its structural character and stratigraphic position imply the channels were formed during the late Pleistocene when sea level was low, and the ancestral rivers, such as the Susquehanna and James, flowed southeastward across the then subaerially exposed surface of the continental shelf. Early correlation of the sedimentary sequences was with the Great Bridge Formation - Sandbridge Formation of the adjacent coastal plain (Shideler et al., 1972; Oaks and Coch, 1973). More recently, this sequence has been assigned to the sedimentary sequences from the

Windsor Formation to Shirley Formation (187 +/- 20 to 90 ka), and to the Sedgefield member (90-70 ka) and Lynnhaven member (70-20 ka ?) of the Tabb Formation (Johnson, 1976; Belknap and Wehmiller, 1980; Cronin et al., 1981; and Peebles, 1984).

UNIT C: This unit exhibits relatively uniform and fairly horizontal stratification, and is composed of homogeneous layers of gray silt and clay. It appears to be the most common sedimentary sequences on the seismic profiles and in the cores. This unit is believed to have formed in a low energy environment, such as an estuary and/or backbarrier lagoon during the later Pleistocene sealevel high stand (20.5 ka to 26 ka (Shideler et al., 1972)).

UNIT D: The uppermost and youngest sedimentary sequence makes up the majority of modern surfacial inner shelf deposits except for local outcrops of older units. This unit is a discontinuous Holocene transgressive sand sheet of fine to medium sand or muddy silt with modern marine fauna (Swift et al., 1977). The origin of the sand sheet is thought to be shoreface erosion and redistribution of the eroded material that resulted from sea-level rise.

Table 2 is a brief summary of the previous stratigraphic investigations and some absolute-age dating results.

TABLE 2

	Dating Technique	Unit according to present study	Approximate sea-level high stand (with respect to modern mean sea level) according to stratigraphic and geomorphic relationships	Age (Years B. P.)
Cronin and others (1981)	Uranium-series	Shirley Formation	14.6 m (48 feet)	187,000 ±20,000
Belknap and Wehmiller (1980)	Amino-acid racemization	Sedgefield Member of the Tabb Formation	9.8 m (32 feet)	70,000 to 90,000
Cronin and others (1981)	Uranium-series	Sedgefield Member of the Tabb Formation	9.8 m (32 feet)	74,000 ±4,000 75,000 ±5,000 72,000 ±4,000

TABLE 2   Major Dated Regional Sedimentary Units and Their Absolute Ages

OBJECTIVES

Simply speaking, the specific objectives of this study are:

(1) to extend the seismic study on the Pleistocene paleochannel systems from the inside Chesapeake Bay to the adjacent area south of the Chesapeake Bay mouth. This task is primarily to determine the geographic distributions and the morphologic characters of the paleochannel systems;

(2) to re-evaluate the interpretations of the depositional environments and the sedimentological conditions for the fill sequences of the paleochannel systems by analyzing the sedimentary structure, lithology, and sequence stratigraphy in the selected vibracores and correlating these information vertically and laterally in a cross-section;

(3) to utilize absolute age determinations/estimates for the establishment of the age-order or the timetable of the paleochannel systems and associated channel fill sequences in the study region;

(4) to approach a quantitive correlation to the multiple sub-layered substrata among the vibracores in order to obtain insights to the relationship between the sediments of the fill sequences and their depositional (hydraulic) environments.

METHODS

In order to accomplish these goals, several study methods were utilized.

1. Shallow Subbottom Seismic Reflection Data

Geographic distribution and morphologic features of the Pleistocene paleochannel systems were determined by interpreting the shallow seismic reflection records which were obtained during the past few year's investigations on the evaluation of sand resources offshore of Virginia Beach (Kimball and Dame, 1987/a; Hobbs, 1990). The seismic surveys were carried out aboard VIMS research ship Bay Eagle in a grid pattern with a loran positioning system (Figure 3).

The VIMS Bay Eagle subbottom reflection system consists of a two channel, dual frequency transceiever, which is connected to a towfish carrying transducers. 3.5 kHz was used because it gave the best comnbination of the penetration and the resolution in the experimental conditions (an overview of the principles involved in this technique can be found in Williams (1982), Dame (1990), and Hobbs and Dame, 1992)).

The seismic profiles are interpreted by tracing their acoustic horizons which are further inferred to sedimentary horizons or sedimentary sequences.

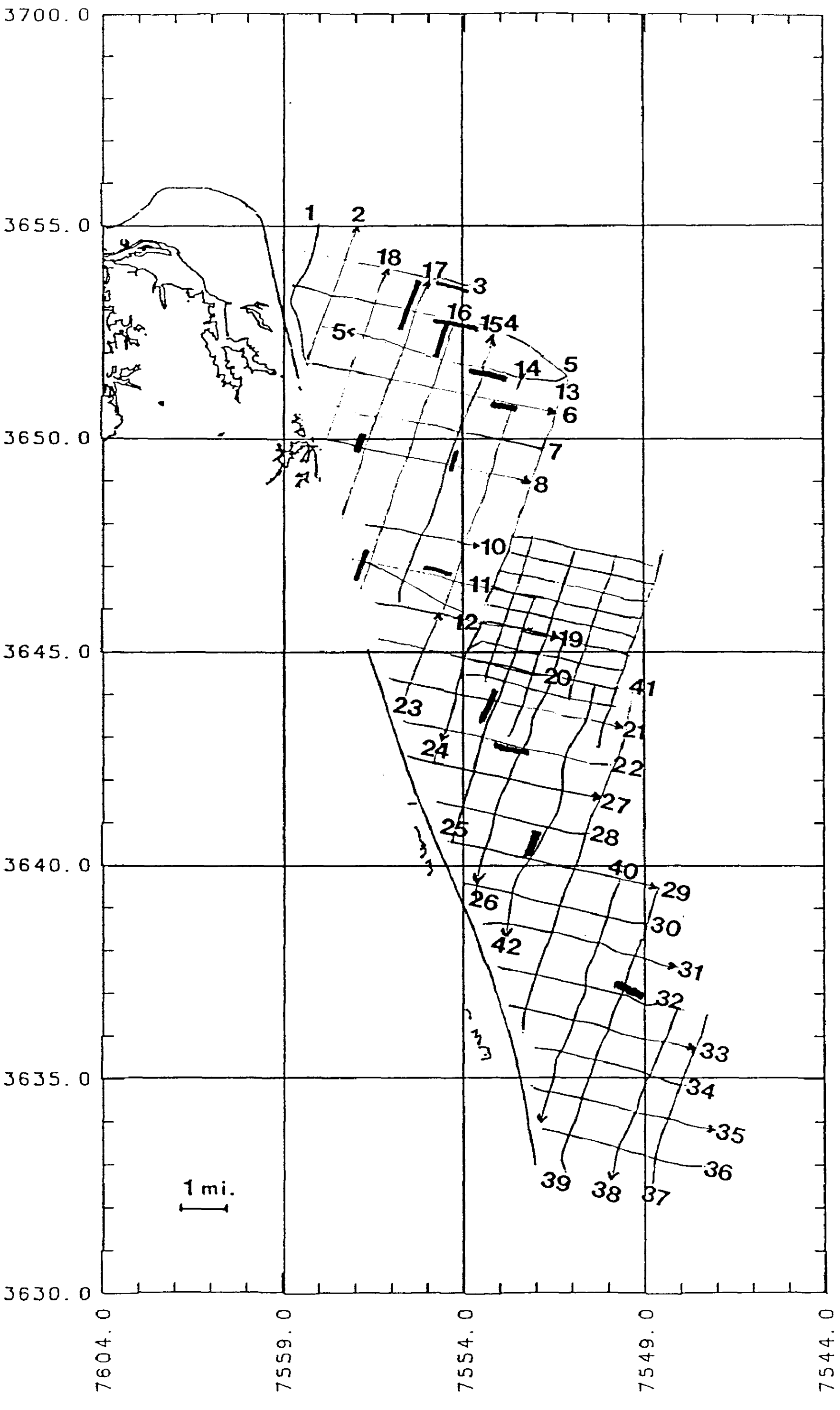


Figure 3 **Seismic Network (major tracks)**

(Heavy-line segments represent the profiles in Figures 5 - 8, Tbl.4)

Nearly sixty tracklines of seismic network in the study area were analyzed systmatically. The result of the trackline interpretations has profoundly illustrated the outlines of the Pleistocene paleochannel systems in the area. The interpretation of the trackline data effectively provided detailed information about morphology and geographic distribution of the paleochannel systems which is listed in Table 4, Figures 5-8 and Figures 9-11 in later chapters

2. Vibracore Sediment Analyses

To supplement the seismic subbottom reflection interpretations, core control is a necessity. This allows the more distinctive acoustic or lithologic stratigraphic units to be recognized and correlated in the seismic record.

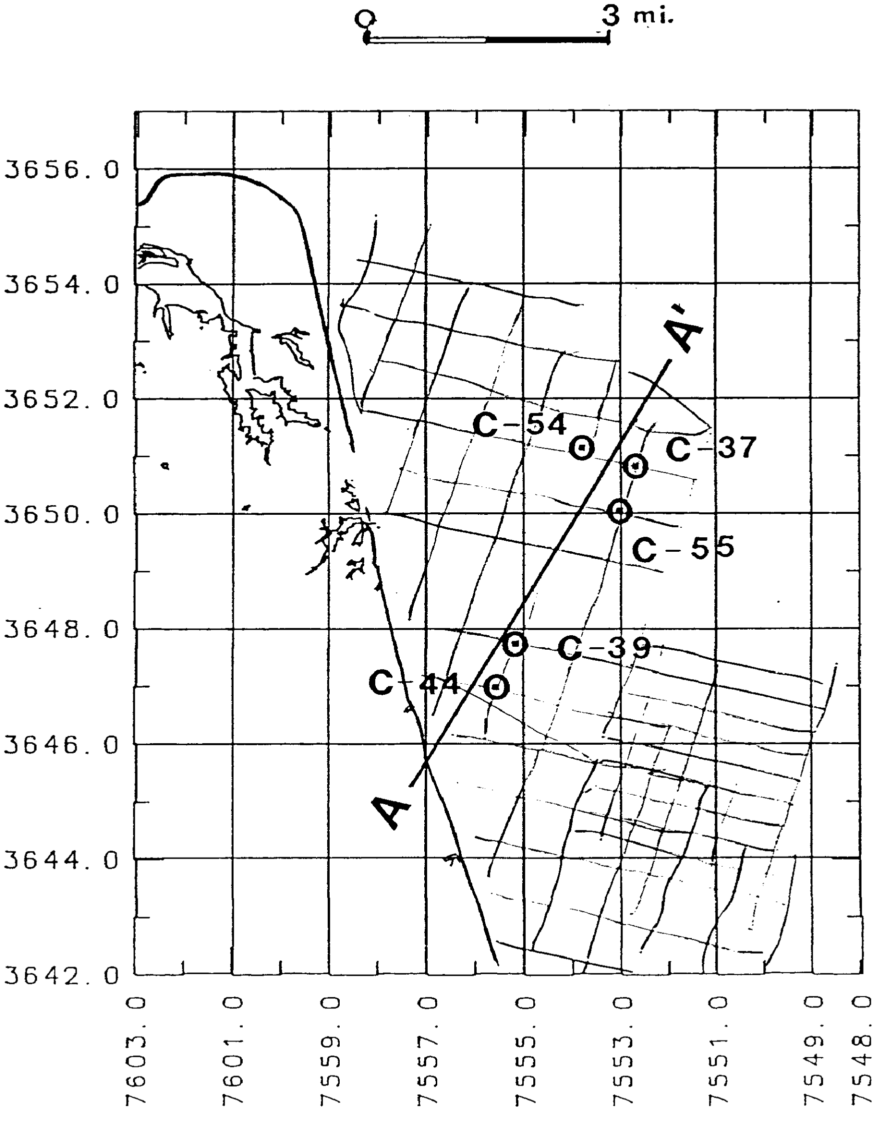
To determine the depositional geology (such as the thicknesses, contact relationships and diagnostic characteristics of sedimentary units, facies and depositional environments, etc.) and chronology of the study area, samples of both surface and subsurface sediments are required. Vibracores provide a mostly undisturbed sedimentary record with some well-preserved physical and biological structures.

In a recent investigation of the offshore Virginia Beach region (Williams, 1986), the U.S. Army Corps of Engineers collected approximately 163 nautical miles (300 km) of single-channel reflection profiles and about 88 vibracores in the northern portion of this study area. Based on previous studies, these vibracores are well-distributed along the upper distal channel valley for two younger major paleochannel systems. The cores penetrate 3 to 7 meters into the substrate. The choice of vibracores in this study was primarily based on the location and the distance of the cores to the acoustically-indicated paleochannel valleys. Due to the limitations of time and budget, however, I picked only three cores, plus two VIMS vibracores drilled during the 1987 investigation, from the representative localities to detail the sedimentary characters and the depositional features in the study area (Figure 4).

Sediment, geochronal, and faunal samples were taken from the cores. Sediments were described visually by routine techniques described in Folk (1974) and in VIMS sediment analysis manual. All the vibracore samples are analyzed through standard grain-size analyses in order to insure standardization of sample descriptions. Vibracores were split into equal halves. Central "channel" samples were then taken from the split cores for each lithological or physical segment of the vibracores. The "channel" samples were sieved and pipetted and/or run on the RSA in accordance with standard sediment analysis procedures as described in Folk and VIMS Manual.

Grain-size analyses are performed to characterize the sediments that make up strata and to suggest some depositional hydraulic environmental features. Results of these analyses were then subjected to further treatment: sedimentological analysis by using Folk, Friedman and other's diagrams(see details in Exercises In Sedimentology by Friedman and Johnson, 1982; Origin Of Sedimentary Rocks by Blatt and Murry, 1980), and

Figure 4 Locations of The Vibracores



(AA': The cross-section on which all the vibracores are projected for stratigraphic correlations in the study) a number of statistical analyses, such as cluster, PCA(EOF), and Q-mode factor analysis (Statistics and Data Analysis in Geology by Davis, 1986). These treatments, combined with the seismic interpretations and vibracore describtions provided useful information on the paleo- sedimentary environments for those channel filling systems.

3. Amino Acid Geochronology

Geochronal studies are important in determining the Pleistocene paleochannel systems, the relative stratifications and the lateral correlations of regional stratigraphy. Three major dating methods were planned to be carried out in this proposed study: Amino Acid Dating, Radiocarbon and Mass Spectrometric U-Th Dating (Table 3 lists three common dating methods for the early Quaternary geochronology). However, due to the time and financial limitations, only amino acid geochronal studies were carried out in this research. Table 3 shows the brief comparason of the three methods.

Amino acids, the basis of protein, exist in organisms. During life they are bonded in the protein, but after death, such bonds break down, releasing the amino acid. As well as releasing free amino acid, those with 'D' isonomers will convert from 'L' to 'D', an interconversion called racemization. The rate of breakdown as well as racemization is temperature dependent, hence for chronological purposes a uniform

Table 3. Some Common Geochronal Measures for Early Quaternary Studies

Dating Method (sample size)	isotope	1/2 life	range	Method	Material
Radiocarbon (10 gm)	C-14	5.7 ka	50 ka 25 ka	decay	wood, peat... coral, molluska...
(TIMS) Mass Spectrometer U-Th (10g)	^{230}Th	75 ka	150 ka	Growth	Organics: coral
Amino acid (0.5 gm)	Amino Acid Diagensis, D/L ratio		200 ka	Recemization	bone, shell

temperature over time generally is necessary. Thus, the variation in the ratio of certain amino acid has been used as a measure of relative age. Since the temperature dependent limitation of the method (for both the rate of protein breakdown and the rate of racemization), the assumption of uniform Quarternary temperature is obviously invalid. However, the dependence on temperature can be dealt with by assuming uniform paleoclimatic conditions within a spatial domain instead of in temporal domain. In other words, shell materials within a particular region would have been subjected to similar temperature variations (Belknap and Wehmiller, 1980; Miller and Hare, 1980; Wehmiller et al., 1988). With recent developments, this technique has been found to be vary reliable when shells from the same genera are compared (Wehmiller and Belknap, 1982; Wehmiller et al, 1988).

For same genera organisms, the D/L ratio is assumed the same. Thus, aminozones are defined by a range or cluster of D/L values. The greater the value, the older the sample, or/and the warmer (the more southernly, in North Hemisphere, the geographic region). The term of "aminostratigraphy" has been coined by Miller and Hare (1980). Absolute AA-dating ages need to be calibrated with other independent geochronal data.

In studies along the central and southern US Atlantic coastal plain, Wehmiller et al. (1982 and 1988) have found that within local regions the AA ages agreed with coral U-series ages and biostratigraphic data in many sites. However, this trend does not hold in South Carolina and central

Chesapeake Bay (Wehmiller et al, 1988; Colman and Mixon, 1989). These differences indicate that there are problems in the fundamental tempreture assumptions in aminostratigraphy and that the conflicting U-series ages may represent the minimum ages for the dating localities. As described earlier, the only coral U-series age in the region can be also questioned because of the low $^{230}Th/^{232}Th$ ratio which implies a diagenetic alternation. Thus, the AA-age here served as a check to other dating results in return.

In this study more than a dozen of amino acid age samples were taken from the vibrocores. But only eight of them stand in good qualification: no remarkable evidence of reworking and in good remaining forms, as well as with suitable dating sizes. All the fossil samples were identified by Drs. Robert Diaz and Linda Schaffner at VIMS of the College of William and Mary. The amino acid dating processes were carried out at Dr. John Wehmiller's Amino Acid Labrotary in the University of Delaware.

RESULTS

1. Geomorphology and Geography of the Paleochannel Systems

The paleochannel systems in the study area are outlined by the seismic reflection network. The seismic reflection profiles delineate the top of strata from the Late Pleistocene through Tertiary (Dame, 1990) in age, which were involoved in the signifigant surficial erosion during at least three major marine regressions. These reflections have been mapped across the study area. Each of them may not represent a single erosional event, rather a composite surface. These topographic features of the reflection profiles lead the determinations of the locality and morphology of the buried paleochannel systems (Figures 5-8).

Different paleochannels or different generations of paleochannels can be traced from the extensive seismic track network which consists of 54 track lines, a total about 680 kilometer track-line survey, covering the offshore area of about 700 km^2(see Figures 1 and 4). The densely spaced survey lines made it possible to correlate the buried paleochannel systems and their host sedimentary sequences, and to determine the relative reliefs and the maximum axial depths for each paleochannel.

Based on the morphologic features of the paleochannels in the seismic profiles and the relative positions of the paleochannels and the fill

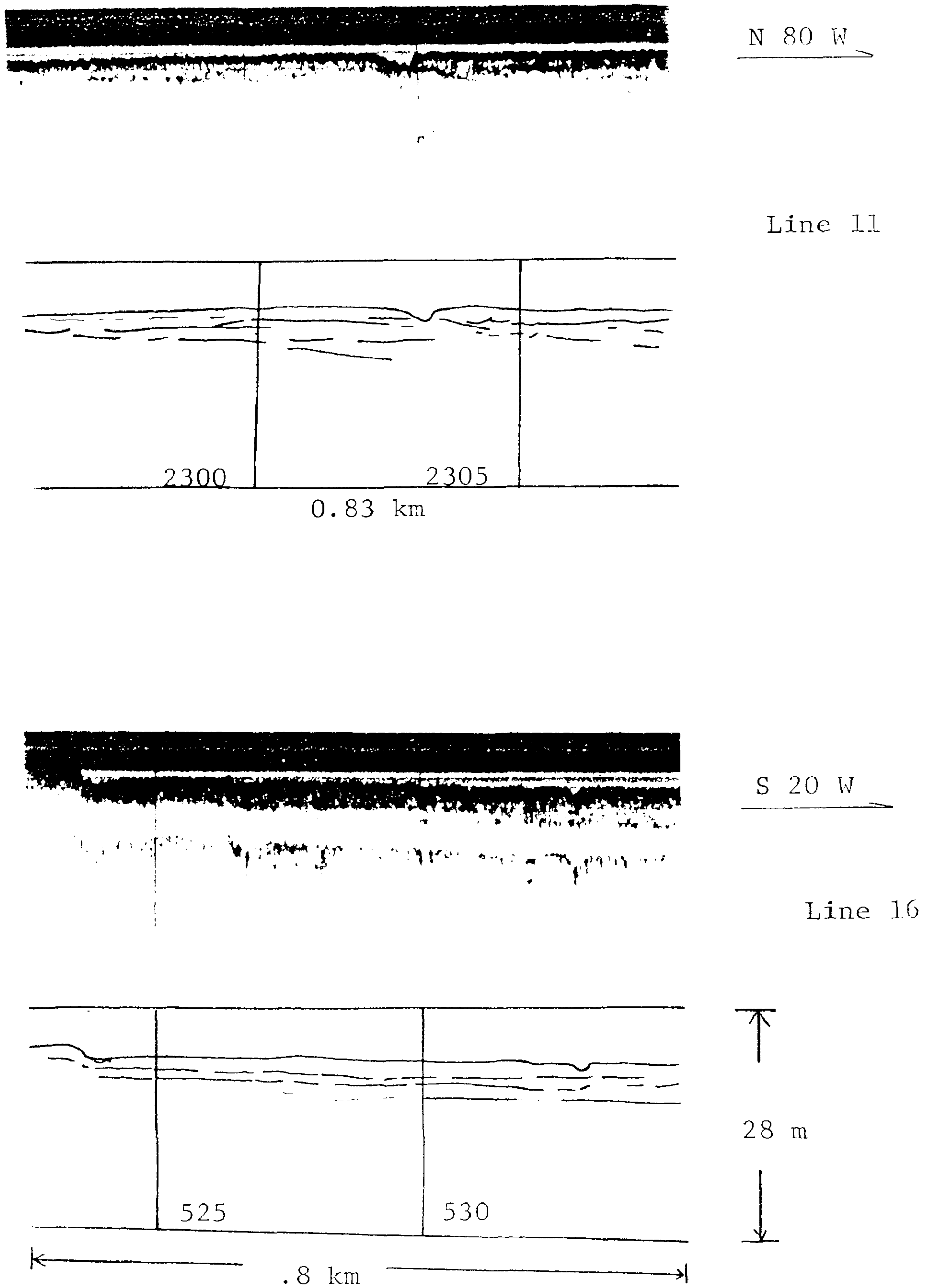


Figure 5 Modern Tidal Channels

(see Figure 3 for the track lines' location)

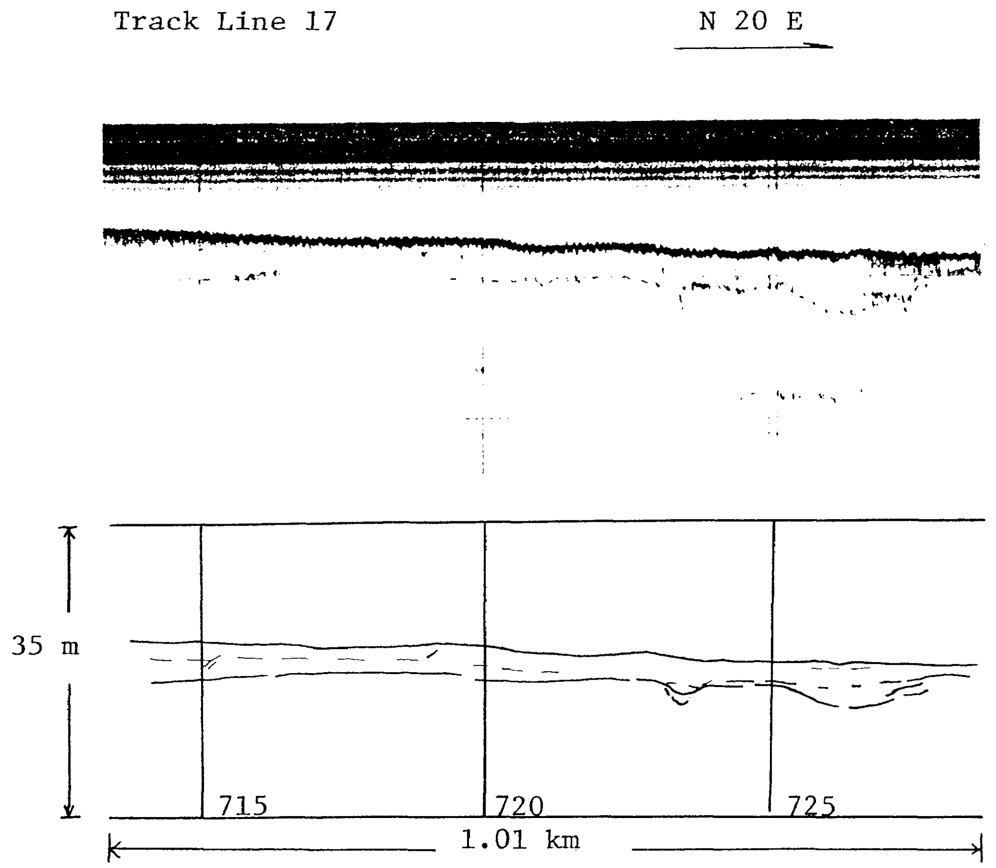


Figure 6 The Upper Paleochannel

(see Figure 3 for track lines' location. "720..." are the field seismic survey numbers)

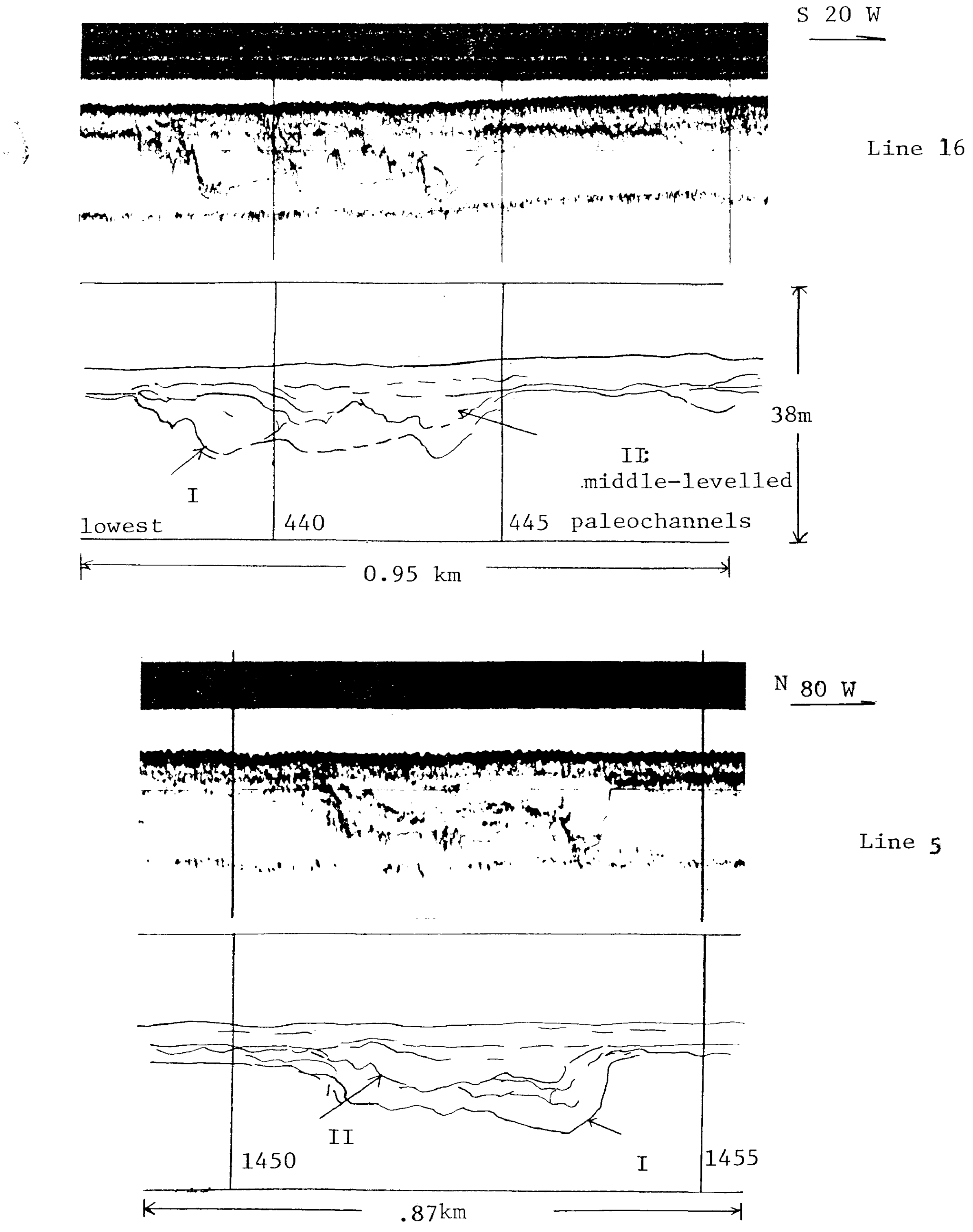


Figure 7 The Lower Two Paleochannels

(I and II for the lowest and the next lowest channels)

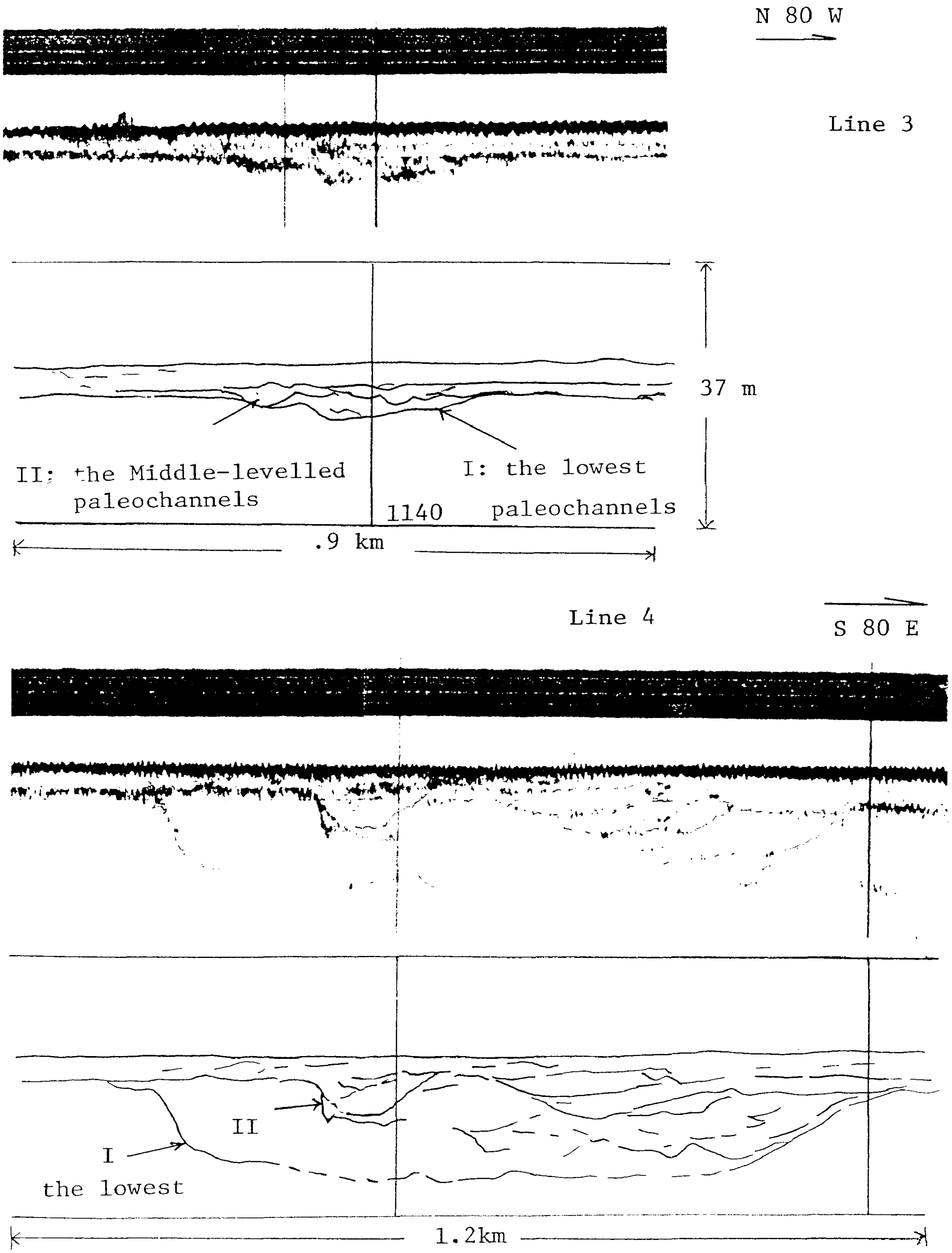


Figure 8 **The Lower Two Paleochannels**

sequences, the reconstructions of the ancient valley systems and their geographic distributions have been made throughout the study area. Three distinct generations of paleochannel systems can be identified in this study region (Figures 9-11).

The two lower drainage valleys among the three have distinct seismic-reflection attributes which are characterized by relatively strong and discontinuous reflections; whereas the upmost (youngest) one is by relatively weak and scattered reflections. The summary of relief and axial depth for the three drainage valleys is listed in Table 4. The relative relief and axial depth of the paleochannels were determined by direct graphic measurements from seismic reflection profiles in this study. These measurements are believed to be quite representative to the original channel features because most of the side-walls of the paleochannels, as well as the the basal fill of sediments, remain apparently primary valley features although both relief and width of a paleochannel could have been modified by erosion before the following marine transgression (filling). Most of the side-walls of the paleochannels appear in steep channel margins in seismic profiles; and natural levees (?) also appear along the paleochannels in some profiles, which confine the boundary of the paleochannel systems (see the seismic reflection profiles of (track line) Line 5 and Line 4 in Figures 7 and 8).

From Table 4, the paleochannel systems in the study area appear diminished in scales from bottom to top, or weakened with time since the

Table 4. Geometrical Features of the Three Paleochannel Systems

	relative relief	axial depth(m)	Width	locations w/ good controls
Present tidal channel	0~4m (1~4m)	-4 to -14	0~.1km (2~10m)	(on Line 11,btw 2300~2305; on Line 16, btw 525~530; on Line 25, stack# 1930);
Upmost Channel	0 to 5m (2~5m)	-12 to -24 (-14~-24)	0~0.2km (50~80m)	(Line 15, near stack 330; on Line 32, near 1605; on Line 17, near 725);
Middle Channel (II)	0 to 8m (4~7m)	-15 to -24 (-18~-24)	0~.6km (.1~.4km)	(on Line 16, near 440~445; on Line 6, around 915; on Line 5, btw 1450~1455; on " 4, btw. 1335~1345; on Line 3, around 1105 on Line 42, near 625);
Lowest Channel (I)	0 to 14m (9~12m)	-15 to -31 (-24~-31)	0~1 km (.2~.6km)	(on Line 22, near 1715; on Line 16, btw. 440~445: on Line 6, around 915; on " 5, btw. 1450~1455; on " 4, btw. 1335~1345; on Line 3, around 1105; on Line 42, near 625).

Late Pleistocene: for instance, the relief of the lowest channel is about 9 to 12 meters with a maximum of 14 meters; respectively, the relative relief for the middle paleochannel system and the upper one are about 4 to 7 m, and 2 to 5; the channel widths also show the trend: from the lowest channel to modern channel the valley width for the three channel systems changes from 0.2-0.6 km, 0.1-0.4 km and 0.05-0.08 km (the modern channel width ranges around 2 to 10 meters).

In most crossings, a single axial channel was found along the valley floor (especially for the upper paleochannel). However, on the north margin of the study area, a composite and/or a multi-cutoff meander loop may be present, this may be especially true for the two lower channels (see Figures 7 and 8).

The two lower channels appear to follow southeastward to southward courses across the study area. The paleochannel of the next lowest channel is almost directly confined within the lowest one's valley system, but has a relatively smaller scale (Figures 10 and 11).

The uppermost paleochannel system in the study area, here called Cape Charles paleochannel system (see texts in later chapters), apparantly has a scattered geographic distribution (Figure 9), trending generally southeastward, but its geometry was not well controlled in this study area. Some reasons for this are: (1)its relatively smaller scale; (2)destruction during erosion and filling; (3)seismic reflecting resolution. For instance, Colman and Hobbs (1987) have pointed out that hard-packed surfacial sand on the shelf could hinder penetration by high-resolution acoustic signals.

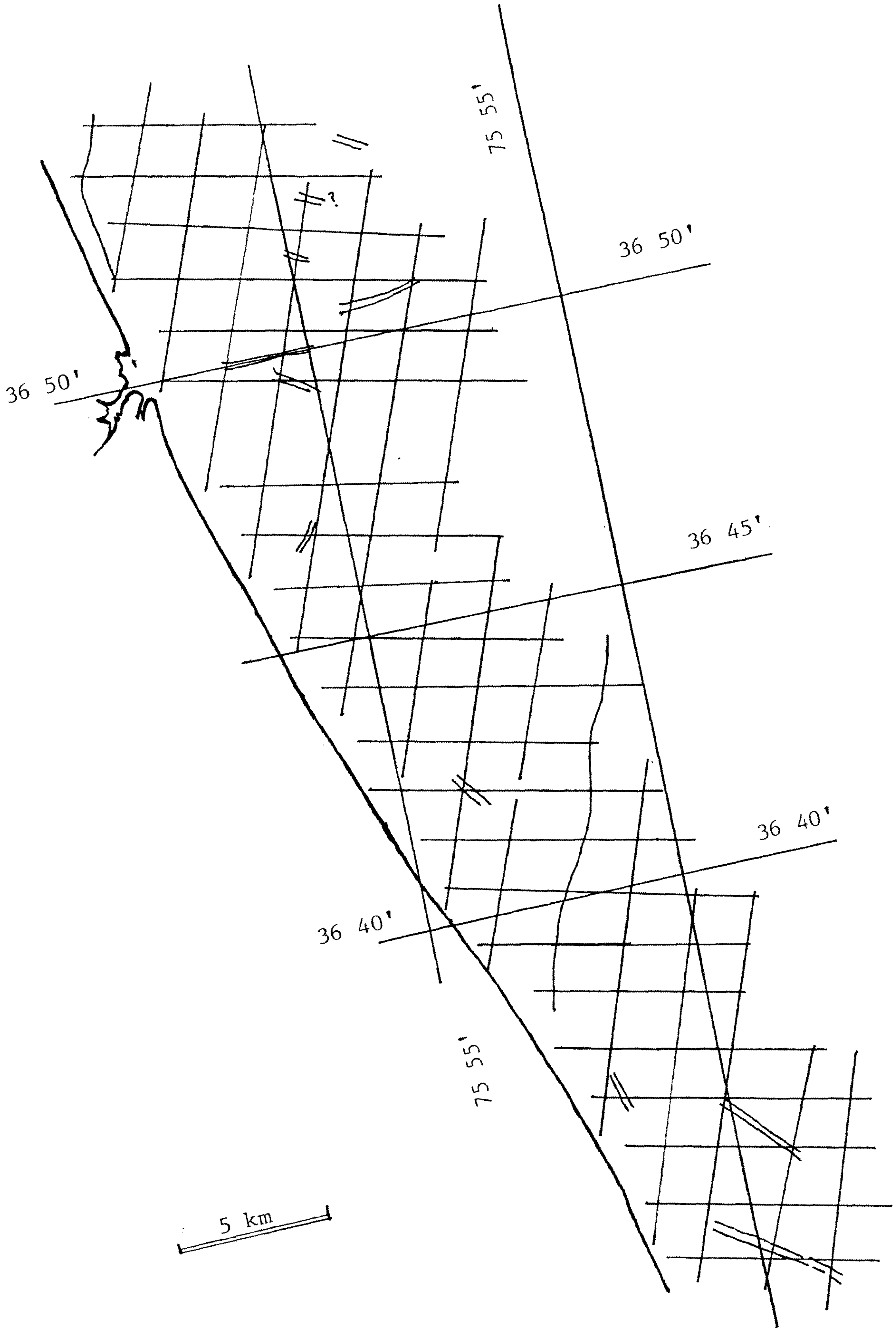


Figure 9. The upmost paleochannel systems(with major tracks)

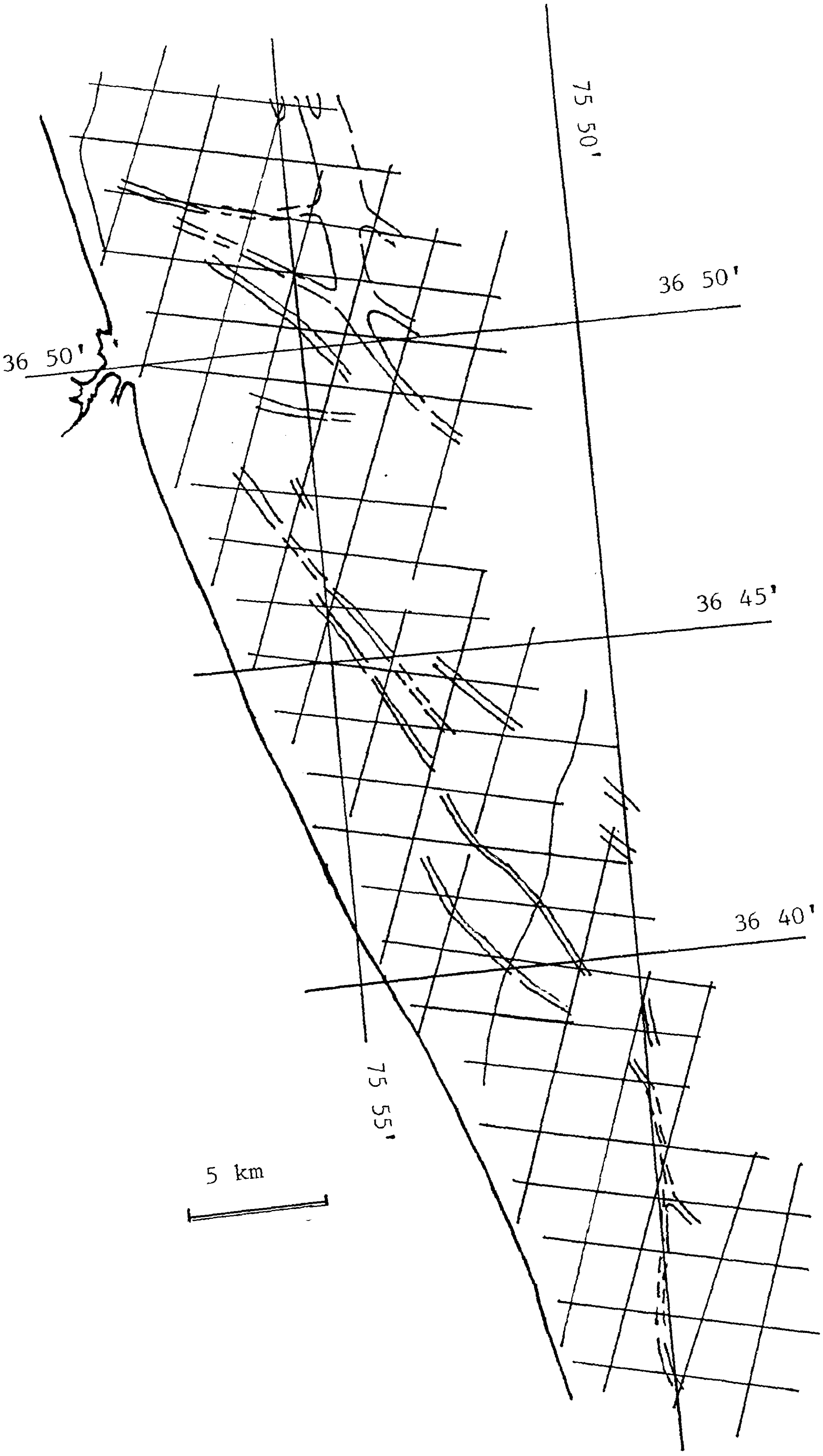


Figure 10. The geographical distribution of the middle-levelled Paleochannel system (only major tracklines drawn)

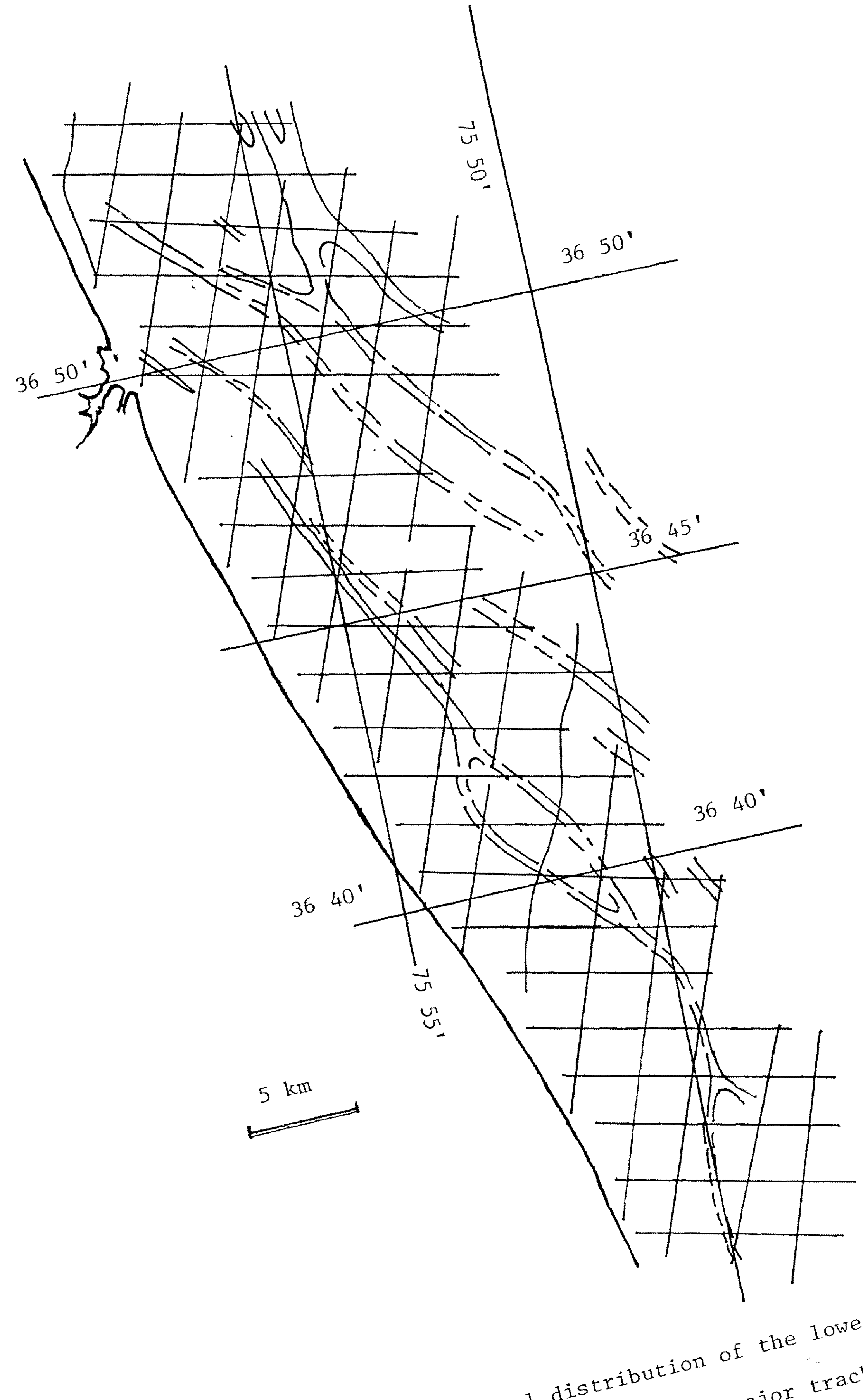


Figure 11. Geographical distribution of the lowest paleochannel system (with major tracklines)

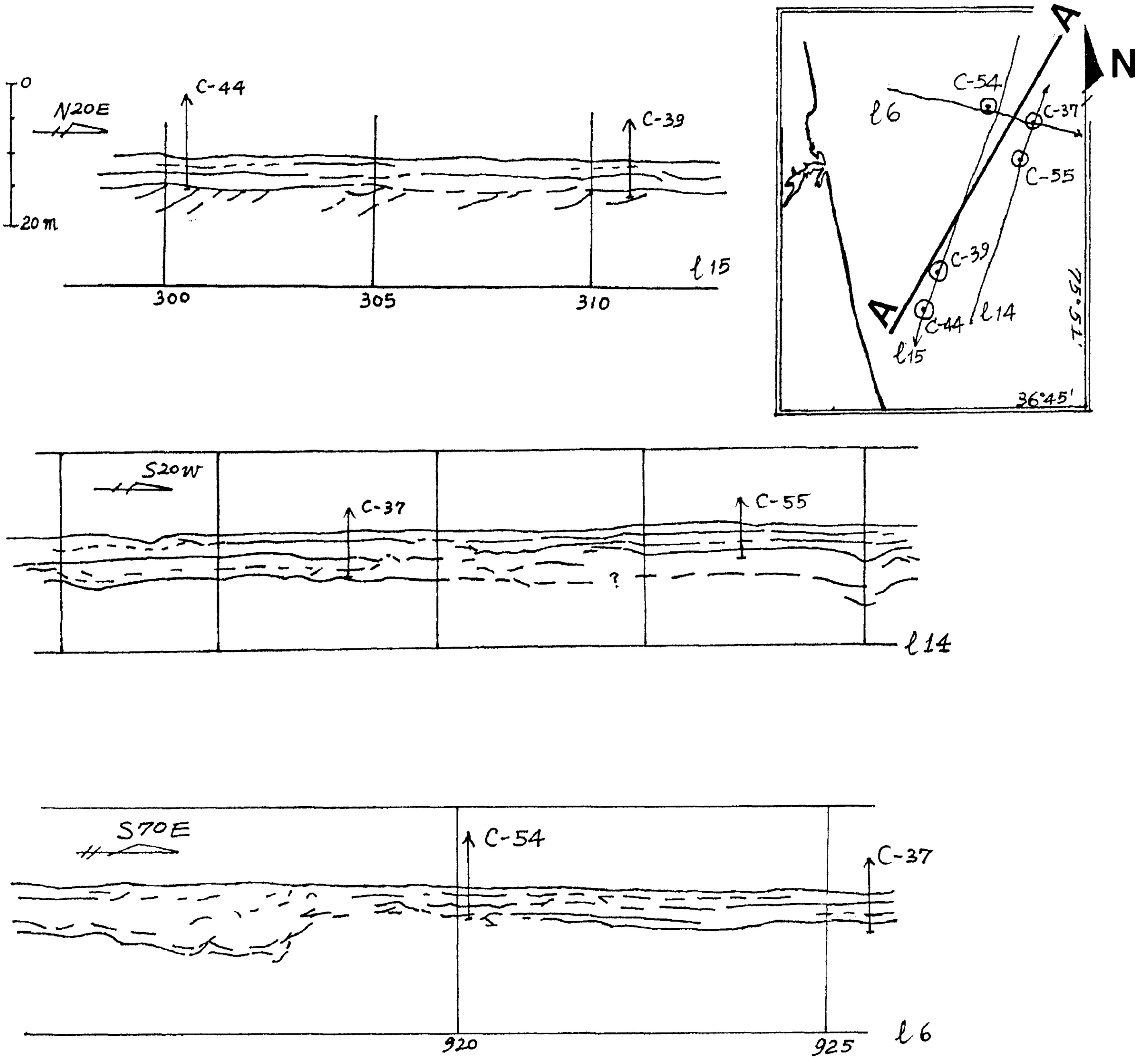
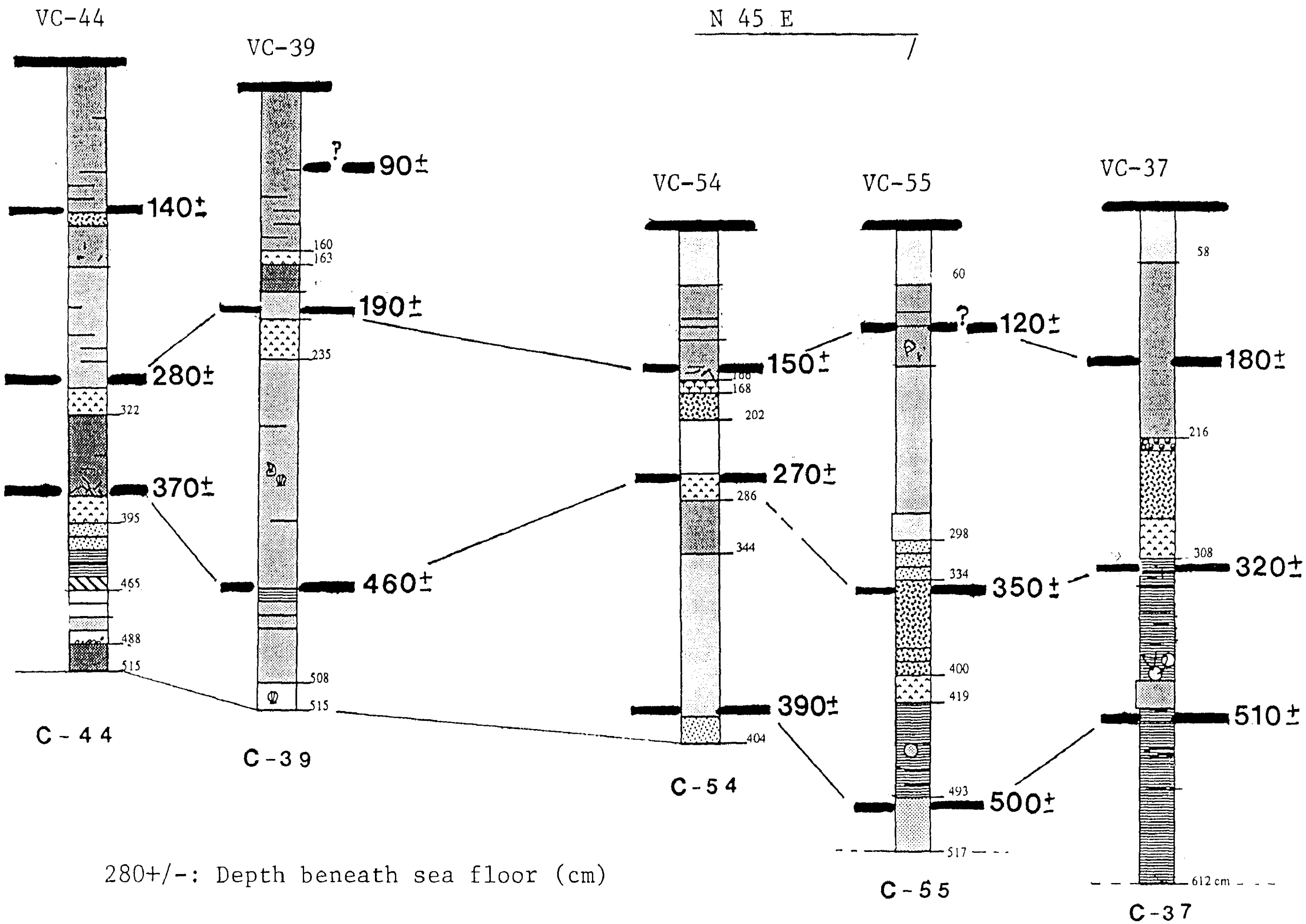


Figure 12 Seismic Stratification

Figure 13 Seismic Stratification (A-A')



280+/-: Depth beneath sea floor (cm)

All vibracores are projected on cross-section A-A'.

Seismic survey resolution: +/- 50 cm.

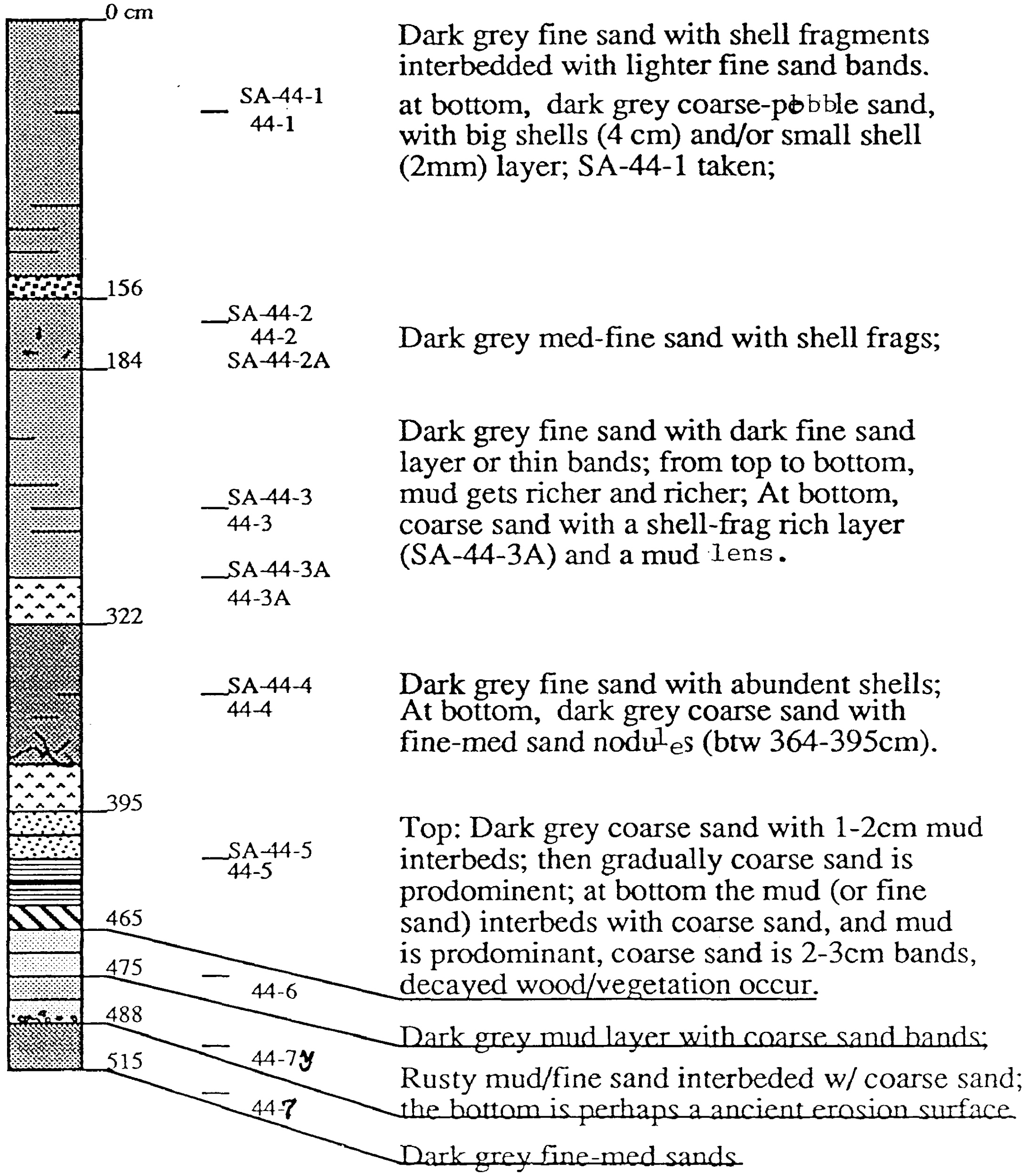
Figures 12 shows some portions of seicmic tracklines 15, 14 and 6 along which five vibracores were taken and examined in detail. The vibracores here provide important cross-checks on the resolution of the seismic survey in this study. It is clear, from Figure 13, that the significant seismic reflection surfaces indicated by obvious reflecting interfaces in the seismic profiles are reasonablly compatible with the major lithological boundaries, such as coarse sand -- fine sand boundary, throughout the A-A' cross-section of the five vibracores, and that the seismic resolutions using the 3.5 kHz band are well confined within a half meter limit (Hobbs, personal communications). Detailed vibracore descriptions can be found in Figures 14-18.

2. Stratigraphy and Sedimentology of the Channel Fill Sequences:

The Stratigraphy of the channel fill and underlying deposits is revealed by the seismic reflection data. In general, the paleochannel fill is transparent to the acoustic signal. To massive sediments, the acoustic reflection appears generally isolated and/or discontinuous. However, at the bases of the paleochannels and at the physically well seperated sediment boundary (e.g., between two sedimentary sequences), a relatively strong reflection is generally present (along a physical boundary).

Only three major seismic stratigraphic units (see Regional Seismic Stratigraphic Units B, C and D in the previous Chapter of "Regional Geology") among the four regional seismic units, are apparent in this study area. (see the seismic reflection profiles in Figure 5 to Figure 8, which

Fig. 14 Log of Vibracore vims-44



Dark grey fine sand with shell fragments interbedded with lighter fine sand bands. at bottom, dark grey coarse-pebble sand, with big shells (4 cm) and/or small shell (2mm) layer; SA-44-1 taken;

Dark grey med-fine sand with shell frags;

Dark grey fine sand with dark fine sand layer or thin bands; from top to bottom, mud gets richer and richer; At bottom, coarse sand with a shell-frag rich layer (SA-44-3A) and a mud lens.

Dark grey fine sand with abundent shells; At bottom, dark grey coarse sand with fine-med sand nodules (btw 364-395cm).

Top: Dark grey coarse sand with 1-2cm mud interbeds; then gradually coarse sand is prodominent; at bottom the mud (or fine sand) interbeds with coarse sand, and mud is prodominant, coarse sand is 2-3cm bands, decayed wood/vegetation occur.

Dark grey mud layer with coarse sand bands;

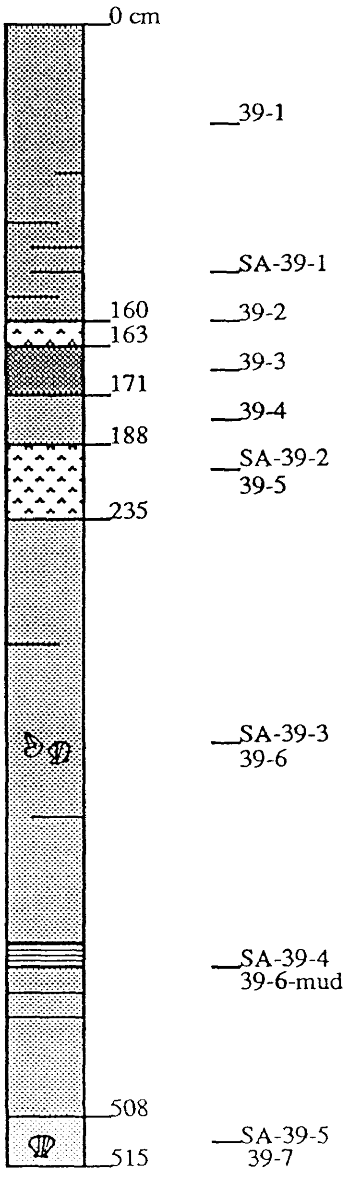
Rusty mud/fine sand interbeded w/ coarse sand; the bottom is perhaps a ancient erosion surface.

Dark grey fine-med sands

'44-5' for sediment samples.
'SA-44-5' for fossil samples for age dating usage.

(see text for details)

Fig. 15 Log of Vibracore vims-39



Dark grey fine sand with shell fragments; occasionally dark organic-rich noduals can be seen (perhaps a piece of decaied wood); there are number of dark bands (1-20mm in thickness) interbeded with light grey ones.

At bottom, coarse sand and pepples occurs; the pepple size are some 4 mm.

Dark grey fine sand ;

Grey fine-medieum sand with dark fine sand layer or thin bands;

Grey med-coarse sand with shells (7-11cm) as well as some pebbles (10mm);

Grey -dark grey fine-med sand;

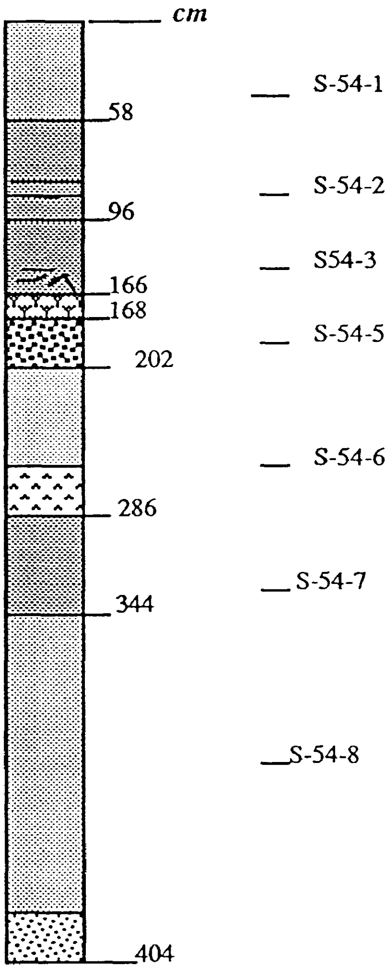
in 277-280cm, there is a shell layer, age sample SA-39-3 was taken;

two shell rich layers occur, and SA-39-4 was taken; a number of mudyy band (12 cm thick) occur.

Color suddenly change from grey into rusty; med-fine sand; some shells and fragments.

see text for details,

Fig.16 Log of Vibracore 86-54



Modern loose medium gray sand, 2~4mm shell fragments can be seen;

58-168cm: Dark gray medium sand, interbeding with ~3mm mud layers, or mixture of the two; 58-96 mud prodominebt, bot shell fragments get rich (166-168cm is shell layer);

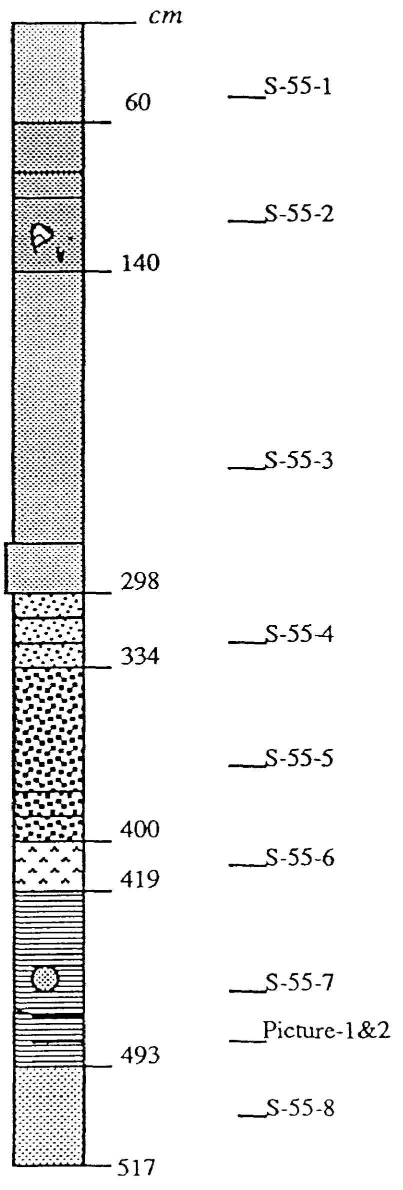
Greenish gray coarse sand

Medium-coarse sand with 2.6cm cobbles, top is heavy-rusty colored and gradually into coarse - pebble bottom portion;

Yellowish gray medium sand, well sorted;

Light yellowish gray / light gray medium ~ coarse sand, from top to bottom gradually get coarser.

Fig. 17 Log of Vibracore 86-55



Coarse to medium gray sand , 2~4mm shell detritals occaionally can be seen;

Dark gray medium sand, interbeding with ~3mm mud layers, or mixture of the two; shell fragments

Light yellow-greenish gray medium sand; bottom get coarser;

gray coarse sand interbedded with greenish gray mud 0.8mm bends, no shell/fragments;

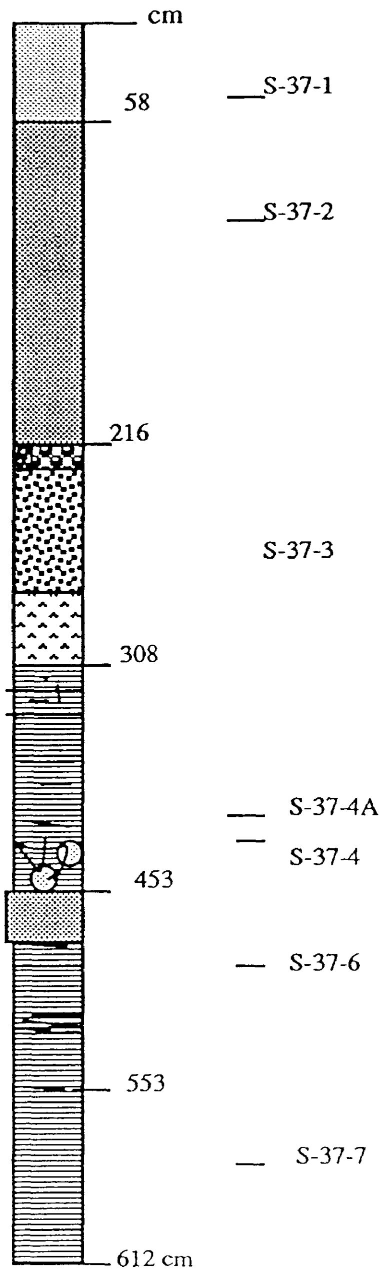
Yellowish gray medium sand with 3mm-sized pebbles, at bottom there are 2 mud /or fine sand layers;

rusty-color coarse sand / pebbles;

mud layer occasionally wity 4mm pebbles or coarse sand noduals, in the middle portion there are 1~3mm thick mud interbedded with 1~4mm thick sand bands. at bottom gradually into sand layer;

Brownish gray medium sand.

Fig. 18 Log of Vibracore 86-37



Coarse to medium gray sand , 2~4mm shell detritals common, at bottom a mud-fine sand layer 2cm thick;

Dark gray medium-coarse sand, with dark and light gray color noduals;

Rusty colored coarse sand, at top pebbles are rich, and gradually get into dark gray coarse-fine sand noduals, at bottom there is a pebble-cobble layer, rock fragments can be as big as 9cm in size;

Greenish gray fine sand / mud with aboundent clam shells of 1-3cm in size; erosion color is brick-red;

Brown-reddish gray mud / fine sand, contain bentonite(?)--popped up.

Reddish gray mud.

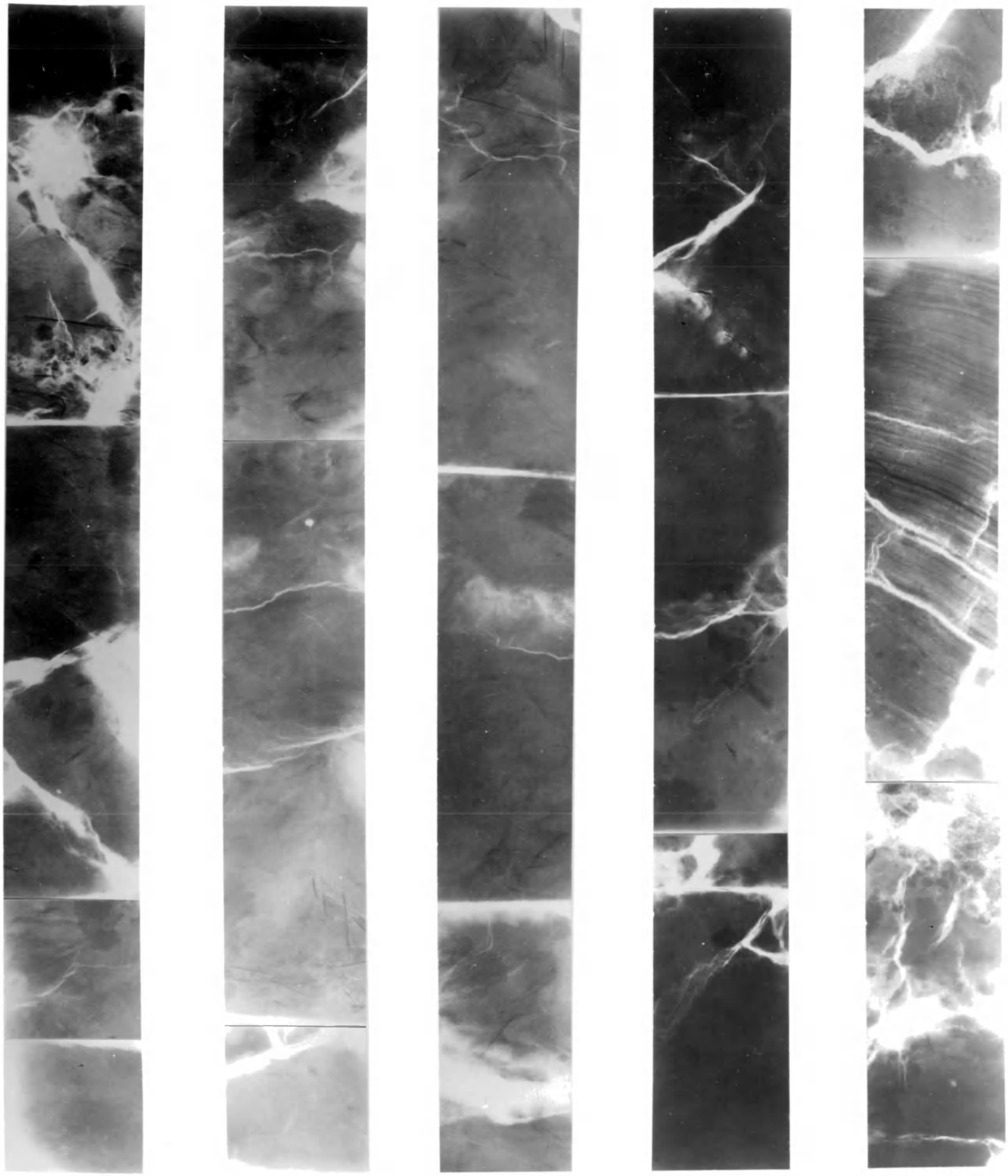
can be considered as the representative of the study area's seismic stratigraphy). The three units, capping the Virginia coastal plain's major erosion surface of the Yorktown Formation, probably are representative of the sedimentary sequences formed during the three periods, early-mid to early Late Pleistocene, the Late Pleistocene, and the Holocene. The generalized stratigraphy (including the seismically faint-signalled Yorktown Formation) is described in the earlier chapter of 'Regional Geology.' Basically, the three-fold seismic stratigraphic framework is similar to those studied in the nearby areas (Colman and Hobbs, 1987; Colman and Halka, 1989; Dame, 1990).

The detailed lithological logs of the fill are described in Figures 14-18. The descriptions of the stratigraphic columns (vibracores) were carried out based on AAPG standard charts and color guidance. The lithologic and petrologic features are relatively similiar in the vibracores each other. Grain-size samples and fossil samples were collected from these vibracores after stratigraphic description and X-ray stratigraphic analyses.

X-ray analysis was also utilized in this study for revealing, in a fine scale and an un-disturbed pattern, the sedimentary structures and the depositional environments, as well as the bioturbation and burrowing traces. The X-ray stratigraphy was carried out on a DINEX 120F X-ray Machine at VIMS Benthic Lab. (The results are displayed in Photos 1a, 1b and 1c; Photo 2 shows fossil layers in the vibracore of Core-39). The X-ray Stratigraphic

Photo 1a

Figure X-Ray Stratigraphy for VB-Core 39

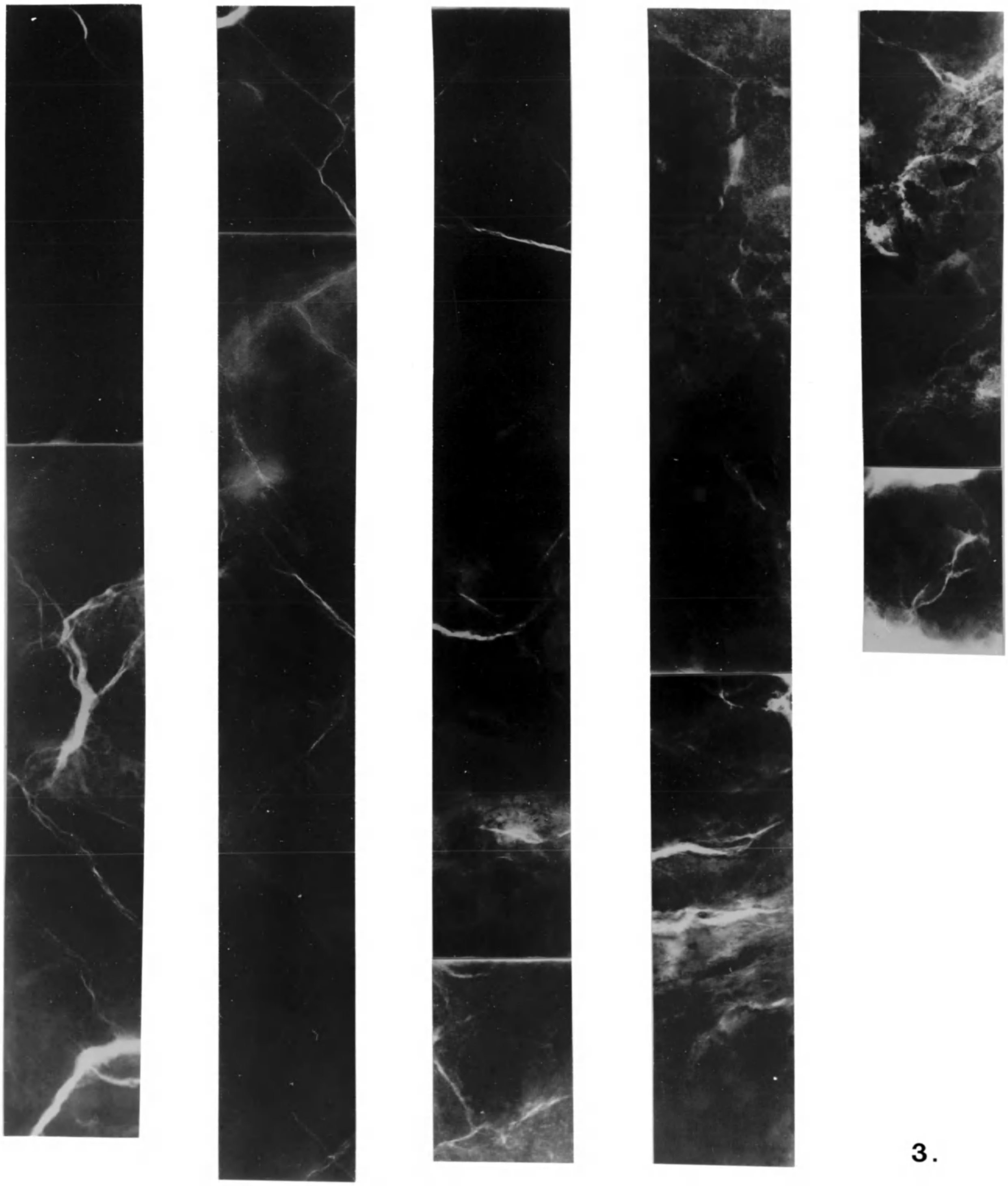


1. a

photo 1b

2.

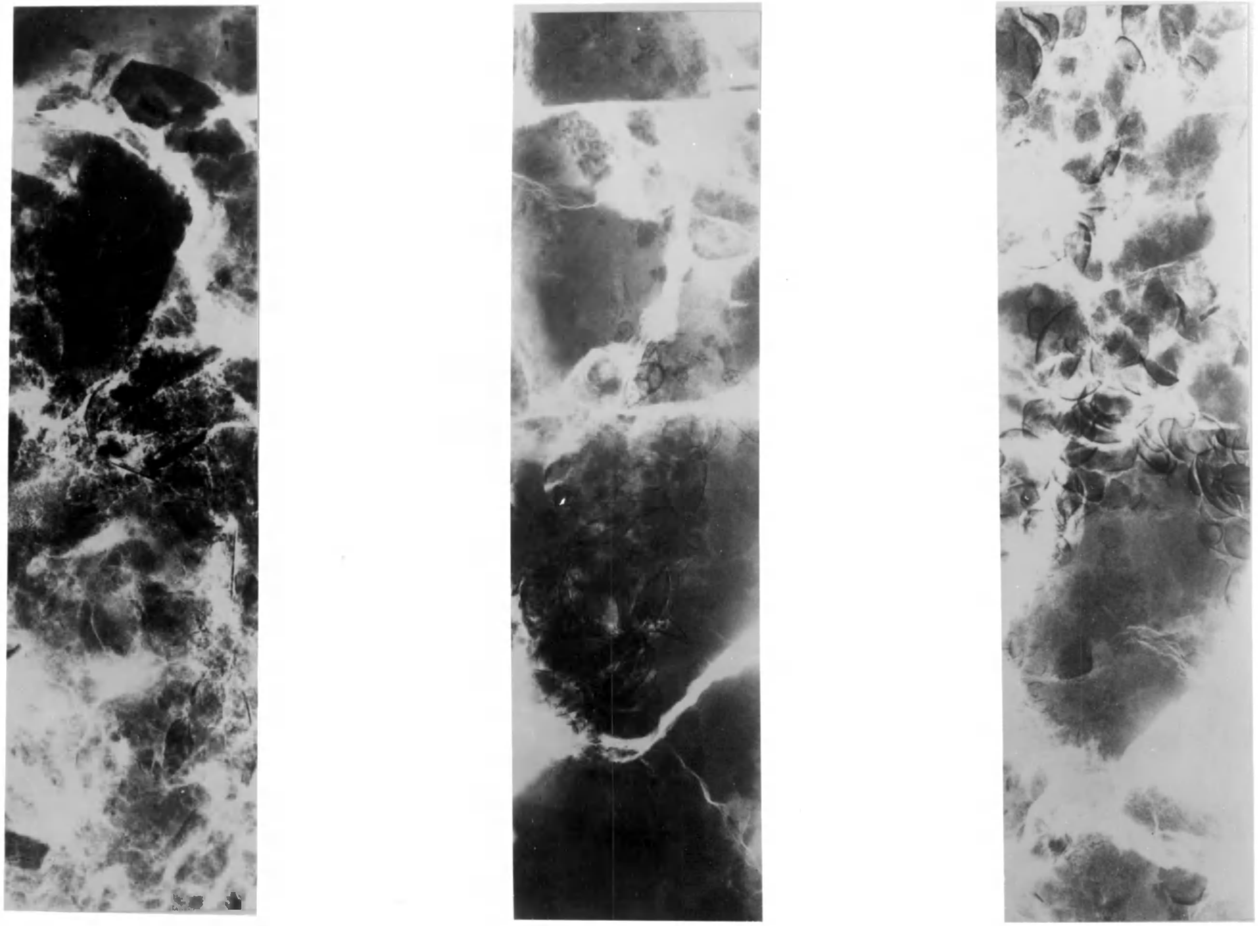
Photo 1C



3.

photo 2.

Figure Some Fossils in VB-44



Analysis Guidance at the VIMS was closely followed. In general, long exposure (2.5 mins) and high voltage (75 kv) were applied in analysing the sediment samples of this study, due to the fact that the predominant sediments in the stratigraphic columns are dense mud and sand, or sand-silt. Photo 1-a to 1-c are a complete x-ray stratigraphy log for the vibracore VB-86-39: at the depth from 160-163 cm, rhythmic bedding was shown, each unit layer has a thickness from 1 to 4 mm. The silt-sandy beddings are not identified by eye in lithological stratigraphic examination. However, the x-ray graphics revealed the rhythmical depositional sequence. Other sedimentary structures, such as scattered fossil (shells) accumulating beds and relatively featureless (homogeneous/massive) beddings were also revealed in the X-ray stratigraphy. The 'homogeneous' beddings in the X-radiography occupy a very large portion of the stratigraphic sequences in this study. The reason for this is probably the primarily low-energy depositional environment (silt-clay minerals with sand aggragation); but other possible explanations are biological agitating at semi- and post- depositional processes and the compacting destruction (for instance, degas/dewater processes could destroy primary depositional structures) (Pettijohn, 1975).

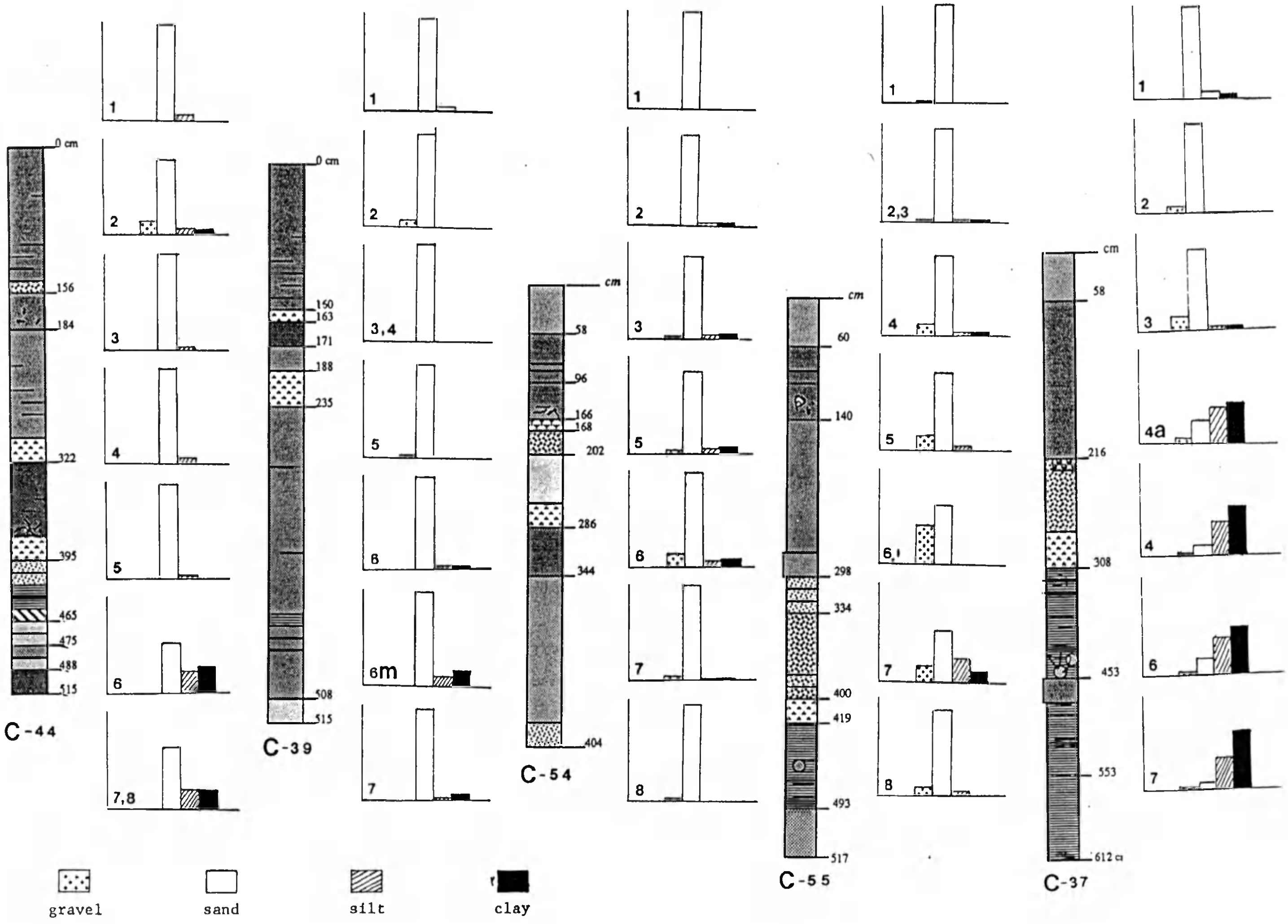
Sedimentologic analyses for these sedimentary sequences are conducted with two aspects: (1)grain-size analysis and its direct indication to the depositional hydrodynamic condition (Dyer, 1980, 1986; Dyer and Soulsby, 1988; Sternberg, 1971); (2)Graphic provenance/depositional environmental analysis majorly based on Folk's and Friedman's empirical diagrams (Folk and

Ward, 1957; Friedman, 1967, 1979; Friedman and Sanders, 1978; Friedman and Johnson, 1982).

(1) Grain-size analysis: based on petrologic and lithologic descriptions of the vibracores, eight(8) layers for VIMS-86-44 (or Core-44), seven(7) layers for VIMS-86-39 (Core-39), seven(7) layers for Army-86-54 (Core-54), eight(8) layers for Army-86-55 (Core-55) and six(6) layers for Army-86-37 (Core-37) were subdivided for each vibracores (Figures 12 to 16 for each column). The sampling locations in these vibracores are also indicated on these figures.

The grain-size study includes two parts of analysis: Pipette Analysis and Rapid Sediment Analysis (RSA). The former analysis is to distinguish finer (4-8 phi) sediments from the rest of the sediments. The latter is for sandy sediments. Detailed laboratory operation can be found in the RSA Guide Book in the VIMS Sediment Laboratory. Figure 19 is a composite display of gravel-sand-silt-clay ratios for each sublayer in all the five cores. It also provides a comparative indication for the hydrodynamic or energy conditions for these sediments in the vibracores. As indicated in this diagram, at least two or three different hydrodynamic conditions appear within the columns, or during the sedimentation history. These RSA data (for each sublayer sample there are thirty-three(33) measurements automatically made (at 33 different phi-value intervals). The consequent 33 x 38(sublayers)-sized data matrix was the foundation for further statistical manipulations. (Table 6 shows a portion of the 33x38 data base). The complete statistical treatment of these grain size data and the analytical

Figure 19 Sediment Distribution Correlation in the Vibracores



results will be discussed in a later chapter.

(2)The sandy portion of sediments (0-4 phi or 0.05-2mm) are sensitive to hydrodynamic conditions and associated variations (Bagnold, 1963; Dyer, 1980 and 1986; Sternberg, 1971), thus the analysis of sandy components has specific meanings for estimating depositional energy environments and sediment provenances. Based on this pressumption, Folk (1957) and Friedman (1967), have developed, so called, size-environment diagrams from more that tens of thousand observations. By analysing the sediment sample's kurtosis(KG) and skewness(SK), Folk (1957) tested KG vs SK diagram in differentiating coastal marine environments, such as beach sand, wind-flat, beach-dune and so on. Instead of using two extreme end-member feature to discriminate sedimentary environments, Friedman (1967 and 1979), Friedman and Sanders (1978), and Friedman and Johnson (1982) used so-called 'skewness vs standard deviation (SK-sigma) diagram,' which was employed to different fluvial enviroment from a beach environment.

In this study, however, neither Folk's nor Friedman's graphics were conclusive for the grain-size data. This may hint that cautions need to be taken when employing these two diagrams for depositional environment analyses.

3. Amino Acid Geochronology

As Wehmiller (1982) and Wehmiller et al. (1988) pointed out, aminostratigraphy relies upon the observation that amino acids contained in fossilized skeletal organic matter (in molluscs, for instance) undergo racemization during diagenesis:

Polypeptides (high weight molecules -> low ones)
----> Free AAs
----> Racemization (L->D)

The L->D change of amino acids is temperature dependent. The racemization rate differs intergenetically as well. And the D/L ratio ranges from 0.0 (modern samples) to 1.0 (equilibrium). The time to equilibrium takes around 0.2 million years (in tropic regions) to 10 million years (at high latitudes). This leads the establishing of so-called kinematic amino-stratigraphic zones along the Atlantic coast (Wehmiller et al., 1982, 1988), which offer estimates of sample ages, rather than "dates".

This study area is within the documented aminozone II (Wehmiller, 1982, 1988). In this region, five aminozones are divided based on D/L ratios:

	D/L	age estimates ka	isotope stage
II-a*	0.16 to 0.22	100 +/- 25	5a to 5e
II-b	~ 0.33	????	????
II-c*	~ 0.44	220 +/- 25	7
II-d	~ 0.59	500 +/- 100	11, 13 or 15
II-e	~ 0.89	----	----

* Well calibrated by U-series and U-Th ages. (Szabo, 1985; Wehmiller,1988)

In this study, all the amino acid analyses were carried out at Dr. Wehmiller's laboratory in the University of Delaware between September and November, 1991. All the D/L ratios are reported in A/I values (two of major Amino acids: Alloisoleucine(-D) and Isoleucine(-L)). The reason for this is simply because the two amino acids are common. Since the D/L or A/I values vary intergenetically, it is important to limit the comparison of amino acid results to fossil groups of which the amino racemization rates are similar. For the data considered in this study, Dr. Wehmiller suggested that the Mercenaria and Rangia racemize at similar rate, and Mulinia and Ensis at a similar rate but slower than the former pair. (Results of amino acid data in this study are displayed in Table 5). Dr. Wehmiller offered the following comments on the analytic results:

> "The preliminary conclusion to be drawn from the results we have obtained is that the Mercenaria A/I values between 0.15 and 0.28 probably all represent 'late Pleistocene' material-- definitely Stage 5 and perhaps Stage 7 (reworked or in place?). We have seen these same ratios in on-shore deposits, and the range of A/I values is quite consistent with a range of ages between about 75,000 and 130,000 years. Belknap calculated ages in this range for each sample that he analyzed-- I prefer to group these apparant ages into a 'Stage 5' age assignment rather than assigning specific ages to each sample because

Table 5 Amino Acid Analysis Result

vb-core#	fossil information	A/I ratio	amino zone#
Army-37-5	Rangia Mactridae	.51, .55, .61	II-d
Vims-44-3	Mulinia cf Lateralis	.10, .11	~II-a
" -44-4	" " "	.14, .15	~II-a
" -44-5	Mercenaria Veneridae	.18, .20	II-a~b?
Vims-39-1	Ensis Solenidae	.01	modern
" -39-3	Spisula Mactridae	.11,	~II-a
" -39-4	" " "	.14	II-a
" -39-5	Nassariidae Nassarius	.15, .21	II-a~b?

> there are so many geochemical factors that can affect the actual A/I measurement."
>
> "The Mulinia samples that I analyzed from the (vibracore Vims-89-44) S-44 are interesting in that they show increasing A/I values with increasing stratigraphic age--this is always a important test! The Mulinia A/I values are quite consistent with a Stage 5 age assignment, and they are consistent with the slightly higher A/I values for Mercenaria from the same core. The Ensis sample from (vibracore Vims-89)-39 is clearly Holocene;..."
>
> "Perhaps the most interesting result is that for the Rangia sample that you sent. This sample is clearly much older than the others, and I note that Belknap also 'found' old Rangia in samples obtained in Dame's study. I can't tell from the limited data whether the two 'old' Rangia are really the same age (by aminostratigraphy) or whether there might be two different ages instead. It certainly appears that there are some middle Pleistocene units being sampled in the area of study"

The above statement well reasons the age-assignments for the amino acid results obtained in this study. The age for the major sedimentary sequences of the two lower channel fill can be infered as Stage 5 and Stage 7 respectively, ranging from about 70,000 years to 250,000 years; the fill age for the upper channel is to be assigned to the Stage 1. Consequently, the ages for the three major paleochannel systems in the area come to be refered to the Stage 8, Stage 6 and the Stage 2 respectively. Further disscusions on age assignments and the stratigraphic correlations for the paleochannel systems will be presented in a later chapter.

4. Sediment Garin-size Factor Analysis And Results

In the earlier description we have discribed how the grain-size analysis was carried out in this study. Rapid sediment analysis(RSA) resulted in a 33 x 38 data matrixfor the study sediments (Table 6). The "33" stands for 33 phi-value intervals in RSA analysis, namely, the sandy sediments of different sizes (0 to 4 phi <or roughly 2 to 0.05 mm>) are measured at 33 equal length intervals; the "38" for 38 substrata sediment samples taken from the five vibracores in this study.

In order to understand the sediment vertical and lateral correlations among the sub-strata sediments, a Q-mode factor analysis was utilized in this study. Other geo-statistic methods, such as PCA, cluster and discrimnant analysis, were employed in early reconnaissance operations.

The PCA (principle component analysis) result (Table 7) only shows that there exist a few 'key' variables which can effectively represent the raw matrix variables (33x38): the first six variables(components) account on nearly 90% sample weight. However, the physical assignments to these principle "representatives" of components (the 'key' variables) are vague. Besides, the operation of a 33x38 matrix is relatively cumbersome, especially when the sample is to be precessed in cluster and/or factor analyses.

Simplification of the raw data matrix was made upon the correlation between sediment grain-sizes and hydrodynamic conditions, or the Shield's

Table 6 The Datafile Used for Discriminant Analysis (part of it)

ROW	Phi	c37.1	c37.2	c37.3	c37.4	c37.5	c37.6	c37.7
1	0.000	0.0538	1.5141	2.9333	0.0000	1.1350	0.0000	2.1072
2	0.125	0.8219	1.0680	5.4518	0.7682	1.2948	0.0000	1.1757
3	0.250	0.0000	1.5617	4.8772	2.9568	6.0172	0.2443	3.8480
4	0.375	0.0000	3.3777	4.5958	2.2830	4.9726	2.5069	2.1939
5	0.500	0.8314	0.6236	6.3708	1.9662	3.9143	1.8112	0.3138
6	0.625	0.0000	2.3798	4.8129	4.9488	2.0688	0.0000	1.5565
7	0.750	0.0000	3.4411	8.3545	2.1557	2.4815	3.3805	2.1914
8	0.875	0.0000	3.5794	5.1616	3.5902	4.4704	2.6028	0.8629
9	1.000	1.6858	1.9354	6.2349	2.5916	2.6386	0.9221	3.0029
10	1.125	0.1198	3.2484	5.3394	8.2074	2.0762	0.9271	0.3887
11	1.250	0.0000	5.1528	4.7127	1.6084	4.3286	1.8904	2.3599
12	1.375	1.5149	3.7439	5.6145	4.8354	2.7057	3.2924	0.2584
13	1.500	0.8588	6.7824	2.0148	3.0367	0.5375	1.1558	2.6424
14	1.625	0.0000	5.6549	4.2701	3.9532	4.0092	1.8717	0.9687
15	1.750	0.4317	8.2358	0.3358	1.1435	1.1953	1.3168	2.1065
16	1.875	2.0174	6.8295	2.1375	5.1030	0.4865	0.8316	0.2639
17	2.000	0.0000	8.0893	1.5537	2.0775	1.6846	1.8405	0.7331
18	2.125	1.1177	7.0561	0.5398	1.9192	1.8914	1.7278	2.0529
19	2.250	1.6392	5.5220	0.9604	1.8326	0.6225	0.0000	0.6261
20	2.375	1.9940	3.3655	0.7947	1.8226	1.8344	1.0372	0.8405
21	2.500	2.1292	1.3014	0.0000	0.0000	0.3389	0.0000	0.0000
22	2.625	0.4005	2.9368	0.7327	3.6961	0.1549	1.9178	1.6275
23	2.750	4.4693	0.2021	0.0000	2.2601	0.9252	0.8148	0.1129
24	2.875	7.3408	1.3538	0.4275	1.5332	1.9867	1.3484	2.7697
25	3.000	16.4705	1.4642	1.6120	2.5644	0.9969	4.1090	5.1457
26	3.125	18.5929	0.2301	0.8420	5.1187	2.4505	7.2499	6.8415
27	3.250	13.2756	1.3826	0.0000	3.3477	4.4253	8.0728	8.8315
28	3.375	7.8445	1.1254	0.0000	4.8251	6.7484	8.8388	7.9800
29	3.500	5.6511	0.0782	0.0000	4.4777	5.7728	10.6381	6.9316
30	3.625	3.4173	0.1057	0.0000	3.2506	6.4656	8.3355	7.6193
31	3.750	2.3528	0.0000	0.0000	2.7525	6.5990	7.5898	5.1696
32	3.875	2.1813	0.0000	0.0000	1.0706	3.0004	4.4634	4.4181
33	4.000	0.3674	0.0000	0.0000	3.4942	3.1539	2.5559	3.5535

each individual sample (38 samples total) →

33 x 38 dimensions

↓ Phi intervals

All sample numbers are the same as the ones in each vibracore logs.

Table 7 PCA Results (Eigenvectors and Scores to Each Sample)

Eigenanalysis of the Correlation Matrix

Eigenvalue	13.619	10.055	5.378	2.028	1.556	1.338
Proportion	0.358	0.265	0.142	0.053	0.041	0.035
Cumulative	0.358	0.623	0.765	0.818	0.859	0.894

Omitted...

SAMPLE NUMBERS

Variable	PC1	PC2	PC3	PC4	PC5	PC6
c37.1	-0.216	-0.030	0.228	0.004	-0.069	0.093
c37.2	0.200	-0.112	0.161	-0.190	-0.089	-0.033
c37.3	0.147	0.121	-0.014	0.367	-0.241	0.264
c37.4	0.004	0.066	0.168	0.095	0.309	0.508
c37.5	-0.064	0.214	-0.010	-0.160	0.213	0.223
c37.6	-0.165	0.119	0.107	-0.251	0.296	0.194
c37.7	-0.190	0.133	0.112	-0.262	0.121	0.061
c39.1	-0.213	0.001	0.237	-0.026	-0.092	0.099
c39.2	-0.159	-0.007	0.227	0.225	-0.332	-0.034
c39.3	-0.189	-0.044	0.228	0.171	-0.231	-0.098
c39.4	-0.076	-0.230	0.071	-0.282	-0.118	0.218
c39.5	-0.080	-0.273	-0.080	-0.037	0.084	0.108
c39.6	-0.071	-0.243	-0.169	0.188	0.195	-0.073
c39.6mud	-0.082	-0.255	-0.107	0.179	0.148	-0.071
c39.7	-0.011	-0.286	-0.035	-0.208	-0.036	0.032
c44.1	-0.211	0.006	0.228	-0.052	-0.068	0.157
c44.2	-0.133	-0.246	-0.093	0.051	0.093	0.043
c44.3	-0.054	-0.267	-0.175	0.101	0.132	-0.025
c44.3mud	-0.001	-0.273	-0.174	-0.051	0.010	0.113
c44.4	0.052	-0.234	-0.114	0.063	-0.094	0.389
c44.5	0.199	0.003	0.060	0.277	-0.052	0.355
c44.6	-0.133	-0.160	0.213	0.153	0.155	0.031
c54.1	0.166	-0.022	0.234	0.105	0.333	-0.135
c54.2	-0.155	-0.135	0.243	0.042	-0.021	-0.113
c54.3	0.128	-0.217	0.062	-0.251	-0.240	0.016
c54.5	0.227	-0.031	0.118	-0.031	-0.095	0.028
c54.6	0.220	-0.088	0.172	-0.081	0.028	-0.067
c54.7	0.187	-0.121	0.178	-0.218	0.027	-0.191
c54.8	0.236	-0.036	0.162	-0.006	0.013	0.038
c55.1	0.189	-0.011	0.229	0.126	0.209	-0.045
c55.2	-0.157	-0.138	0.256	0.040	-0.132	-0.108
c55.3	0.216	-0.042	0.205	0.078	0.137	-0.030
c55.4	0.203	-0.100	0.061	-0.023	-0.216	0.225
c55.5	0.062	-0.288	-0.013	-0.085	0.025	0.063
c55.6	0.215	0.015	0.133	0.112	0.125	-0.098
c55.7	-0.241	-0.009	0.171	-0.038	0.084	0.010
c55.8	-0.154	-0.191	0.082	0.294	0.153	-0.093

Table. 8 The Raw Data For The Selected Phi Intervals

Phi	0.0	.5	.75	1.25	1.5	2.75	3.25
THE SAMPLES (THE SAME ARRANGEMENT)	0.0000	0.0000	0.000	9.689	36.792	100.313	297.969
	10.0491	22.1424	33.157	52.995	35.532	1.300	8.897
	30.8711	52.8813	29.830	2.126	6.079	0.000	0.000
	8.5664	6.2455	4.660	3.313	5.309	6.548	9.699
	23.6177	9.7400	16.990	4.692	2.443	3.631	17.369
	2.1416	29.6349	16.572	11.544	0.000	7.143	70.770
	24.4331	13.9144	14.984	13.375	3.975	0.717	56.076
	0.0000	23.3376	0.000	13.833	0.000	51.485	533.186
	5.2201	27.8814	45.154	8.591	18.777	13.606	55.577
	0.0000	0.0000	0.000	0.000	0.000	133.470	493.366
	0.0000	22.5718	14.729	36.966	92.154	18.837	62.776
	0.0000	14.8905	25.148	25.045	56.955	69.708	46.540
	0.0000	0.0000	0.000	0.000	158.867	798.369	47.027
	0.0000	14.6138	40.638	30.217	107.594	322.842	40.734
	0.0000	14.3780	10.218	44.752	145.143	101.126	34.670
	0.0000	0.0000	0.000	7.267	17.197	34.225	665.906
	18.6233	0.0000	0.000	22.290	60.891	101.371	66.178
	8.1789	24.5368	16.350	49.326	190.524	376.992	25.192
	0.0000	46.1465	25.672	21.262	201.616	141.654	0.000
	5.4191	17.0516	8.483	8.915	32.328	18.695	5.323
	18.1301	29.3471	22.577	12.811	15.531	15.437	6.005
	1.6430	2.0774	4.943	5.975	11.108	27.563	19.066
	0.0000	16.7611	30.862	42.100	30.122	19.617	11.563
	0.0000	0.0000	185.740	304.016	12.131	78.130	0.000
	0.0000	0.0000	6.343	28.609	29.049	110.960	82.987
	14.7563	7.8454	11.075	33.906	46.808	5.040	13.110
	23.2506	15.6616	23.985	42.547	24.420	4.932	0.000
	7.8490	10.8050	38.352	56.004	41.972	6.250	0.000
	3.5596	13.6384	28.983	164.416	80.354	3.585	0.000
	21.3106	19.2695	23.709	52.885	20.125	6.572	0.000
	15.2324	71.9626	114.227	116.189	11.061	3.882	18.043
	0.3656	0.0000	8.088	28.999	29.809	38.235	45.447
	1.8762	21.8373	53.537	51.202	19.167	16.148	0.000
	12.1531	13.4686	23.813	9.390	29.837	2.269	2.490
	3.9053	0.0000	16.700	35.158	70.742	26.693	13.669
	15.7909	20.8879	32.660	43.303	4.691	10.422	0.000
	15.4234	3.5292	12.837	16.439	9.403	67.199	114.757
	3.2700	0.0000	8.458	7.916	18.496	68.540	28.918

sediment threshold curve in the sea (Sternberg, 1971; Dyer, 1980 and 1986). This led the raw data matrix of 33x38 into a 38x7 matrix(Table 8). This step of manipulation significantly decreased the computational time required, and assess an explainable multivariable correlation pattern. Also, it eliminated grain-size components that might form groupings among themselves "for lack of any unifying characteristic other than rarity" (Diaz, 1989).

Q-mode factor analysis was employed to ordinate the simplified grain-size data and to find clearly physical assignment for explanation to the data. Basic algorithms for this method can be found in Davis (1986). Operation of the analysis was performed using StatisticPac (modified) programs. Table 9 lists the factor analysis results(factor loadings, factor scores and explained variable percentages). The first five factors (variables) accounted more than 94% of the total variance. In order to achieve more straightforward physical meanings for the factors (physical assignments), a rotating of the factor coordinate was performed which resulted in a clear distinction among the factor scores. Axes (or factors) I, II, and III have relatively higher loading values (Table 10) and are considered to be closely related to the grain-size components of 3.25 phi, 2.75 phi and 1.25 phi. (The first three axes were correlatively plotted in Figures 20 and 21). Three or four groups can be then recognized: the Group I (or G-I), G-II, G-III, (and G-IV), representing the grain-size components 1.25 phi, 2.75 phi, 3.25 phi, (and 1.5 phi).

Based on the Q-mode factor analysis, a quantative correlation for the

TABLE 9. Q-mode Factor Analysis Result

38 (samples) x 7 (grain-sizes)

Factor Loadings Matrix

1	0.3937	-0.3028	-0.5840	0.4395	0.4591	-0.0897	-0.0154
2	0.4647	0.0697	-0.4944	-0.7150	0.1304	0.0479	0.0651
3	0.8693	0.2606	0.3272	-0.0659	0.1116	0.1508	-0.1725
4	0.7587	0.3384	0.4751	0.1428	0.0788	-0.1831	0.1550
5	-0.2682	0.8564	-0.2419	-0.0616	0.0024	-0.3551	-0.0786
6	-0.4397	0.7570	-0.0137	0.1365	0.3212	0.3294	0.0564
7	-0.4990	-0.3329	0.5133	-0.3041	0.5136	-0.1411	-0.0239

Factor Scores Matrix

a	-1.1449	-0.3857	0.9824	-0.0843	0.3022	-0.2746	-0.2250
b	0.3607	0.0286	0.2262	-0.6412	-1.0308	0.0869	0.5453
c	0.5154	-0.3918	-0.9034	-2.3022	-0.7136	1.4595	1.1571
d	-0.1879	-0.8407	-0.4693	0.8710	-0.4773	0.3528	0.0389
e	-0.1309	-0.6762	-0.0490	0.2331	-0.9202	0.7803	-0.4076
f	0.0515	-0.6398	-0.2418	-1.0450	-0.5155	0.8807	1.1102
g	-0.0773	-0.7091	-0.0720	0.0143	-0.5591	0.5027	0.1870
h	-1.0007	-1.1108	1.1930	-1.8653	1.7146	-0.3332	1.3492
i	0.3979	-0.3935	-0.3374	-0.7549	-0.0828	0.8476	-1.7052
j	-1.4492	-0.9202	1.5695	-0.4798	1.4497	0.2818	-0.0727
k	-0.1812	0.4189	-0.1046	-0.8594	-0.8097	-1.2167	0.0177
1	-0.2012	0.2408	0.1693	-0.3675	-0.7919	0.1253	-0.6191
m	-2.0734	3.2080	-0.2606	1.0736	1.4441	2.8810	1.2228
n	-0.4460	1.5988	0.1104	-0.1483	0.1821	1.0161	-1.2392
o	-0.4862	1.2027	-0.1575	-0.3049	-0.7772	-1.8943	-0.4471
p	-1.5584	-1.2505	2.0240	-0.9918	2.0419	-1.3432	-1.1018
q	-0.5430	-0.0570	-0.2832	1.1753	0.1150	-0.6335	-0.0115
r	-0.4876	2.3343	-1.1604	0.0966	1.3210	-1.1114	0.1924
s	-0.1699	1.9802	-1.3041	-2.0607	-0.3612	-1.9424	-1.6002
t	-0.1274	-0.3830	-0.5484	0.0283	-0.6520	0.1178	0.2344
u	0.3413	-0.5224	-0.8588	-0.4051	-0.0888	0.5965	0.3337
v	-0.4743	-0.5354	0.1770	0.5204	-1.2240	0.5969	0.0980
w	0.1772	-0.0334	0.2965	-0.3649	-1.0668	0.3557	0.1591
x	3.3671	1.6020	3.7893	1.0990	0.3025	0.4394	-0.7792
y	-0.6379	-0.0580	0.6192	0.4811	-0.7411	0.4625	0.8036
z	-0.1073	-0.1975	-0.1045	0.4823	-0.7876	-0.5869	0.1368
aa	0.7932	-0.8119	-1.4777	1.6573	1.5380	-0.7389	-0.1441
bb	0.5019	-0.0997	-0.0605	0.6249	-0.2477	-0.4012	-0.7733
cc	0.9033	0.7434	0.7341	0.4187	-0.5235	-2.2710	3.8988
dd	0.8551	-0.7472	-1.3368	1.3444	1.3835	-0.6284	0.6965
ee	2.8217	0.0852	-0.9733	-2.0154	2.0863	0.8532	0.0944
ff	-0.4532	-0.2271	0.5107	0.5139	-1.1510	0.0445	0.3314
gg	0.6635	-0.0389	0.2789	-0.4660	-0.7077	0.7785	-0.6719
hh	0.2285	-0.5831	-0.8377	0.7357	0.1116	-0.0628	-1.3811
ii	-0.2474	0.1322	0.1198	0.8107	-0.8783	-0.9110	-1.0761
jj	0.7944	-0.7171	-0.9040	0.7758	0.7856	0.2084	0.2865
kk	-0.0974	-0.8653	-0.4993	1.4241	1.1632	0.0426	-0.4195
11	-0.4900	-0.3799	0.1439	0.7764	-0.8335	0.6387	-0.2191

38 SAMPLE NUMBERS (see text for detials)

Percent of total variance explained by 7 factors

31.6663	24.2320	17.7203	12.0575	8.7627	4.5872	0.9740

Table 10 Rotated Scores For the First Four Q-mode Factors
(For the Raw Data of 38 x 7)

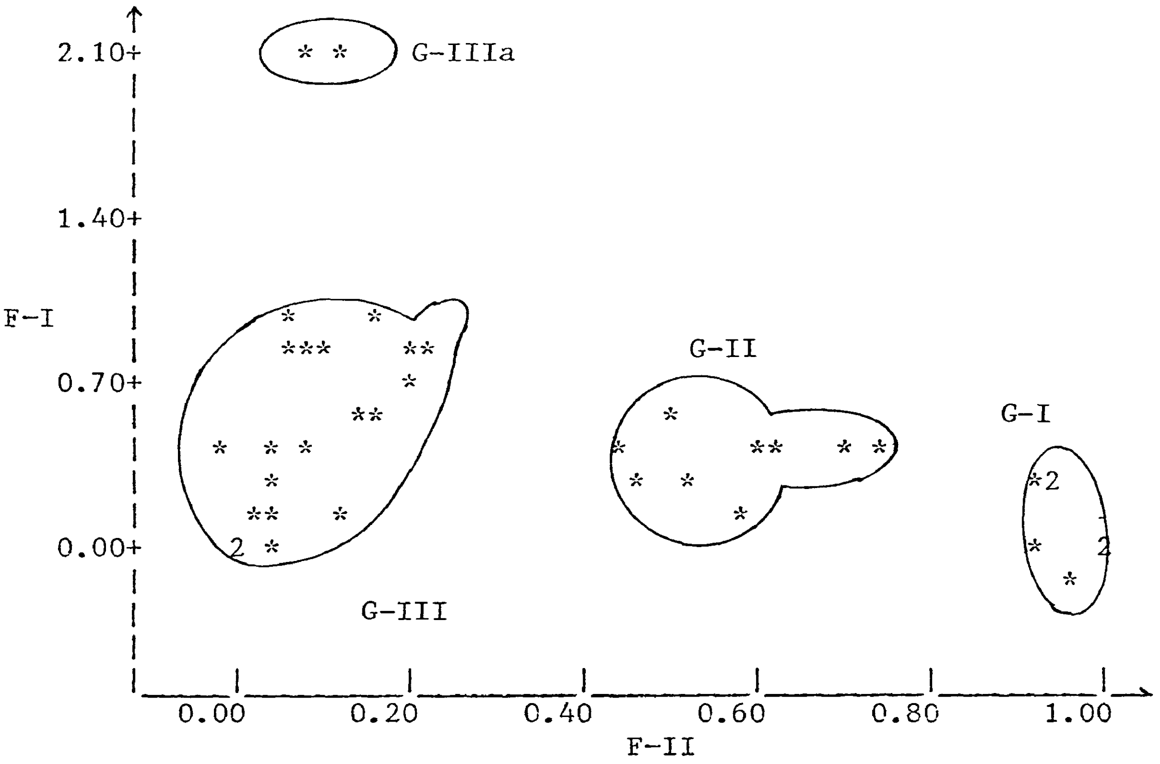
Phi values**	1	0.1197	0.0268	-0.0019	-0.1408
	2	0.2249	0.0647	-0.0111	-0.6170
	3	0.4219	0.0728	-0.0559	-0.5352
	4	0.7180	0.0333	-0.0725	0.1955
	5	0.4717	-0.0529	0.4183	0.4552
	6	-0.1302	0.0026	0.9032	-0.2392
	7	-0.0474	0.9929	0.0272	0.1016

The Phi numbers 1, 2, 3, 4, 5, 6, and 7 represent the following Phi values (respectively):

1: 0.0 (phi)
2: .5
3: .75
4: 1.25
5: 1.5
6: 2.75
7: 3.25

(see text for detial)

Figure 20 Correlation Plot for Factors I and II

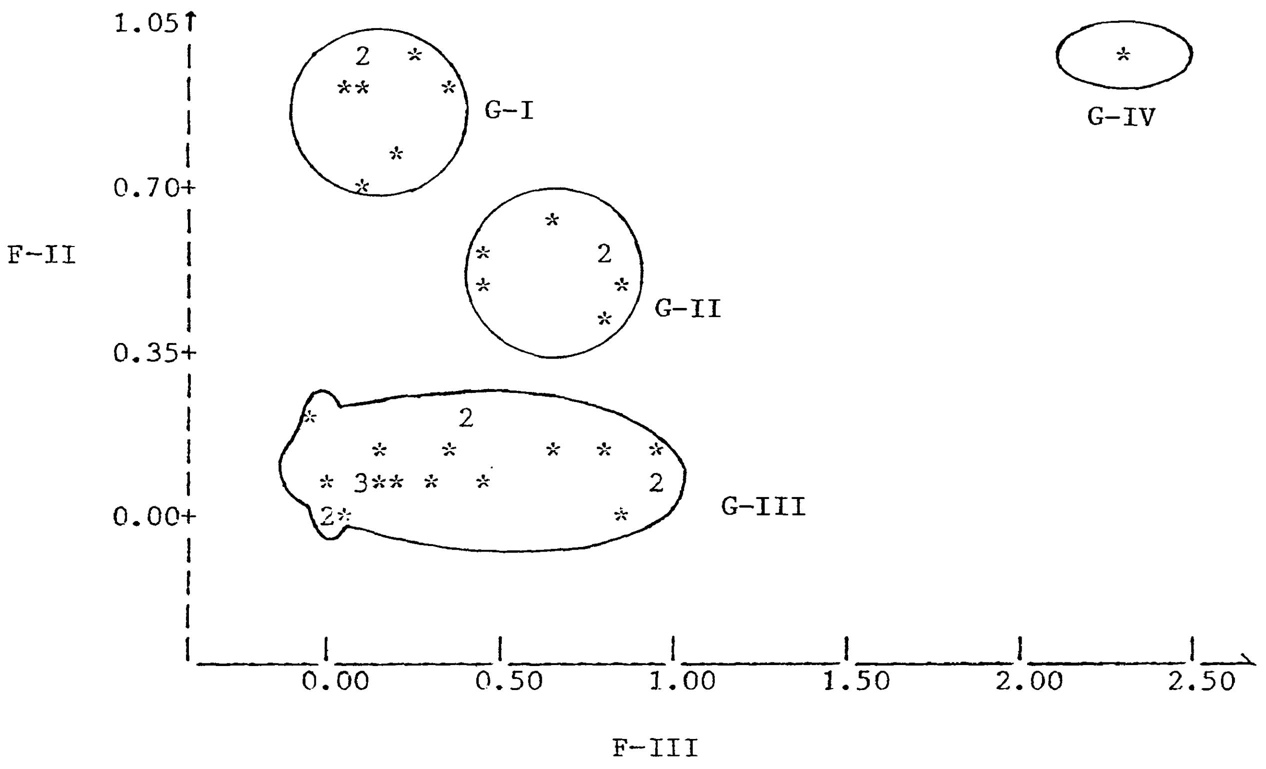


*: grain-size sample

2: two superposed samples

(see text for detial)

Figure 21 The Correlation Plot for Factors II and III

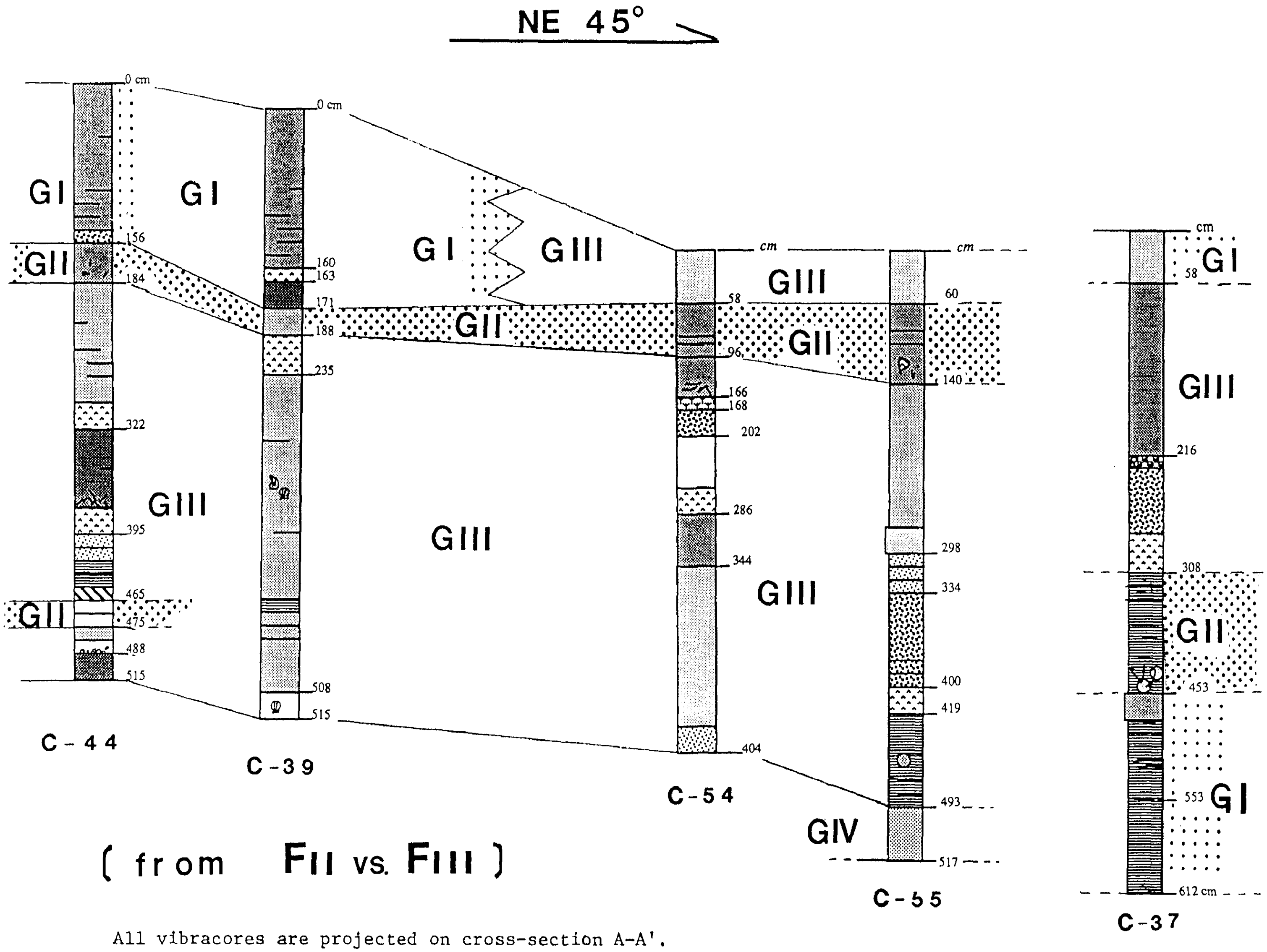


* : grain-size sample

2 : two superposed samples

(see text for detial)

Figure 22 Statistical Arrangement for the Substrata (A-A')



(from FII vs. FIII)

All vibracores are projected on cross-section A-A'.

G-I, -II and -III: for factor groups. See figures 20 & 21.

multiple sub-layers among the vibracores was made (Figure 22, the so-called geo-statistical arrangement diagram). In this diagram, one can find that three major stratificational units can be outlined by the Q-mode factor groupings (G-I, G-II, and G-III), and that the two distinctive regimes at the top and the bottom (G-I and G-III) are apparantly interrelated by a narrow transitional zone G-II throughout the A-A' cross-section.

DISCUSSION

1. Geomorphology and Age Assignments of The Major Paleochannel Systems:

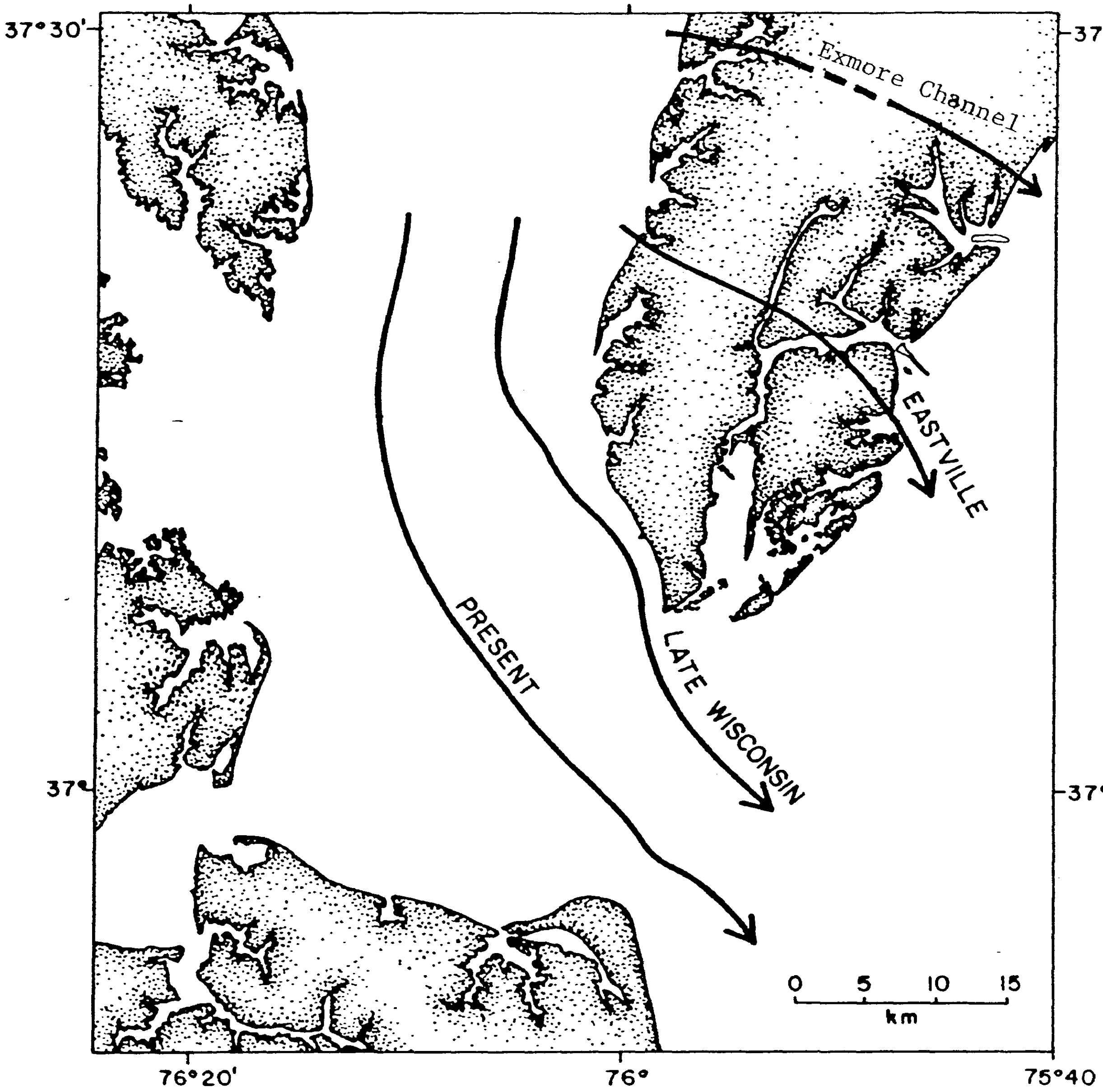
The geometry and fill stratigraphy of the Late Pleistocene paleochannel systems beneath Chasapeake Bay have been well documented (Colman and Hobbs, 1987 and 1988; Colman and Halka, 1989; Mixon, 1985; Shideler et al., 1984; Colman et al., 1991; and Hobbs, 1990). Three generations of paleochannel systems, the Cape Charles Channel, Eastville Channel, and Exmore Channel, have been identified. Multiple across-profile mappings within the bay have shown that seismic reflection profiles and interpretive cross sections of the main stem of the Exmore paleochannel are commonly cut by a major tributary of the Eastville paleochannel.

The similar physical characteristics can also be identified in this study region: the lowest paleochannels are often cut by a younger (upper) paleochannel systems (see Figures 7-8). The seismic reflection features of the upper (youngest) paleochannel system and the two lower paleochannel systems in the study region are characterized respectively by the relatively weak reflections, and by relatively strong-and-irregular reflections.

The major geomorphological difference of the paleochannel systems between the two regions is that beneath the bay all three paleochannels cross beneath the Delmarva Penisula east-southeast ward into the Atlantic Ocean (Figure 23; and Figures 9-11). The paleochannels in this study region,

Figure 23 Three Generations of Paleochannel System in the Bay

(from Colman et al, 1988)



(See text for detials)

however, are oriented more to the south ---- apparently inherited from the more southerly located ancient rivers (the ancient James River?). The ancient Susquehana River has been considered the major tributary of the Eastville and Cape Charles paleochannels in the bay (Mixon, 1985; Colman and Hobbs, 1987; Colman et al., 1988; and Colman et al., 1990).

The amino acid dates for the fill sequences and 'basal' sediments range from A/I values 0.01 to 0.61 representing Quaternary oxygen-isotope Stage 1, Stage 5 and/or Stage 7, through Stage 13, namely ranging in age from modern age to middle Pleistocene of approximately 500 thousand years (ka) BP. Except for some of the extreme Rangia ages which came from a muddy section of an unusual core (Vibracore 37), the amino acid groups for the sedimentary fill sequences are distributed as A/I values of 0.01, 0.11-0.14, and 0.15-0.21, corresponding to the isotope Stage 1 (Holocene), Stage 5 (100+/-25 ka) and Stage 7 (210+/-25 ka). Consequently, the ages for the major paleochannel systems in this study area are assigned to Stage 2, Stage 6 and Stage 8, correspondent to 30+/-10 ka, 150+/-25 ka and 260+/-20 ka BP.

Comparing these age assignments with the paleochannel ages beneath the bay, one finds that the paleochannel systems in this study region are compatible in age with the relatively better-studied Cape Charles paleochannel, the Eastville paleochannel and the Exmore paleochannel (Colman and Mixon, 1988; and Colman et al., 1990). So, the three generations of the paleochannel systems in this study region are then named as age equivalents of the Cape Charles, Eastville, and Exmore paleochannel systems (Figures 24-26).

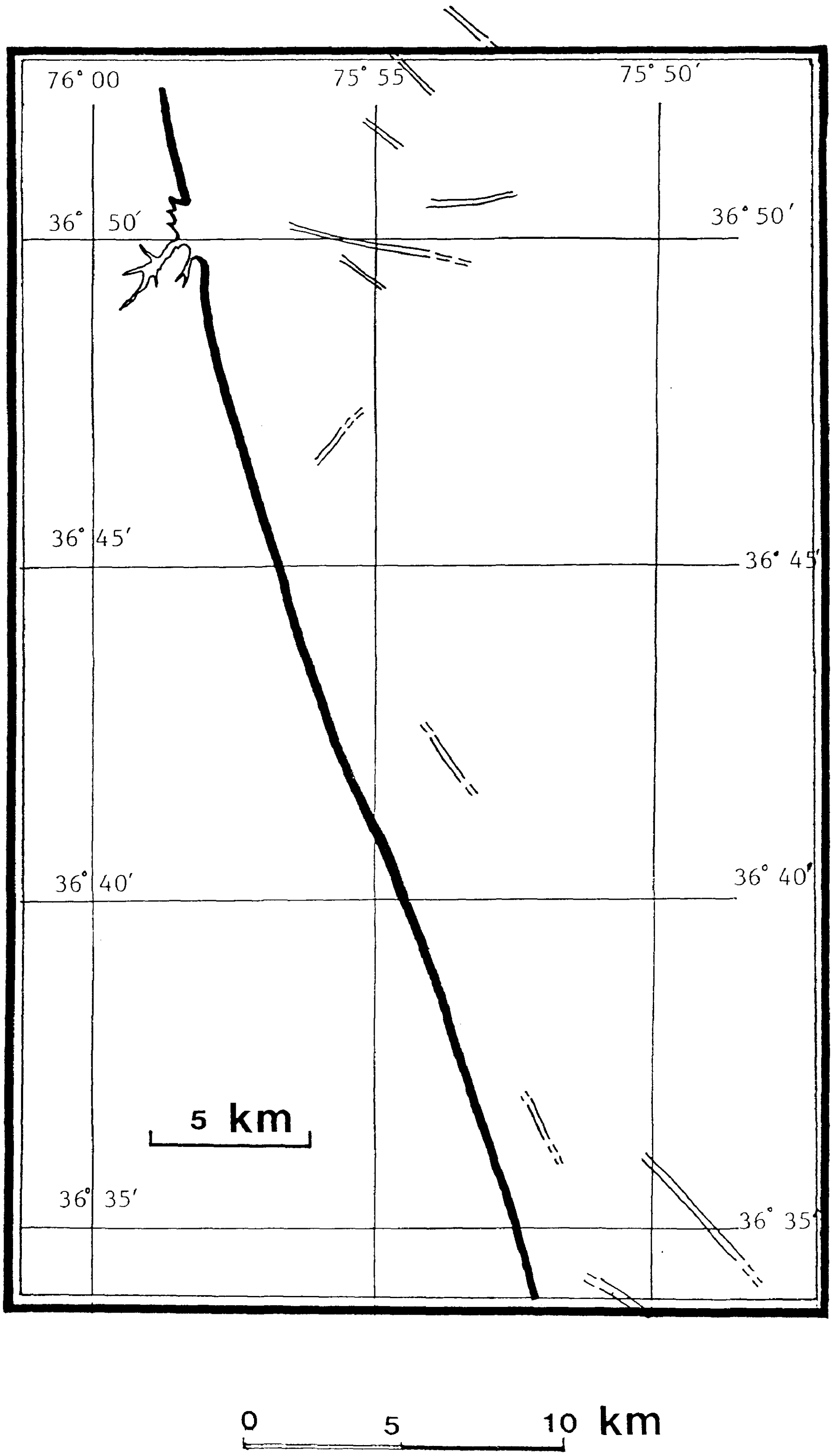


Fig. 24 Scattered Cape Charles Channel

(see text for details)

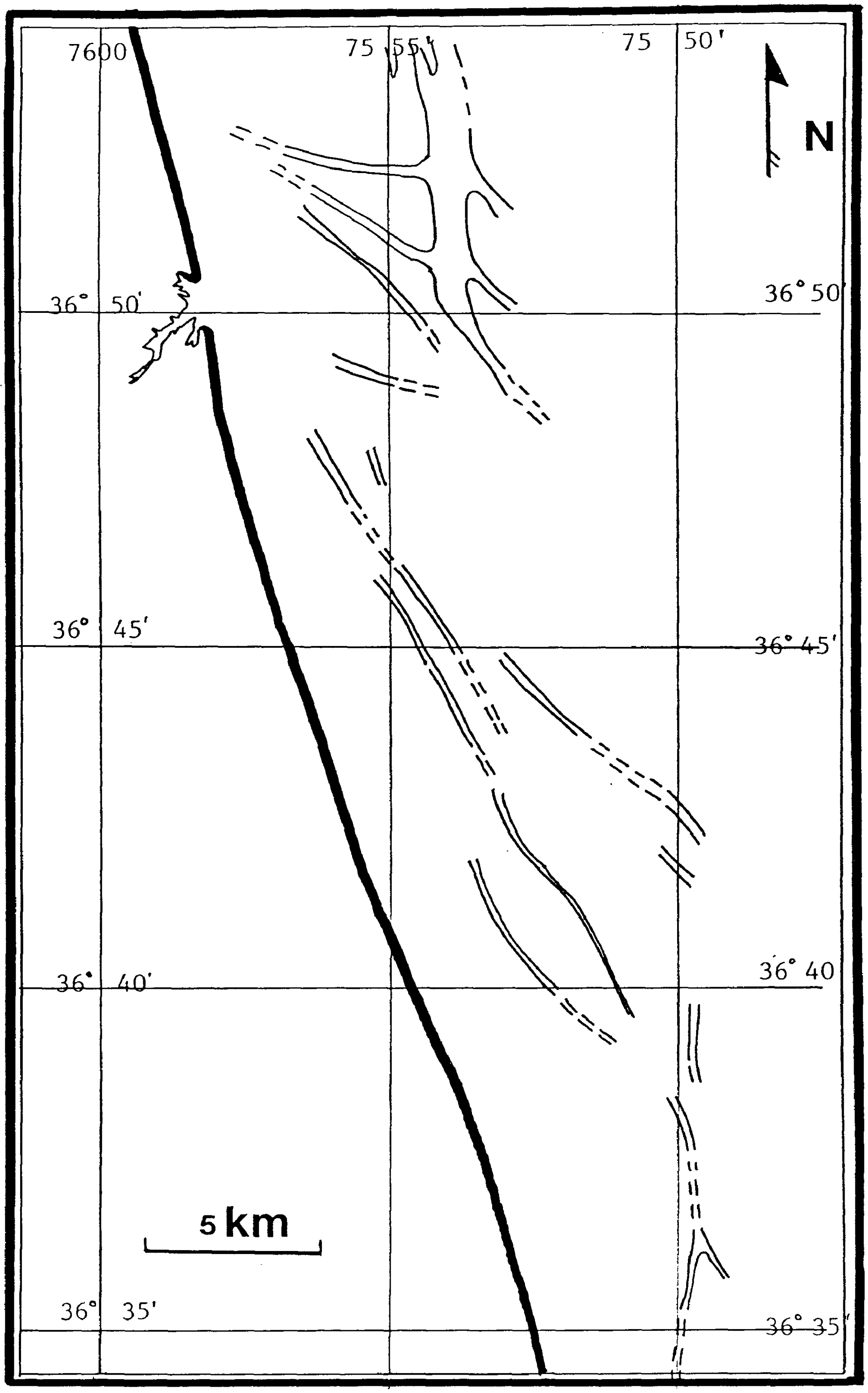


Figure 25 The Eastville-Aged Paleochannel

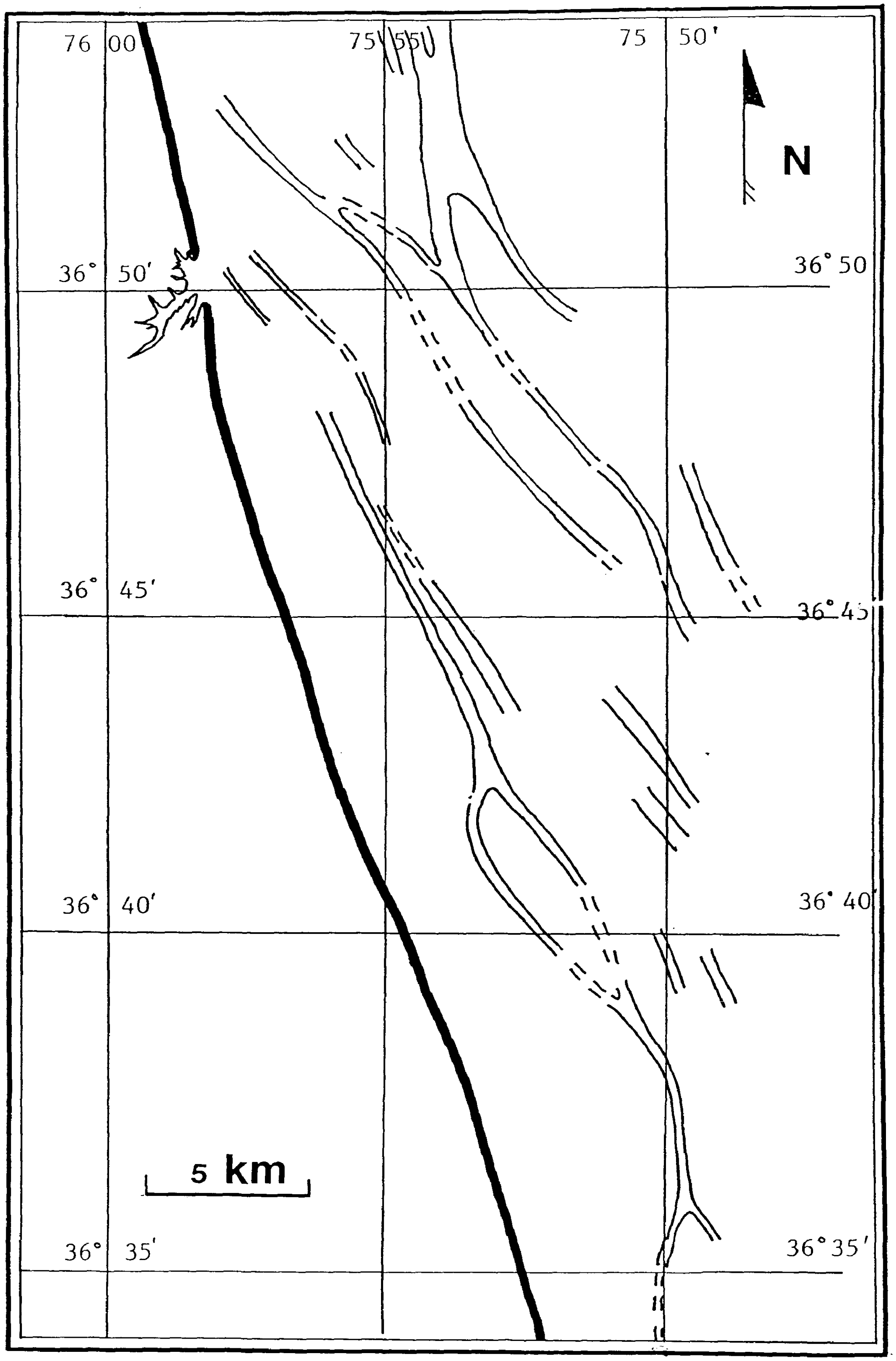


Figure 26 The Exmore-Aged Paleochannel

Recent studies on Europen Pleistocene sedimentary sequences have suggested that Stage 11, rather than Stage 7(or 9), is a more important interglacial marine deposition period (Sarnthein et al, 1986). Thus some authers (Colman et al., 1988) suggest that the Exmore paleochannel beneath the bay might hvae formed during Stage 12 rather than Stage 8 (or 10). However, the morphology and geographic distribution of the three paleochannel systems in this study region seemingly do not favor this. The middle-level (next youngest) paleochannel system is, in most seismic-reflection profiles, well confined within the lowest (oldest) channel's valley system. This probably indicates that the scale of the next oldest paleochannel system is relatively small and did not exceed the oldest one's configuration. If looking at the well-evidenced global Pleistocene sea-level curve, we may be able to rule out the possibility that the two lower paleochannel systems in this study region were formed during the Stage 6 and Stage 12.

(Even if the Exmore paleochannel beneath the bay is assigned in age to Stage 12, the age assignments for the lowest paleochannel system in this study is probably still corespondenses to Stage 8. Because the period between Stage 12 and Stage 6 was long enough to have significant transgression-regression sequences developed which can not be thoroughly eraesed from the sedimentary record. One question is, then, whether or not the lowest paleochannel system in this study region is compatible in age with the Exmore paleochannel beneath the bay).

2. Fill Stratigraphy and Depositional Environments

Based on the seismic reflection characteristics, the lithological, sedimentological and stratigraphic features of the vibracores, and the amino acid geochronal determinations, the cross-section (AA') stratigraphic correlation was carried out (Figure 24) on which all the selected vibracores were projected on the AA' at the NE 45° direction.

From the cross-section correlation diagrams, there are three or four major stratigraphic units that can be identified in the substrata sedimentary sequences which are inferred in this study to the sedimentary sequences of the Holocene (early and late phases), the Late Pleistocene, the undivided Middle-Late Pleistocene, and the undivided Tertiary-to-Pleistocene deposits.

The upmost (youngest) sedimentary sequences, with an amino acid A/I value of 0.01 or less, making up the majority of modern top and surfacial inner shelf-beach deposits, represent the Holocene transgressive sand sheet. A thin coarse sand layer, often with local accumulation of marine fossil bands, occurs in most vibracores. This may refer to the major diastem between lower and upper Holocene deposits which occured about 6,000 - 7,000 years ago when Holocene rate of sea-level rise slowed (Bowen, 1978). The lithology of the upmost paleochannel fill consists of interbedded muddy sand, silt and peat, characterizing a restricted river-estuary to open-bay and to modern marine beach environment. This seems well supported by the lithological evidence from the five vibracores. From the Figures 14 to 18, we can find that the upmost sedimentary sequences in all the samples of the five vibracores have similar lithological features, indicating similar depositional environments for these sequences.

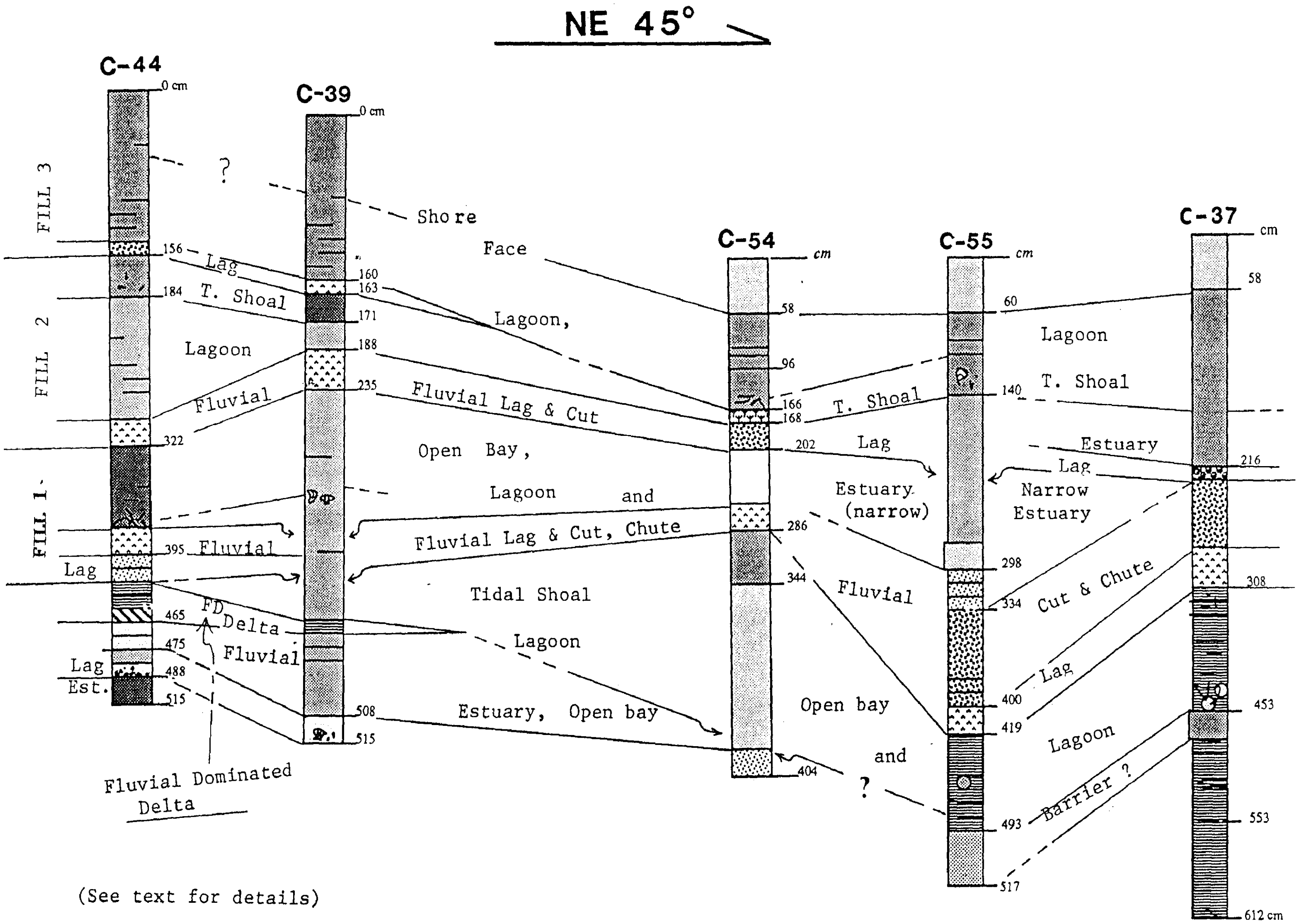
Below the Holocene sequences, the two lower sedimentary units of each fill are characterized on seismic reflection profiles by relatively strong and discontinuous reflections. These characteristics, together with lithological and sedimentological data from the vibracores, indicate that these sedimentary units are fluvial to river-mouth delta deposits, typically consisting of coarse sand to fine gravel.

From the vibracore logs (Figures 14-18), one can find that the fill of the lowest paleochannel is generally made up of, from bottom to top, coarse sand and some 2-3mm sized pebbles, often with thin (<0.4 cm) silt-mud belts or nodules; upward into fine sand to sand layers with occasional dark bands or thin layers, sometimes with rusty-colored bands. Bottom fragments of vegetation can be observed in most of the vibracores. Shell bedds or shell fragment layers (0.5-2cm in thickness) can also be found in the fill sequences. These sedimentary features indicate that the sequences were being deposited in a complex coastal environment in which delta, localized fluvial chutes or cutting outlets, tidal channels, estuaries, lagoons, marshes, and bay-mouth or tidal shoals exerted themselves. This resulted the establishment of the multi-facies sedimentary sequences. At the very bottom, or beneath the fill of the lowest paleochannel valley, a well-sorted thick medium sand layer is gradually truncated by a mud(silt)-coarse sand interbedding sequences (each band of the interbedds is generally 1-3 mm in thickness, Photo 3) which probablly originated in a fluvial dominated deltaic environment during a marine regression (Figure 14). Above the deltaic sequences, a coarse sand and/or fine gravel sequence commonly occurs in the bottom sequence of the fill (Figures 14 and 17) which is apparently a fluvial basal lag deposit or a chute fill in some cases; dark (organic-rich) bands in the middle and upper portion of the fill sequences were likely generated in estuarine, lagoonal to marsh environments, especially where vegetation occures in the dark bands; the layered shell deposits are related to tidal shoal (bay-mouth to marine beach) environments. The upper portion of the paleochannel fill is generally prodominated with fine-medium well-sorted sand. The overall sedimentery sequences indicate a regressive to transgressive evolution which is vertically marked with the establishment of a consequent facies complex (A fluvial dominated regressive delta, coastal fluvial channel, restricted estuary and lagoon, to tidal shoaling beach deposits) (Blatt et al., 1980).

Figure 27 is a simplified reconstruction of the depositional environment for the fill sequences of the three generation paleochannel systems in this study area. It was mainly based upon "coarse-grained" analyses of the lithological, sedimentological and aminostratigraphical data from the five vibracores. No detailed paleontological study, especially on spore and pollen, was involved in the reconstruction.

The amino acid A/I ratios for the lowest paleochannel fill range from 0.21 to 0.10. As discussed in earlier chapters, the age assignment for the fill sequences is infered here to oxygen isotope Stage 8, namely 260+/-20 ka BP.

Figure 27 Reconstruction of Depositional Environments (A-A')



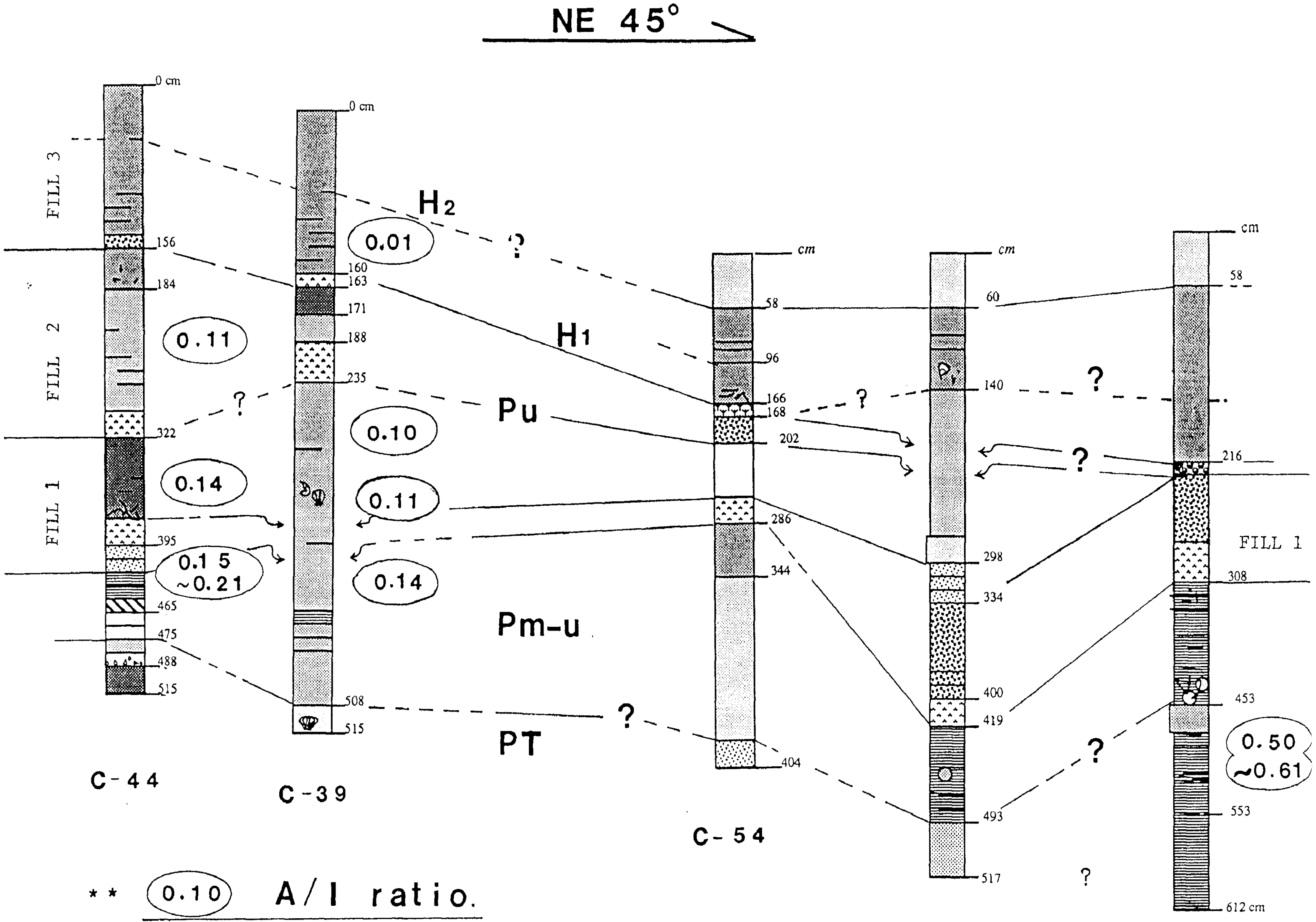
(See text for details)

The middle paleochannel fill is characterized by sedimentary development similar to the lowest one's. As described in vibracores 39, 44 and 54 (Figures 14-18), the paleovalley is filled with, from bottom to top, coarse sand with pebbles and shell fragments, fine-medium sand, fine sand-muddy sediments often interrupted by shell and/or shell fragment layers as well as dark muddy bands. In general, the major difference between the two lower paleochannel fill sequences are that the fill of the mid-level paleochannel system does not have a mud-sand interbedding unit of sediment at bottom, and represents a relatively smaller-scaled channel valley and filling sequences. This may further imply that the age assignment for this paleochannel is prefered to be Stage 6 that was generated "shortly" after the previous channel (Stage 8) was being filled.

Figure 28 shows the stratigraphic correlations among the five vibracores. In this figure one finds that the major boundaries of these amino-stratigraphic units match the boundaries drawn from the seismic stratifications (Figure 13) and the depositional environments (Figure 27). This may imply the validity of our elucidations to the depositional environment, the seismic stratification, and the aminostratigraphy.

The multi-cycled channel incisions and back-fillings in this reconstruction are clearly related to sea level fluctuations in the mid-Atlantic Bight (Colman and Hobbs, 1987). Every major cycle of the glacial-interglacial revolution started with a very low sea level stand (as low as 150 m below the present sea level). The shoreline was far east out onto the present day shelf. If the preceding interglaciation ended gradually,

Figure 28 Stratigraphic Correlation (A-A')



H1, H2 for upper/lower Holocene; Pu,m for upper/middle Pleistocene;

PT for undivided sedimentary sequences from Tertiary to Pleistocene.

a regressive fluvial delta could be built up along the retreating river mouth. Intergrated fluvial system deeply incised previous sedimentary sequence(s) creating many valley walls and interfluves, often leaving coarse lag deposits behind. As sea level rose during the interglacial period, the fluvial system was filled with sediments, so did the chutes and the interfluves. A further rise of sea level might have generated coastal physiographic units, such as a estuary, open bay, lagoon, barrier-spit, tidal delta, and shoreface. Sediments from both landward and seaward sources were trapped in these units. Marine organism, especially shell (mollusca) species, were washed over along tidal shoals and/or beaches that become the shell (fossil) layers present in stratigraphic columns. The cross-section correlations of depositional environments among the vibracores (Figure 27) here can also be considered as a sedimentary facies model for representing the geologic history of the paleochannel systems in this region.

3. Geostatistical Rearrangement and Its Stratigraphic Implication

Based on the Q-mode factor analysis, a so-called 'geo-statistic rearrangement' for the vibracore substrata was made (Figure 22) which simplifies the multi-sublayered sedimentary sequences into three or four depositional enviornment-orientated statistic units. These units can be well correlated among the vibracores. The only exception in the re-arrangement, assumed here as a rarity, occurs in the vibracore Core-37. The causes for the exception are not clear. It may have something to do with the vibracore's location ---- Core-37 was drilled in the area very close to the dredged U.S. Naval "Atlantic Channel" (Williams, 1988); it may also be an artifact generated by the mathematical operation.

According to the study of the sedimentary facies and lithology, we find it plausible to assign the factor analytic groups of G-I, G-II and G-III (Figure 23) to the following physical entities: the G-I is representative of a marine dominated (beach-surfzone-shoreface-inner shelf) depositional environment condition, the G-III of a fluvial active depositional environment condition, and the G-II of a transition zone between the two. The G-IV is assigned to the same depositional environment condition as G-I. This is based on the correlation between the two on the sediment factor laoding diagram (Figure 22).

The phrase "depositional environmental condition" is utilized here to refer to a specific regime in the geo-statistical world which does not necessarily correspond to the reality of the coastal environment or the associated hydraulic condition.

A question that arises from the physical assignments is how a relatively coarser component of G-I is assigned to a marine dominated environment, whereas the finer sediments of G-III to a fluvial system? A hypothetical answer is that the statistics picked up a grain-size population that is not the one commonly plotted in a grain-size <u>compositional</u> distribution diagram. Instead, it may have picked up a weight- or shape-orientated sub-population, such as the one suggested by Cook and Gorsline (1972), and Niedoroda et al. (1989 and 1991). Recent research on coastal marine sedimentation (Niedoroda et al., 1991) has shown that there are always two grain-size populations of sediments being distributed along a long-term erosion coastal depositional zone: a granular finer upper shoreface sand, and a coarser lower shoreface-inner shelf sand. The former represents a substantial amount of rip-current fallout which originates from breaking wave-driven processes within surf zone; the latter represents a major lower shoreface to inner shelf sand. The more spherical grains could be relatively larger (coarser) along the marine beach (the finer grains are washed over into the offshore environments), but they have to be relatively much finer in a fluvial dominated systems (only wind transported fine grains have more spherical shapes).

Comparing the geostatistical arrangement of sub-strata with the output of both the stratigraphic correlation and the reconstruction of the depositional environments (Figures 22, 27, and 28), one can find that the Q-mode factor analysis on the rearrangement of the substratum units (sub-layers) provides a simplified picture about the depositional environments on which the fill sequences of the two lower paleochannel systems are grouped into a single category, infered as "a fluvial-estuary dominated depositional system"; whereas the fill sequence of the upper paleochannel system basically remains as an unit of a "shallow marine depositional system."

It is encouraging that the output of the Q-mode factor analysis matches the lithological and stratigraphic observations well. This hints that the selected grain sizes, from the RSA sandy sediment, at the Phi values of 0.0, 0.5, 0.75, 1.25, 1.5, 2.75 and 3.25, are plausible in the statistic operation to delineate, at least at a large scale, the depositional environment condition for the fill sequence of the paleochannel systems in this region. The agreement of the Q-mode factor analysis with the lithology further reenforces the credibility of the methods.

4. Synthesis of the Analysis Results

Comparing the major seismic stratifications (Figure 13) with the output of the depositional environment reconstruction (Figure 27), aminostratigraphy (Figure 28), and geostatistics (Figure 22), one finds that the major boundaries in these diagrams are compatible. For instance, the primary depositional environment boundaries can be well correlated with the aminostratigraphic ones (Figures 27 and 28).

The primary, seismic reflecting boundaries (Figure 13) appear conformable with, but higher than, the corresponding lithological, or depo-environmental, boundaries (usually 0.2 to 0.5 meter above). The reason is that a strong seismic reflecting signal recorded on the seismic reflection profile generally comes from an interface between two sharply different sedimentary assemblies (layers), for example, between a coarse sand layer and a fine sand or muddy layer. And such a reflection interface often indicates the top surface of the coarse sediment assembly (layer). Whereas, the lithological, or environmental, boundaries start from the very bottom of the assembly (layer). This difference is well indicated in Figure 13 on which the primary seismic reflecting surfaces are systematically above the lithological boundaries.

The geostatistical arrangement of the multi-layered substrata (Figure 22) divides the whole unit of the fill sedimentary sequeces in the A-A' cross-section into two major geo-statistical segments: a shallow marine dominated sedimentary entity, and a fluvial-estuarine dominated one. This division appears plausible as the lithological, aminostratigraphical, and seismological outputs are compared with the geostatistical result. The transitional zone between the two segments (the G-II in Figure 22) seemingly however, does not closely follow the outlines of the physical (lithological and aminostratigraphycal) boundary. It apparently moves through the inferred Pleistocene-Holocene timeline (aminostratigraphical boundary) in the cross-section. This may imply a strong sediment reworking process during that period of geological time; it also could be a artificial effect generated by the geostatistics.

SUMMARY

Results from the closely-spaced, high-resolution seismic survey, the vibracore stratigraphic analysis, geochronal control, and geostatistic manipulation embrace the following:

1. Three major paleochannel systems were identified from the seismic reflection profiles in this region. The two lower paleochannel systems have a similar geographic distribution pattern, trending south southeast; whereas the upper paleochannel system has a scattered pattern. The apparent scales of the valley relief and axial depth for the three paleochannel systems diminish from bottom to top;

2. Fossils collected from the fill sequences of the paleochannel systems in five selected vibracores provided more than ten amino acid dates ranging in amino acid A/I value from 0.01 to 0.21. Three A/I groups of 0.01, 0.10-0.15 and 0.15-0.21 were categorized and are correpondent to the oxygen isotope stages of Stage 1, Stage 5, and Stage 7. Thus, the three paleochannel systems were infered to be the Stage 2, Stage 6 and Stage 8, corresponding to 30 +/-10 ka, 150 +/-20 ka and 260 +/-20 ka BP respectively. This implies that the three major paleochannel systems in the study area, on the continental shelf south the Chesapeake Bay's mouth, are compatible in age with the Cape Charles, Eastville, and Exmore paleochannels beneath the bay;

3. The study on the sedimentary structure, lithology and stratigraphy from the selected vibracores, combined with geochronal data and X-ray stratigraphic study, resulted the re-construction of depositinal environments for the fill sequences of the major paleochannel systems. Three major depositional cycles (some of them are only partially preserved) were outlined, which are featured with multi-facies sedimentary sequences representing a broad physiographic complex ranging from the fluvial channel (lag, chute, flood plain...), to fluvial dominated delta, tidal channel, estuary, marsh, lagoon, bay-mouth, tidal shoal and shoreface etc;

4. Using grain-size data, a Q-mode factor analysis was carried out which demonstrates a geostatistical correlation for the multiple sub-layered substrata in the vibracores. Three factor groupings were recognized and physically assigned to three conjunctive depositional environment conditions. The statistic simplication indicates that the fill sequences of the three paleochannel systems can be further categorized as a "shallow marine sedimentary environment (Beach-surfzone-shoreface-inner shelves)," and a "fluvial-estuarine dominated environment;"

5. The synthesis of the seismological interpretation, the depositional environment reconstruction, the amino acid geochronal determination, and the geostatistical simplification shows a general agreement among the outputs of the various approaches of methodology. This further supports our earlier conclusions.

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