ABSTRACT

Title of Dissertation: SUBAQUEOUS SOILS OF SINEPUXENT BAY, MD

George Paul Demas, Doctor of Philosophy, 1998

Dissertation directed by: Professor Martin C. Rabenhorst
Department of Natural Resource Sciences
and Landscape Architecture

Subaqueous sediments represent an important resource component of shallow water environments which have generally been viewed from a strictly geological, geochemical, and benthic ecological perspective. The need for estuarine resource inventories, the development of the discipline of pedology, and the similarities between shallow water and terrestrial systems warrant consideration of sediments using a pedological framework. Therefore, the objective of this study was to evaluate a pedological interpretation of shallow water sediments. The study area was a 1,300 ha portion of Sinepuxent Bay, just west of Assateague Island. A methodology was formulated for creating a detailed bathymetric map utilizing over 23,000 geo-referenced depth data points. Using terrain analysis, twelve landscape units were identified representing seven distinct landforms based on slope, bathymetry, landscape configuration, and geomorphic setting. Eighty-five profiles were described and 9 representative profiles were sampled for characterization of chemical and physical attributes. Laboratory and morphological data demonstrated that the processes outlined in the generalized theory of soil genesis (Simonson, 1959) were actively functioning in the profiles. Evaluation of subaqueous soil attributes by landform showed that the soil-landscape paradigm (Hudson, 1992) was applicable in subaqueous environments. Therefore, a subaqueous soil survey could be undertaken utilizing a pedological approach. *Keys to Soil Taxonomy* (Soil Survey Staff, 1996) was utilized in developing six subaqueous soil series and the soils of the study area were delineated by soil-landscape unit into thirteen soil mapping units. Soil characteristics and soil mapping were compared with submersed aquatic vegetation (SAV) biomass data, which illustrated the impact of subaqueous soil properties on the growth and survival of SAV. This study demonstrates that shallow water sediments can be viewed as subaqueous soils. Furthermore, by utilizing a soil-landscape model, subaqueous soils can be efficiently mapped and included as a basic component of resource inventories and should be addressed in estuarine restoration programs.

SUBAQUEOUS SOILS OF

SINEPUXENT BAY, MARYLAND

by

George Paul Demas

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland at College Park in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
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Advisory Committee:

Professor Martin C. Rabenhorst, Chair/Advisor
Professor Delvin S. Fanning
Associate Professor Michael S. Kearney
Professor John C. Stevenson
Professor Richard A. Weismiller

PREFACE

Into the distance, a ribbon of black
Stretched to the point of no turning back
A flight of fancy on a wind swept field
Standing alone my senses reeled
A fatal attraction holding me fast, how
Can I escape this irresistible grasp?

There's no sensation to compare with this
Suspended animation, a state of bliss
Can't keep my mind from the circling sky
Tongue-tied and twisted, just an earth-bound misfit, I.

(courtesy of David Gilmour of Pink Floyd)

The evolution of this work was intensely affected by the deaths of my mother, father, and brother. My parents had always wanted my brother and me to reach as high as we could in our goals. No one in our family had ever graduated from college except my uncle, Carl Demas, with a B.A. in Architecture. During the early to mid-1980's my brother and I made a number of significant mistakes that were major disappointments to our parents. Through our own misjudgment we became involved in things we should never even have considered. We were aware it was not only personally detrimental, but it hurt our parents even more so. For some reason I managed to disassociate myself, but my brother was not so fortunate. While I began a career as a Soil Scientist with USDA-SCS, he continued in the same direction. Regrettably, I knew why he had continued. The same reasons I had been originally involved and trapped.

I miss my family deeply and I wish my parents were here to see what they had always dreamed of. I thank God for my loving wife, the friends who have supported me, and for the faith and strength to resist what for some truly is a fatal attraction.

DEDICATION

All of our love and all of our pain
Will be but a tune
The Sun and the Moon
The Wind and the Rain
Hand in hand we'll do and die
Listening to the bands that made us cry
We'll have nothing to lose
We'll have nothing to gain
Just to stay in this real life situation
For one last refrain

(courtesy of Roland Orzabal of Tears for Fears)

This research program began January 1, 1994, only three months after my marriage to Susan Yates in October 1993. Her support during the course of the program can not be overstated. Her encouragement and assistance in the midst of crises were crucial to my own doubts about what I was doing, and even why I was doing it. In March of 1994, just prior to my entrance seminar, my brother passed away unexpectedly which affected me deeply. She stood by unwaveringly. In August 1995 my mother passed away and trauma hit once again, this time during an intense period of fieldwork. I was shattered and felt lost again. Through her love she again helped me through the loss to continue with the research. In December 1996 my father passed away at Christmas time. I had lost my entire family in less than three years. I was emotionally ready at that point to give up on it all. I had married a vibrant, optimistic, wonderful woman; and within three months we had begun a four year journey through an emotional nightmare. To my wife Susan I dedicate this work. May others be as lucky to experience the love, faith, and loyalty I have.

ACKNOWLEDGEMENTS

There are many who have contributed to the development of a concept into the reality of this research, among them organizations, colleagues, and friends.

I thank the Maryland Agricultural Experiment Station for providing the majority of funding to carry out the project; Dr. Jeri Berc, former State Conservationist in Maryland, and the USDA-Natural Resources Conservation Graduate Studies Program for funding the course work and purchase of the Global Positioning System unit; the Worcester County Board of Commissioners for providing funds for office space and letter of support; the Worcester Soil and Water Conservation District Board, Mr. Elwood Waters, Mr. Dan Redden, Mr. Clinton Hudson, Dr. Turp Garrett, and Mr. Gerald Holloway, for their patience while I was trying to attend classes and perform field research while assigned to the Soil Survey Update for their county. I also would like to thank the Maryland Farm Bureau for their letter of support in our funding requests.

Another important aspect which can not be overlooked was the inspiration, encouragement, and assistance of many friends and colleagues during the time I spent in graduate school. Dr. John E. Foss inspired me early in my college career to study soils and provided guidance during my Master's degree program. His enthusiasm for soils was a major reason why I gradually developed my own fascination with soil science. Dr. Delvin S. Fanning, who became my advisor after Dr. Foss went to North Dakota and is a member of the Ph.D. advisory committee, had (and still has) the uncanny ability to point out my strengths and weaknesses. Dr. Michael S. Kearney, another advisory committee member who I was fortunate to have as an instructor for 3 geomorphology courses, inspired my interest in the processes of landform expression critical to this study. Dr. Richard Weismiller encouraged me throughout the study, both as an advisory committee member and through his timely advice spoken from the heart. I also thank Mr. Richard L. Hall for his encouragement and for teaching me the original "series concept"; Ms. Elesa Cottrell, USDA-NRCS State Conservationist in Delaware, for giving me the opportunity to work in Delaware; and her constant encouragement and faith in me; Mr. David Doss, USDA-NRCS Maryland State Conservationist, who continued to support the project after Dr. Berc was promoted; Dr. Craig Ditzler and Dr. Robert Ahrens of USDA-NRCS who supported the conceptual aspects of the study at both the regional and national level; and Dr. Ritchie Shoemaker, M.D. who gave me his friendship, encouragement, and performed the physical repairs I required after some of the more grueling fieldwork (torn rib muscles, busted kneecaps, and other assorted sprains and bruises). A heartfelt thanks also to Mr. William Davis of Snow Hill, more of an "older brother" than a friend, for his interesting ways of "keeping my feet on the ground" and repairing the boat and other equipment I damaged during the research project.

Many others assisted on much of the field and laboratory work required for the study. First and foremost I wish to thank Ms. Kellie Merrell, who recorded a majority of the field description notes, performed a majority of the water quality and SAV biomass work, and taught me about SAV ecology in the field. Mr. Bruce Nichols, District Conservationist for Worcester County, helped to do the soil borings, vibracoring, and acted as a sounding board for new ideas and concepts. Mr. Thomas E. Dowd, Maryland Dept. of Natural Resources, helped perform the elevation surveys required to link the tide gauge to a USGS benchmark and assisted during the bathymetric sounding runs.

Mr. Jeff Merrell also assisted on the bathymetric runs, and introduced the computer contouring package essential to the terrain analysis portion of the study. The laboratory work would never have been completed without the assistance of Steve Burch, Monisha Kaul, and Suzanne Wald. They spent nearly three months helping me run all the soil analyses. Mr. Steve Nechero of the USDA-NRCS Cartographic Division digitized the soil survey and created the map that was the focal point of the research.

I would also like to thank Bruce Hornsby, David Gilmour, and Roland Orzabal for their kindness in allowing me to quote their work. They have the gift to be able to capture, through their music, emotions and feelings that cannot be expressed in words.

Finally, I wish to thank the three persons, whose influence dominated throughout the work. Mr. James H. Brown, USDA-NRCS State Soil Scientist in Maryland, approved work-release time to perform the fieldwork and write the dissertation. No matter what happened during the course of the study, whether personal or professional, he would always find the time to talk to me, encourage me, understand me; and when crises arose, his words of friendship and support could turn tears to laughter. He showed me that the true "ties that bind" originate in the heart.

Dr. J. Court Stevenson, Professor at Horn Point Environmental Laboratory also played a major role during the study. His knowledge of SAV ecology, I believe, is unsurpassed in the region. I have learned a great deal from him in the past four years. From the start, he believed in the project and what we were trying do. His good-natured attitude, common sense, friendship, and enthusiasm were (and are) greatly appreciated. He was also quite well-versed in the operation of the vibracorer, which became critical after my kneecap and ribs were damaged during the extraction of the first few cores.

Finally, I wish to thank my advisor, Dr. Martin C. Rabenhorst, Professor of Pedology at the University of Maryland. Not only did he have a seemingly infinite level of tolerance, his guidance and advice were crucial to my own personal and professional development. His friendship was even more important during the period when my family passed away. He was always somehow able to tone down my excitement and tendency to jump at things just enough to keep me firmly in the "scientific" realm.

To Kellie, Jim, Court, Marty, and all of the rest of you, thank you. What I have tried to express in words is no where near what is in my heart.

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INTRODUCTION

When the seed is broken
Nothing left to grow on
When you lose the seed
It's hard to bring it on back

But the tide will rise
And the tide will fall
We'll be out on the water
Before the break of dawn

The tide will rise
And the tide will fall
Oh, we'll be working on the water
When the long, long day is done

The tide will rise!

(courtesy of Bruce R. Hornsby)

The decline of the Chesapeake Bay estuary over the past 25 years has had scientific, economic, and emotional impacts on all who enjoy or work the water. The precipitous fall of waterfowl, rockfish, shad, oyster, crab, and submerged aquatic vegetation (SAV) populations led to the 1987 Chesapeake Bay Agreement (Chesapeake Bay Program, 1991). The goal of the agreement was to develop "guidelines for the protection of habitats and water quality conditions necessary to support the living resources found in the Chesapeake Bay system, and to use these guidelines in the implementation of water quality and habitat protection programs". The closure of the Maryland striped bass (*Morone saxatilis*) fishery on January 1, 1985 was one protection program that was implemented prior to the formal agreement.

Potential causes for the decline of many species included overfishing, disease, nutrient enrichment, suspended solids, dissolved oxygen, toxic contaminants, and light attenuation. Scientists were called on to research, identify, and propose possible solutions to overcome these problems (Chesapeake Executive Council, 1989; Chesapeake Executive Council, 1990). The establishment and publication of the *Habitat Requirements for Chesapeake Bay Living Resources* (Chesapeake Bay Program, 1991) outlined the habitat factors affecting each species in an effort to provide a framework to"work toward the goal of restoring the Chesapeake Bay". Yet, among these, one aspect of Bay's decline seemed to capture the most attention. The unheralded loss of submersed aquatic vegetation (SAV) was soon implicated in many of the Bay's problems. This was emphasized in the *Chesapeake Bay Submerged Aquatic Vegetation Habitat Requirements and Restoration Targets: A Technical Synthesis* (Chesapeake Bay Program, 1992) where it states:

> "One of the major factors contributing to the high productivity of Chesapeake Bay has been the historical abundance of submerged aquatic vegetation (SAV). SAV in Chesapeake Bay include some twenty freshwater and marine species of rooted, flowering plants. SAV provide food for waterfowl and are critical habitat for shellfish and finfish. SAV also effect nutrient cycling, sediment stability, and water turbidity".

Submerged aquatic vegetation beds perform a variety of important ecological functions. They are feeding sites for waterfowl, nurseries and cover areas for juvenile shellfish and finfish, and their leaves provide a substrate for the attachment of eggs and organisms such as barnacles. Without sufficient SAV populations, efforts to reverse the decline of other Chesapeake Bay species would remain in jeopardy.

Research efforts were therefore directed towards identifying the causes for the

SAV decline. In 1992, the Chesapeake Bay Program published a synthesis of research that indicated poor water quality was the culprit. Five water quality parameters were identified that, if corrected, would allow the seagrasses to once again flourish. Although there has been some natural increase in SAV in the past few years (Orth et al., 1992), restocking efforts have not been successful in areas where the 5 water quality parameters had improved enough to meet the minimum requirements (Stevenson et al., 1993).

If poor water quality was the main reason for SAV decline, then why weren't replanting efforts effective where water quality had improved? The emphasis on water quality by many estuarine scientists has not fully provided the answers. But one factor, the relationship between SAV and the sediment, was understudied. In the 348 pages of text contained in the *Habitat Requirements for Chesapeake Bay Living Resources* (Chesapeake Bay Program, 1991), only one paragraph discusses the substrates on which SAV occur. The total information provided states:

> "The distribution of submerged aquatic vegetation in Chesapeake Bay is dependant on the ability of the sediment to provide not only mechanical support for the plants, but also nutrients. In general, SAV are unable to grow in very coarse substrates (boulders, stones, and gravel) and occur in more stable sediments composed of sand or mud. Organic matter in the sediments leads to formation of anaerobic sediment which can enhance the availability of certain nutrients to SAV. However, too much organic matter can cause total oxygen depletion so that SAV growth is unlikely."

Yet in a subsequent publication, *Chesapeake Bay Submerged Aquatic Vegetation Habitat Requirements and Restoration Targets: A Technical Synthesis* (Chesapeake Bay Program, 1992), the minimum SAV habitat requirements "are defined as the minimal water quality levels necessary for SAV survival". In 186 pages of text there is no reference to sediment characteristics or their possible role in SAV restoration efforts.

Although water quality conditions are significant to SAV growth and survival, some interesting observations concerning sediment characteristics can be found in a *Field Guide to the Submerged Aquatic Vegetation of Chesapeake Bay* (Hurley, 1990). For example, it is noted that "eelgrass [*Zostera marina*] grows primarily on sandy substrates". In the case of Widgeon grass (*Ruppia maritima*), "although [it] can occasionally be found growing on soft, muddy sediments, it is more common on sandy substrates". Redhead grass (*Potomogeton perfoliatus*) "seems to grow best on firm muddy soils...". Hydrilla (*Hydrilla verticillata*) "is generally found on silt to muddy substrates".

The observation that different species of submersed macrophytes occur on (or "prefer") different types of substrates echoes a fundamental component of terrestrial ecology and agriculture. Specific suites (or types) of plants are frequently associated with particular soils, and, the survival and productivity of those plants are linked to the soil's characteristics.

It was this concept that lead to the development of this study. The interdisciplinary approach we have applied, combining both estuarine biology and soil science is an example of a way we could approach these kinds of complex problems in the future. What may seem obvious to one discipline may be unheard of in another. But unless we work together in an unbiased fashion, we will never fully discover the truth.

The tide may appear to have ebbed for the Chesapeake Bay, but it is hoped that this research will increase our optimism that the tide will indeed rise again!

CHAPTER II

REVIEW OF LITERATURE

INTRODUCTION

To investigate the development of a protocol for the classification and mapping of estuarine shallow water sediments it is necessary to consider the known attributes and distribution of those sediments, discuss their relationship to the growth and survival of submersed vegetation, and ultimately propose a possible framework in which an inventory of sediment resources could be developed. The task is not as simple as stated above due to a number of fundamental differences in the basic concepts which underlie the available methods. The selection of one mapping approach over the other will, by necessity, introduce bias in the way data are gathered and interpreted. For this reason it is critical to examine present methods and provide a clear justification for the application of a new approach.

SEDIMENTS

The Historical Emphasis of Geologic Concepts On Sediment Research

The study of sediments involves many related disciplines such as hydrology, geology, and chemistry. Due in part to the lack of comprehensive soils data in subaqueous environments, it is imperative to examine published data from these other disciplines to determine the present state of knowledge concerning the characteristics of sediments and their distribution within estuarine systems. Interest in sedimentary environments was initially generated within the geologic community. Although there were some early attempts to study estuarine sediments by limnologists (lake sediment scientists) and pedologists (soil scientists), the concentration of pedologists on agricultural concerns and limnologists on lake sediments left estuarine sediment research in the geologic realm. Geologists were largely interested in sediments because of their relationship with sedimentary rocks found on uplands, and particularly with oil bearing strata. As a result, numerous studies have been performed which primarily focused on documenting sediment attributes and distribution in relation to these facets of geologic interest. Due to the historical dominance of the geologic community in estuarine sediment research, the present conceptual basis to sediment mapping is rooted solidly within a geological framework. The near exclusive focus on the geologic aspects of estuarine sediments remained intact until ecologists began to relate benthic communities to substrate characteristics (Sanders, 1958; Rhoads, 1974). Yet even with the inclusion of ecological concepts, the historical emphasis of geologic concepts in the study of estuarine substrates has had major impacts on the mapping of sediments and on ecological interpretations. In order to evaluate organism-sediment relationships, ecologists have relied on the methods and interpretations of sediments previously established by the geologic community.

The geologic perspective, as applied to sediments, leads to four general areas of concentration. Characterization and mapping studies have provided valuable data on the physical and chemical attributes of estuarine sediments. Geochemical studies have focused on sediment chemical processes and environmental aspects of sediments such as heavy metal enrichment, pesticide retention, nutrient accumulation, sedimentation, and elemental cycling. Paleo-environment studies have attempted to determine the environments and processes which influence the deposition of sediments to further understand present day subaqueous and terrestrial environments. Geophysical studies have concentrated on the mechanisms that control the distribution of surficial sediment texture, bathymetry, and estuarine landforms.

At the inception of sediment research, little was known about sediment distribution. For this reason, most studies relied on a sampling and mapping approach which utilized cross-section or grid pattern sampling schemes. This is a particularly useful approach when initiating the study of an unknown object or region. As will be seen, this method was, and remains, the dominant method of sampling in sediment research.

Characterization and Mapping Studies

The majority of sediment research has focused on acquiring sediment characterization data and mapping their distribution. These types of studies are still being performed in many estuaries, such as the Maryland coastal bays system where sediment data only recently became available (Wells et al., 1996). Analyses of sediment cores concentrate mainly on particle size, organic carbon content, mineralogy, and to a lesser degree, sulfur and other components. As early as 1937, Krumbein and Aberdeen examined the sediments of Barataria Bay in Louisiana to determine their textural (particle size) attributes and distribution within the estuary. Channels were composed of dominantly coarse materials (sands), while sediments in areas of quieter water were more fine-textured (silty). High organic carbon contents were found to be associated with fine textured sediments, while sandy textured sediments exhibited significantly lower levels.

In a similar study of the physical characteristics of San Francisco Bay sediments (Louderback, 1939), coarser materials were found adjacent to shorelines (presumably from shoreline erosion processes), with progressively finer sediments occurring with depth and distance from the shore. The particle size attributes of Cape Cod and Buzzards Bay in Massachusetts (Hough, 1940; 1942) were found to be coarse textured in high energy areas and fine textured in low energy environments. Organic carbon, averaging 2 percent, was found once again to be associated with the finer sediments. These studies focused on the particle size and organic carbon content of the *surficial* layer (generally assumed to represent the upper 5 to 10 cm), rather than the sediment column (or profile) as a whole. One of the problems with comparing the results of these studies with other research is the lack of well defined particle size classes. As further studies were performed which included particle size, the terms "coarse textured" and "fine textured" were later replaced with specific particle size classes.

In an investigation of Pamlico Sound, Wells (1989) compiled characterization data from cores taken over the past 40 years. For areas with little information, samples were taken and analyzed to fill the data void. Textural samples were analyzed using the procedure of Carver (1971) and then converted to the modal grain size phi scale developed by Wentworth (1922). Table 2-1 shows the grade limits and nomenclature in the Wentworth system. From these data, maps were drawn illustrating the spatial distribution of such individual characteristics as surface texture and percent calcium carbonate. For the map of surface texture (modal grain size), five texture classes were recognized. The textural classes delineated for Pamlico Sound were coarse sand, medium sand, fine-very fine sand, silt, and clay. The map scale utilized was 1:1,130,000,

Table 2-1. Wentworth's Particle-Size Classification System (Wentworth, 1922).

Grade Limits (mm)	Grade Limits (phi units)	Class Name
>256	< -8	Boulder
256-128	-8 to -7	Large Cobble
128-64	-7 to -6	Small Cobble
64-32	-6 to -5	Very Large Pebble
32-16	-5 to -4	Large Pebble
16-8	-4 to -3	Medium Pebble
8-4	-3 to -2	Small Pebble
4-2	-2 to -1	Granule
2-1	-1 to 0	Very Coarse Sand
1-1/2	0 to 1	Coarse Sand
1/2-1/4	1 to 2	Medium Sand
1/4-1/8	2 to 3	Fine Sand
1/8-1/16	3 to 4	Very Fine Sand
1/16-1/32	4 to 5	Coarse Silt
1/32-1/64	5 to 6	Medium Silt
1/64-1/128	6 to 7	Fine Silt
1/128-1/256	7 to 8	Very Fine Silt
1/256-1/512	8 to 9	Coarse Clay
1/512-1/1024	9 to 10	Medium Clay
1/1024-1/2048	10 to 11	Fine Clay

or 11.3 km/cm. The map for calcium carbonate content was made at a similar scale. In this study, the additional particle size samples were gathered using an Ekman grab sampler which obtained a "scoop of the upper few centimeters of the sediment". The depth of surficial sampling in the previous studies could not be accurately determined because of the use of various techniques including "grab" and core sampling.

In addition to particle size and organic carbon distribution, mineralogy of the sediment has been another important component of characterization studies. In one of the first comprehensive characterization studies of the Chesapeake Bay, Ryan (1953) analyzed sediment cores to determine their textural and mineralogical attributes. Samples were taken using a "snapper" device or Dietz-Emory coring tube. The entire contents of the snapper sampler or the upper 6 to 8 inches of the tube cores were analyzed for particle size. A surficial sediment texture distribution map was developed which included four sediment classes based on Wentworth's scale (Wentworth, 1922). In this case, "surficial" refers to the upper 5 to 20cm, depending on the sampler used. The classes recognized were gravel and coarse-grained sand, medium-grained sand, fine and very fine-grained sand, and clayey silt. Within the sandy surficial sediments, quartz was found to be the most abundant mineral. Chlorite was most abundant in the very-fine grained sands and silts. In Albemarle and Pamlico Sounds, North Carolina, Wells (1989) found quartz was the main mineral constituents of sandy surficial sediments, while kaolinite and illite were abundant in what are referred to as "muddy sediments".

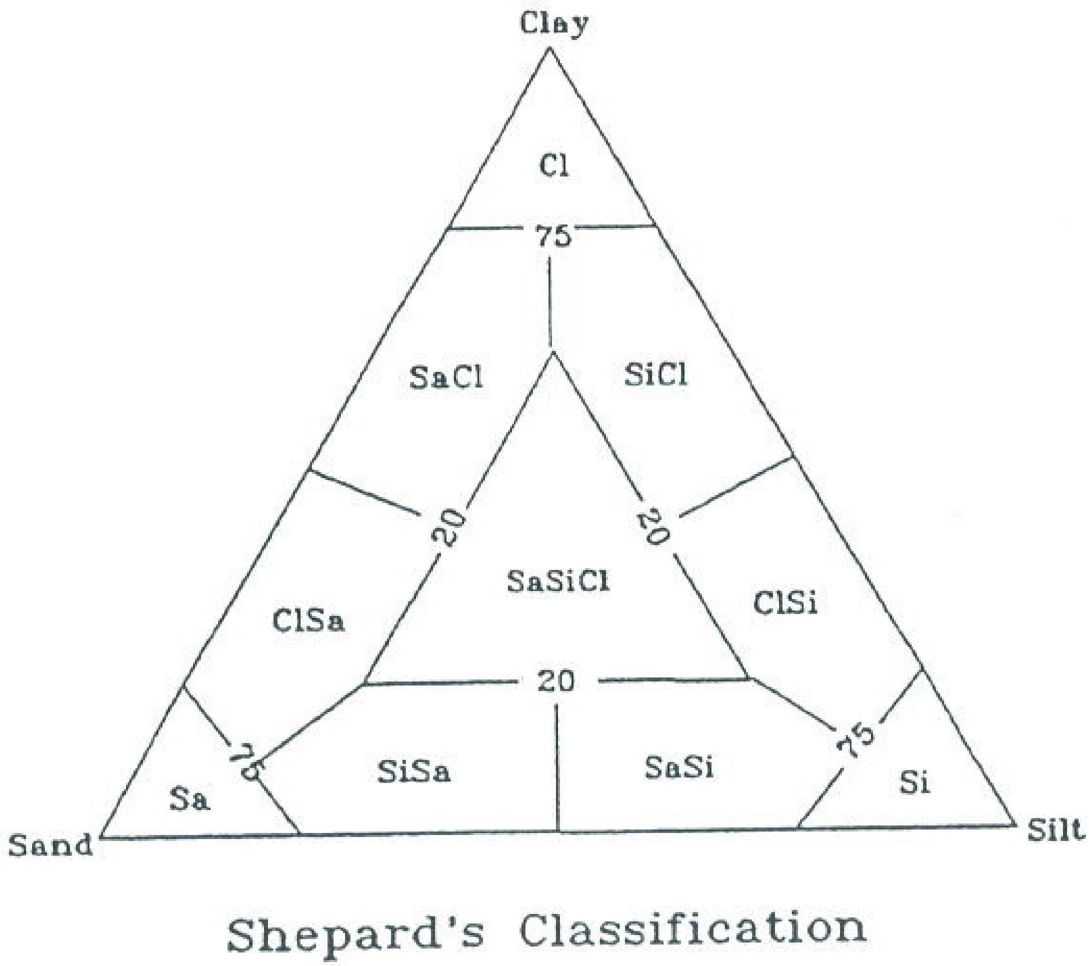
Another mineralogical study which may help illustrate the influence of the geologic perspective utilized heavy metal and rare earth element distribution in the St. Lawrence Estuary to provide a method for determining the original source of the sediments (Coakley and Poulton, 1993). The concentrations of sediment chromium (Cr), iron (Fe), nickel (Ni), and zinc (Zn) were highest along the western shore and were suggested to be a result of inflow from the St. Lawrence River. The presence of cesium (Ce) and lanthium (La) along the northeastern shore was related to inflow of sediment from the monazite rich geologic area to the north. Monazite is a mineral especially rich in both Ce and La. Source area for sediment was also studied in the Maryland coastal bays system where Kochel and Wampfler (1989) examined barrier island washover areas to determine the role of eolian (wind) and overwash processes in the development of overwash fans. Quartz originating from the Assateague Island dunes was found to be the most abundant mineral in the overwash fans.

Folger (1972a) presented the first comprehensive report summarizing the results of sediment characterization studies of 45 estuaries, lagoons, deltas, and embayments in the United States. This report was a compilation of data obtained from both published and unpublished sources. For each estuarine system, data were presented concerning the geologic setting, bathymetry, hydrology, sediment texture (bottom and subbottom), and sediment composition (including organic carbon, mineralogy, and other attributes). Normalization of sediment texture classes from the source maps could not be performed because of the wide variety of particle size nomenclature. The methods to report sediment texture used in the original studies included Wentworth's scale (Wentworth, 1922), Shepard's textural classes (Shepard, 1954), poorly defined descriptive terminology, and raw numerical data. The numerical particle size data were normalized to those of Inman's (1952) sediment texture classes, and in most other cases based on the mean, median, or modal grain sizes of the samples. In characterizing "bottom" sediment textures, no explanation is given concerning the depths to which this term refers. In the discussions of "subbottom" texture the depths range from 0.46 to 42 meters. Textural attributes were shown as delineations while organic carbon content was illustrated by isobars.

In the mid-Atlantic region, Kerhin (1980) compiled a series of maps of several individual characteristics of the sediments of the Chesapeake Bay much in the same way as Folger (1972a,b). The concentrations of water, total carbon, organic carbon, and sulfur in surface samples were illustrated using isobar maps. For sediment texture distribution the map shows delineations for each type. In this case particle size classes are based on Shepard's textural triangle (Shepard, 1954). Figure 2-1 illustrates Shepard's triangle and nomenclature. A majority of the data was collected in water depths greater than 4 meters. In a similar study of Assawoman Bay, Maryland (Wells et al., 1994a) surficial sediments were sampled on a 500m by 1000m grid using a dredge sampler, and analyzed for particle size and contents of sulfur, carbon, nitrogen, and six metals including Cr, Cu, Fe, Mn, Ni, and Zn. Averages and ranges for each were determined on a bay-wide basis and presented on separate maps.

In a characterization study which included the project area evaluated in this research, Wells et al. (1996) examined the physical and chemical properties of sediments in Newport and Sinepuxent Bays, Maryland. A Lamotte sampling dredge was used to collect samples on a 500m by 500m grid. One of the stated objectives of the study was to "map the areal distribution of the surficial sediments and their characteristics". Surficial sediments in this study were defined as representing the upper 5cm. In a discussion of sediment type distribution, the textural analyses are presented on a

Figure 2-1. Shepard's Textural Triangle (Shepard, 1954)



bay-wide basis. For Sinepuxent Bay the average textural composition of the sediment was found to be 78% sand, 14% silt, and 7% clay. In a previous study of Assawoman Bay, Maryland, sediments were also characterized on a bay-wide basis as "silty", averaging 44% silt, 31% sand, and 25% clay (Wells, 1994a). As in other studies (see Folger, 1972a,b; Kerhin, 1980; Wells, 1989), a map is presented which shows the distribution of various sediment "types" (figure 2-2). This should not to be confused with the way the term "type" is used within the pedological community. Soil taxonomic systems have generally used the term "type" to describe a class of soils with similar ranges in numerous chemical and physical characteristics occurring within a defined vertical control section. In sediment literature, the term "type" is used exclusively to denote surficial particle size class. For example, a map of sediment "types" of Newport and Sinepuxent Bays is presented which does not show sediment *taxonomic* types, but rather delineations of different surficial *textural* types (Wells et al., 1996). These types, or classes, are again based on Shepards textural triangle (Shepard, 1954), which appears to be one of the more frequently used systems in sediment literature much like the United States Department of Agriculture (USDA) textural triangle is the standard for pedological studies (figure 2-3).

The studies cited above have all contributed to our general knowledge of sediment attributes. Characterization studies are critical in that they provide a foundation of data from which other concepts and hypotheses can be developed. However, the data presented in these studies are commonly treated individually and sampling methods and depths are not standardized. In all of the aforementioned studies the methods utilized to gather data took the form of a cross-section, grid, or random

Figure 2-2. Distribution of sediment "types" of Assawoman and Isle of Wight Bays, Maryland (Wells et al., 1994a).

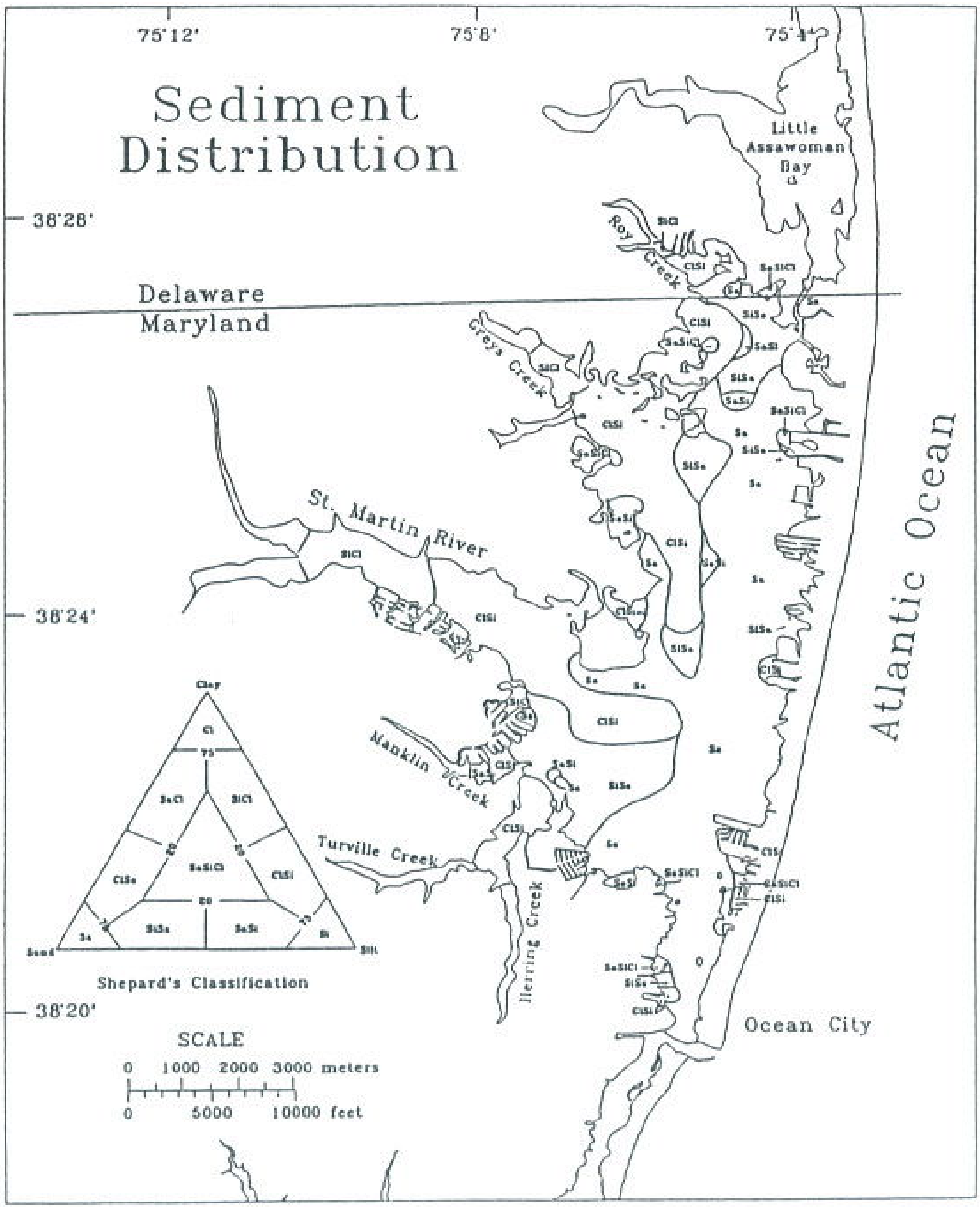
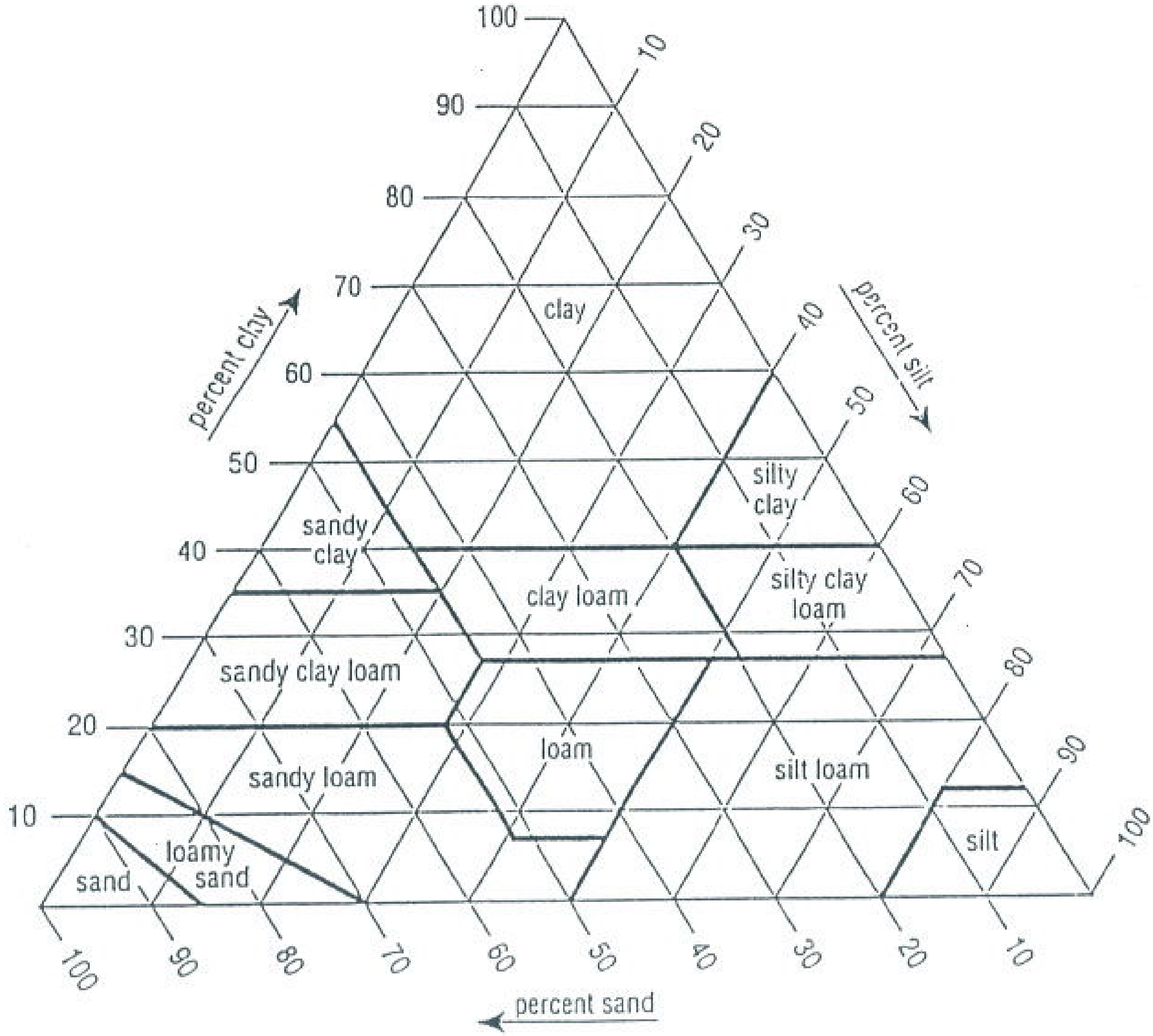


Figure 2-3. USDA-Natural Rsources Conservation Service Textural Triangle (Soil Survey Division Staff, 1993b)



pattern of site selection. These methods of sampling are common to nearly all sediment research and many geologic studies. Once the data were gathered, each parameter was then analyzed individually or on a bay-wide basis. Thus, the distribution of each sediment characteristic was treated as a unique component and there was no attempt to synthesize the various data components into a single coherent system of mappable classes. Due to the lack of a defined taxonomic control section and the use of dredge and snapper samplers, the depth to which "surficial" refers to is variable, making it difficult to determine what combination of characteristics exist at any one location and to what depth they occur. Another problem with the results of these studies is the lack of a standardized system of particle size classes. The failure of workers to define and standardize methods of sampling and textural classifications obscures their results.

These characterization studies, of which many were commissioned and/or performed by the United States Geological Survey (USGS) and State Geological agencies (such as the Maryland Geological Survey), are a reflection of the dominant conceptual framework underlying the majority of published sediment studies. The overwhelming majority of the information obtained in these studies has been from areas of greater than 4 m water depth. Thus, a very large data gap exists in shallow water habitats, areas critical to benthic plants and animals. This concentration on deep water areas of estuaries appears to be a result of the inherent bias of the geological framework. Although important to our understanding of the history, development, formation, and overall geologic nature of the estuary, the areas of greatest importance to living resources have not been examined.

Geochemical Studies

Geochemical studies of sediments have been similar to characterization studies in that most research has concentrated on the presence and abundance of various components to understand the processes involved with their formation or to characterize the levels of particular pollutants such as nutrients and heavy metals. For example, sediment characteristics and toxic substances were characterized in submersed macrophyte beds at varying salinities by Cornwell and Stevenson (1988). The different chemical environments of freshwater, brackish, and saline waters were shown to have an impact on the retention of some toxic compounds.

Valente et al. (1989) used remote sensing techniques to determine eutrophication parameters in the sediments of Naragansett Bay, Rhode Island. The parameters examined included the apparent redox-potential discontinuity (determined by photogrammic analysis) which is characterized by the boundary between the lighter colored iron-hydroxide surface and the underlying gray to black layer. The data indicated that this method could be used to assist in the identification of eutrophication "hot spots" and assist in determining the sources of nutrient enrichment.

Although early studies of the Maryland coastal bays focused primarily on water quality (Sieling, 1959), sediments analyzed for Cd, Cr, Cu, mercury (Hg), lead (Pb), and Zn indicated sediment concentrations were not ecologically significant (Allison, 1975). Wells et al. (1994a) found heavy metal concentrations in Assawoman Bay, Maryland sediments similar to levels from other estuaries not impacted by industrial activities. In contrast, sediment metal concentrations in the Thames estuary were found to contain elevated levels of metals similar to other estuaries in industrialized areas of the United

Kingdom (O'Reilly Wise et al., 1997).

Heavy metals were also the focus of Cornwell (1986). Elevated levels of trace metals were found to occur at the sediment-water interface in Toolik Lake, Alaska. These results could have been interpreted to be a result of anthropogenic inputs such as industrial discharge. Yet the levels found were inconsistent with inputs from recent watershed disturbances. It was found that the high concentrations of Mn and Fe in the sediment as oxides near the interface influenced the distribution of trace metals. Trace metals are often associated with Mn and Fe oxides, either through adsorption to the oxide surface or incorporation into the crystal structure (Burdige, 1993). The comigration of porewater Mn, Fe, and trace metals to the sediment-water interface and their subsequent precipitation as oxides suggested that diagenetic processes, rather than anthropogenic inputs, were responsible for the enrichment.

In a study concerning nutrient cycling and enrichment in the Potomac River, Callender and Hammond (1982) examined nutrient exchange at the sediment-water interface. Very low phosphorus (P) fluxes were attributed to sorption by sedimentary ferric oxyhydroxides. Sundby et al. (1992) also emphasized the importance of the association of particulate phosphate and iron oxides in sediments. Sediment porewater profiles of Fe and phosphate content remained almost constant to a depth of 5-15 cm, directly below which rapid increases in concentration were noted. Manganese concentrations were different in that the rapid increase occurred closer to the sediment surface. This confirmed the principle that Mn reduction precedes Fe reduction in the sequence of utilization as electron acceptors for microbial organic matter decomposition.

The processes of sulfate reduction and benthic oxygen (oxic) respiration in the breakdown of sediment organic matter were the focus of a study by Canfield (1989). The microbial breakdown of organic matter is partially determined by the availability of the most efficient oxidant and the redox state of the sediment. The data indicated that sulfate reduction and benthic oxic respiration oxidized equal amounts of organic carbon in nearshore marine sediments where the overlying water column was highly oxygenated.

The role of upland soil erosion and subsequent sedimentation in tidal and subtidal environments was examined by Stevenson et al. (1988) in Dorchester County, Maryland. Sediment budgets indicated the tidal marshes were not trapping enough sediment to keep pace with sea level rise, resulting in the conversion of some marsh areas to open water. It was suggested that the trapping of sediment from eroding uplands and shorelines was more significant in subtidal areas dominated by submersed macrophytes, rather than in the adjacent tidal marshes. The rapid accumulation of new sediment in the submersed macrophyte beds could impact both the plants and sediment through the displacement of the redox discontinuity layer.

The above studies concentrated more on the vertical processes occurring in the sediment rather than on their horizontal distribution. Understanding of the chemical processes which occur in sediments is an important contribution to our overall knowledge, but due to the concentration of many studies on the geologic aspects of these processes it is difficult to ascertain their ecological impact. Interdisciplinary approaches (such as those of Stevenson et al., 1985; Stevenson et al., 1988; Cornwell and Stevenson, 1988; and Demas et al., 1996) would appear to be the best method to overcome this problem.

Paleo-Environment Studies

Another facet of sediment research has focused on the identification and reconstruction of paleo-environments. In an effort to understand the development of oil bearing strata, an examination of six Potomac River sediment cores (Trask, 1932) indicated that organic content alternately increased and decreased with depth within the cores. This was believed to indicate that post-Pleistocene climatic fluctuations (which would have effected the rate of sea-level rise) may have played a role in the banding of organic layers within the sediment profiles. It was suggested that the present rate of organic matter accumulation was much less than it was in "the not remote past".

Wells et al. (1994b) studied the geophysical framework of Assawoman and Isle of Wight Bay, Maryland. Seismic profile cross-sections documented the presence of paleo-channels and the shallow stratigraphic sequence within the two bays. The paleo-channels represented ancient extensions of the Greys and Roy Creeks and the St. Martins River. The buried surfaces and channels identified were believed to represent pre-transgressive surfaces, of which some may have formed directly on Pliestocene deposits. The age and nature of the surfaces were not definitively determined.

Sedimentary structures were examined in Pamlico Sound, North Carolina to determine if paleo-estuarine environments could be identified on modern terrestrial landscapes (Katuna and Ingram, 1974). Sedimentary structure was classified based on the degree and type of banding (or lamination) within the sediment cores. Twelve physical sedimentary structures and four biogenic sedimentary structures were found. The cores were taken from estuarine and lagoonal environments such as channels, terraces, shoals, and central basins. Many of the estuarine and lagoonal environments exhibited markedly different types of sedimentary structure. For example, terrace cores contained flaser bedding, lenticular laminations, clay inclusions, load casts, and mottled bedding due to bioturbation. In contrast, grassy shoals were nearly devoid of physical structures due to bioturbation and the presence of submersed aquatic plant roots. Based on these results, the identification of sedimentary structures in terrestrial positions could help determine the type of paleo-estuarine or lagoonal environments they formed in. Similarly, in lake environments, sediments with specific structures change horizontally and vertically, and each facies reflects a specific process or environment of sedimentation (Reading, 1978).

These studies further illustrate the influence of a geological perspective on the interpretation of sediment data through their concentration on the reconstruction of paleo-environments. Yet, of greater significance to sediment mapping efforts was the recognition by Katuna and Ingram (1974) that specific types of sedimentary structure could be associated with specific subaqueous landforms. According to Hakanson and Jansson (1983), the processes of sedimentation are closely related to the hydrological flow patterns and the bottom topography.

Geophysical Studies

The most applicable sediment research efforts pertaining to this study have been geophysical in nature. In the 1940's the sediments of Cape Cod and Buzzards Bays were examined and described by Hough (1940, 1942). The distribution of different surficial sediment textural classes was found to be related to the flow regime within the bays. Coarser textured sediments were more likely to be present in areas exposed to wave and current action nearshore or adjacent to shoals, while finer textured sediments were common in more quiescent deeper water environments and protected shoreline embayments. Flow regimes were also implicated as the controlling mechanism in the distribution of particle size and organic carbon in Barataria Bay (Krumbein and Aberdeen, 1937) and San Francisco Bay (Louderback, 1939).

Folger (1972b) correlated sediment characteristics with the geologic, hydrologic, and bathymetric characteristics of 4 estuaries of the United States. He concluded that bottom sediment texture distribution patterns were controlled largely by hydrology (tidal range and flow regime), geology (sediment source), and bathymetry (topography). In the Chesapeake Bay, a large and deep estuary, silt and clay are abundant in the main channel and deep central area while fine to medium sands dominate the margins. In Pamlico Sound, a large but shallow estuary, the widespread distribution of sand is due to barrier island washover fans, inlet deltas, and the action of waves on the shallow bottom.

In a study of the Chesapeake Bay, six sediment "types" were found with each "more or less characteristic of their environment" (Ryan, 1953). *Normal Western Shore Sands* consisted of well-sorted coarse to fine grained sands whose source was the western bay shoreline. *Western Shore Terrace Sands* were poorly sorted medium to coarse sands that form a terrace extending bayward from the Calvert Cliffs area. *Eastern Shore Near-Channel Sands* showed a high degree of textural variation, increasing in median grain diameter adjacent to the mid-bay channel. *Eastern Shore Drowned Flat Sands* typically occurred on broad flats near Tangier Island and the mouth of the Pocomoke River. They were well sorted and generally fine to medium textured sands. *Chesapeake Bay Muds* were generally fine textured, though the silt/clay content varied in the samples. They occurred in the deeper water channels. Sand content increased nearer the mouth of the Bay. The last type, *Chesapeake Bay Entrance Clastics* were dominantly coarse sands and gravels and were thought to be a result of shifting continental shelf sediments. All of the above data and distribution information was obtained from cores extracted in greater than 4 m of water, with a majority originating in areas of 10-30 meters water depth. Of significance to this study was the association of the six sediment types with specific areas of the estuary. It was suggested that the distribution of sediment types was probably related to geologic formations and/or hydrologic processes. But, a closer review of the descriptions of each type reveals the possibility that subaqueous landforms might also be a factor. The sediment types were found to be associated with an underwater terrace, broad flats, channels, and the shallower margins of the Bay.

One of the more crucial findings in a study of the sediments of Pamlico Sound, North Carolina (Wells, 1989) was the "sharp" particle size changes associated with textural transition zones. This was believed to indicate that in shallow estuaries with low tidal range and low bottom current velocities, there is little large scale dispersion of particles. In addition, sediments were well sorted and were not "smeared" across bathymetric gradients. The abrupt changes in surface texture implied that a relationship existed between bathymetry and modal grain size.

The most important observation of these studies was that flow regimes and bathymetry could control the distribution of different sediment particle size classes. Each mode of transport typically involves a narrow suite of particle size classes. Thus, if the mode of transport (in this case, flow regime) is known, some predictions can be made concerning the textural distribution of the deposited sediment. The recognition that sediment grain size was related to bathymetry (and therefore, the contour of the subaqueous landscape) provides further evidence which suggests the notion of a systematic (or explainable) variation in sediment properties. Sediment texture may not merely be a reflection of the source area's geology, but rather a result of processes inherent to an estuarine environment; the *same* processes responsible for the formation of various subaqueous landforms.

Summary

All of the aforementioned studies have made important contributions to our understanding of sediment composition, sediment sources, and other important features. The limitations to much of the information, especially in terms of ecological studies, are the result of the emphasis on geologic concepts and methods for the acquisition, presentation, and interpretation of sediment data. For example, each sediment characteristic is typically presented individually on maps. In some cases, these may be delineations of particle size, while in others, the maps may be concentration isobars for organic carbon or other parameters. The lack of uniformity in attribute classes results in confusion as to what the classes actually represent. The use of Wentworth's scale (1922), Inman's classes (1952), Shepard's classes (1954), and subjective terminology for particle size classes is an example of one of the problems associated with sediment texture maps. In order to compare the maps, normalization of the data is required to perform the comparison. In other cases, numerous maps may need to be overlain to determine a more holistic concept of the sediment attributes at a specific site.

The lack of standard sampling depths and methods also presents a problem in understanding the implications of sediment maps. The wide variety of samplers commonly used in the field for surficial sampling would be adequate if the sediment was uniform with depth. However, the surface oxic layer in some sediments may be relatively thick or may not be present at all. Due to the design of the samplers, the actual depth of sampling varies. The analyses of these samples may at times reflect a "mixed" sample of surface and subsurface layers which may have significant differences in particle size and geochemistry. Analyses of "surficial" samples which include the redox discontinuity layer will be very different from those which do not. This could be critical to the accuracy of an ecological or environmental interpretation such as the sediment's effect on aquatic plant roots or the potential for acid-sulfate weathering. Thus, it is very difficult to determine what combination of sediment characteristics exist at any one location and what impact they may have on benthic plants and animals.

In addition to these problems, a majority of sediment maps are being produced at scales and with attribute classes which are inappropriate for detailed ecological work. While most United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS) soil survey maps are produced at 1:24,000 or 1:12,000, many of the available sediment maps are produced at scales of 1:1,000,000 or smaller (see Folger 1972a,b; Kerhin, 1980; Wells, 1989; Wells et al., 1996). Another major difference between soil maps and sediment maps is that sediment maps typically present only surficial characteristics (upper 5cm), while soil maps present the characteristics of the soil column (upper 200cm). Sediment maps can therefore be viewed as 2 dimensional maps, a surface attribute over area. In contrast, soil maps are 3-dimensional, delineating column attributes over an area.

The last, and possibly most important, limitation of historical sediment data is the relative lack of information in shallow (less than 2 m) water areas. Shallow water habitats are critical to the growth and survival of benthic organisms such as clams, oysters, crabs, and aquatic plants. The lack of standard sampling techniques, variable surficial sampling depths, no defined "vertical" control section, lack of an adequate mapping protocol, no formal sediment taxonomic system, and the small scale of sediment maps makes it almost impossible to determine ecological relationships at the level now required to enhance and restore estuarine benthic communities. These problems can only be resolved by developing a new mapping approach more applicable to modern needs.

Even with the above noted limitations, the acquisition of sediment data has set the stage for the possible development of a classification scheme and mapping protocol. The efficiency of the present sampling and mapping methods could be improved if evidence of systematic variation of sediment properties could be confirmed and used to develop a conceptual predictive model. The suggestion of this possibility may already exist in the evidence that suggets that sediment distribution is systematically related to bathymetry/bottom topography (Folger, 1972a,b; Hakanson and Jansson, 1983; Wells, 1989), estuarine landforms and/or environments (Katuna and Ingram, 1974), flow regimes (Krumbein and Aberdeen, 1937; Hough, 1942; Folger, 1972a,b; Hakanson and Jansson, 1983), and location/landform within the estuary (Ryan, 1953).

SUBMERSED AQUATIC VEGETATION

The Function of Submersed Macrophyte Roots

Although the relationship between water quality parameters and submersed aquatic vegetation (SAV) has been explained in several studies (Twilley and Barko, 1990; Chesapeake Bay Program, 1991; Stevenson et al., 1993), a more critical issue which remains unaddressed concerns the relationship between sediments and the submersed macrophytes which they support. The original concept of *soil* as a medium for plant growth (Simonson, 1968) is based partially on the relationship between functioning plant roots and the soil as a source of plant nutrition. If aquatic plant roots interact with the substrate for nutritional purposes, then sediment might be better understood as soil.

Many aquatic plants have structures similar to roots, but their function in plant nutrition varies. Some algae, such as kelp (*Laminaria sp.*), have root-like structures, or "holdfasts, whose sole function is to anchor the algae to the sediment. In contrast, submersed macrophytes such as eelgrass (*Zostera marina*) or widgeon grass (*Ruppia maritima*) have true rooting structures including root hairs, an endodermis, rhizomes, and nodes. While the visual appearance of submersed macrophyte roots is very similar to terrestrial plant roots, their function was a topic of controversy for nearly 100 years (Sculthorpe, 1967).

The results of submersed macrophyte plant nutrition experiments from the late 19th century were mixed in their opinions on root function. The two opposing viewpoints can be summarized as follows:

1) The roots of submersed macrophytes are primarily (if not exclusively) for

anchoring, and the nutrients for plant growth are obtained from the water column.

2) The primary function of submersed macrophyte roots is to obtain essential nutrients from the sediment.

Some evidence suggests that the plants absorbed nutrients from the water column through the shoots, leaving the role of roots confined to attachment and stability. The "anchoring only" view relied on the morphological observations that the roots of many submersed macrophytes are less developed, having less root hairs and reduced vascular systems when compared to terrestrial plants (Sculthorpe, 1967). On the other hand, others argued that in comparison to holdfasts, the presence of developed root systems with root hairs and rhizomes in some species of submersed macrophytes (such as *Zostera marina*) implied that the roots were functioning organs, actively removing nutrients from the sediment in much the same way terrestrial plants obtain their nutrition from the soil. The presence of a conspicuous endodermis on aquatic plant roots provided additional morphological evidence because of the similarities to terrestrial plant roots. Sculthorpe (1967) states that

> "in view of the ... importance of the endodermis in regulating lateral movement of water and ions in terrestrial roots, it is difficult to reconcile the prominence of the endodermis in aquatic plant roots with the notion that absorption and transport do not occur".

Experiments carried out by Pond (1905) attempted to clarify the aquatic root controversy by examining the differences in aquatic plant growth on different substrates. In one experiment, plants were grown in two tanks with natural lake water, one tank containing clean washed sand and gravel as a rooting medium while the other tank contained natural lake bottom mud. The plants growing on the lake mud had 33 percent more growth than those rooted in the clean sand/gravel mix. Other experiments also had similar results, suggesting that the substrate nutrient content, and therefore, root absorption, was a determinant of aquatic plant growth. Two of Pond's most notable conclusions were:

> 1) "Many of the [aquatic] plants rooting in soil develop root hairs, and the presence of these structures is the rule rather than the exception", and
> 2) "The roots of these [aquatic] plants are organs of absorption as well as attachment".

Although Pond (1905) had made a definitive statement based on experimental data, the debate on aquatic root function continued for decades. Pearsall (1917) interpreted distribution patterns of aquatic plants in relation to the chemical properties of the substrate as an indication that aquatic plants depend on nutrients absorbed from the sediment. King (1943), in a nutrient uptake study of waterweed (*Elodea densa*), suggested that because submersed macrophytes could obtain water and nutrients through their leaves, the roots had no major function other than anchoring. Waisel and Shapira (1971) claimed that though roots are essential to the healthy functioning of aquatic plants, they do not play a role in the absorption and/or translocation of nutrients. Den Hartog and Segal (1964) clearly expressed this view by stating

> " [aquatic plants]... are almost completely dependant on the aquatic medium for their metabolism. They obtain their mineral salts, their oxygen, and their carbon dioxide direct from the water".

The various interpretations of root morphology and the lack of direct experimental evidence for nutrient absorption by aquatic plant roots made resolution of the controversy extremely difficult (Sculthorpe, 1967). Carefully designed experiments were soon carried out to more accurately determine the pathway of nutrient uptake in rooted aquatic plants. It was not until the late 1960's that experimental data finally began to dispel the notion that nutrient uptake occurred exclusively through the foliage. McRoy and Barsdate (1970) studied phosphorus (P) uptake in eelgrass (Zostera marina) and found that the roots did in fact absorb P from the sediment. Tomlinson (1969) studied the function of turtle grass (*Thallassia testudium*) roots and concluded that aquatic plant roots have similar functional characteristics as their terrestrial counterparts. Bristow (1975) echoed the same sentiment in a review of the structure and function of aquatic plant roots. With the documentation of the nutritional function of aquatic plant roots, subsequent research soon began to more clearly establish the extent to which aquatic plant roots obtain nutrients from the sediment.

Uptake of Sediment Phosphorus

Bole and Allen (1978) studied the uptake of sediment phosphorus (P) by eurasian watermilfoil (*Myriophyllum spicata*) and hydrilla (*Hydrilla verticillata*). The results indicated that the roots obtained 38.5% of the plant's P requirement from the hydrosoil (sediment). Although the roots were shown to play a major role in P uptake, it was noted there were times that the roots appeared to stop performing that function. As P concentrations were increased in the water column surrounding the shoots, root uptake of sediment P decreased. It appeared that some aquatic plants could "choose" the mode of uptake based on the nutrient availability in the water column and sediment.

The results of a sediment-P mobilization study (Barko and Smart, 1980) indicated that the roots of submersed macrophytes were capable of supplying the P required for growth exclusively from the sediment. Although the results seemed to establish that P was obtained primarily through the roots, this could have been an artifact of the design of the experiment. The plants were rooted in high P sediments while the shoots were isolated in a nutrient-free water column. The notion that the roots may behave differently under varying water column nutrient availabilities (Bole and Allan, 1978) could help explain the increased root function. However, by preventing any shoot absorption of P during the experiment, the results provided firm evidence that the roots of submersed macrophytes are functioning organs rather than holdfasts.

The function of roots in the uptake of nutrients was further studied by Barko and Smart (1981) to determine if aquatic plant roots could completely satisfy their nutritional requirements exclusively through the roots. As in previous studies, the overlying water column was held relatively nutrient-free to determine the extent to which the roots were mobilizing nutrients from the sediment. Four different aquatic plants mobilized 70-97% of sediment P, enough to meet or exceed their P requirements.

Further evidence of P uptake by eurasian watermilfoil (*Myriophyllum spicatum*) was found in a study of sediment P mobilization under natural freshwater conditions (Smith and Adams, 1986). Naturally occurring concentrations of water column P were used in the experiment to simulate the conditions to which submersed macrophytes are typically exposed. The results indicated that up to 73 percent of the total P uptake by the plant was through the roots. This value is in agreement with other studies indicating 70-100% of total P was obtained through the roots (Carignan and Kalff, 1980; Moeller et al., 1988).

Carignan (1982) quantified the root's role in P uptake through the development of a mathematical model to estimate the relative contributions of sediment P (via roots) and water column P (via shoots) in aquatic plant nutrition. Along with analyzing the results of nine other studies, additional data was obtained utilizing a radioisotopic P method. To help address the issue of P uptake from the water column versus sediment sources, the sediment and water column P concentrations were held at nearly equal values. By creating an artificial condition in which P concentrations in both the sediment and water column were sufficient to support the plants, the relative contribution of roots and shoots under differing sediment and water column P conditions could be more quantitatively established. When grown under these conditions, eurasian watermilfoil (*Myriophyllum spicatum*), wild celery (*Vallisneria americana*), and water stargrass (*Heteranthera dubia*) derived 28-36% of their P needs from the sediment.

These studies of P uptake, under different water column and sediment P concentrations, were the first direct experimental evidence that aquatic plant roots were functioning organs for aquatic plant nutrition. This is not only significant in understanding root-sediment relationships, but also in understanding the habitat characteristics controlling the growth and survival of submersed macrophytes. The variation in root contributions to plant nutrition suggests that in areas of an estuary which are low in water column P, the sediments are critical in aquatic plant nutrition. This could be important in SAV restocking efforts such as those underway in the Chesapeake Bay.

Uptake of Sediment Nitrogen

Most studies have shown that nitrogen (N) can be assimilated by roots of SAV. Though one study indicated that N would be obtained from the water column through the shoots (Den Hartog and Segal,1964), Barko and Smart (1981) found that 3 species of aquatic plants obtained greater than 92% of their N requirements through root uptake. It was suggested that N uptake by shoots was likely to be negligible in natural environments because sediment N availability is usually much greater than N in the water column (Barko and Smart, 1981). In an attempt to address the relative contributions of N uptake via roots and shoots, Short and McRoy (1984) found that as water column N increased, root uptake of N decreased. It would appear that most submersed macrophytes are capable of utilizing either the roots or shoots for N uptake, depending on the availability of N in the sediment and water column.

In general, ammonium is the most abundant form of N available in sediments and is also the most preferred form of N for submersed plant uptake (Dennison et al., 1987). In a study of seagrasses and nutrient availability, Short (1983) found that as eelgrass (*Zostera marina*) colonized an area over a 4 year period, the pool of sediment ammonium decreased. Barko et al. (1988) found that Hydrilla (*Hydrilla verticillata*) reduced the available N in sediment by as much as 90 percent. They also found that over time, potassium (K) levels in the sediment increased by as much as 30 percent, suggesting that K taken up through the shoots was translocated to the roots where it was then exchanged for ammonium ions. Barko (1982) had previously shown the primary source for K obtained by submersed macrophytes was the water column.

Other Evidence of Root Function

Another similarity to terrestrial plant roots was noted in the creation of iron hydroxide plaques around aquatic plant roots. These plaques have also been observed in wetland soils, where they are commonly referred to as oxidized root channels (Federal Interagency Committee for Wetland Delineation, 1989). The plaques form as a result of oxygen being transported to the roots via the lacunal system of submersed macrophytes (Carpenter et al., 1988; Sand-Jensen and Prahl, 1982). The adsorption of phosphate ions by these plaques has been described as an "iron curtain" because of their affect of reducing phosphate availability to the roots (Chambers and Odum, 1990). Plaques surrounding wild celery (*Vallisneria americana*) roots were found to have twice as much phosphate and two times as much iron as nearby bulk sediment samples (Wigand et al., 1996).

Further evidence that aquatic plant roots behave like terrestrial roots was furnished by Wigand and Stevenson (1994) through their discovery of mycorrhizae on the roots of wild celery (*Vallisneria americana*) in the Chesapeake Bay. This suggests that fungal associations with submersed macrophytes may be more common than originally believed (Farmer, 1985). It would appear that the mycorrhizae perform a similar beneficial function for aquatic plants as they do for terrestrial plants (Malloch et al., 1980), in this case by increasing the amount of phosphate available to the roots.

In a review of literature, Barko et al. (1991) discussed sediment interactions with submersed macrophyte growth. Table 2-2 shows the plant nutrients and their likely source. For nitrogen and phosphorus, the main source is the sediment. In addition, sediments also supply iron, manganese and micronutrients as well. The water column is

Table 2-2. Primary sources of nutrient uptake by submersed aquatic macrophytes (after Barko et al., 1991)

Submersed Aquatic Plant Nutrient	Primary Source
Nitrogen	Sediment
Phosphorus	Sediment
Iron	Sediment
Manganese	Sediment
Micronutrients (Zn, Cu, B, Mo)	Sediment
Calcium	Open Water
Magnesium	Open Water
Sodium	Open Water
Potassium	Open Water
Sulfate	Open Water/Sediment
Chloride	Open Water

the dominant source for many minor nutrients and also for the macronutrient potassium. In effect, the original debate over roots versus shoots was framed too simplistically. The results of numerous studies point to both modes of uptake, depending on the nutrient involved and the ambient concentration of the nutrient in the overlying water column. Although both mechanisms occur, the most important result of all of the above cited research is the definitive resolution that roots of submersed macrophytes do function similarly to their terrestrial counterparts and are a significant pathway for the uptake of plant nutrients.

Sediment Characteristics Affecting Aquatic Plant Growth

In addition to the obvious positive effects of sediment as source of nutrients, other sediment characteristics can also have an impact on the growth of submersed macrophytes. Barko and Smart (1986) studied numerous sediment related growth limitations on eurasian watermilfoil (*Myriophyllum spicatum*) and hydrilla (*Hydrilla verticillata*). Sediment samples from forty different sites were taken and analyzed to determine their physical and chemical properties. The plants were then grown on each sediment to evaluate any growth differences in relation to sediment attributes. In addition, some sediments were manipulated in their nutrient status, organic matter content, and other parameters and total SAV biomass was determined at the end of each experiment.

One of the experiments indicated that sediment organic matter content had a negative effect on the growth of both submersed macrophytes in the study. Growth was significantly decreased when organic matter levels were greater than 20 percent (12 percent organic carbon). The reduced growth was postulated to be a result of three potentially interacting mechanisms. Phytotoxins produced by the decomposition of organic matter may be detrimental to the roots (Armstrong, 1975), root metabolism may be severely reduced due to the increase in anaerobic conditions (Armstrong, 1978), and organic matter complexation of some nutrients may reduce overall nutrient availability.

Carpenter et al. (1983) examined the redox state of sediments to determine if the transfer of oxygen by aquatic plants to their roots could help counter the accretion of organic matter related toxins and reduce their deleterious impact. The results indicated that although the redox potential was substantially increased in the rhizosphere, this was not sufficient to detoxify reduced phytotoxins or enhance the decay of the organic matter. The production of sulfides during the decomposition of organic matter was implicated due to their high toxicity to plant roots.

Sediment density is another factor that has been shown to effect the growth of submersed macrophytes (Barko et al., 1991). Sediment densities of 0.9-1.3 g/ml and sand contents greater than 75 percent resulted in reduced growth. Densities of 0.2 g/ml or less also resulted in diminished growth. In low density sediments, the authors suggest that the longer diffusion distances result in lower nutrient uptake. In high density sandy sediments, the naturally low fertility of sand was felt to be the major factor affecting growth (Barko and Smart, 1986).

First suggested by Pearsall (1917), sediment slope might also be a controlling mechanism in submersed macrophytic growth. To test this concept, Duarte and Kalff (1986) evaluated macrophyte biomass on a variety of slopes in a freshwater lake in Vermont. At slopes greater than about 2.4 percent, biomass production was significantly lower than would be expected. This may be due to differences in the physical stability (or slumping potential) of sediments at differing slopes. The mathematical model developed in the study indicated that slope accounted for 72% of the variation in the maximum submerged macrophyte biomass.

Summary

It is now well established that sediments have an impact on the growth and survival of submersed macrophytes. This is in part due to the fact that aquatic plants rely on the sediment for many of their nutritional needs (under natural conditions when water concentrations of nutrients are low). This confirms Pond's (1905) view concerning the nature of the sediment. Due possibly in part to the similarities in root function and morphology of submersed macrophytes and terrestrial plants, Pond (1905) refers to the sediment throughout his report as soil. Many other studies from the 1800's cited by Pond also refer to the sediment as soil. Yet at some point there was a change in nomenclature. In some studies the term soil was replaced by "hydrosoil" (Bole and Allan, 1978), but in a majority of more recent studies, the substrate is referred to as sediment. The conceptual differences between "sediment" and "soil" are significant and the implications of the change are numerous. The original concept that the substrate for rooted submersed macrophytes was *soil* was appropriate then, and may be even more appropriate now. As Pond (1905) writes in a very forceful statement

> "...ought not these facts...engage physiological botanists anew in a study of the dogma that the roots of aquatic plants serve only as organs of attachment? It may be possible that they have a certain nutritive function for the plant...[and] it is evident that these [rooted] aquatics are dependant on the *soil* for optimum growth".

The inspiration of Pond (1905) to investigate aquatic plant root function contributed to the "roots vs. shoots" controversy. The meticulous examination of phosphorus uptake in recent years provided the experimental evidence to confirm that the roots of submersed macrophytes are essential to aquatic plant nutrition. Additional interactions between the roots and the sediment were documented in a variety of other experiments. Not only were the plant roots affecting the sediment, sediment characteristics were having an impact on the growth and survival of the plants.

The establishment of this relationship, the relationship between functioning roots and the sediment as a source of plant nutrition is, I believe, a fundamental component of the original concept of soil as a medium for the growth of plants. Thus, the sediment is not merely a substrate for anchoring, it is also a nutrient supplying *medium for rooted aquatic plant growth.*

SOILS

Shallow Water Sediments in a Pedological Framework

The preceding two sections have discussed sediment characteristics, possible explanations for their distribution; and established that submersed macrophytes utilize the sediment in much the same way that terrestrial plants utilize soil. The final issue to be examined concerns the underlying philosophy behind the possible approaches (or methods) available for sediment mapping. Each method employs significantly different fundamental assumptions which ultimately affect the way in which data are collected, interpreted, and presented. The choice of approach can be considered a result of the answer to one basic question: Is the material sediment or soil? Although the question may seem trivial, the ramifications of the answer are enormous.

Though "soil" and "hydrosoil" were used occasionally in sediment studies (Pond, 1905; Bole and Allan, 1978), the use of the term "sediment" has remained the dominant nomenclature applied to estuarine substrates since the 19th century. The historical emphasis of geologic concepts and the choice to identify the substrate using geologic terminology may have lead to the principal sediment mapping approach and concepts being applied today. Sampling in a grid pattern implies either the attribute(s) being studied occurs in no discernible pattern, or, the cause of the distribution is unknown (Wilding and Drees, 1983). An advantage of the grid pattern is that given a sufficiently detailed grid spacing, it is possible to determine delineations with a high degree of accuracy. For example, many Order 1 soil surveys employ a grid sampling pattern (Soil Survey Division Staff, 1993a). This level of soil survey is primarily used for small areas (such as research plots, building sites, and septic fields) and grid spacings are typically less than 15 meters. The disadvantage of this method is that it is costly, time consuming, and only applicable in specific situations. In the case of sediment mapping, the grid spacing is commonly greater than 500 meters. In addition, the mapping of "surficial" sediment characteristics and the concept of sediment as merely a geologic formation has unintentionally reduced the adequacy of the data for detailed ecological work. Any alternative method would therefore view the sediment as a biological as well as geological formation, be capable of delineating a 3-dimensional view of the sediment column, and incorporate a more efficient and economic sampling method based on a predictive conceptual model. To more fully understand an alternative method, a pedological approach, it is necessary to outline in detail the basic tenets of pedology.

Shallow Water Sediments and the Definition of Soil

One of the issues to be resolved is whether sediments meet the definition of soil as understood by pedologists. *Soil Taxonomy* (Soil Survey Staff, 1975), the United States system for the classification of soils, defines soil as:

> "Soil, as used in this text, is the collection of natural bodies on the earth's surface, in places modified or even made by man of earthy materials, containing living matter and supporting or capable of supporting plants out-of-doors. Its upper limit is air or shallow water. At its margins it grades to deep water or areas of rock or ice".

Since 1975, *Soil Taxonomy* has undergone a number of revisions and additions mainly in the criteria for determining the proper taxonomic placement of soils. A revision of the definition of soil has also been proposed. This definition (Soil Survey Division Staff, draft 1996) states:

> "Soil in this text is a natural body comprised of solids (mineral and organic matter), liquid, and gases which occurs on the land surface, occupies space, and one or both of the following: is organized into horizons or layers that are readily distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy or matter or is capable of supporting plants out-of-doors. This definition is expanded from the previous version in *Soil Taxonomy* to include soils in areas of Antarctica where pedogenesis occurs, but where the climate is too harsh to support higher plant forms.
>
> The upper limit of soil is the boundary between soil and air, shallow water, live plants, or plant materials that have not begun to decompose. Areas are not considered to have soil if the surface is permanently covered by water deep enough that only floating plants are above the water surface. Soil's horizontal boundaries are where it grades to deep water, barren areas, rock, or ice. In some places the separation between soil and non-soil is so gradual that clear distinctions cannot be made."

In the *Soil Survey Manual* (Soil Survey Division Staff, 1993b), additional information concerning the definition is presented, stating:

"Bodies of water that support floating plants, such as algae, are not soil, but the sediment below shallow water is soil if it can support bottom-rooting plants such as cattails or reeds".

Foth (1978), in *The Fundamentals of Soil Science*, takes a somewhat narrower perspective stating that "Soil (is the) unconsolidated material on the immediate surface of the earth that serves as a natural medium for the growth of land plants". This definition makes reference to "land plants" which implies that the vegetation being supported is terrestrial in nature, thereby excluding soil from the realm of aquatic plants. This notion is echoed by Nikiforoff's (1959) view that soil is the "excited skin of the subaerial segment of the earth's crust". In this case, the upper limit of soil is defined as the atmosphere, once again excluding aquatic environments. *Webster's New World Dictionary* (1974) defines soil as "the surface layer of the earth supporting plant life". Although the definitions of soil vary to some degree, the majority of pedologists agree that soil characteristics are a result of pedogenic processes and soils must also be capable of supporting natural vegetation.

In contrast, sediment is defined as "unconsolidated material derived from pre-existing rocks by processes of denudation" (Whitten and Brooks, 1972). *Webster's New World Dictionary* (1974) defines sediment as "matter deposited by wind or water". As can be seen, the definition of sediment does not contain any reference to its function as a substrate for plant growth. This concept is a major philosophical difference between "sediment" and "soil". The reference to plants (Soil Survey Staff, 1975) and rooted plants (Soil Survey Division Staff, 1993b) implies that for material to be considered soil, it must not only be a medium for attachment and stability, but also function as a nutrient source available to rooted plants.

The controversy then is not whether soils are a medium for plant growth, but rather to what *types* of plants is the definition referring? The idea of soil as a medium for plant growth has probably been the main concept of soil since mankind turned from hunting-gathering to a more agrarian society. It quickly became obvious to early farmers that some soils produced healthier more productive crops than others (Simonson, 1968). In the 18th century, many agriculturalists believed that plant roots fed directly on soil particles. Jethro Tull (1733) believed his cultivator broke the soil into particles fine enough that more were exposed to the root for consumption. It wasn't until the 19th century when agricultural chemists began to examine plant nutrition that the nutritional and chemical relationships between the root and soil were established. Therefore, the *types* of plants referred to in the various definitions of soil must rely on root-soil interaction for their nutrition. This relationship is the underlying science behind the concept that "soils are capable of, or presently supporting plants out-of-doors" (Soil Survey Staff, 1975). What may seem on the surface as a somewhat simple-minded statement to be included in a scientific definition actually has significant scientific and philosophical implications. Although physical support is important, I believe that the plants that soils support must have functioning roots that can utilize the soil as a source of nutrition. This is the key to understanding both the original concept and present definition of soil.

The concept that soils support plant growth is an obvious offshoot of their relationship with agricultural crops (Fanning and Fanning, 1989). The definition contained in *Soil Taxonomy* may reflect an agricultural bias due to its development under the auspices of the United States Department of Agriculture. Although the driving reason for the study of soils originated in the desire for producing crops, the fact remains that one of the most important functions of soils in ecosystems is their use as a medium for growing plants. This may be why, as Fanning and Fanning (1989) state "a plant related definition will probably be maintained for most soil classification and survey purposes".

Herein lies the first and foremost basic philosophical tenet that affects the way in which estuarine substrates could be examined. To confidently apply a pedological approach, it is essential that the materials meet the definition of soil. Species of submersed aquatic vegetation have been shown to rely on the sediment for root absorption of some of their nutrition. Therefore, estuarine substrates are capable of, or presently are supporting bottom-rooted plants, thereby establishing that shallow water estuarine sediments are soil as defined in *Soil Taxonomy* (Soil Survey Staff, 1975; Soil Survey Division Staff, draft 1996) and the *Soil Survey Manual* (Soil Survey Division Staff, 1993b). As V.V. Dokuchaev, the father of Soil Science was purported to have said (Coffey, 1911):

> "the soil is considered a biological as well as a geological formation, and unless the material has been influenced by life in some form it must be classed as rock and not soil".

Shallow Water Sediments and the State Factors of Soil Formation

Having established that sediments at least meet a portion of the pedological definition of soil, the decision to change nomenclature immediately alters the underlying philosophical concepts which could be applied to the mapping of underwater substrates. Much in the same way that the term sediment compelled the use of a geologic framework, the applicability of the definition of soil provides the opportunity to examine substrates from a pedological perspective.

Pedology is the science that studies the characteristics, evolution, and distribution of soils as organized natural bodies at the earth's surface. The characteristics of soils were initially examined primarily in relation to plant growth. The first systems to classify land based on the soil's suitability for plant growth were developed by the Chinese nearly 4,000 years ago and revisited by the Romans 2,000 years later (Simonson, 1968). With the inception of geology in the late 18th century, the study of soils began to incorporate new concepts that were not related in some way to plant growth. This resulted in the view that soils were the product of the weathering of rock, whether in place or after transport (Simonson, 1986). Thus, soils began to be viewed as unique geographic entities that were merely a by-product of the underlying geology. This geologic perspective to soil mapping and classification held sway for most of the 19th century and was a major component of the conceptual framework applied in early soil survey efforts begun in 1899 in the United States. For example, in the Soil Survey of Worcester County, Maryland (Bonsteel and Carter, 1904) it is remarked that "considering the fact that the area lies entirely within one geological province, a relatively large variety of soil types is found". The 1904 soil survey has only 9 soil types compared to 73 soil types (or phases) in the most recent soil survey update (Demas and Burns, 1997).

Unknown to most soils researchers, the Russian soil scientist, V.V. Dokuchaev (1948) proposed the first break from the geologic perspective in 1883 by presenting the concept that soil is an independent natural body which "can not be mistaken as surface rocks". He also believed that soils were a result of the interactions of plants and animals, local climate, parent rocks, topography, and the age of landscapes. This approach to the study of soils was later popularized by Jenny (1941) who described the primary factors affecting soil formation by the equation $S = f(C, O, R, P, T)$. His equation illustrated that a soil (S) is a function of five state factors: climate (C), organisms (O), relief (R), parent material (P), and time (T). This was an attempt to explain the wide range in soil types and soil characteristics found throughout the world. This approach addressed the systematic variation in soil properties as related to the five soil forming factors and further implies that soils have unique genetic histories. The publication of these concepts and their later inclusion in soil classification systems completed the break from the early geologic perspective of soil genesis. The concept of soil as an organized natural body resulting from the interaction of the five state factors of soil formation provided the basis from which the discipline of pedology arose.

To apply a pedological approach to the study of sediments, not only should sediments meet that portion of the definition of soil related to "supporting plants", but they must also have been affected by pedogenic processes. Therefore, having established that shallow water sediments are indeed a medium for the growth of plants, the next issue to resolve is whether previously established sediment characteristics and processes can be regarded as a function of the of the five state factors of soil formation.

Climate, or the environment in which a soil forms, is classically conceptualized in terms of temperature and precipitation. One of the more important aspects of climate involves precipitation, or the vertical movement of water through the soil profile. In shallow water environments, water is primarily flowing horizontally across the sediment surface, as well as moving into the profile. Thus, the traditional role of precipitation in leaching processes is inapplicable in sedimentary environments. A more important aspect of climate in sediment is temperature. Temperature has an impact on sediment characteristics by determining the redox potential and the location of the any redox discontinuity layers (or redox boundaries). In addition, temperature will control the rate of many chemical reactions. Nedwell and Floodgate (1972) found that most of the sulfide production in a set of anaerobic sediments came from sulfate when temperatures were above 5-10 C° , and from organic sulfur when below these temperatures. The rate of organic matter decomposition is also temperature dependant, the rate increasing with increasing temperature (Odum and de la Cruz, 1967).

Organisms can also play a role in determining sediment characteristics. Katuna and Ingram (1974) noted that vegetated shoals did not exhibit any distinct sedimentary structure due to bioturbation and the presence of submersed macrophyte roots. Wells et al. (1996) noted that in Sinepuxent Bay, Maryland "all [sediment] cores except for the sandy ones showed some degree of bioturbation". Rhoads (1974) suggested that deposit feeders supplied a food source for bottom dwelling organisms by transferring organic matter from anaerobic layers to the sediment surface. Submersed macrophytes have been shown to create iron rich plaques (oxidized root channels) in the adjacent sediment due to the pumping of oxygen to the roots (Caffrey and Kemp, 1991; Chambers and Odum, 1990). As summarized by Day et al. (1989), benthic organisms alter the sediment in five ways. These include bioturbation, organic carbon depletion, the production of binding agents such as shells and mucous, biodeposition, and oxygenation of anaerobic sediments.

The role of relief (topography) in determining sediment characteristics is illustrated by a number of studies. Modal grain size (surface texture) was found to be related to bathymetry and estuarine environments (Wells, 1989; Katuna and Ingram, 1974). In the Chesapeake Bay, Ryan (1953), found that two of the six noted sediment types occurred respectively on "broad flats" and on an underwater "terrace". Slumping or creeping of the sediment in lacustrine environments has also been found to occur on slopes greater than 5 percent (Duarte and Kalff, 1986).

The effect of parent material on sediment characteristics is ultimately related to their point of origin. A sediment derived from barrier island washover materials will be dominantly sandy, composed mainly of quartz, and be inherently infertile (Kochel and Wampfler, 1989). In contrast, a sediment derived from more loamy materials may exhibit finer textures, contain higher amounts of weatherable minerals, and exhibit higher levels of natural fertility (Wells et al., 1996). Coakley and Poulton (1993) demonstrated that the source area of parent materials of sediments of the St. Lawrence estuary could help explain sediment composition.

Of the five state factors of soil formation, the component of time is universally applicable to shallow water sediments. For example, the degree of bioturbation will be related to the length of time organisms have been active in the sediment. The development of sedimentary structure and subaqueous landforms will depend on the time available for the action of the processes responsible for their expression.

From the above discussion it would seem reasonable to propose that the development of sediment characteristics can also be described as resulting from the interaction of the five state factors of soil formation. Although not necessarily acting in a traditional sense, the unique combination of these factors appear to control the resulting sediment characteristics.

Shallow Water Sediments and the Generalized Theory of Soil Genesis

The final issue to address in determining whether shallow water sediments can be considered soil involves the processes by which sediments form and/or change. The fundamental pedogenic processes were considered by Simonson (1959) to be additions, losses, transfers, and transformations. These processes are responsible for horizon differentiation (formation of pedogenic layers) in a soil profile. Materials which do not show evidence of these processes therefore would not have true soil horizons, and to consider them as soil might not be entirely appropriate.

Additions occur in sediments in much the same way they occur in soils, mainly through the deposition of new sediment or organic residues. Based on sedimentation rates in Sinepuxent Bay, Maryland estimated to be 0.34 cm/yr (Wells et al., 1996), new mineral material is being added to the system in a fashion similar to the deposition of sediment on a floodplain. The addition of organic matter to the sediment is a result of the death and decay of both aquatic animals and plants. Bach et al. (1986) estimated that less than 30% of the annual biomass production in eelgrass (*Zostera marina*) beds in North Carolina was ultimately exported from the system.

Loss from the soil, as proposed by Simonson (1959), generally occurs through leaching, seepage, and erosion. In shallow water sediments, the main process responsible for losses is erosion. Scouring of an area may occur during storms or periods of high flow. The action of waves in very shallow water areas contributes to the resuspension and movement of sediment. The result may be the removal of the oxygenated surface layer and exposure of underlying anaerobic layers. Erosion, such as by wave action, has also been cited as a loss by Boyd and Wood (1997) in a discussion of aquaculture pond soil formation. The conditions under which pond bottom soils develop are very similar to subaqueous soil environments except that they are periodically drained for maintenance.

Transfers within a soil profile are commonly conceptualized in terms of eluviation and illuviation. Due to their permanent saturation, the classic concept of a transfer may not be directly applicable to sediments. But, as defined by Simonson (1959) and Fanning and Fanning (1989), transfers may also include diffusion phenomena, nutrient recycling, and pedoturbation (bioturbation). The diffusion of oxygen into the sediment from the overlying water column is in part responsible for the yellowish color and thickness of the surface horizon (Fenchel and Riedl, 1970). In the upper 5-15 cm of the sediment profile, phosphate concentration is buffered by adsorption-desorption equilibria with the sediment, and surface adsorbed phosphate may be released to pore water as needed to replace dissolved phosphate that escapes to plant roots or the overlying water column (Sundby et al., 1992). The transfer of feces, pseudofeces, and sediment from burrows to the sediment surface, and oxygen downward by benthic organisms can be significant (Day et al., 1989). Deposit feeding benthic organisms, which are responsible for these transfers, were referred to as "conveyor belt" species by Rhoads (1974).

Transformations (Simonson, 1959) in a soil can be considered as organic or mineral transformations. Mineral transformations may be simple, where the original structure of the mineral remains intact; or they may be complex, where the original structure is lost and new minerals may form. One example of a simple mineral transformation in terrestrial soils is the alteration of micas to expansible 2:1 clay minerals (Fanning and Fanning, 1989). Another example is the reduction of iron oxides which allows iron in solution to move in the soil profile and reprecipitate elsewhere. In sediments, the formation of ferrous sulfides can be considered to be an example of a complex mineral transformation. This process has been termed sulfidization by Fanning (1978). Iron oxides present in the original sediment are reduced producing ferrous iron in solution. Bacterially-mediated reduction of sulfate (from seawater) to sulfide during the oxidation of organic matter results in the precipitation of ferrous sulfides, of which pyrite is the most common (Morse et al., 1987). The characteristic black color imparted by monosulfides in some layers of a sediment is an indicator of this process (Day et al., 1989; Fanning et al., 1993). In addition, oxidation of organic matter in sediment profiles results in their transformation to humic substances. Episodes of anoxia in the Chesapeake Bay have been attributed to the depletion of dissolved oxygen due to the decomposition of algal remains at the sediment surface (Chesapeake Bay Program, 1992; Harding et al., 1992).

Based on the evidence presented in the preceding discussions, sediments meet the definition of soil (Soil Survey Staff, 1975; Soil Survey Division Staff, 1993); their general characteristics are a result of the interaction of the five state factors of soil formation (Jenny, 1941); and their layers (horizons) created as a result of the processes outlined in the generalized theory of soil genesis (Simonson, 1959).

A Pedological Approach to the Study of Shallow Water Sediments

Establishment of the applicability of the definition of soil, the five state factors of soil formation, and the four general processes of soil genesis to sediments necessitates a change in terminology and perspective. It is therefore proposed that the present approach to mapping *shallow water sediments* be discarded in favor of a pedological approach to the classification and mapping of *subaqueous soils*.

A pedological approach to mapping is related to the systematic variation of soil properties (Wilding and Drees, 1983). Although it is very difficult to quantify individual state factors in Jenny's equation, pedological studies have been conducted wherein sites were selected to minimize the variations in four of the factors so that the remaining state factor could be better understood, quantified, and used in mathematical models. An example of this approach is the identification of a chronosequence, where soil properties are evaluated as a function of time or soil age. Griffin and Rabenhorst (1989) used ^{210}Pb dating to determine that the rate of accretion in selected Maryland tidal marsh soils was "keeping pace" with sea level rise. Rabenhorst (1997) later presented the concept of the chrono-continuum, which translates points in a topographic sequence into points in time. This concept was applied to tidal marsh areas where the elevation of the soil surface was, in effect, a function of sea level rise over time.

Another example of studying one of the five state factors is the climosequence. Rabenhorst and Wilding (1986) examined soil development as a function of climate on the Edwards Plateau, Texas. From east to west in this region precipitation decreases while pan evaporation rates increase. By selecting sites with similar parent materials and landscape positions, pedogenic features could then be examined in relation to the climate/moisture gradient. Soils formed in the dryer, western portion of the study site were calcareous and calcic and petrocalcic horizons were frequently found. In the more humid eastern section, soils were generally non-calcareous and argillic horizon development was common on stable landscapes. Ruhe and Scholtes (1956) evaluated the age and development of Iowa landscapes using fossil pollen and radiocarbon dating. In this bio-climosequence, historical fluctuations in climate from cooler/wetter periods to warmer/drier periods affected the vegetive assemblies, resulting in paleosols whose attributes could be related to both climate and vegetation.

Of the five factors, relief (topography) has perhaps been studied the most intensively. Milne (1936) first suggested the concept of a catena, which is considered to be an interlocking arrangement of soils across a changing landscape. The catena was effectively the concept of a toposequence. Topographic variation can have a major impact on the chemical, physical, and morphological characteristics of a soil. Watson (1965) noted that the catena concept was particularly valuable in the classification and mapping of soils in areas where hydrologic conditions are more variable than the parent material. With the introduction of the catena concept, a clear relationship between soils and topography became evident. The recognition that soil characteristics were related to landscape position suggested that soils were systematically distributed across the landscape. Thus, the analysis of landforms became critical to understanding the distribution of soils.

The "science of landforms" (Ruhe, 1975), or geomorphology, is defined as the "systematic examination of landforms and their interpretation as records of geologic history" (Howell, 1957). In one of the classic studies of soils and geomorphology, Ruhe

(1956) found that specific soils or soil associations occurred in a predictable way on five distinct geomorphic surfaces in Iowa. Although the degree of soil aeration and drainage variation were similar on all surfaces, there were distinct contrasts in soil characteristics depending on the age of the geomorphic surfaces. Thickness of the sola, thickness of the B horizon, and clay content of the B horizon increased from soils on the youngest surface to soils on the oldest surface.

In a study of geomorphic surfaces in North Carolina, Daniels et al. (1970) again found direct correlations between some soil characteristics and the geomorphic surface the soils occurred on. Solum thickness, number of soils with plinthite, and gibbsite content increased from the youngest to oldest surface. It was also noted that some soil properties exhibited curvilinear change over time. It was suggested that changes in water table regime due to landscape development was the reason for these non-linear relationship.

The integration of geomorphology and soil genesis was more fully elucidated by Daniels et al. (1971). The authors state that a "strong link should exist between these two sciences because they deal with parts of the same thing". Examples of case studies were presented to illustrate how geomorphic concepts improved the interpretation of soil genesis and landscape position. In one study, differences in soil properties initially appeared to be exclusively a function of slope. But the identification of a surficial loess layer of variable thickness indicated that there were depositional and erosional events which effected the interpretation of the age of the surface (and the soils). Thus, without the knowledge of the erosional modification of the landscape, soil development might mistakenly be assumed to be entirely related to slope differences.

In another study of geomorphic surfaces in North Carolina, Daniels and Gamble (1978) found that the stratigraphy and identification of the geomorphic surfaces established the framework within which the soil forming factors functioned. The textural properties and suites of soils expected on each surface were related to the origin of the materials which made up each surface. Yet soil morphological differences occurred within each geomorphic surface. This indicated that dissection of the surface, and the landscape position of a soil on that dissected surface, was responsible for the distinct sequences of soils associated with each geomorphic unit.

Soil-landscape relationships in the Piedmont of Maryland were studied by Darmody and Foss (1982). Loess deposits had previously been identified as a distinct geomorphic unit (Foss et al., 1978) on the Maryland coastal plain and as a thin mantle in the Maryland Piedmont. The results indicated that where slopes were gentle the loess was relatively thick, leading to the development of the Chester soil series. On steeper slopes, such as the shoulder of the landscape, erosional process had stripped the loess mantle resulting in the development of the Glenelg soil.

In a comprehensive discussion of pedology and geomorphology, Hall (1983) summarizes the major concepts concerning the soil-landscape relationship. Five landscape components are presented along with the soil properties which may be expected on each. The summit of a landscape is considered to be the most stable position. Uniform retention of water leads to more uniform soils. On the shoulder of a slope, surface runoff of water is maximized leading to a highly unstable and erosional surface. At this position, organic carbon content and solum thickness will be minimal. The backslope position is dominated by transportation of materials and water. It is considered to be relatively unstable. Where mass movement of materials is high, the presence and/or degree of development of diagnostic horizons is highly variable. The footslope position is a constructional surface and is relatively unstable. Due to mass movement, seepage, and non-uniform deposition of material, the soils associated with this position are very heterogeneous. The toeslope is another highly unstable surface due to the dominance of constructional events. These soils are derived from both eroded material from higher landscape positions and deposition of alluvial material from nearby floodplains. Thus, toeslope soils are highly variable due to combinations of materials of different origin, periodic flooding, and possible buried stream channels. Paleosols, or buried soils, are also common in the toeslope position. These geomorphic concepts have since become fully integrated in pedological research.

The utilization of landscape position in soil survey activities is essential to the development of soil maps and interpretations (Soil Survey Division Staff, 1993b). Hudson (1990) illustrates how soil mappers have intuitively relied on the soil-landscape relationship to delineate soils. Yet until the philosophical and scientific basis of soil survey was presented in written form as the soil-landscape paradigm, each soil surveyor learned it through the daily experience of delineating soils in the field. The pedological paradigm refers to the use of landforms as a tool to predict the variation of soils across the landscape (Hudson, 1992). The soil-landscape paradigm can be considered to be a synthesis of the five state factors of soil formation (Jenny, 1941) and the catena concept (Milne, 1936). The components of the soil-landscape paradigm (Hudson, 1992) can be summarized as follows:

"1) Within the soil-landscape unit, the five soil forming factors interact in a distinctive manner. As a result, all areas of the same soil-landscape unit develop the same kind of soil.

2) The greater the difference between the conterminous areas of two soil-landscape units, the more abrupt and striking the discontinuity between them. The more similar the two conterminous areas of soil-landscape units, the less striking or abrupt the discontinuity tends to be.

3) The more similar two landforms are, the more similar their associated soils.

4) Adjacent areas of different soil-landscape units have predictable spatial relationships.

5) Once the relationship among soils and landscape units have been determined for an area, the soil type can be inferred by identifying the soil-landscape unit".

This paradigm is the basis for much of the soil resource inventory activities presently underway in the United States. Yet, as will be seen, the soil-landscape paradigm has yet to be applied to sediments in shallow water estuarine environments.

This is not to say that sediments have been entirely neglected within the soil science community. The pedological examination and mapping of sediments has been performed in the past, but usually because of a need for information concerning land use. An example of this was the mapping of the Dutch polder soils for engineering data prior to the building of dikes (R.W. Simonson personal communication, 1993). In the early part of this century permanently submersed soils were mapped along the eastern edge of the Florida Everglades in an area slated for drainage and development (Baldwin and Hawker, 1915). Besides these few instances, sediment mapping has generally been neglected by soil survey programs.

Shallow Water Sediment Taxonomic Systems

Although little effort has been directed towards field mapping of sediments, much more work has been done towards developing a suitable pedologically based classification scheme. Initial attempts at classifying sediments originated in Europe in the late 1800's and early 1900's. v.Post (1862) was the first to classify sediments, introducing the terms dy and gyttja to describe lake sediments. The gyttja is described as a gray or reddish gray coprogenic formation consisting of plant fragments, mineral grains, pollen grains, spores, and the exoskeletons of insects and crustaceans. The dy is brown or blackish brown and was considered to be a gyttja mixed with brown humus. Potonie (1908) further broke down these two classes based on whether the humus was acidic or neutral. The term sapropel was introduced to describe bluish black sediments high in sulfides and methane. Kubiena (1948), in an attempt to develop a soil classification scheme, proposed three divisions for soils, one of which was subaqueous soils (including the terms dy, sapropel, and gyttja). Muckenhausen (1965) described the soil classification system proposed for the Federal Republic of Germany based largely on that presented by Kubiena (1953) in which subaqueous soils were included as "subhydric soils" and four types were proposed. These included dy, gyttja, protopedon, and sapropel. These four types were later defined by Arbeitskries Bodensytematik (1985). As one of the first, and perhaps only, attempts to classify sediment as soil, the definitions are somewhat general, relying mainly on the physical composition of the material. Table 2-3 provides the attributes of each subhydric soil type.

Although they are not permanently submersed, aquaculture pond soils have also been examined pedologically and proposals have been made to establish a system of

Table 2-3. German classification scheme for subaqueous soils (after Arbeitskreis Bodensystematik, 1985).

Subaqueous Soil Type	Subaqueous Soil Type Attributes
Protopedon	Subaqueous soils composed of different sediments without macroscopic humus, containing various organisms
Gytta	Subaqueous soils composed of organic and/or mineral sediments (typically limnic in nature). Generally high nutrient content and good aeration. Found most often in freshwater areas.
Sapropel	Subaqueous soils composed of odiferous organic sediments often with metallic sulfides, high nutrient contents, and poor aeration.
Dy	Subaqueous soils typically composed of humic-acid gels with low nutrient content and poor aeration.

nomenclature for horizon designation (Munsiri et al., 1995). The soils on the bottom of aquaculture ponds are submerged for extended periods, but differ from subaqueous soils in that they are drained periodically.

The official soil classification system of the United States, as presented in *Soil Taxonomy* (Soil Survey Staff, 1975), does not include any specific reference to subaqueous soils. Periodic revisions, including the most recent (Soil Survey Division Staff, draft 1996), have also failed to address the question of subaqueous soils. This may be in part due to a lack of comprehensive data, the desire of some pedologists to limit "soil" to terrestrial environments, or more importantly, the lack of an impetus to do so. Soil Taxonomy (Soil Survey Staff, 1975) does make reference to "limnic" materials, describing classes for marl, coprogenic earth, and diatomaceous earth. These materials are clearly defined, but there are no class limits and they are not included in any taxonomic key.

SUMMARY

With the advent of many estuarine restoration programs and formal goals for the restocking of submersed aquatic vegetation (Chesapeake Executive Council, 1992), the necessity of developing a classification and mapping scheme for sediments is now apparent. Just as the role of soils in wetland ecosystems became more prominent because of their ecological significance and wetland protection efforts (Federal Interagency Committee for Wetland Delineation, 1989), it would seem that the time has come to formally propose a comprehensive subaqueous soil classification system and begin a systematic inventory of estuarine subaqueous soil resources.

The presently applied concepts and methods in sediment mapping are, in some cases, inappropriate, inefficient, and lack the detail required for ecological work. The mapping of "surficial" characteristics is 2-dimensional, variable in depth, and at times does not fully characterize the attributes of the rooting zone of aquatic plants or the burrowing zone of other benthic organisms. The sampling pattern is widely spaced and frequently does not take into account sediment variation which may be related to bottom topography, flow regime, landforms, geomorphic characteristics, or landscape position.

Of greater importance, the present view of sediment does not include its relationship to living organisms, or its role as a medium for the growth of higher plants. The reasons that shallow water sediments should be considered subaqueous soils were eloquently summarized by Goldschmidt (1958) in his classic book, *Geochemistry*, where he states

> "For shallow waters with rooted vegetation the inclusion of bottom soils in the pedosphere may be as unquestionable as it is for the soils of mangrove swamps or flooded paddy fields... For the 'soil' nature of the uppermost layers of bottom sediments, the following reasons may be considered. They are a habitat of living organisms... Their content of organic matter is in many respects closely comparable to the humus soils on the land as regards both carbon and nitrogen. The uppermost bottom sediments show a distinct zoning, comparable to that of soils, by the gradual bacterial oxidation of organic matter in their uppermost horizons. The bottom soils are subject to processes of oxidation or reduction, of leaching, and base exchange in contact with the hydrosphere. This 'zoning', of course, is not to be confused with sedimentary stratification. The author thinks that soil is to be defined as the habitat for living organisms...and that subaquatic soils ought to be included in the pedosphere."

OBJECTIVES

Therefore, the objectives of this study were to evaluate a pedological interpretation of shallow water sediments through i) development and application of a subaqueous terrain analysis methodology, ii) assessment of evidence for pedogenic processes in subaqueous sediments, iii) testing of the soil-landscape paradigm for the classification and mapping of subaqueous soils, and iv) explore the use of subaqueous soil surveys for ecological and environmental applications.

CHAPTER III

A PEDOLOGICAL APPROACH TO TERRAIN ANALYSIS IN A SUBAQUEOUS ENVIRONMENT

INTRODUCTION

Terrain analysis, or topographic analysis, has become increasingly important in pedological research and soil survey activities. The pedological concept of terrain analysis may have begun with the work of Ruhe (1956). Through examination of soils on different landforms in Iowa it was found that specific suites of soils occurred at specific geomorphic-landscape positions. Further evidence of the relationship between landscape position and soil attributes was presented by Daniels et al. (1971) in a series of case studies. In one of the case studies, *A Hillslope Study in Uniform Material*, the slope gradient of the site was implicated as a major controlling factor in soil development. A more direct association between terrain and soil characteristics was provided by Hall (1983) in a discussion of the five hillslope components. Each hillslope component could generally be expected to exhibit specific soil attributes. The identification of the general terrain and landforms of an area for soil survey was considered by Hudson (1990) to be the conceptual basis for soil mapping. The relationship between soils and terrain attributes is formally acknowledged in the Soil Survey Manual (1993b) and has been recommended by Demas and Brown (1997) to become a more significant component in collegiate and USDA-NRCS training programs for inexperienced soil surveyors.

Terrestrial Terrain Analysis

Terrain analysis has been used in a number of ways in terrestrial pedological applications, including understanding pedogenic relationships, identification of paleosurfaces, wetland delineation, and soil survey. Evans and Roth (1992) used U.S. Geological Survey (USGS) 7.5 minute topographic maps to determine hillslope aspect, position, shape, elevation, and landform relief in an effort to quantitatively determine the modal concept and pedogenic attributes of two similar soils mapped in a region of New Hampshire. The analysis of landform parameters helped to more efficiently discriminate the two soils for mapping purposes and permitted genetic inferences about their depositional environments.

The determination of wetland soil characteristics has benefitted from terrain analysis techniques. Doolittle et al. (1995) used terrain analysis techniques to determine landforms types in which electromagnetic (EM) induction measurements would be taken in a Virginia study area. The apparent conductivity of soil materials can be estimated by EM measurements. EM values were highly correlated with floodplain, low terrace, and dissected upland positions. With the advent of advanced computer capabilities, digital elevation models (DEMs) have become more prominent in wetland soil investigations. Moore et al. (1993) used a DEM to predict such soil attributes as A horizon thickness and organic matter content. Thompson et al. (1997) used a DEM to determine if the spatial patterns of hydromorphic soils in an area of Minnesota could be predicted by the spatial distribution of terrain attributes. Terrain attributes commonly found associated with hydric soils included concave slopes of low (<2-3%) slope located less than 1-2 m above the lowest topographic depression. It was suggested that terrain analysis be used in wetland soil delineations as an adjunct tool to enhance the decision making process of field scientists.

Terrain analysis has also been used to help identify and determine the areal distribution of paleosurfaces. Rebertus et al. (1989) used field transit data to create DEMs for two sites in Delaware in a study of loess mantle thickness overlying the paleosurface of the Pennsauken geologic formation. Transit elevation data collected was highly detailed, representing about 0.03 ha/elevation measurement. The loess mantle-paleosurface contact was determined using ground-penetrating radar (GPR). From the data, three-dimensional diagrams were made of the present day surfaces and paleosurfaces. The present day surfaces were relatively uniform while the topographic variations of the paleosurfaces were much more pronounced. The short-range variability in loess mantle thickness significantly affected the taxonomic placement of the soils within the study areas. It was suggested that in these types of areas more general mapping units (such as associations, undifferentiated groups, or complexes) be used in soil surveys instead of more narrowly defined consociations. Doolittle et al. (1990) used GPR in a cranberry bog in Massachusetts to determine the depth of peat deposits. The peat/mineral interface data were then used to develop a terrain map of the paleosurface. The resulting contour maps indicated the cranberry bog had developed within a kettle, a remnant depressional feature of glaciated regions.

Soil survey applications of terrain analysis have been utilized since the development of the catena concept (Milne, 1936) and the establishment of soil-geomorphic relationships (Ruhe, 1956). The influence of topography on soil characteristics, and the identification of soil-landscape units is essential to soil survey activities (Soil Survey Division Staff, 1993a,b; Hudson, 1990, 1992). In small soil survey areas (<600,000 ha) such as county level soil surveys along the east coast of the U.S., terrain analysis and identification of landscape units is often done in the field by the soil surveyor. Rahman et al. (1997) suggest that soil surveys in areas of >1 million ha, such as those frequently encountered in the western U.S., could be more efficiently and economically performed utilizing computer generated terrain attributes from DEMs and ground-truthing using soil transect data. Their results for a forested mountain area of Wyoming indicated that terrain analysis techniques and the use of geographic information systems (GIS) would be especially suited to the development of general soils maps prior to the onset of detailed soil survey projects.

Terrain analysis has quickly become an important tool in terrestrial pedological research and soil survey. The generation of digital elevation maps from USGS contour maps or on-site transit surveys can be easily accomplished. The more highly detailed the topographic information, the greater the likelihood of accurate identifications of terrain attributes, and ultimately, the identification of soil-landscape units. Thus, terrain analysis is not merely the development of detailed contour maps, but a significant tool for the development of conceptual relationships between terrain attributes, landforms, and their associated soils.

Subaqueous Terrain Analysis

In subaqueous environments terrain analysis, as pedologists understand it, has not been performed. Contour maps of permanently submersed areas have been created using bathymetric data and utilized to identify underwater landforms such as channels and shoals. Detailed bathymetric maps are also frequently made for areas slated for dredging. Although useful for navigation and fishing purposes, the bathymetric data is typically not sufficiently detailed and accurate for immediate pedological or ecological applications. The reasons for this may be the inherent difficulties associated with the examination of permanently submersed estuarine environments.

One of the problems associated with performing subaqueous terrain analysis is the relative imprecision of the locations of the depth data collected. Compared to terrestrial situations where exact elevation transects can be precisely located, on the open water it is much more difficult to determine exactly where a depth sounding is taken. Thus, many bathymetric studies rely on cross-section methods to determine the location of each transect. For example, Katuna and Ingram (1974) utilized a series of buoys placed in line between two terrestrial landmarks to provide locations for depth data along a number of cross-sections. As global positioning systems (GPS) have become more available, some studies have utilized the U.S. Coast Guard Beacon for triangulation, resulting in location accuracies of ± 5-10 m (Wells et al., 1994a, 1996). Although more efficient and less time-consuming than the buoy/cross section method, the GPS/beacon method may still have errors of up to ± 10 m.

Another problem encountered in the study of subaqueous environments is the relative dearth of detailed bathymetric data. The development of DEMs from existing

USGS topographic maps for terrestrial areas are commonly used in terrain analyses. The level of bathymetric data available for many areas is insufficient to confidently generate a DEM with detail equivalent to terrestrial DEMs. For example, bathymetric maps developed for Assawoman and Isle of Wight Bay, Maryland were based on 170 depth sounding within the 4,560 ha study area, or 26.8 ha/sounding (Wells et al., 1994a). In Sinepuxent Bay, Maryland, the bathymetric map is based on 51 readings in 1,275 ha, or 25 ha/sounding. In a study of the Chesapeake Bay, Ryan (1953) used 213 soundings in 1.2 million ha, or 5,354 ha/sounding. Katuna and Ingram (1974), in a study of Pamlico Sound, North Carolina, used 22 continuous fathometer paper charts of cross-sections for development of a bathymetric map of the 0.5 million ha system. In contrast, terrestrial terrain analysis studies rely on elevation data typically representing <1 ha/data point (Rebertus et al., 1989; Thompson et al., 1997).

The last problem is that associated with tidal fluctuations. In a terrestrial environment, elevation data collected at one time of the day will be identical to data collected at any other time of the day (or month for that matter). In subaqueous settings affected by tides, this is not the case. A depth sounding at low tide may be significantly different than a sounding at the same location 6 hours later at high tide. Unless tidal range is extremely small or non-existent (such as in a lake setting), normalization of depth soundings would need to be performed to create an accurate bathymetric map. Small tidal ranges have been cited to explain the use of water depth data recorded at the time of sediment sampling for the creation of bathymetric maps (Wells et al., 1994a).

Recent technological advances have provided the means to address the difficulties presented by subaqueous environments. The problem of location can be resolved utilizing "real-time" GPS units. These units are capable of providing locations in unobstructed areas of <1 m accuracy without the need for post-processing or time corrections (Rockwell Corp. Staff, 1994). To increase the amount of data obtained in a study area, computer software has been developed which allows the simultaneous collection of location ("real-time" GPS units) and depth sounding (fathometer) data. To account for tidal fluctuation, digital tide gauges have been developed that can store over 500 tide height measurements and the precise time and date they were collected (Remote Data Systems Staff, 1994).

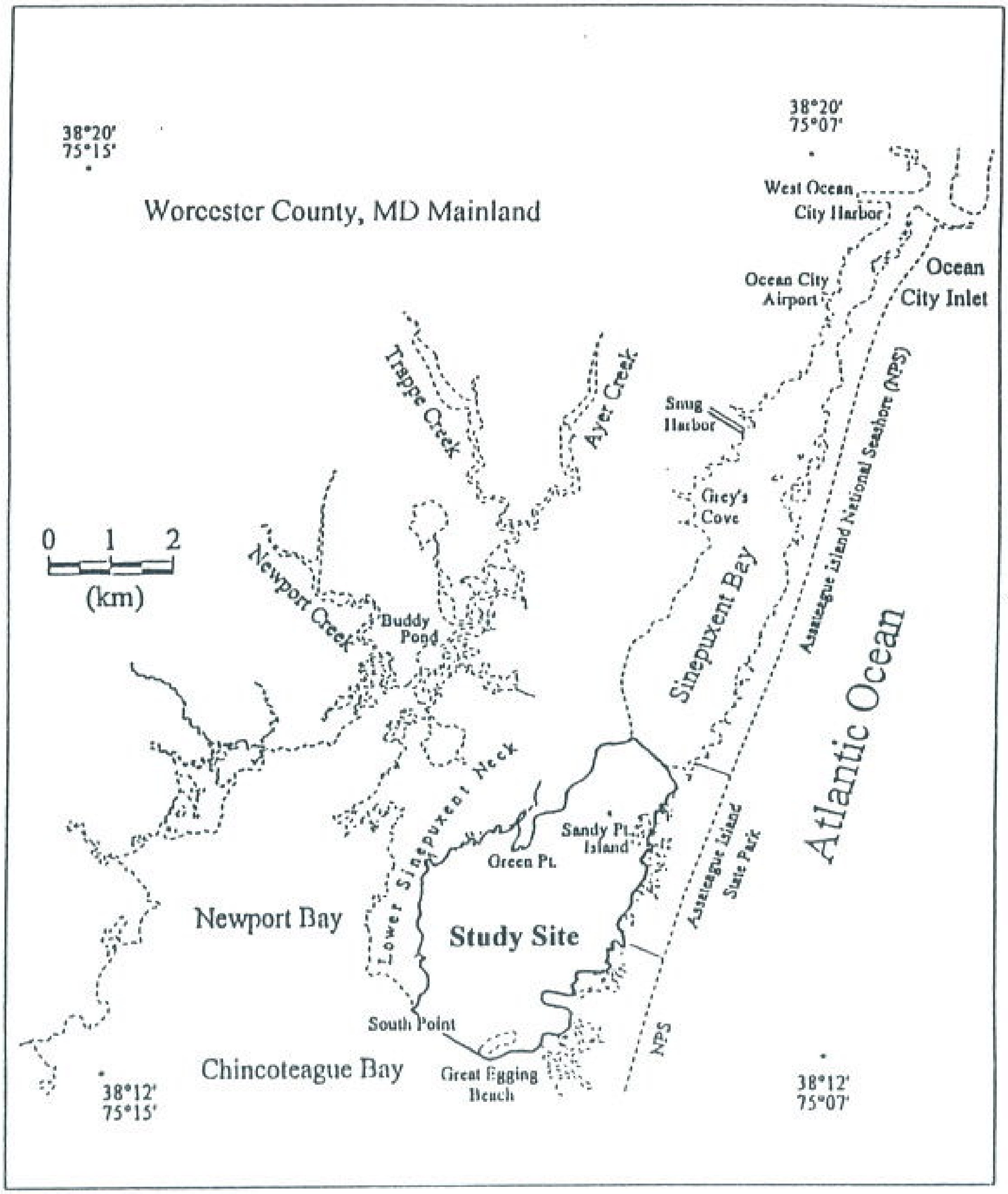
The objectives of this study were therefore to (i) evaluate the effectiveness of available technology in collecting detailed elevation (bathymetric) data in a subaqueous environment and (ii) develop a pedological protocol for subaqueous terrain analysis and identification of subaqueous landforms and landscape units.

MATERIALS AND METHODS

The site selected for this study was a 1,300 ha portion of Sinepuxent Bay, Maryland (figure 3-1). Sinepuxent Bay is a coastal estuary bounded to the east by the Assateague Island barrier system and to the west by the Worcester County mainland. The bay is generally shallow (<4.5 m) and has a relatively small tidal range of 0.5-0.75 m (U.S. Dept. of Interior, unpublished data). It is connected to the Atlantic Ocean by the Ocean City inlet 9 km to the north and the Chincoteague inlets 45 km to the south.

A Raytheon DE-719C marine research fathometer was used for the collection of

Figure 3-1. Sinepuxent Bay study site (base map from Maryland Geological Survey).



bathymetric data. An Odum Digitrace unit was installed in the fathometer to accommodate digital output of the data. The fathometer was calibrated each day prior to beginning data collection and checked periodically during actual sounding runs. Accuracy of the unit once calibrated could be expected to be < 1 dm.

A Rockwell PLGR+ PPS GPS unit was utilized for the collection of location data. Prior to each day of data collection, the unit was first allowed to download the "almanac" for the day, a process required to ensure operation at maximum accuracy levels. A Figure of Merit (FOM) value notation of 1 indicated the unit was operating at an accuracy level of <10 m in obstructed areas, or <1 m in unobstructed areas (Rockwell Corp. Staff, 1994). All location data collected was monitored to ensure FOM 1 levels. No data were collected at FOM values greater than 1.

The GPS unit and fathometer were both connected through serial ports of a laptop computer installed with Geolink XDS software (GeoResearch Inc. Staff, 1994). The software provides the capability of simultaneously recording time of day, "real time" GPS location data, and fathometer soundings. Because of continuous data collection capabilities, test runs were performed to evaluate the level of detail of the collected data. All data collected in this study was obtained at a boat speed of approximately 7.25 kilometers per hour (kph) with soundings/locations recorded every 5 seconds. This resulted in soundings spaced approximately 10 m apart.

A Remote Data Systems WL40 Tide Gauge was installed on a dock piling at the north end of the site to record tide data during the course of each day of bathymetric data collection. Tide heights were recorded every 10 minutes. At the end of each day, the tide gauge data were downloaded to the computer for later analyses. The tide gauge calibration point was set at 0 Mean Sea Level (MSL) through an elevation survey linked to USGS benchmark U141 located on the Verrazano Bridge between Assateague Island and the Worcester County mainland. These data were later used to normalize all fathometer soundings to depth below MSL.

Bathymetric surveys were made during the Spring of 1996. The survey consisted of cross sections, "edge" surveys, and main channel surveys. The mainland and barrier island edge was hand digitized and labeled as 0 MSL prior to combining and manipulation of the bathymetric data. A map illustrating the locations of bathymetric runs is shown in figure 3-2.

A bathymetric map of the site was created using the Surfer6 contouring software package (Keckler, 1995). All location data, by necessity, were converted to decimal degrees and "duplicates" were edited out. This was required due to the tendency of the software to average points located too close together. The map developed was based on the Kriging method (Odeh et al., 1992, Keckler, 1995) with a 100 by 100 node capacity.

RESULTS AND DISCUSSION

Over 23,000 geo-referenced fathometer soundings were collected in the 1,300 ha study area (approximately 0.06 ha/sounding). The bathymetric map developed from the data is shown in figure 3-3. Five contour intervals were selected for depths of less than1.0 m and three intervals for depths of 1.0-2.0 m to provide adequate detail in areas capable of supporting submersed aquatic vegetation (SAV). The most detailed bathymetric map of the site prior to this study is shown in figure 3-4 (Wells et al., 1996).

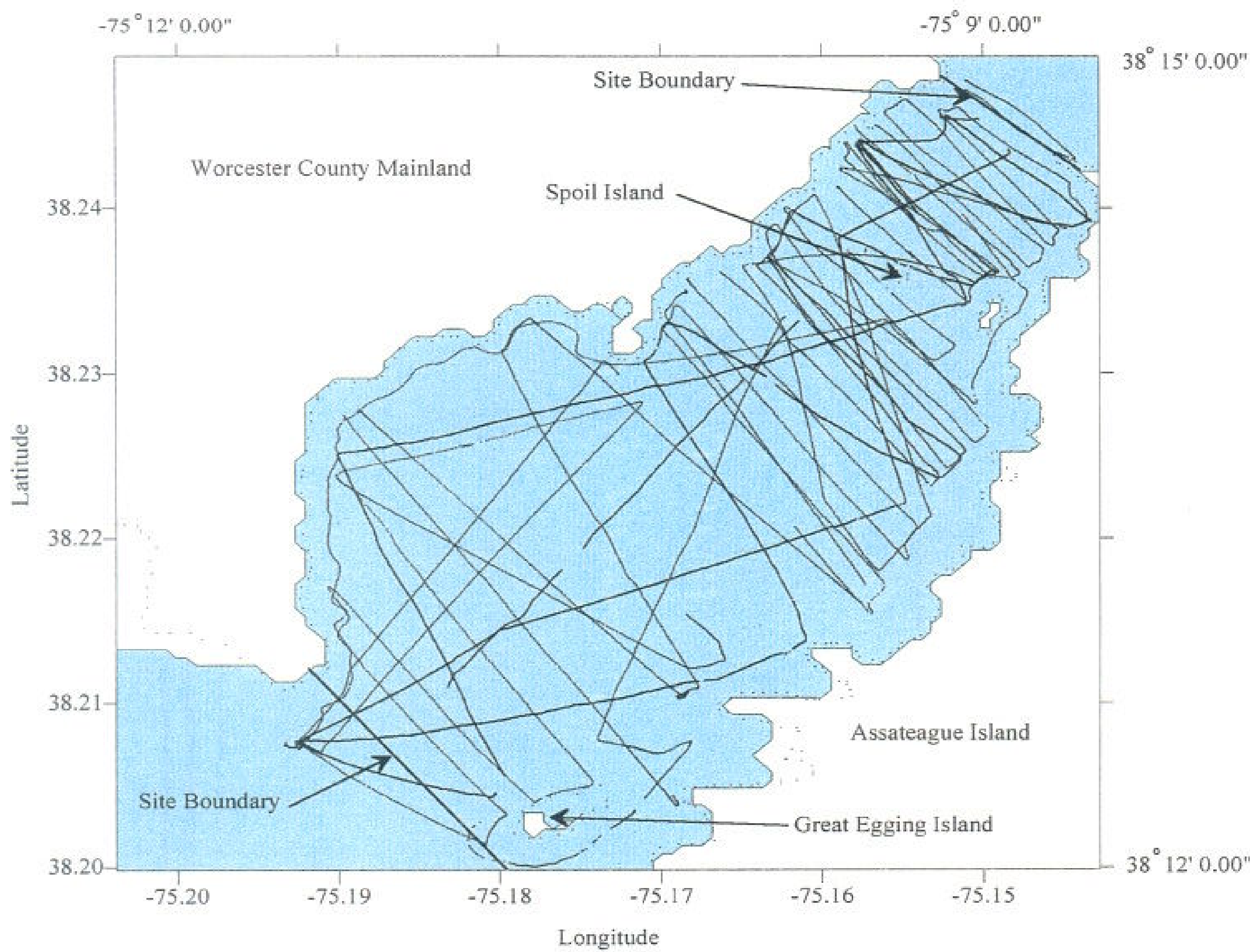


Figure 3-2. Location map of bathymetric runs in Sinepuxent Bay. Distance between successive readings was approximately 10 m.

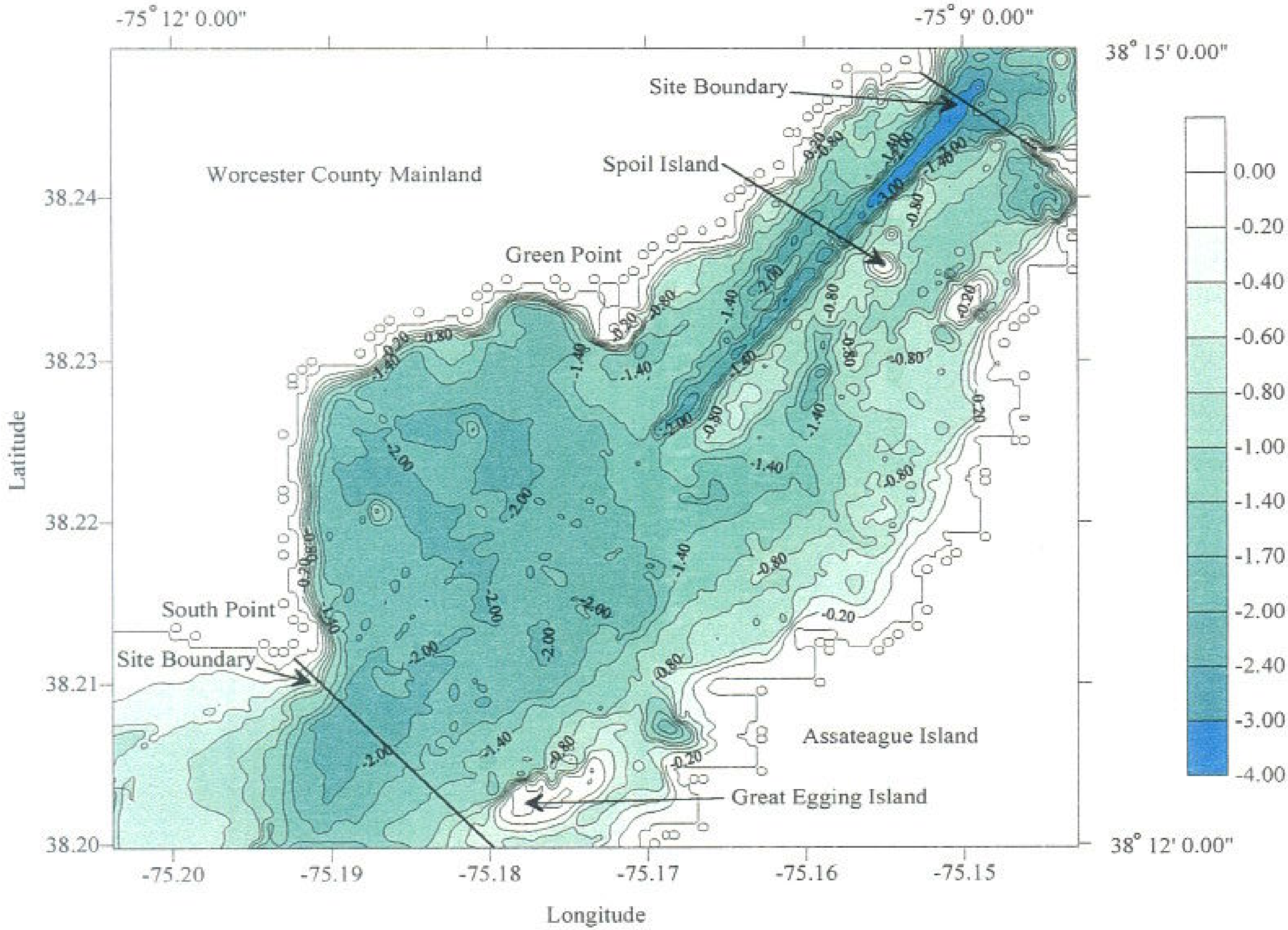
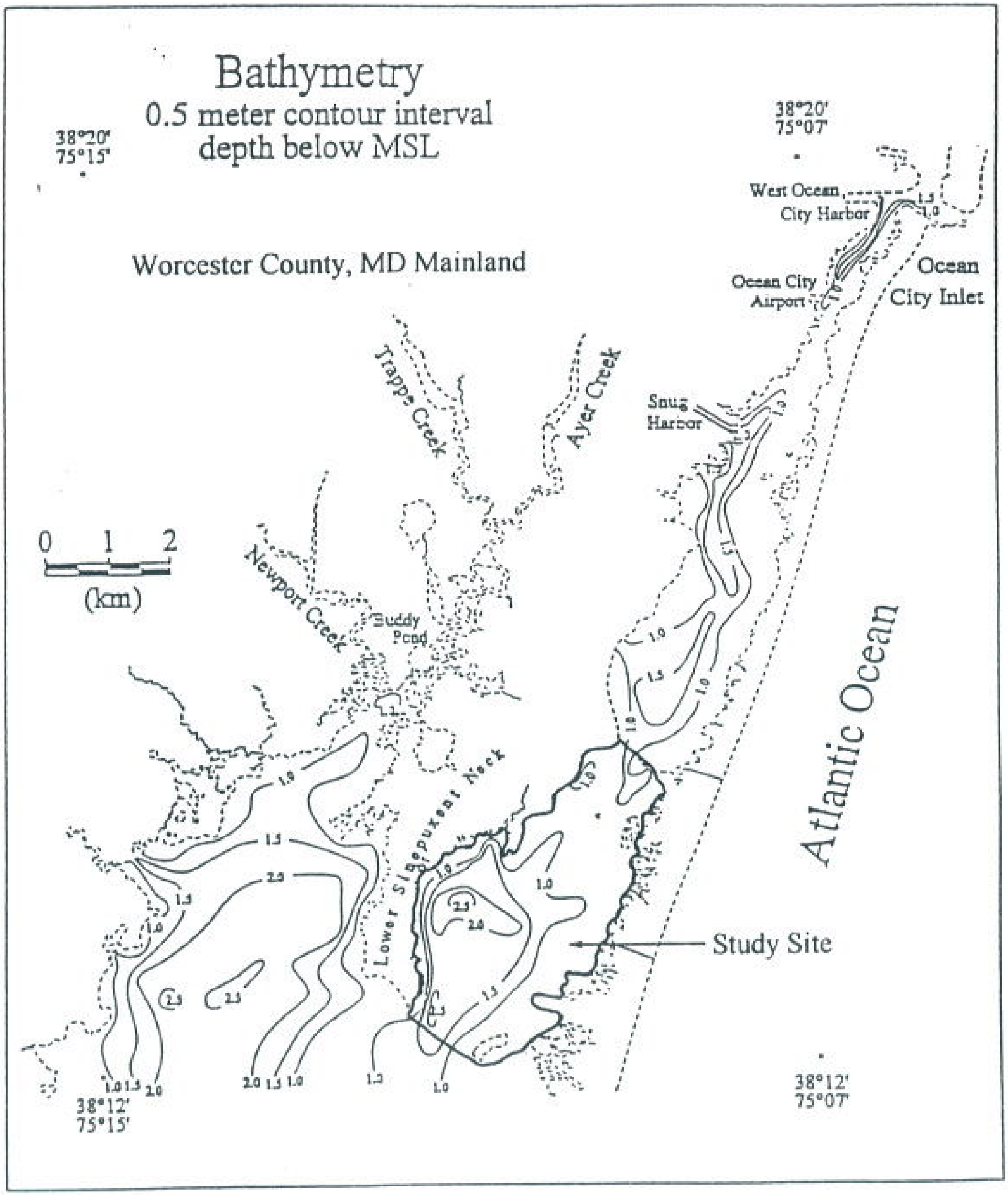


Figure 3-3. Bathymetric map of Sinepuxent Bay (depth in meters below MSL)

Figure 3-4. Bathymetric map of Sinepuxent Bay (Wells, et al., 1996)



Based on the detailed subaqueous topographic map 12 distinct subaqueous landscape units were identified. These landscape unit distinctions were made on the basis of slope gradients, concavity, convexity, and actual elevation (bathymetry). Further consideration of geomorphic attributes in addition to infrared photography and 3-dimensional surface plots later resulted in the combination of some units due to their overall similarities.

The eleven subaqueous landscape units A-K and the Central Basin shown in figure 3-5 can be considered to represent 7 distinct subaqueous landform types. The first landform (landscape unit A) is a shallow Mid-Bay Shoal (running NE-SW) which, through examination of USDA-NRCS 1938 and 1957 aerial photography, was probably created from dredged material sometime in the late 1930's or early 1940's. The channel from which the material originated is 3-4 m deep and runs adjacent to the shoal along the eastern edge. Water depth in this unit ranges from 0.1-0.9 m and slopes range from 0-0.8%. The steepest slopes in this unit are adjacent to the edge of the spoil island. The remainder of the unit has a slope range of 0-0.3%. This unit, though dominantly level, has a slight convex configuration in cross-section. The shoal and spoil island can be seen easily in the 3-dimensional surface plot shown in figure 3-6.

Another landform type identified occurs on the extremely shallow sandy curvilinear areas adjacent to the barrier island tidal marshes. These are subaqueous Overwash Fans derived from barrier island washover events (landscape units B and K). Water depths range from 0.1-0.8 m and slopes range from 0-0.8%. The trend in slope is generally from southeast to northwest and very gradual, with slope lengths exceeding 200 m. The barrier island tidal marshes adjacent to these units are only 0.1-0.3 m

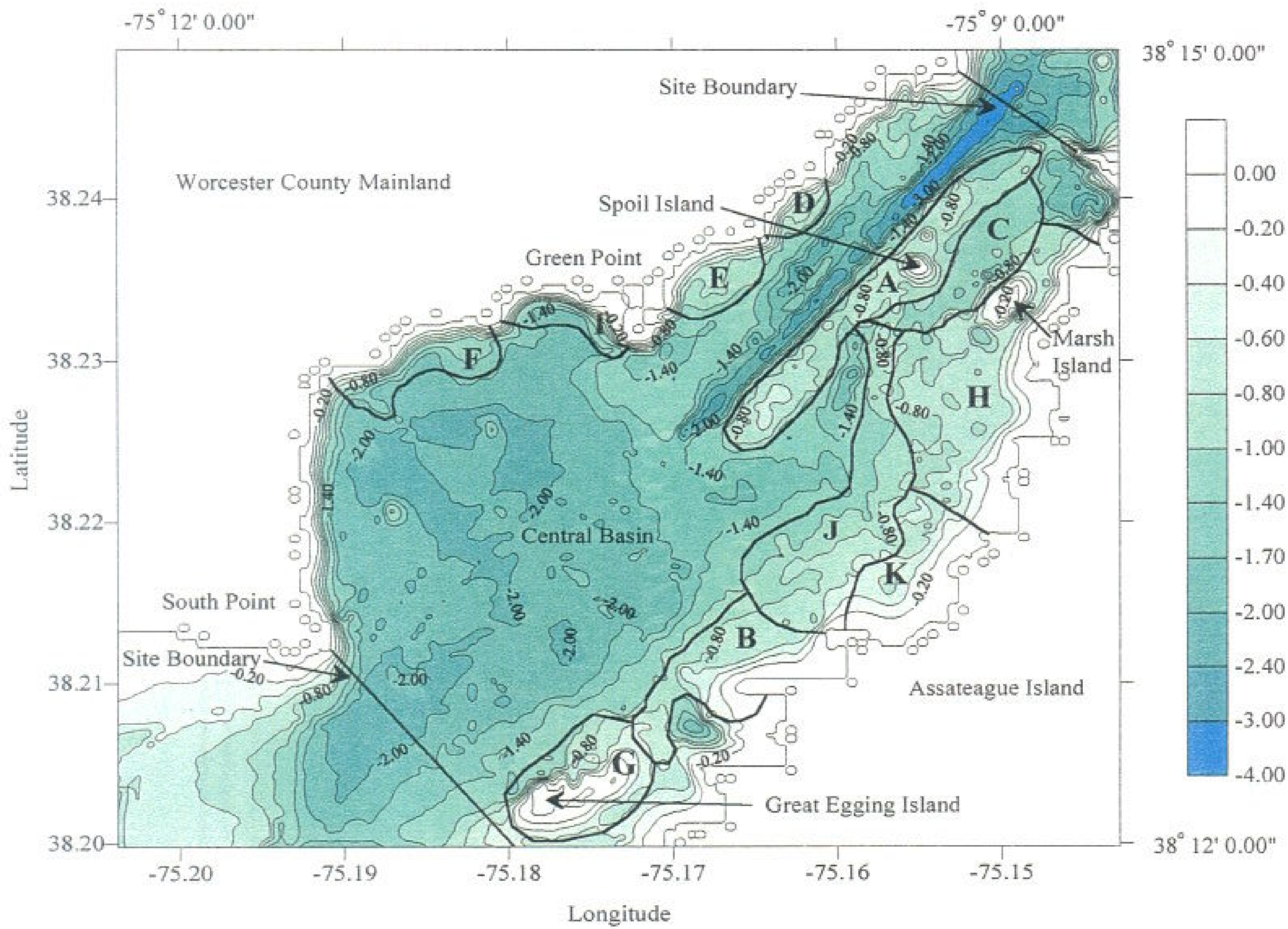


Figure 3-5. Subaqueous landscape units A-K and the Central Basin identified in Sinepuxent Bay (depth in meters below MSL)

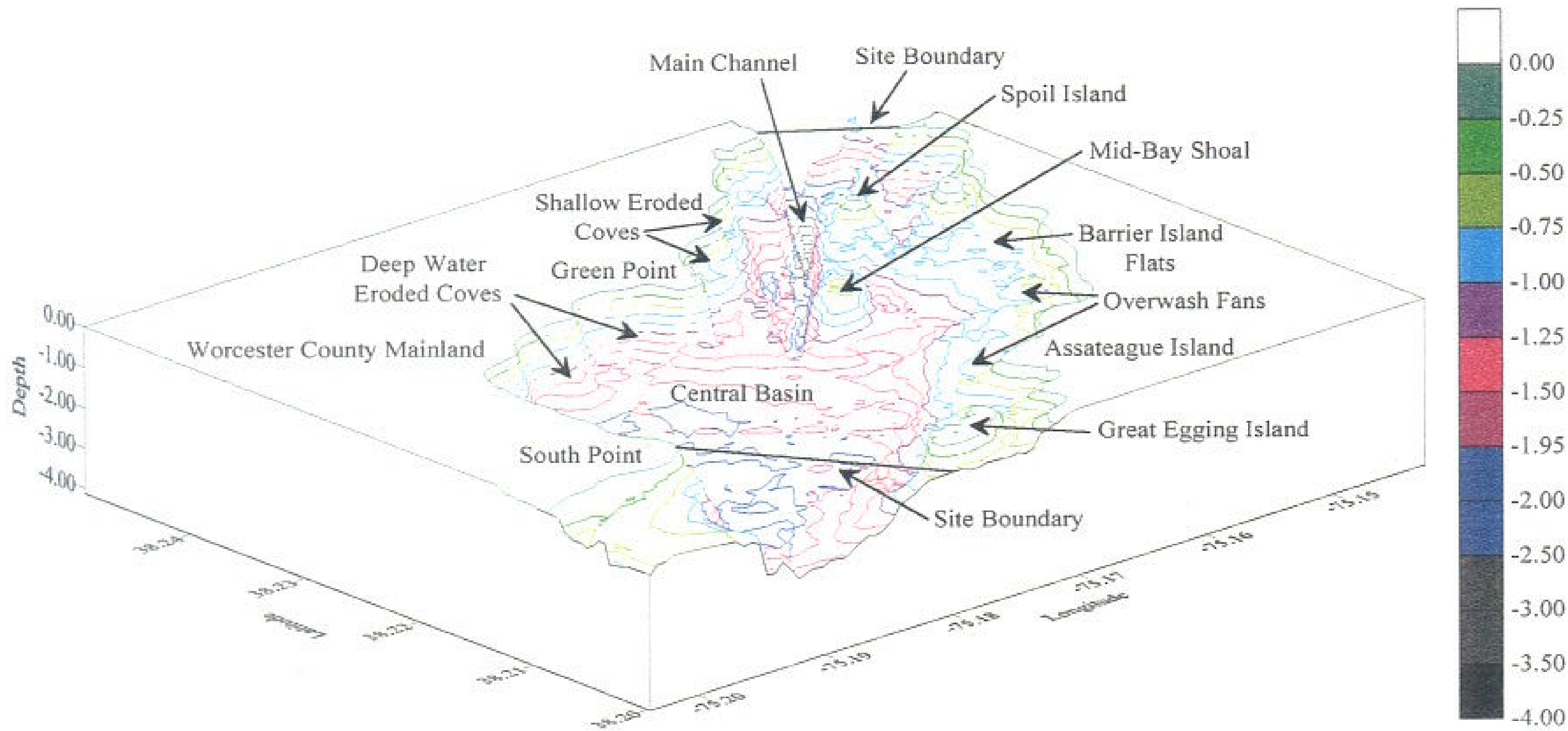


Figure 3-6. 3-dimensional surface plot of Sinepuxent Bay study area viewed from southwest to northeast (depth in meters below MSL)

above MSL exhibited in a nearly vertical cut. Figure 3-6 provides a view from which the gradual nature of the slope can be readily observed.

Adjacent to the Worcester County mainland in the northern half of the site, a third landform type was identified which is represented by two shallow, eroded coves (landscape units D and E). Water depth ranges from 0.1-1.2 m. Slope in these units range from 0-1.0%, and lengths of slope are significantly less than those encountered in the barrier island overwash unit. Slope trends are from northwest to southeast. There is a steep cut along the mainland/bay boundary of about 1 m where erosive forces have cut into each cove. The Shallow Mainland Coves can be seen along the northern half of the site in figure 10. Review of USDA-NRCS aerial photography from 1938 and 1957 indicated these coves were cut into the mainland by as much as 20 m over the past 40-50 years.

A landform representative of silty Deep Mainland Coves (embayments) adjacent to eroding mainland tidal marshes was identified in the southern half of the study site (landscape units F and I). Water depth of these units ranges from 1.2-2.0 m with a slope of 0.2-0.8%. The markedly steep cut of nearly 1.5-2.0 m along the mainland is most obvious in figure 3-6 just south of Green Point.

The fifth landform type, Barrier Island Flats, is a sandy region surrounding Marsh Island and adjacent to the barrier island marshes (landscape unit H). This landform has not been impacted by washover events as much as landscape units B and K (overwash fans). The washover sands are not as thick and buried marsh surfaces are commonly found within the upper 1 m of the sediment column. Water depth ranges from 0.2-0.9 m and slopes range from 0.1-0.3%. This unit is a shallow flat featureless plain.

The sixth landform type is representative of the gently sloping Transitional Zones (landscape units C and J) between the barrier island overwash dominated units (B, H, and K) and the dredge shoal or central basin in the southern half of the site. It is also composed of the transitional zone from Great Egging Island to the central basin (landscape unit G). Water depth in these units ranges from 0.6-1.4 m and slopes range from 0-0.4%. Slope configuration is generally concave in the northern half of the site and more linear to the south.

The last landform identified within the site was the Central Basin in the southern half of the site. The central basin is a nearly level featureless plain with water depths of greater than 2.0 m and slopes of < 0.2%. The main channel (depths of 2.5-4.1 m) enters the central basin from the northeast and may be considered an extension of the basin. The increase in depth near the northern site boundary is a result of past dredging operations.

CONCLUSIONS

The significance of identifying subaqueous landforms is twofold. First, the approach utilizing available technology resulted in a highly detailed and accurate bathymetric map. This approach provided a level of detail significantly greater than that found in many previously published sediment studies (Folger 1972; Katuna and Ingram, 1974; Ryan, 1953; Wells et al., 1994; Wells et al., 1996). Second, and of greater pedological importance, the level of data detail was sufficient to perform terrain analysis for the identification and delineation of subaqueous landforms. This was a significant step in the effort to understand the nature of subaqueous landforms and their distribution.

The establishment of a protocol for subaqueous terrain analysis and identification of subaqueous landforms provides a basis from which the examination of sediment-landscape relationships could be utilized in pedological, ecological, and environmental research. Once established, the landforms could be examined from a pedological perspective to determine if shallow water sediments would be better viewed as subaqueous soils, and if so, utilized to perform an inventory of subaqueous soil resources in estuarine shallow water habitats.

CHAPTER IV

PEDOGENESIS AND THE SOIL-LANDSCAPE PARADIGM IN A SUBAQUEOUS ENVIRONMENT

INTRODUCTION

The writings of Dokuchaiev (1948), Jenny (1941), Simonson (1959), and more recently, Hudson (1992), are the foundation upon which the science of pedology and soil survey have been built. Not only do they define what pedologists study, but they also outline the basic factors and processes that allow pedologists to interpret and map soil characteristics. Thus, any attempt to broaden the scope of pedology must, by necessity, adhere to these fundamental principles and philosophy.

Since the inception of pedological research, debate concerning the inclusion of subaqueous materials in the definition of soil and soil taxonomic systems has arisen periodically. In the 1860's v.Post (1862) developed a system of nomenclature for subaqueous soils but at that time, soil classification systems were in their infancy. In the United States, early classification schemes completely disregarded subaqueous materials (Marbut, 1935). Kubiena (1948) proposed a soil classification system that once again included subaqueous soils. Yet even though adopted as soil types in the soil taxonomy of Germany (Arbeitskries Bodensystematik, 1985), *Soil Taxonomy* (Soil Survey Staff, 1975) and *Keys to Soil Taxonomy* (Soil Survey Staff, 1996) remain void of any reference to subaqueous soils.

The main question at the center of the debate seems to be related to both the concept of the "upper limit" of soil and the actual definition of soil. Many pedologists believe that the upper limit of soil must be the atmosphere (Foth, 1978; Nikiforoff, 1958;

Simonson, 1959), while in other cases the boundary is considered to include shallow water (Soil Survey Division Staff, 1993b; Demas 1993; Demas et al., 1996). A more important aspect of the debate concerns the present definition of soil. The two main components of the pedologic definition of soil are that soils must be "capable of or presently supporting plants out-of-doors" (Soil Survey Staff, 1975) and/or they must show evidence of horizon differentiation due to pedogenic processes (Soil Survey Division Staff, draft, 1996). Therefore, to be considered soil, a material must show evidence that the four components of the generalized theory of soil genesis (Simonson, 1959) are actively functioning. The interaction of these factors and processes is responsible for the resulting soil characteristics. These interactions play an important role in the ability of pedologists to understand the distribution of different soils. For example, additions may be more significant in a floodplain position while transfers may be dominant in a summit position. Hudson (1992) summarizes this concept as the soil-landscape paradigm, the predictive tool in which pedologists rely on the notion of systematic variation (Wilding and Drees, 1983), where soil properties can be explained by (or related to) landform, landscape position, or one or more of the five state factors.

The objectives of this study were therefore to (i) determine if there is sufficient evidence of pedogenic processes to support the concept that shallow water sediments are soil and (ii) evaluate the effectiveness of the soil-landscape paradigm in understanding the distribution of shallow water sediments in a subaqueous environment.

MATERIALS AND METHODS

The site selected for this study was a portion of Sinepuxent Bay, Maryland, which is a shallow (< 5 m) coastal estuary. It is bounded to the east by Assateague Island and to the west by the Worcester County mainland. Atlantic ocean water enters and exits the site from the north through the Ocean City Inlet and from the south through the Chincoteague Inlet. Tidal range in the bay is small, ranging 0.5-0.75 m (U.S. Dept. of Interior, unpublished data).

Through the use of a Rockwell PLGR+ Global Positioning System (GPS) unit, Raytheon DE-719cm marine research fathometer, and Geolink external device system (XDS) software, a detailed bathymetric map of the 1,300 ha site based on over 23,000 depth data points was generated. Twelve individual landscape units were identified based on bathymetry, slope, landscape configuration, and geomorphic setting. Landscape units which were similar were combined into representative landform types. Three landscape units were unique enough to stand alone as distinct landform types. Within Sinepuxent Bay seven major landform types were identified using both descriptive nomenclature and commonly used estuarine terminology (Chapter III).

A total of 85 sediment profile descriptions were recorded, of which 75 were performed in the field, 9 were done in the laboratory after extrusion of vibracore samples, and one was described based on data reported by Wells et al. (1996). The locations of the 3 field profile descriptions along the cross-section X-X', the 5 field profile descriptions along cross-section Z-Z', and the locations of the 10 vibracore sampling sites (A-Rep through J-Rep, and CB-1) in Sinepuxent Bay are shown in figure 4-1. Morphological descriptions of all profiles followed the procedures and notations outlined in the *Soil Survey Manual* (Soil Survey Division Staff, 1993b). The area in the southern portion of the study site identified as the Central Basin landform characteristically has water depths of 1.8-2.3 meters. Perhaps due to degraded water quality in this area (and increased bathymetry), submersed aquatic vegetation generally is not found at these depths. In addition, at depths greater than 1.5 m, sampling and descriptions of sediment profiles becomes more complicated and time consuming. Because the objectives (to examine pedogenesis and systematic variation in shallow water environments) could be accomplished in areas of shallower water (facilitating more rapid procurement of field descriptions), fieldwork was concentrated in areas with water shallower than approximately 1.5 m. Physical and chemical data reported from a vibracore sample collected in the Central Basin landform (Wells, et al., 1996) were re-evaluated from a pedological standpoint and utilized in this study.

Representative pedons were sampled using a vibracoring device and 7.6 cm aluminum pipe during the summer and fall of 1996. After extraction of each core the end of the pipe was filled with ambient bay water and sealed. The cores were then transported to Horn Point Laboratory and stored in a walk-in freezer until later taken to the University of Maryland in College Park. The frozen cores were extruded in March 1997 and profile descriptions were recorded. The cores were sampled by horizon, placed in plastic bags, sparged with nitrogen, sealed and kept in the freezer until all sulfide analyses were completed.

Acid-volatile sulfides (AVS) and chromium reducible (mainly pyrite) sulfides (CRS) were determined using the procedure of Cornwell and Morse (1987). Samples

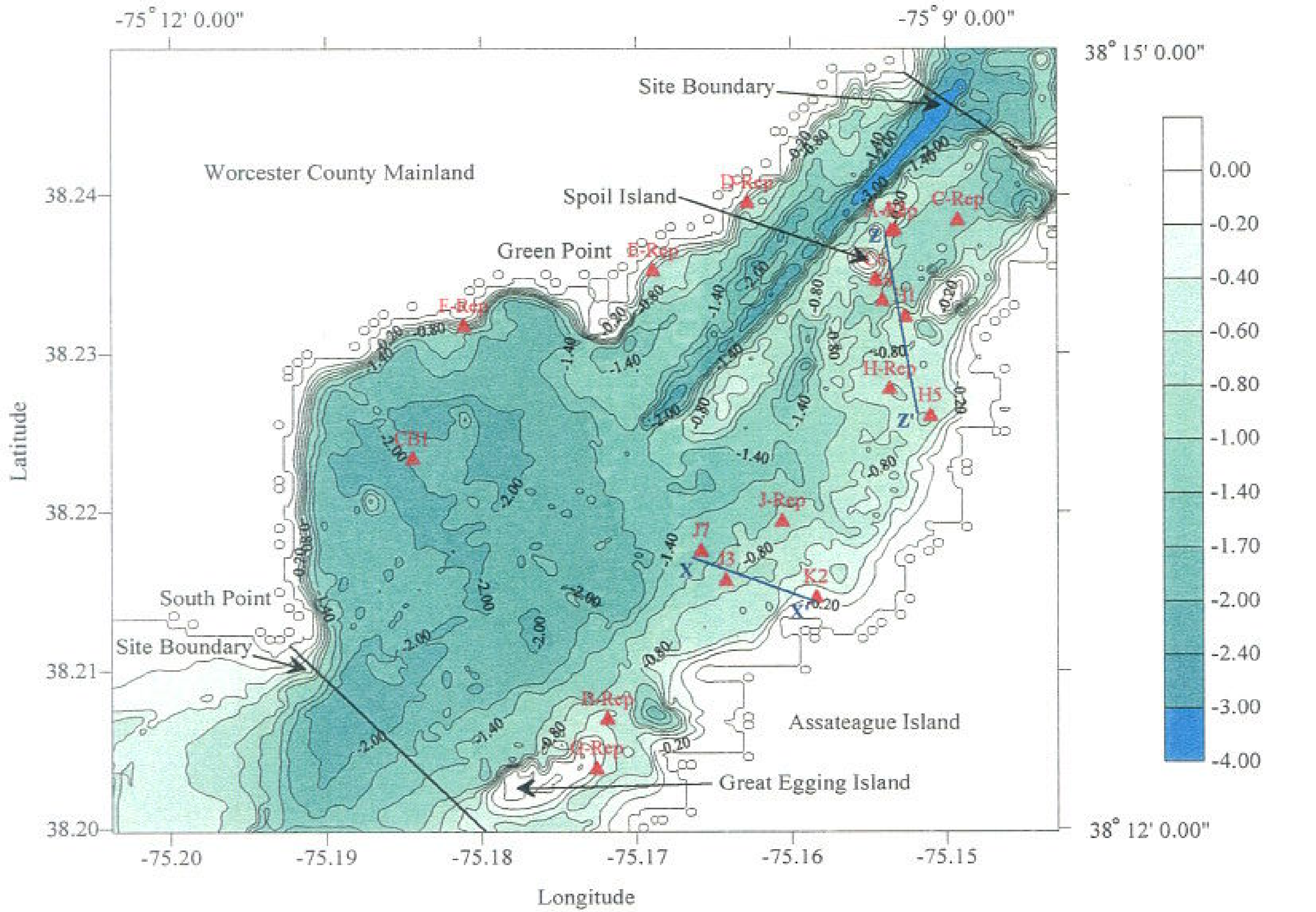


Figure 4-1. Location map of cross-sectons X-X', Z-Z', their associated profiles, and vibracore sampling sites (depth in meters below MSL)

were handled under a nitrogen atmosphere in a glove-bag prior to analysis. After all sulfide analyses were completed, samples were air-dried, crushed, and sieved for other analyses. Particle size analyses were performed utilizing a modified pipette method (Kilmer and Alexander, 1949), where prior to analysis, samples were dialyzed to remove salts. Organic carbon content was determined using the combustion procedure of Rabenhorst (1988). Total carbon was determined by combustion at 1050° C using a Leco CNH Analyzer equipped with an infra-red detector (Campbell, 1992). Calcium carbonate ($CaCO_3$)-carbon content was calculated by difference between total carbon and organic carbon. Total suspended solids in the water column were measured using a modified gravimetric method (Banse et al., 1963), wherein samples were taken in the field and filtered immediately. Radiocarbon analysis of buried organic horizons was performed by Beta Analytic, Inc. in Miami, Florida using a standard radiometric analysis with acid wash pre-treatment. A Libby ^{14}C half-life of 5568 years was used for age calculations, and years before present refers to years before 1950 A.D.

RESULTS AND DISCUSSION

Pedogenic Processes in Shallow Water Sediments

Although there have been proposals to consider shallow water sediments as subaqueous soils (v.Post, 1862; Kubiena, 1953; Goldschmidt, 1958; Muckenhausen, 1965; Ponnamperuma, 1972; Demas et al., 1996), the prevailing view in the ecologic, geologic and pedologic communities is that shallow water sediments are non-soil. To consider sediments as soil, it would be imperative that pedogenic processes be actively functioning in support of horizon differentiation. Although differing layers within a sediment column are often identified, the mere presence of distinct layers does not necessarily warrant their recognition as soils. The critical question is whether the identified layers can be considered soil horizons. The four major processes leading to soil horizon differentiation were described by Simonson's generalized theory (1959) as additions, removals, transfers, and transformations.

Many additions to sediments can be documented in a variety of ways, but they may not necessarily lead to horizon differentiation. Shell fragments observed in the sediments of Sinepuxent Bay were identified as the remains of oysters (*Crassostrea virginica*) and various bivalve mollusks such as hard clams (*Mercenaria mercenaria*), jacknife clams (*Ensis directus*), and razor clams (*Tagelus sp.*). Shell fragments were observed in 70 profile descriptions (83%) with quantities ranging from 1-40% (appendix A). Fully intact shells of the marsh periwinkle snail (*Littorina irrorata*) were observed in 17 (20%) sediment profiles descriptions at depths ranging from 18 to 110 cm. While visible in field descriptions, the quantity of $CaCO_3$ contributed by these organisms was generally small. Analysis of the 9 representative profiles showed calcium carbonate levels of < 0.6%. In some environments $CaCO_3$ may precipitate from seawater, but in this site it is thought to be mainly biogenic. Different layers were at times identified on the basis of shell content, but the addition of shells might not be considered as contributing to horizon differentiation if the $CaCO_3$ fragments are allogenic. However, where these biogenic carbonates are added to the sediments as a result of the activity of benthic organisms they might be legitimately considered as pedogenic additions.

Mineral material is also being added to Sinepuxent Bay sediments, which is particularly evident in sediment profile F-Rep (table 4-1) where the surface layer of an organic paleosol has been buried to a depth of 92 cm. A buried organic layer at a depth of 150 cm in the sediment column (Oeb horizon) from a similar profile approximately 80 m from the F-Rep core site, yielded a wood sample which was dated radiometrically at 1430 ± 60 years B.P. (before 1950). Including the depth of the water at this location, the elevation of the sampled wood fragment is approximately 2000 mm below mean sea level (MSL). The average rate of addition can be calculated to be approximately 1 mm/yr, which is very close to long term sea-level rise estimates for this region (Hicks et al., 1983; Rabenhorst and Griffin, 1989). The addition of mineral material to sediment profiles could be considered analogous to terrestrial sedimentation processes on floodplains, which exhibit a number of discontinuities that are considered soil horizons. Sinepuxent Bay sediments, in some cases, also exhibit discontinuities similar to alluvial soils. However, in both cases (terrestrial floodplains and shallow water sediments) this might be considered simply the accumulation of parent material rather than a process leading to horizon differentiation.

The addition of organic debris is also evident in the shallow water sediments of Sinepuxent Bay. Partially decomposed organic fragments were described in 65 sediment profiles (77%), with quantities ranging from 1-80%. Larger fragments that could be identified included eelgrass (*Zostera marina*) blades and saltmarsh cordgrass (*Spartina alterniflora*) stems. Although changes in the concentration of organic fragments might lead to the designation of a distinct layer, the presence of organic fragments alone does not indicate that pedogenic horizon differentiation is occurring. Organic carbon (OC) data from nine Sinepuxent Bay sediment profiles are presented in figure 4-2. These data

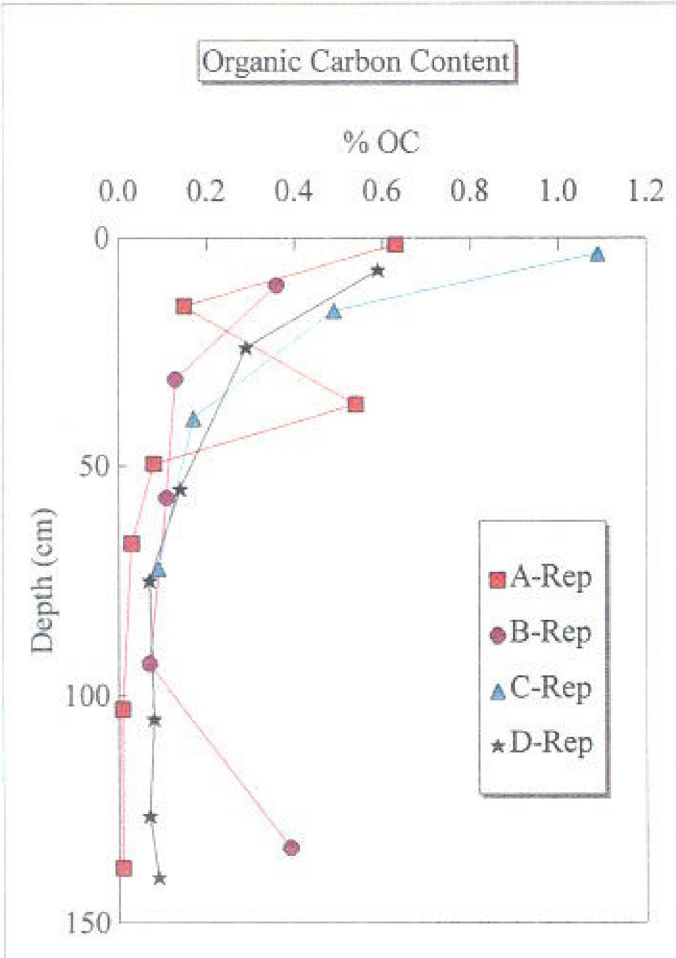
Table 4-1. Field morphological description of sediment profile F-Rep of the Deep Mainland Coves.

PROFILE F-Rep 38° 13' 54.48" N, 75° 10' 51.96" W
Sample S97MD047-001
fine-silty, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-5	S	N 2.5/			5	10YR 2/1		sg	l			a
Cg1	5-11	S	5Y 3/1			2	N 2/		sg	l			a
2Cg2	11-24	SiC	5Y 3/2						m	fi	1.0		c
2Cg3	24-57	SiCL	10B 4/1						m	fi	1.0		c
2Cg4	57-92	SiC	5Y 4/2						m	fi	1.0		c
Oeb	92-122	Mpt	5Y 3/2			20	7.5YR 3/2						g
Oab	122-139	Mk	N 2.5/										

REMARKS: Profile description by G. Demas at time of core extrusion, March 1997

0% vegetative cover
Textural classes based on particle size analyses



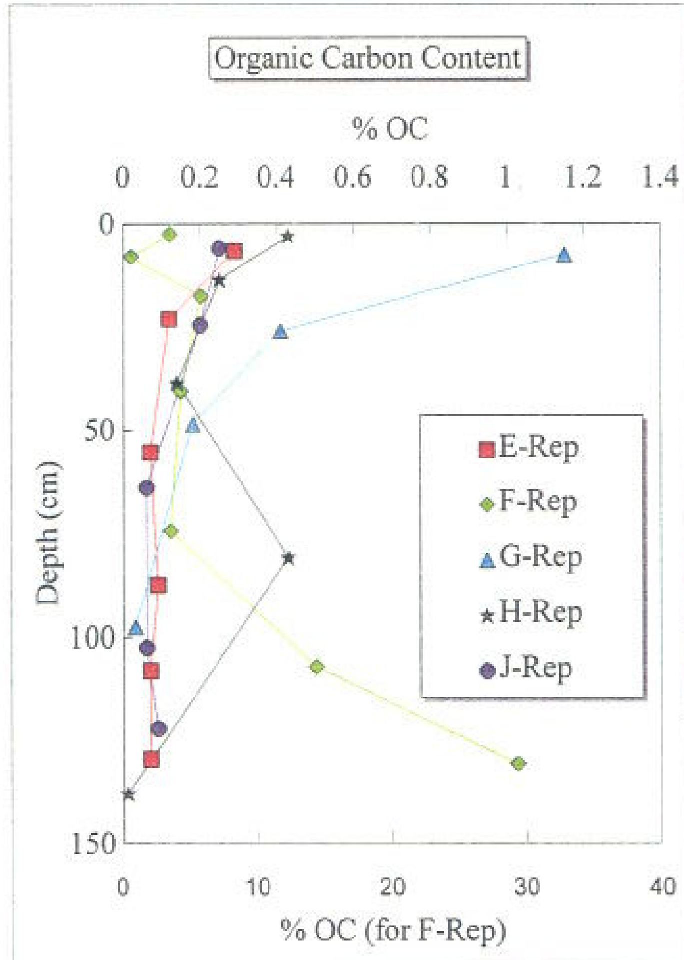


Figure 4-2. Organic carbon content of the Mid-Bay Shoal (A-Rep), Overwash Fans (B-Rep), the Transition Zones (C-Rep, G-Rep, and J-Rep), the Shallow Mainland Coves (D-Rep and E-Rep), the Deep Mainland Coves (F-Rep), and the Barrier Island Flats (H-Rep).

suggest that ochric epipedons are forming as a result of pedogenic processes. When plotted versus depth, all nine profiles exhibit similar depth function which appear to be similar to those of terrestrial soils. Elevated levels of C in the surface layers accompanied by (sometimes irregular) decreases with depth are exactly what are found in terrestrial analogs. Thus, evidence of organic matter accumulation and development of A horizons in Sinepuxent Bay sediment profiles is of pedogenic significance.

Removals, or losses, represent another pedogenic process cited by Simonson (1959). Removals in terrestrial soils occur mainly through the processes of leaching, seepage, erosion, and decomposition. The most common removals cited in terrestrial soils are those associated with leaching. In shallow water sediments leaching and seepage may not be important due to the low hydraulic gradient inherent in a permanently submersed environment. However, a removal which frequently occurs in shallow water sediments is that associated with erosion. Total suspended solids (TSS) in the water column is one indicator of the amount of material being eroded from the sediment surface and resuspended. Although major storm events may also be partially responsible for increases in TSS through delivery of eroded terrestrial sediment, strong winds or storms may increase wave amplitudes in the bay, causing a disruption of laminar flow in the viscous sub-layer (Mann and Lazier, 1991). This may result in a significant increase in turbulence at the sediment surface causing a marked increase in erosion and resuspension of sediment particulates. Average TSS in Sinepuxent Bay in June 1996 was approximately 140 mg/l while in November 1996 the average value was only 63 mg/l. The region including Sinepuxent Bay received average rainfall (7.5-10 cm/month) during both months (USDA-NRCS, unpublished data). Because eelgrass

(*Zostera marina*), the dominant vegetation in Sinepuxent Bay, is a temperate climate seagrass and in Sinepuxent Bay is near the southern limit of its habitat (Sculthorpe, 1967), the highest productivity occurs in the spring and fall, while die-back usually occurs during the hotter summer months (Chesapeake Bay Program, 1991). A die-back of vegetation exposes the sediment surface to erosive forces. Therefore, the large increase in suspended solids in June probably reflects an increase in surface erosion attributable to a decrease in vegetation. Although erosion is undoubtedly occurring, this process might tend to be viewed as opposing horizon differentiation.

Another removal from shallow water sediments concerns the decay of organic matter. If decay and loss of organic matter did not occur in sediments, then surface layers would become increasingly enriched and exhibit high levels of organic carbon. Primary production in SAV beds is reported to be 100-1500 g dry wt./m^2, with approximately 20-50% in below ground components (Sculthorpe, 1967). In an investigation of the decomposition rate of eelgrass detritus in sediments, Burkholder and Doheny (1968) found that more than 60% of sediment eelgrass detritus was degraded and consumed by microbes in approximately 3 months. Eight of the nine sampled profiles in vegetated and sparsely vegetated areas exhibited OC contents of 0.25-1.09%. These values would likely be higher if loss through microbial decomposition was not occurring. The highest value of surficial organic carbon (3.45%) occurred in an area void of SAV, but adjacent to eroding organic tidal marshes. Thus, the continuous processes of addition and removal of organic matter may be responsible for development of sediment surface layers with relatively low, but steady state organic carbon levels similar to terrestrial soils.

Examples of transfers (Simonson, 1959) in terrestrial soils include illuviation, wicking, diffusion, and bioturbation. The classical concept of eluviation (or leaching) has previously been discussed as inapplicable in permanently submersed environments due to the weakness of the hydraulic gradient. The process of wicking, by definition, also does not occur in sediments due to the need for the surface layer to reach lower moisture potentials to facilitate movement of dissolved constituents towards the surface. Diffusion occurs in terrestrial soils when dissolved ions (or molecules) "move from zones of higher concentration to zones of lower concentration leading to a build-up of the substance in a given part of the soil if a mechanism is operating there to take the ions or molecules out of solution" (Fanning and Fanning, 1989). The "light brown" color of some surface layers is an indication of oxygen diffusion across the sediment/water column interface (Fenchel and Riedl, 1970). This zonation is generated as a balance between consumption of oxygen by benthic micro-organisms during organic matter decomposition, and the diffusion of oxygen from the overlying water column into the sediment surface layer. In the absence of burrowing benthic organisms, the "light brown oxidized layer" would only range up to a few millimeters in thickness, depending on sediment surface texture (Fenchel and Reidl, 1970). The process of diffusion alone therefore would be of a very limited magnitude if considered a pedogenic transfer resulting in horizon differentiation. Bioturbation in terrestrial soils, which also occurs in shallow water sediments, is typically thought of as a process opposing horizon differentiation. In some terrestrial systems, bioturbation such as by ants, termites, earthworms, and crustaceans can lead to soil horizons with distinct chemical and physical properties (Thorp, 1949). In shallow water sediments, the activity of burrowing benthic organisms (such as tubeworms or clams), can lead to the formation of an oxidized surface layer which can be up to 10-15 cm thick. This is a result of both the direct transfer of oxygen by the organisms and also the increase in diffusion due to intensive biogenic mixing and irrigation of tubes and burrows (Rhoads, 1974). Morphological descriptions of sediment profiles in Sinepuxent Bay indicate that there were at least 18 surface layers (21%) which exhibited high chroma (3 or greater) colors (appendix A). These layers were often 10 cm or less in thickness and had abrupt boundaries to low chroma (2 or less) layers directly below. The thickness of these surface layers is an order of magnitude larger than would normally be expected in an undisturbed sediment, and is considered to be the result of the combination of diffusion and bioturbation transfer processes. Morphological evidence of bioturbation includes the observations of live tubeworms (*Spiochaetopterus oculatus*), mudworms (*Scolecolepides viridis*), hard clams (*Mercenaria mercenaria*), and worm casts (burrows) in the upper 25 cm of 27 profiles (32%). Thus, the processes of diffusion and bioturbation in tandem can be considered transfers which promote horizon differentiation.

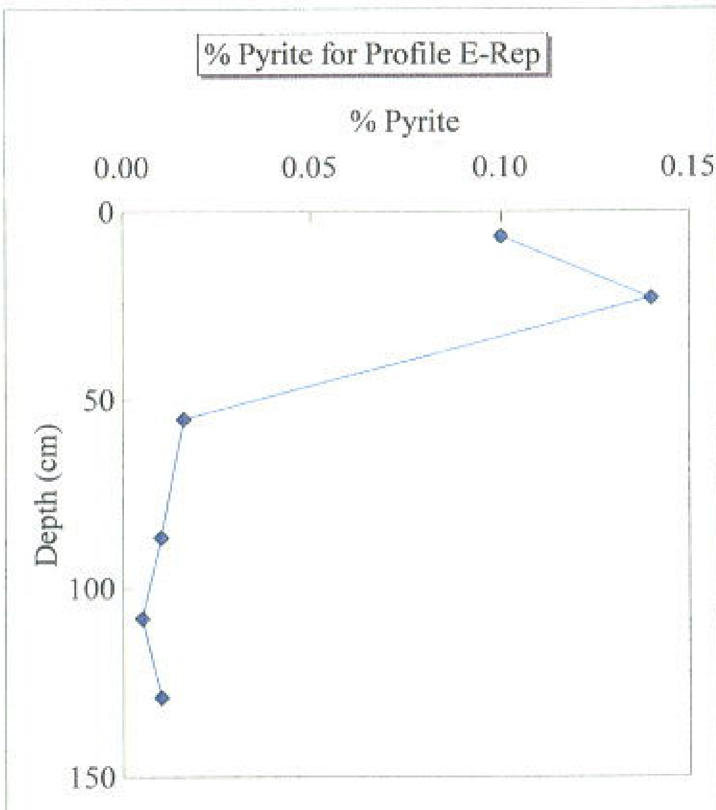
The last pedogenic process conceptualized by Simonson (1959) is that of transformations. Although many of the transformations common to terrestrial soils do not occur in subaqueous environments, there are important mineral transformation that do occur in estuarine systems. The process by which sulfides form in anaerobic conditions has been termed sulfidization (Fanning and Fanning, 1989), the dominant end product of which is pyrite (FeS_2). This process commonly occurs in tidal marsh soils and shallow water sediments in areas affected by estuarine waters. The key elements required for the process include sulfate reducing bacteria such as *Desulfivibro sp.*, a source of sulfate, a source of reactive iron, organic matter as a microbial substrate, and anaerobic conditions. During this process iron oxides in the oxidized surface layer are reduced to soluble ferrous iron. At the same time, sulfate from seawater is reduced by microbes during their oxidation of organic matter. The critical by-product of the sulfate reduction is HS^-, which can then react with the iron in solution to form iron-sulfide compounds such as mackanawite (FeS), greigite (Fe_3S_4), and ultimately pyrite (FeS_2). The reaction, in simplified form, is shown in the equation below (after Pons et al., 1982):

$$\underset{(s)}{Fe_2O_3} + \underset{(aq)}{4SO_4^{-2}} + \underset{(s)}{8CH_2O} + \underset{(g)}{1/2O_2} \quad \underset{(s)}{2FeS2} + \underset{(aq)}{8HCO_3^{-1}} + \underset{(l)}{4H_2O}$$

The main zone of sulfide formation within the sediment column occurs below the boundary between the oxygenated surface layer and the anaerobic subsurface layer. In the surface layer (0-13 cm) of sample S97MD047-007, the olive brown color (2.5Y 4/3) is an indication of the effect of oxygen diffusion. Figure 4-3 shows the pyrite content with depth of profile E-Rep. The maximum pyrite content occurs in the zone directly below the oxygenated surface layer and then continues to decrease further with depth.

Additional evidence of pedogenic transformation in Sinepuxent Bay sediments can be found in the organic components. Typical carbon:nitrogen (C:N) ratio data for fresh seagrass (SAV) residues are approximately 20:1 to 30:1 (Levington, 1982). These values are similar to C:N ratios for terrestrial grasses which range from 20:1 to 37:1 (Brady and Weil, 1996). Microbial decomposition of organic residues in terrestrial soils results in a lowering of C:N values. For example, C:N ratios in surface horizons of terrestrial soils typically range from 8:1 to 15:1. C:N ratio data from Sinepuxent Bay

Figure 4-3. Pyrite content with depth for sediment profile E-Rep of the Shallow Mainland Coves

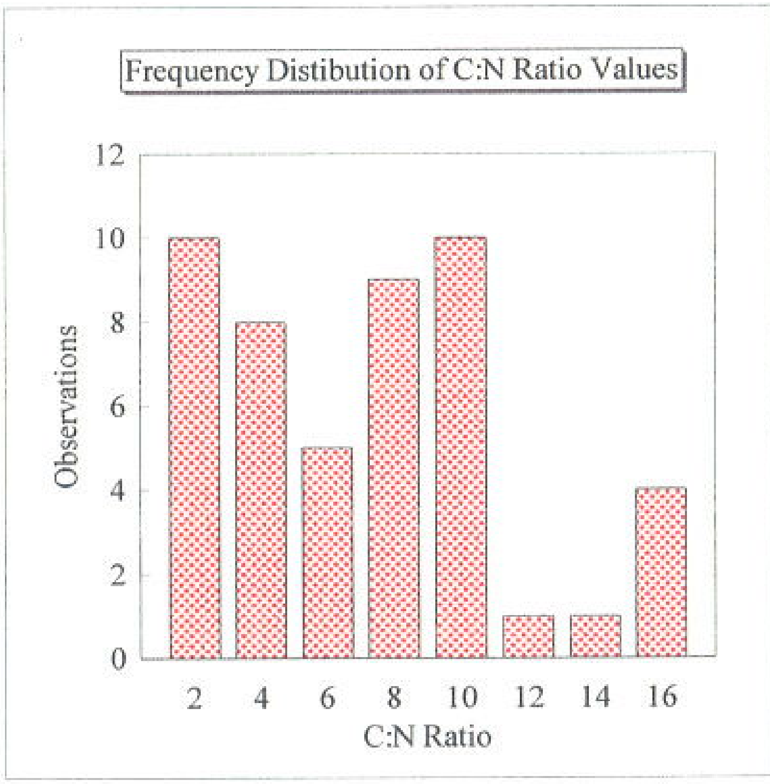


sediment layers range from 2:1 to 14:1. Of the 48 sediment layers analyzed for C and N, 90% exhibited C:N ratios of less than 10:1 (figure 4-4). The lowering of C:N ratios in Sinepuxent Bay sediments is an indication of the pedogenic transformation of organic matter to other humic substances.

The evidence presented above supports the contention that pedogenic processes are actively occurring in shallow water sediments and they would be better viewed as *subaqueous soils*. These observations provided the impetus to propose a modification to the definition of soil in *Soil Taxonomy* (Soil Survey Staff, 1975) which accommodates shallow water sediments that support submersed aquatic vegetation. This proposal has been reviewed and accepted by the USDA-NRCS National Soil Taxonomy Committee. The new definition of soil, as it will appear in the next edition of *Soil Taxonomy*, is shown below:

> "Soil in this text is a natural body comprised of solids (mineral and organic matter), liquid, and gases which occurs at the earth's surface, occupies space, and has one or both of the following characteristics: 1) is organized into horizons or layers that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter and/or 2) is capable of supporting rooted plants in the natural environment. This definition is expanded to include soils in areas of Antarctica where pedogenesis occurs, but where the climate is too harsh to support higher plant forms.
>
> The upper limit of soil is the boundary between soil and air, shallow water, live plants, or plant materials that have nor begun to decompose. Areas are not considered to have soil if the surface is permanently covered by water too deep (typically greater than 2.5 m) for the growth of rooted plants. Soil's horizontal boundaries are where it grades to deep water, barren areas, rock, or ice. In some places the separation between soil and non-soil is so gradual that clear distinctions can not be made."

Figure 4-4. Frequency distribution of C:N ratios of all landforms from analyzed sediment layers with greater than 0.10% organic carbon.



The Soil-Landscape Paradigm in a Subaqueous Environment

Subaqueous Soil Properties as a Function of Landform

To accurately evaluate whether the soil-landscape paradigm (Hudson, 1992) functions in a subaqueous environment, it would be useful to consider the underlying supporting concept of systematic variation. Systematic variation is a gradual or marked change in soil properties as a function of landforms, geomorphic elements, or the five state factors of soil formation (Wilding and Drees, 1983).

An important question to resolve in evaluating the suitability of using the soil-landscape paradigm in a subaqueous environment is whether there exists systematic variation among the landforms. Selected attributes of each of the seven landform types are shown in table 4-2. In an effort to compare landforms, all subaqueous soil profiles described in Sinepuxent Bay were classified according to *Keys to Soil Taxonomy* (Soil Survey Staff, 1996). The classifications of soils found in each landform are shown in table 4-3. The dominant soil components of the landforms differ at the subgroup level of *Soil Taxonomy*. The three major subgroup classifications found in Sinepuxent Bay were Typic Sulfaquents, Typic Psammaquents, and Sulfic Fluvaquents. When particle size family is included in the classification, 4 dominant classifications are found. These include Typic Psammaquents, coarse-loamy Typic Sulfaquents, fine-silty Typic Sulfaquents, and coarse-loamy Sulfic Fluvaquents. Although there appears to be soil taxonomic differences between the landforms, at this level of *Soil Taxonomy*, three landforms exhibit the same dominant classification. To further investigate if the classification of the soils is systematically related to landform, series criteria were applied to the soils of each subaqueous landform. Series criteria are used to separate

Table 4-2. Subaqueous landform types, landscape unit composition, average depth, and average slope identified for Sinepuxent Bay.

Landform Type Name	Landscape Units	Average Water Depth (m below MSL)	Average Slope
Mid-Bay Shoal	A	0.7	0.3%
Overwash Fans	B, K	0.6	0.4%
Shallow Mainland Coves	D, E	0.7	0.5%
Deep Mainland Coves	F, I	1.9	0.5%
Barrier Island Flats	H	0.6	0.2%
Transition Zones	C, G, J	1.2	0.2%
Central Basin	--	2.1	0.2%

Table 4-3. Classification of subaqueous soil profiles in each Sinepuxent Bay landform. All profiles classified according to *Keys to Soil Taxonomy* (Soil Survey Staff, 1996).

Landform Name	**# Profiles Total)**	**Classification (*Soil Taxonomy*)**	**# Observed**
Mid-Bay Shoal	10	co-lo, Typic Sulfaquents	6
		s, Typic Sulfaquents	4
Overwash Fans	11	Typic Psammaquents	11
Barrier Island Flats	9	co-lo, Sulfic Fluvaquents	6
		Typic Psammaquents	2
		co-lo, Typic Sulfaquents	1
Shallow Mainland Coves	15	Typic Psammaquents	11
		co-lo, Typic Endoaquents	4
Deep Mainland Coves	14	fi-si, Typic Sulfaquents	10
		fi-si, Terric Sulfihemist	1
		fi-lo, Sulfic Fluvaquents	1
		co-lo, Terric Sulfisaprists	1
		co-lo, Typic Halaquept	1
Transition Zones	26	Typic Psammaquents	15
		s, Typic Sulfaquents	5
		co-lo, Sulfic Fluvaquents	4
		co-lo, Typic Sulfaquents	1
		co-lo, Haplic Sulfaquents	1
Central Basin	1	fi-si, Typic Sulfaquents	1

soils at the finest level of distinction in *Soil Taxonomy* (Soil Survey Staff, 1975). The main criteria for differentiating these proposed soil series are shown in table 4-4. These criteria indicate that six soil series can be identified representing the seven major landforms. This supports the notion that subaqueous soil properties are a function of landform. Previous research in the Chesapeake Bay and Pamlico Sound, NC by Ryan (1953), Pickett and Ingram (1969), and Katuna and Ingram (1974) had indicated the possibility that sediment type distribution is related to estuarine landforms.

The Mid-Bay Shoal is very shallow and the subaqueous soils exhibited high sulfide, sandy loam or loam horizons in the upper 30 cm of 9 of the 10 descriptions (appendix A). In 8 of the 10 descriptions, 4-7 lithologic discontinuities are noted. These discontinuities were probably a result of past dredging activities. Particle size in the profiles also varied with depth, with finer textured horizons or pockets noted at depths below 45 cm. At 9 of the 10 description site, field estimates of SAV cover ranged form 50-90% (the remaining site had 15% cover). The presence of dense SAV plays a significant role in determining sediment characteristics in extremely shallow environments through their reduction of the impact of wind generated wave agitation (Madsen and Warnke, 1983). The subaqueous soil properties of the Mid-Bay Shoal are similar to sediment characteristics on similar vegetated shallow longitudinal shoals in Pamlico Sound, NC which were found to be somewhat poorly sorted, and frequently had organic debris and finer textured pockets or layers within the columns. In contrast, unvegetated shallow shoal sediments were found to be well sorted and void of organic debris or clay inclusions (Katuna and Ingram, 1974). Well sorted in this context means

Table 4-4. Series criteria differentia for subaqueous soil series proposed for Sinepuxent Bay, Maryland.

Subaqueous Soil Series Name and Classification	**Series Criteria Differentia**
Fenwick	subaqueous, permanently flooded
(Typic Psammaquents)	3 chroma or higher surface horizons
	firm-very firm consistence below 25 cm
	low organic carbon content, high fine sands
Newport	subaqueous, permanently flooded
(Typic Psammaquents)	3 chroma or higher substratum horizons
	low organic carbon content
	0-5% coarse fragments in substratum horizons
Sinepuxent	subaqueous, permanently flooded
(co-lo, Typic Sulfaquents)	sulfidic materials at 0-50 cm
	SL, SiL, or L textures in control section
	greater than 4 discontinuities
South Point	subaqueous, permanently flooded
(fi-si, Typic Sulfaquents)	sulfidic materials at 0-50 cm
	buried histic epipedon at 60-190 cm
	high organic carbon content
Tizzard	subaqueous, permanently flooded
(co-lo, Sulfic Fluvaquents)	buried Ag horizon at 50-100 cm
	sulfidic materials at 50-100 cm
Wallops	subaqueous, permanently flooded
(Typic Psammaquents)	mixed characteristics

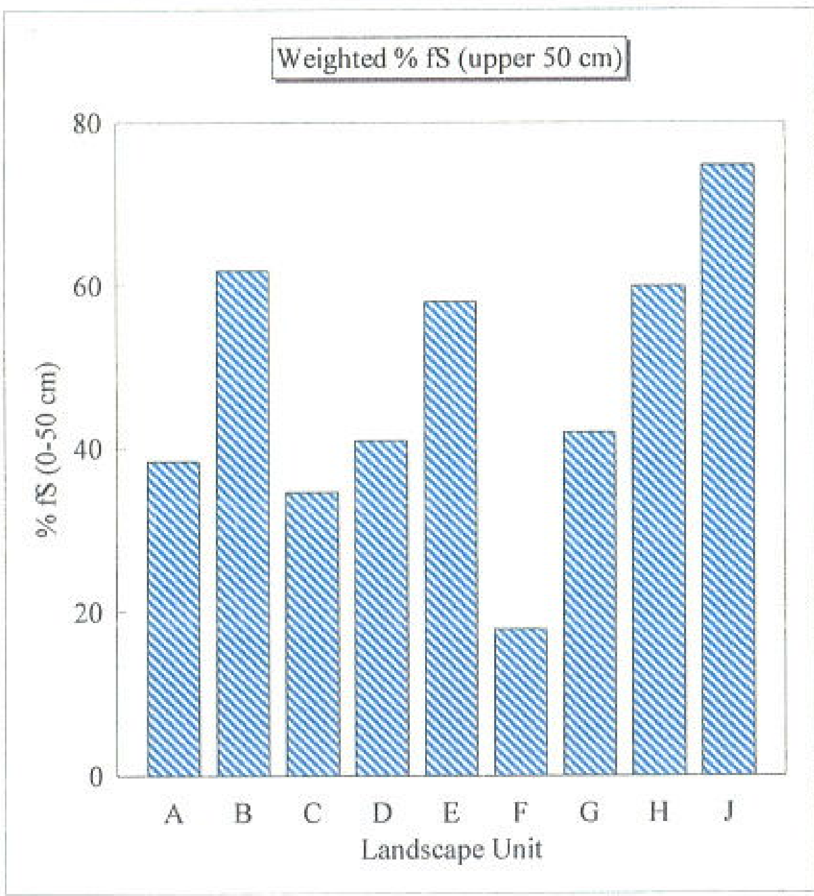
"particles all more or less of one size" (Whitten and Brooks, 1972) while poorly sorted refers to a more heterogeneous mixture of particle sizes.

The subaqueous soils of the Overwash Fans exhibit a weighted fine sand content (upper 50 cm) of 62% (unit B, figure 4-5), firmest consistence, a general lack of discontinuities, and little or no organic fragments. The high fine sand content and lack of discontinuities may be a result of the uniformity of material being deposited during barrier island washover events and the dominance of wave generated currents. Due to the very shallow water depths, this environment would be dominated by wave agitation and winnowing by slow longshore tidal currents. The above noted characteristics are like those found in a similar environment in Pamlico Sound, NC where wave generated currents and constant agitation resulted in well sorted, very fine or fine sand sediments with little or no visual organic debris and low shell contents (Pickett and Ingram, 1969).

The Shallow Mainland Coves were unique to the site, having brighter 3 chroma substrata horizons in 13 of the 15 descriptions. This could be an indication of groundwater intrusion from the mainland, or perhaps the remnant colors of terrestrial soil substrata. At 13 of the 14 description sites, estimates of SAV cover ranged from 20-100%. One site had only 1% cover. The presence of dense SAV would restrict wave activity effects and also act as a baffle for the trapping of fine suspended particulates (Carpenter, 1981; Ackerman and Okubo, 1993). Of the 5 descriptions exhibiting surface textures of sandy loam or finer, SAV coverage ranged from 50-95%.

The Barrier Island Flats exhibited buried Ag horizons within 105 cm of the surface in 8 of the 9 subaqueous soil profile descriptions. The representative pedon for this landform had a weighted fine sand content (upper 50 cm) of 60%, an indication

Figure 4-5. Weighted fine sand content (0-50 cm) for the Mid-Bay Shoal (landscape unit A), the Overwash Fans (landscape unit B), the Transition Zones (landscape units C, G, and J), the Shallow Mainland Coves (landscape units D and E), the Deep Mainland Coves (landscape unit F), and the Barrier Island Flats (landscape unit H).



that washover events are as important as in the Overwash Fans (unit H, figure 4-5). A few of the buried surfaces contained woody fragments, indicating that at some time in the past when these areas were stable (and sea level lower) they were probably wooded swamps. Wave generated currents were also dominant on this landform and would be very similar to those of the Overwash Fans. The presence of silt loam and loam textured buried surface horizons probably indicates that overwash materials are gradually extending over the old marsh surfaces. Subaqueous soil characteristics probably reflect the combination of the dominance of wave agitation and reduced impact of overwash events.

The Deep Mainland Coves had the highest silt, clay, and organic carbon contents within Sinepuxent Bay. This landform is dominated by low tidal currents and the depth of the landform is below the wave base of normal wave activity in the bay. This would allow finer particles such as silts and clays to settle out of suspension. Buried O horizons were noted in 10 of the 14 profile descriptions. The coves are adjacent to tidal marshes mapped as loamy, mixed, mesic Terric Sulfihemists (Demas and Burns, 1997). The combination of the low energy environment and proximity to the marshes could account for the high organic carbon, silts, and clays of the landform. Pickett and Ingram (1969) found similar characteristics in deep water embayments adjacent to tidal marshes in Pamlico Sound, NC.

The Transition Zones were the most heterogeneous landform of the six. Some profiles exhibited discontinuities or buried surfaces while others did not. Some profiles had abundant shell contents, while others had abundant organic fragments. The heterogeneity of this landform owes its origin to its geomorphic position and moderate energy environment. In these areas both wave generated and tidal currents are active. These areas are also located adjacent to more well defined landforms and therefore would incorporate some of their characteristics as well as others.

The Central Basin subaqueous soils were very similar to those of the Deep Mainland Coves. This landform is entirely dominated by tidal currents, but the > 2.0 m water depth and wide expanse of the landform reduces their impact and makes wind generated wave agitation negligible. The subaqueous soil CB-1 was dominated by a texture of silty clay loam with sandy loam and loam textures at or near the surface. The increase in sand content at the surface may be a result of increased delivery of coarser particles in bed load during periods of higher tidal current energies caused by storm events. The sediment characteristics of the central basin were also found to be similar to those of deep water embayments in Pamlico Sound, NC (Pickett and Ingram, 1969).

Subaqueous Soil Properties as a Function of Landscape Position

In addition to the landform relationships noted above, systematic variation of soil properties can also be considered a function of landscape position. The five basic hillslope elements (or landscape positions) are identified as the summit, shoulder, backslope, footslope, and toeslope (Ruhe, 1975). In terrestrial environments, a number of factors contribute to relationships between soil characteristics and landscape position. These include, erosion, deposition, geomorphic setting, hydrology, geology, and ecological considerations. In subaqueous environments, similar controlling factors apply, but the processes or mechanisms behind them are quite different. Thus, to evaluate the relationship between landscape position subaqueous soils, the dominant processes affecting each need to be understood.

Two critical components of estuarine environments are bathymetry and flow regime (Folger 1972a,b). Bathymetry can become important due to its control on wind generated wave activity. These waves are produced by wind blowing across the water surface. The wave face against which the wind blows experiences higher pressure than the front face, which is sheltered from the wind. This difference in air pressure propagates the wave in the direction the wind is blowing. Depending on wind speed, wave agitation may occur if the wave height is larger than the water depth. Thus, very shallow areas (such as the Overwash Fans) may be significantly effected by wave agitation when the wave base is deeper than the water depth. In deep water areas (such as the Central Basin), the wave base during normal weather conditions is generally shallower than the substrate, thereby reducing the effect of wave agitation.

Flow regime can also be a controlling factor due to its influence on the movement (in suspension or bed load) and settling of particulates. Flow regime includes both tidal and wind generated currents. Twenhofel (1932) presented data which indicated flow velocities of < 70 cm/sec at the surface were not sufficient to begin the movement of particles. Typical tidal currents were found to be less than 12 cm/sec in areas of >1.5 m water depth in nearby Chincoteague Bay (Casey and Wesche, 1981). Therefore, large expanses of deep water (such as the Central Basin) are less affected by tidal and wind generated currents than shallow water areas, causing lower water velocities which facilitate the settling of fine particles (silts and clays). The settling out of fines could also be enhanced when flow velocities are near zero, such as during daily periods of high and low tide. In contrast, a reduction of cross-sectional area through which a given volume of water can flow will increase current velocity. In constricted flow areas (such as landscape unit C), this could result in finer particles being swept through in suspension and coarser particles being deposited as bed load. This would also suggest that in large expansive deep water areas finer particles could settle out, while in shallower regions of the bay they might be swept away due to the increased water velocities. Although the concepts above generally hold under normal conditions, storm events could radically increase flow velocities and wave agitation for short periods.

Cross-section X-X' (figure 4-1) occurs across landscape units K and J, within which 3 subaqueous soil profiles, K-2, J-3, and J-7 are described (tables 4-5 through 4-7). The profile descriptions along cross-section X-X' exhibit landscape-attribute relationships analogous to terrestrial systems, but resulting from different mechanisms and processes. In this transect, K-2 could be considered to be in a summit position located on one of the Overwash Fans. Due to the very shallow water depths, this environment would be dominated by wave agitation. Profile K-2 is highly uniform with depth, exhibiting no discontinuities or organic fragments and low shell contents. It was classified as a Typic Psammaquent. Particle size data from two profiles in similar positions (B-Rep, S97MD047-003; H-Rep, S97MD047-009) had weighted fine sand contents (upper 50 cm) of 60-62% (figure 4-5). At this landscape position, the dominance of wave generated currents and the thickness of overwash materials results in a well sorted, relatively homogenous subaqueous soil profile.

Profile J-3, in what could be considered a backslope position, is also relatively uniform with depth, exhibiting no discontinuities, a gradual increase in shell fragment content below 2 cm, and organic fragments in the substrata. This soil was classified as a

Table 4-5. Field morphological description of subaqueous soil profile K-2, in a summit position on the Overwash Fans.

PROFILE K-2 38° 12' 52.84" N, 75° 9' 30.08" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-2	fS	5Y 4/2						m	fr			a
Cg1	2-25	fS	5Y 3/2	N 2.5/	c2d				m	fi			c
Cg2	25-60	fS	N 2.5/					5	m	fi			c
Cg3	60-75	fS	10Y 4/1	N 2.5/	c1d			5	m	fi			c
Cg4	75-80	fS	5Y 3/1					2	m	fi			

REMARKS: Profile description by G. Demas and K. Merrell, 6/16/97

0% vegetative cover
Periwinkle shell at 55 cm
Comon rutile and garnet grains in Cg2 horizon
Auger refusal, dense sands

Table 4-6. Field morphological description of subaqueous soil profile J-3, in a backslope position on the Transition Zones.

PROFILE J-3 38° 12' 56.98" N, 75° 9' 51.23" W
Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Conc.	Organic Fragments (%)	Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
A	0-2	LS	5Y 5/3						m	vfr		2f-3vf	a
Cg1	2-38	S	N 2/	5Y 4/2	f2d	2	10YR 3/2	2	sg	l		2vf	g
Cg2	38-75	S	N 4/	N 2/	f1d	1	10YR 3/2	10	sg	l			c
Cg3	75-100	S	5Y 6/1			3	7.5YR 3/2	20	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/30/96

65% cover widgeon grass (*Ruppia maritima*)
Yellow isopods with red stripes present at surface
1% gravel present in Cg2 and Cg3 horizons
Periwinkle shells at 80 and 100 cm
Organic fragments in Cg1 horizon eelgrass (*Zostera marina*) blades

Table 4-7. Field morphological description of subaqueous soil profile profile J-7, in a toeslope position on the Transition Zones.

PROFILE J-7 38° 13' 3.24" N, 75° 9' 56.88" W
coarse-loamy, Sulfic Fluvaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
A	0-5	S	10YR 4/3					10	sg	l			c
2Cg1	5-14	cS	5Y 3/2	10YR 2/2	c2f			5	sg	l			a
3Cg2	14-42	LS	5Y 5/1	5Y 3/1	c2d				m	vfr			c
4Agb	42-70	fS	5Y 3/1			20	7.5YR 3/2		sg	l			c
5Cg3	70-100	SL	5Y 4/1						m	fr	0.8		

REMARKS: Profile description by G. Demas, K. Merrell, B. Nichols, 8/12/96

0% vegetative cover
Few pockets 5GY 4/1 loam in 4Cg3 horizon

Typic Psammaquent. Water depth at this site is somewhat deeper than at the K-2 site, and wave generated currents would probably still dominate but tidal currents might also become involved. This landscape position is at the edge of the overwash fan and what is termed the basin slope by Katuna and Ingram (1974). The additional influence of tidal currents and slightly reduced influence of wave agitation might result in the delivery of more organic and shell fragments to the sediment.

The last profile on the transect, J-7, was located in what could be considered a toeslope position of the basin slope. This profile was comparatively heterogenous with depth, exhibiting 4 discontinuities and a buried surface. This profile was classified as a coarse-loamy Sulfic Fluvaquent. The deeper water greatly reduces the impact of wave agitation and tidal currents become the main energy source. This landscape position therefore would be less impacted by currents than the other two sites along the transect. This would result in poorly sorted subaqueous soils with organic debris and shell fragments. The influence of the overwash materials is also less evident at this site. The coarse sand horizon (2Cg1) may be a result of deposits produced by increased current velocities during a past storm event.

Another cross-section (Z-Z') was also examined to evaluate the relationship between landscape position and subaqueous soil properties. This transect is located in the northern portion of the site and crosses landscape units H, C, and A (figure 4-1). The profiles and their associated landscape/landform positions along this transect are H-5 (summit/Barrier Island Flats), H-1 (shoulder), C-8 (toeslope/transitional channel), C-6 (backslope), and A-2 (summit/Mid-Bay Shoal). Their profile descriptions are shown in tables 4-8 through 4-12, respectively. The two subaqueous soil profiles in summit

Table 4-8. Field morphological description of subaqueous soil profile H-5, in a summit positition on the Barrier Island Flats.

PROFILE H-5 38° 13' 34.10" N, 75° 9' 9.11" W

coarse-loamy, Sulfic Fluvaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-4	LS	N 2/						m	vfr		2f-3vf	a
Cg1	4-38	S	5GY 4/1	N 2/	c2d			15	sg	l			g
Cg2	38-70	S	N 5/	5GY 3/1	f2d	2	10YR 3/2	30	sg	l			c
2Cg3	70-93	LfS	N 5/			8	7.5YR 3/2	12	m	fr			a
3Agb	93-100	SiL	5GY 3/1			10	7.5YR 3/2		m	fr	0.9		c
3Cg4	100-118	L	5GY 3/1	10YR 3/2	f1d				m	fr	0.9		

REMARKS: Profile description by G. Demas and K. Merrell, 9/13/96

100% cover eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*), mixed bed
Clams present near surface
Finely ground shells in Cg1 and 2Cg3 horizons
10YR 3/2 features in 3Cg4 horizon banded

Table 4-9. Field morphological description of subaqueous soil profile H-1, in a shoulder position on the Barrier Island Flats.

PROFILE H-1 38° 13' 56.82" N, 75° 9' 9.47" W
Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-6	S	2.5Y 5/2						sg	l			a
Cg1	6-20	S	5Y 4/1	5Y 5/3	f2d				sg	l			g
Cg2	20-48	S	5GY 3/1					2	sg	l			a
Cg3	48-62	LS	N 2/					1	m	vfr			c
Cg4	62-95	S	5GY 3/1	N 2/	f2d	1	N 2/	3	sg	l			g
Cg5	95-110	S	5Y 5/1	N 3/	f2d			5	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/23/96

20% cover algae
Finely ground shells in Cg5 horizon
Few pockets N 3/ sandy loam in Cg5 horizon

Table 4-10. Field morphological description of subaqueous soil profile C-8, in a toeslope/channel position on the Transition Zones.

PROFILE C-8 38° 14' 0.27" N, 75° 9' 14.63" W
coarse-loamy, Haplic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-10	S	N 3/					1	sg	l			c
Cg1	10-32	S	N 4/					2	sg	l			c
2Agb	32-70	SL	10Y 5/1			5	7.5YR 3/2	3	m	fr	0.8		c
3Cg2	70-140	S	10Y 5/1	N 3/	c2d	1	7.5YR 3/2	6	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 6/18/97

0% vegetative cover
Surface littered with shells
Periwinkle shell at 85 cm
Few pockets 5GY 3/1 loam in Cg1 horizon
Organic fragments in 2Agb horizon appeared to be wood fragments

Table 4-11. Field morphological description of subaqueous soil profile C-6, in a backslope position on the Transition Zones.

PROFILE C-6 38° 14' 4.91" N, 75° 9' 16.12 W
sandy, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-10	SL	N 2/						m	fr	0.9	2f-2vf	a
Cg1	10-22	S	10Y 2.5/1	N 2/	f2p	3	2.5Y 3/3	1	sg	l			c
Cg2	22-70	S	10Y 2.5/1						sg	l			g
Cg3	70-90	S	10Y 5/1	N 3/	c1d			2	sg	l			g
Cg4	90-140	LS	10Y 5/1			5	2.5Y 3/3	5	m	vfr			

REMARKS: Profile description by G. Demas and K. Merrell, 6/18/97

50% cover eelgrass (*Zostera marina*)
Few pockets N 3/ sandy loam in Cg4 horizon
Periwinkle shell at 95 cm

Table 4-12. Field morphological description of subaqueous soil profile A-2, in a summit position on the Mid-Bay Shoal.

PROFILE A-2 38° 14' 16.38" N, 75° 9' 11.87" W
coarse-loamy, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Conc.	Organic Fragments (%)	Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
A	0-3	S	10YR 3/3						sg	vfr		2f-1vf	c
Ag	3-8	S	N 2/					10	sg	vfr		1f-2vf	c
2Cg1	8-26	L	N 3/	5Y 3/1	f2f				m	fr	0.8-0.9	1f	a
3Cg2	26-58	S	5GY 3/1					2	sg	vfr			a
4Cg3	58-84	fS	5GY 4/1	N 2/	band			3	sg	vfr			c
5Cg5	84-96	SL	5Y 2.5/1	5Y 5/1	f2p			10	m	fr	0.8		g
5Cg6	96-106	S	5Y 5/1	2.5Y 2/2	f1p	4	7.5YR 3/2		sg	vfr			c
6Cg7	106-120	cS	2.5Y 4/2	5Y 3/1	f3d			5	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/20/96

60% cover eelgrass (*Zostera marina*)
Few thin (1-2 cm) bands of N 3/ silt loam in 3Cg2 horizon
Surface littered with shells, tubeworm colonies

positions at each end of the transect (H-5 and A-2) were classified as a coarse-loamy Sulfic Fluvaquent and a coarse-loamy Typic Sulfaquent, respectively. The loamy sand surface texture, buried surface horizon (3Agb), and fine sands in profile H-5 again illustrates the influence of a 100% cover of submersed aquatic vegetation, the reduced thickness of overwash materials, and wave generated currents. The discontinuities in profile A-2 are likely a result of dredge disposal activity in combination with the surficial influence of SAV beds on wave agitation. The two subaqueous soil profiles in shoulder and backslope positions (H-1 and C-6) did not exhibit discontinuities or buried surfaces, had shell fragments deeper in the profile than all other profiles along the transect, and were classified in sandy textural families (Typic Psammaquent and sandy Typic Sulfaquent, respectively). The subaqueous soil profile in the middle of the transect, C-8, was located in the toeslope position in a channel marking a transitional area between the Barrier Island Flats and the Mid-Bay Shoal. This particular profile illustrates the influence of increased tidal current velocities due to a constriction of the volume available for tidal flow. This landscape position is protected by the Mid-Bay Shoal and Barrier Island Flats to either side and tidal currents of moderate energy dominate. The subaqueous soil was littered with shell fragments at the surface, contained plant debris, had a sandy loam horizon, and pockets of finer textured material in the surface horizon. This is similar to transitional channel areas examined in Pamlico Sound, NC (Katuna and Ingram, 1974) which exhibited similar clay inclusions, surface shells, and plant debris indicating that the channel area accumulated relatively coarse material (such as shell fragments) swept into the depressional area by higher velocity currents moving between the shoal and the barrier island.

Subaqueous Soil Properties as a Function of the Five Soil-Forming Factors

The five state factors of soil formation were originally conceptualized by Jenny (1941) as climate, organisms, relief (topography), parent material, and time. Later, Jenny (1980) introduced the concept of the "dot factor" to account for processes which affect soil formation (such as fires or major storm events) that can not be readily handled by within one of the original five state factors. Although it is difficult to isolate the effects of one factor from that of the others, investigation of soil properties sometimes allows the formulation of generalized concepts concerning the impact of each.

Climate is known to significantly influence terrestrial soil properties, but the effects are generally much easier to quantify over great distances. Climatic differences over shorter distances may or may not be significant and within a given study area may be non-existent. Within a subaqueous environment, differences in precipitation are meaningless (unless one considers precipitation driven erosion and delivery of terrestrial materials). Thus, within the Sinepuxent Bay study area, the effect of climate on subaqueous soil properties was difficult to evaluate. The effect of climatic variation could become apparent on a larger scale if the subaqueous soils of Sinepuxent Bay were compared to those of areas such as Naragansett Bay, Rhode Island or Pamlico Sound, North Carolina. The scope of this study precluded sampling in significantly different climatic regions. Nevertheless, the effect of climate might be inferred to effect the pedogenic transformation processes of sulfidization and organic matter decomposition demonstrated in this study which are known to be temperature dependant in a subaqueous environment (Odum and de la Cruz, 1967; Nedwell and Floodgate, 1972).

Another characteristic which could be considered a soil forming factor in a subaqueous environment is flow regime. Jenny (1980), in a re-evaluation of his original equation, proposed the use of the "dot factor" for those processes which did not fit neatly within one of the five state factors. The erosion, subsequent movement, and deposition of terrestrial soil particles is related to the velocity of precipitation runoff (which in turn could be considered a function of topography). The energies associated with tidal and wind driven currents may be analogous to the energies associated with terrestrial erosion and deposition processes. Runge (1973) discussed the concept of energy as a component of soil formation and the influence of external environmental controls on soil properties. Data obtained in this study support previous research indicating flow regimes have an impact on subaqueous soil properties (Krumbein and Aberdeen, 1937; Louderback, 1939; Hough, 1942; Pickett and Ingram, 1969; Folger, 1972 a,b; Wells, 1989).

Both flora and fauna can dramatically influence the characteristics of soils. Earlier in this chapter, both morphological and chemical characteristics were discussed to illustrate the impact of organisms on the subaqueous soils of Sinepuxent Bay in ways similar to those documented in previous studies (Sanders, 1958; Rhoads, 1974; Fenchel and Reidl, 1970; Carpenter, 1981; Caffrey and Kemp, 1991; Ackerman and Okubo, 1993; Wigand and Stevenson, 1994). The accumulation of organic matter (figure 4-2) is a dramatic illustration of the effect of SAV and benthic fauna on subaqueous soil properties. Benthic organisms were shown to increase the thickness of oxidized surface horizons through their burrowing activities in tandem with diffusion processes. Subaqueous soil calcium carbonate levels were also were also linked to the biogenic production of shells and subsequent incorporation into soil horizons after the death of the organism. Evidence that submersed aquatic vegetation can act as a sediment trapping baffle to increase the quantity of finer particles in the surface horizon and provide greater subaqueous soil stability through root structures and the reduction of wave generated currents has also been presented.

Topography is another state factor that can significantly effect the expression of soil attributes. Transect data presented previously in this chapter demonstrate the effect of topography and support other evidence of the influence of landscape position and the associated flow regime on subaqueous soil properties (Krumbein and Aberdeen, 1937; Hough, 1942; Ryan, 1953; Folger, 1972 a,b; and Hakanson and Jansson, 1983). Such subaqueous soil characteristics as the depth to buried surfaces, number of discontinuities, depth to sulfidic materials, shell fragment content, and organic debris content were found to be related to their position on the subaqueous landscape.

The impact of parent material has also been studied and shown to be a significant factor effecting soil characteristics. The seven major landforms and the major parent materials for Sinepuxent Bay are shown in table 4-13. The Deep Mainland Coves have formed from silty organic rich materials (eroded from marshes near the mainland) overlying organic paleosols. The subaqueous soils formed in these materials retain both silty textures and elevated OC levels as seen in pedon F-Rep (table 4-3 and figure 4-2). Subaqueous soil profile CB-1 (table 4-14) from the Central Basin exhibits characteristics similar to the Deep Mainland Coves such as a buried organic horizon and silty textures. Organic carbon content of the surface and subsurface horizons were less than 2.0% (Wells et al., 1996), indicating the influence of eroded organic marsh materials is of less importance possibly due to the distance from the mainland shoreline.

Table 4-13. Landform types, sampled pedons, and their associated parent materials in Sinepuxent Bay.

Landform Type Name	Sampled Pedons	Dominant Parent Material(s)
Mid-Bay Shoal	A-Rep	Dredge Spoil
Overwash Fans	B-Rep	Barrier Island Overwash Materials overlying Loamy Paleo-Terrestrial Estuarine Tidal Marsh Materials
Shallow Mainland Coves	D-Rep, E-Rep	Mixed Estuarine Materials overlying Paleo-Terrestrial Materials
Deep Mainland Coves	F-Rep	Silty Terrestrial Estuarine Tidal Marsh Materials
Barrier Island Flat	H-Rep	Barrier Island Overwash Materials overlying Loamy Paleo-Terrestrial Estuarine Tidal Marsh Materials
Transition Zones	C-Rep, G-Rep, J-Rep	Mixed Estuarine Materials
Central Basin	CB-1	Silty Estuarine Materials

Table 4-14. Field morphological description of subaqueous soil profile CB-1 of the Central Basin.

PROFILE CB-1 38° 13' 24.10" N, 75° 11' 03.90" W
fine-silty Typic Sulfaquent

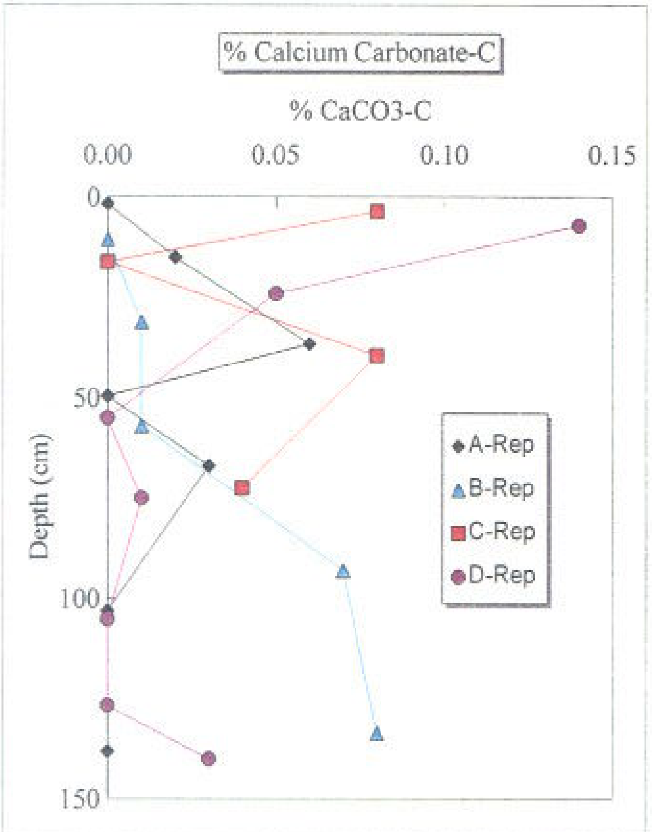
Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-5	SL	5GY 2/1	5G 4/1	c2d				m	fr			a
Cg1	5-27	L	5GY 4/1						m	fr	0.8		a
Oi	27-30	Pt	7.5YR 3/2										a
2Cg2	30-68	SiCL	5GY 4/1			10	7.5YR 3/3		m	fi	1.0		

REMARKS: Original profile description by D. Wells, 5/8/95. Pedologically described by G.Demas, September 1997.

Another example of the influence of parent material can be found in the subaqueous soil characteristics of the Shallow Mainland Coves. The parent material for this landform is loamy estuarine sediments overlying inundated materials previously in a terrestrial position. Landward erosion of the coves removed the upper horizons of previously existing mainland soils, exposing their substrata to inundation. Subsequent deposition of water borne sediment resulted in a duality of parent material. Thus, values for organic carbon content in the substrata are very low (< 0.10%) and are similar to those found in present day terrestrial soil substrata. These soils also had extremely low levels of pyrite (< 0.01%), which reflects the terrestrial nature of the parent material.

The uniformity and "clean" nature of barrier island overwash materials is evident in the data from profiles B-Rep of the Barrier Island Overwash Fans and H-Rep of the Barrier Island Flats. Although both were dominated in the upper part of the profile by parent materials originating from barrier island washover events, the depth to buried marsh surfaces played a significant role in the influence of parent material on both subaqueous soil characteristics and taxonomic placement. For example, the upper 50 cm of profiles B-Rep and H-Rep exhibited extremely low $CaCO_3$-C levels, indicating that shell fragments were not a significant component of the parent material (figure 4-6). Both profiles were also dominated by fine sand textures (figure 4-5). Barrier island washover materials have been shown to be composed of well sorted quartz fine sands, and exhibit extremely low levels of organic fragments, shell fragments, and other debris (Kochel and Wampfler, 1978).

Dredge Spoil is the dominant parent material for the Mid-Bay Shoal, from which subaqueous soil profile A-Rep was sampled. This profile was poorly sorted, exhibiting



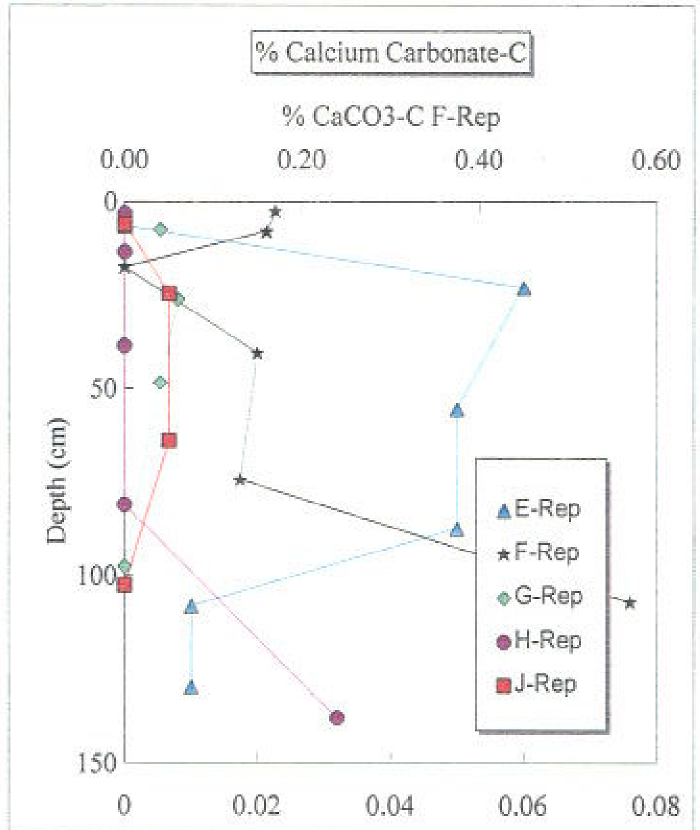


Figure 4-6. Calcium carbonate content with depth for the Mid-Bay Shoal (A-Rep), Overwash Fans (B-Rep), Transition Zones (C-Rep, G-Rep, and J-Rep), Shallow Mainland Coves (D-Repand E-Rep), Deep Mainland Coves (F-Rep), and the Barrier Island Flats (H-Rep).

intermediate levels of coarse sand (0-50 cm), clay (0-50 cm), and fine sand (0-50 cm; figure 4-5) in comparison to subaqueous soils from other landforms. This is an indication of the heterogeneity of particle size distribution which might be expected in a subaqueous soil profile composed of dredge materials which were probably mixed during their deposition. The data clearly illustrate the influence of parent material in each subaqueous landform and is similar to results from other studies that indicate some subaqueous soil properties can be directly related to parent material (Trask, 1932; Ryan, 1953; Wells, 1989; Coakley and Poulton, 1993).

Jenny's fifth state factor is time, and a number of studies have demonstrated the impact of time on the degree of pedogenesis and expression of various terrestrial soil properties. In Sinepuxent Bay, the influence of time on subaqueous soil properties was difficult to determine, but the documentation of one subaqueous Inceptisol implies that time is a factor in subaqueous soil development. Although the influence of time on subaqueous soil properties may be intuitively obvious (Trask, 1932), the application of chronosequence concepts could help to quantify this relationship. While not within the scope of this project, a possibility for future investigation might be to examine the depth of buried surface (Agb) horizons in the Barrier Island Flats, which gradually increases with distance from the Barrier Island. By using radiometric dating methods such as ^{14}C and ^{210}Pb, the age of the overlying material could be estimated, allowing inferences to be made concerning the length of time needed for the expression of various subaqueous soil properties such as the development of ochric epipedons.

CONCLUSIONS

The results of this study have implications for both the conceptual and applied aspects of pedology. Of greatest pedologic significance is the evidence which shows that the soil forming processes envisioned by Simonson (1959) are active in a subaqueous environment. In some cases the four components of the generalized theory of soil genesis are direct counterparts of classical terrestrial pedogenic processes. At other times they are analogous to terrestrial systems, but unique to subaqueous environments. Therefore, different types of pedogenic models will need to be developed which more adequately address and incorporate concepts from marine and coastal geology and geomorphology. Nevertheless, the proof that subaqueous soil horizon differentiation is a result of pedogenic processes reaffirms the pedologic concept of soil and extends the scope of pedology into shallow estuarine ecosystems. Thus, scientific verification has been provided which supports the contentions of Pond (1905), Kubiena (1948), Goldschmidt (1958), Muckenhausen (1965), Ponnamperuma, (1972), and Demas et al. (1996) that shallow water sediments should be included in the realm of pedology.

In relation to the field application of pedological concepts, the systematic variation of subaqueous soil properties and the suggested applicability of the soil-landscape paradigm in shallow water environments is especially significant. This study presents a rudimentary conceptual model to explain the systematic variation of subaqueous soil properties across the subaqueous landscape in a barrier island back-bay estuary. The landform analysis conducted in this study confirms that subaqueous soil properties are in part a function of landform. The bathymetry, flow regime, and geomorphic setting associated with subaqueous landforms dramatically affects the properties and classification of subaqueous soils on those landforms. While subaqueous soil properties are related to landscape position, there are clear differences with terrestrial systems. Although geology and geomorphic setting are still involved, the classic catenary concepts of erosion, deposition, and hydrology are not directly transferrable to a subaqueous environment. Erosion and deposition do occur, but as a result of tidal currents, wave generated currents, and wave agitation.

Evidence was presented which confirms the influence of organisms, parent material, and topography on subaqueous soil properties. Although the impact of time and climate could not be directly demonstrated in this study, the data indicate that subaqueous soil properties are in part a function of the state factors of soil formation (Jenny, 1941). In addition, evidence was also presented which supports the concept of the "dot factor" of soil formation (Jenny, 1980). The documentation of systematic variation in subaqueous soil properties suggests that the soil-landscape paradigm could be applied with confidence in a subaqueous environment for the purpose of generating a subaqueous soil resource inventory.

Therefore, by applying an approach using the concepts, models, and tools of pedology, this study demonstrates that shallow water sediments are *subaqueous soils*.

CHAPTER V

SUBAQUEOUS SOIL SURVEY OF SINEPUXENT BAY, MD

INTRODUCTION

Nearly 4,000 years ago soil properties were recognized as being crucial to agricultural production and soil classes based on productivity were used by early Chinese, Greek, and Roman civilizations (Simonson, 1968). Yet, due to the scarcity of records and their fragmentary nature, it is difficult to determine if soil classes were ever delineated on maps by these societies. One of the first "modern" soil resource inventories was produced and published during the 1790's in England (McCracken and Helms, 1994). In the United States, the first federally supported soil survey was begun in 1899 and examined a 250 square mile area near Hagerstown, Maryland. As soil survey efforts continued, changes in concepts and technologies induced changes in soil classification systems and soil mapping procedures. For example, the emphasis on geologic formations and surface texture in early soil surveys (Whitney, 1896) was gradually replaced with the concept that soil properties were not strictly a product of parent material, but reflected the additional influences of climate, organisms, relief, and time. Soil classification schemes have also changed over time, moving through the geologic slant of Whitney (1900), the inclusion of additional soil properties (Marbut, 1935), the genetic emphasis in the mid 19th century, culminating in the morphogenetic system now found in *Soil Taxonomy* (Soil Survey Staff, 1975). Thus, soil survey utilizes a method of soil classification, map unit development, and delineation that incorporates concepts related to pedogenic processes and the systematic variation of soil properties across the landscape (Hudson, 1992).

The present state of sediment mapping may be analogous to the conceptual state of early soil survey efforts. Sediment maps commonly portray individual surficial characteristics such as texture (Folger 1972 a,b; Katuna and Ingram, 1974; Kerhin, 1980; and Wells, 1989), and are frequently discussed in a geological framework, relating sediment attributes to geologic formations or geologic processes (Trask, 1932; Ryan, 1953; Katuna and Ingram, 1974; Wells et al., 1994b). It would appear that the concept of sediment as organized natural bodies which are a medium for plant growth has yet to be incorporated into sediment research. While proposals have been put forth concerning sediment classification (v.Post, 1862; Potonie, 1908; Kubiena, 1948; Demas et al., 1996), none have been officially adopted for application during resource inventories.

To initiate a soil resource inventory it is necessary that the materials being examined in the survey area meet the definition of soil and exhibit systematic variation across the landscape (Soil Survey Division Staff, 1993b). Previous studies have demonstrated that subaqueous materials are capable of or presently support rooted plants (Demas, 1993), that subaqueous soil properties can be considered a product of the five state factors of soil formation (chapter IV; Demas et al., 1996), and that subaqueous soil horizon differentiation can be considered a product of the pedogenic processes of additions, losses, transfers, and transformations (chapter IV). In addition to meeting the criteria noted above, it is essential that soil-landscape relationships can be identified and understood (Hudson, 1992). Terrain analysis of Sinepuxent Bay, MD demonstrated that available technology could provide the detailed data necessary to identify and delineate subaqueous landscape units and landforms (Demas and Rabenhorst, 1998, in press).

The objectives of this study were to (i) examine subaqueous soils within a pedological framework utilizing established soil survey procedures, and (ii) evaluate the suitability of this approach for the classification and mapping of the subaqueous soils of Sinepuxent Bay, Maryland.

MATERIALS AND METHODS

The site selected for study was a portion of Sinepuxent Bay, Maryland, a shallow (< 5 m) coastal estuary bounded to the east by Assateague Island and to the west by the Worcester County mainland. Atlantic ocean water enters and exits the site from the north through the Ocean City Inlet and from the south through the Chincoteague Inlet.

Terrain analysis of the site was performed using over 23,000 geo-referenced depth data points. These data were collected with a Rockwell PLGR+ GPS unit and Raytheon DE-719cm Fathometer and normalized to 0 Mean Sea Level (MSL) using tide data collected by a Remote Data Systems tide gauge linked to USGS benchmark U141 at the north end of the site. Subaqueous landforms were identified based on bathymetry, slope, configuration, and geomorphic setting (Demas and Rabenhorst, 1998, in press).

Subaqueous soil profiles were examined in the field utilizing a standard bucket auger, a sand head auger, and a McCauley peat auger. Subaqueous soil profiles sampled for laboratory analyses were extracted using a vibracore device. Soil morphological descriptions were made of 85 subaqueous soil profiles in Sinepuxent Bay utilizing the procedures and notations outlined in the *Soil Survey Manual* (Soil Survey Staff, 1993b). Soil descriptions were distributed over the various identified landforms for the purposes of developing soil mapping units. The approach of examining soils by landform was based on systematic relationships established in a previous study where different subaqueous soils were shown to occur on different landforms (Chapter IV). Subaqueous soil classifications were based on *Keys to Soil Taxonomy* (Soil Survey Staff, 1996).

Of the 85 soil profiles documented, 75 were field descriptions, 9 were vibracores described and sampled for laboratory analyses, and one was a vibracore description based on data from Wells et al. (1996). The locations of all subaqueous soil profile description sites are shown in figure 5-1. Five unlabeled locations in the southern portion of the site were surface horizon samples from Wells et al. (1996).

Supporting documentation for subaqueous soil classification included particle size analyses, acid-volatile (AVS) and chromium reducible sulfides (CRS), and total and organic carbon. Particle size analyses were performed utilizing a modified pipette method (Kilmer and Alexander, 1949). Samples were dialyzed prior to analysis for the removal of salts. AVS and CRS analyses were performed utilizing the procedure of Cornwell and Morse (1987). Organic carbon was determined using the procedure of Rabenhorst (1988), while total carbon was determined by combustion at 1050° C (Campbell, 1992) so that calcium carbonate-carbon could be calculated by difference.

Procedures for soil survey correlation followed those presented in the *Soil Survey Manual* (Soil Survey Division Staff, 1993b). The completed soil survey map was generated by USDA-NRCS Cartography and Geospatial Center in Fort Worth, Texas. The published map (Demas, 1998) is available on the USDA-NRCS world-wide website (ftp://ftp.ftw.nrcs.usda.gov/pub/ams/md.tar.gz). The map produced for presentation in this chapter was developed using the Surfer6 contouring software package.

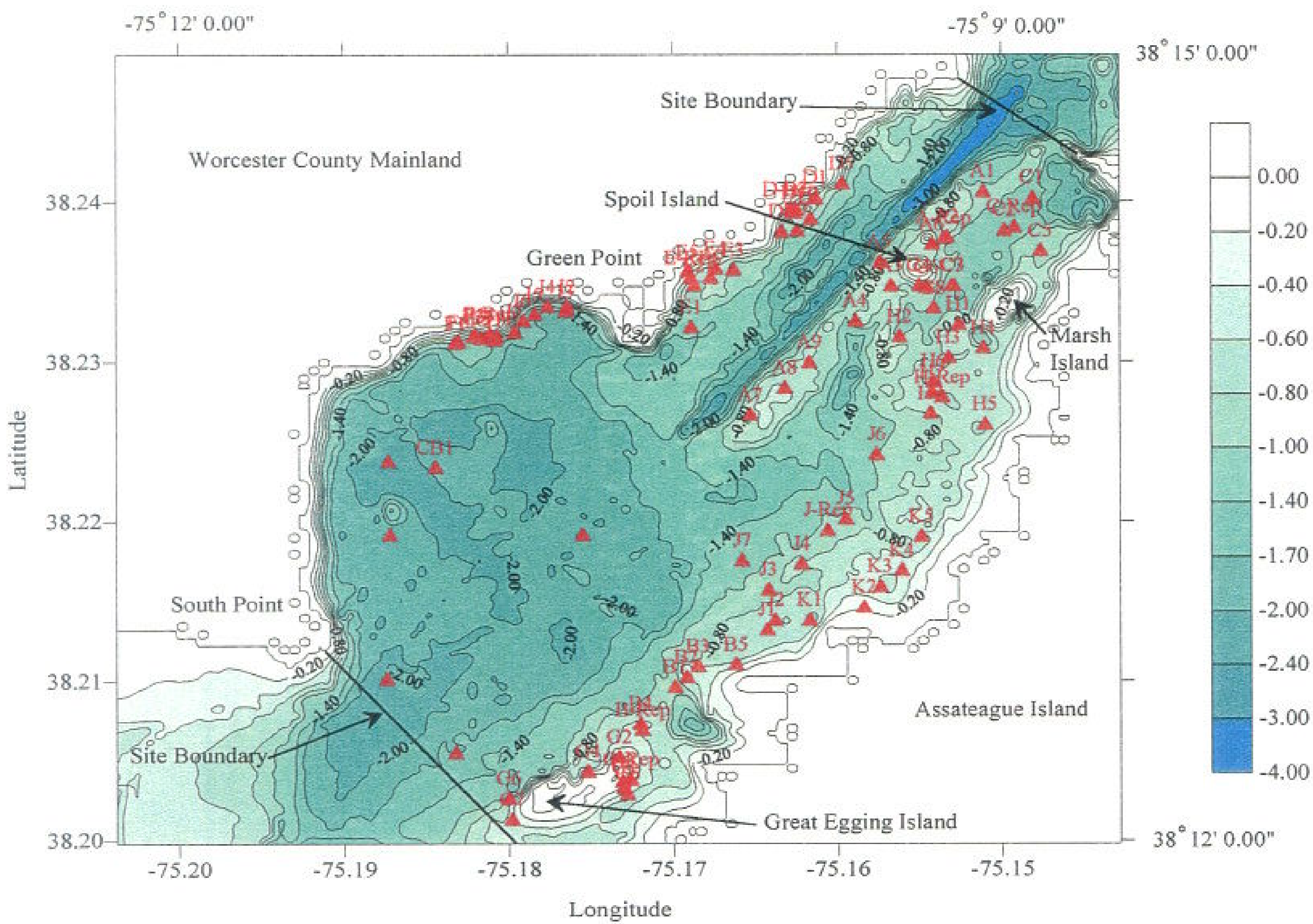


Figure 5-1. Location map of pedons and vibracore sampling sites (depth in meters below MSL))

RESULTS AND DISCUSSION

Mapping Strategy

One of the first steps taken in making a soil survey is the identification of major landforms in the survey area. The landforms can then be delineated cartographically, which results in the initial generation of possible soil boundaries. Once the landforms have been identified and delineated, field soil morphological transects are performed to determine the composition of soils on each landform. Care is taken to record the landform type and landscape position of each soil boring to help in understanding soil differences in terms of the soil-landscape paradigm. From these data, the soils of each landform can then be analyzed and assessed.

It is at this point that soil classification becomes important in the next step in the mapping process. Through the classification of each soil profile found on a particular landform, the dominant soil taxa and taxonomic purity of each landform can be determined. Soil series can then be developed which represent the dominant taxonomic components. Mapping units in soil surveys typically are named to represent the most important soil series phases for each landform (or landscape), of which surface texture and slope are the most common. Thus, mapping units are specifically linked to the landscapes or landforms on which they occur. For example, the soil map unit "Evesboro loamy sand, 5-10 percent slopes" in the Worcester Soil Survey update is described as being found on "ridges and ancient dunes" while the map unit "Othello silt loam" is found on "low-lying flats and depressions" (Demas and Burns, 1997). The final step in making a soil survey is the delineation of soil phases within each previously delineated landform.

Landform Composition

In Sinepuxent Bay, seven major landforms were identified (Chapter III). These were the Mid-Bay Shoal, Barrier Island Flats, Overwash Fans, Shallow Mainland Coves, Deep Mainland Coves, and Central Basin. Of the 85 subaqueous soil profiles described on the seven Sinepuxent Bay landforms, 82 were classified in the Entisol soil order (Soil Survey Staff, 1996). *Soil Taxonomy* is a hierarchal system consisting of six categories or levels: order, suborder, great group, subgroup, family, and series. Entisols are considered "young" soils with minimal soil development. The two most frequently observed diagnostic horizons were histic and ochric epipedons. Of the three profiles which were not Entisols, two had buried organic horizons close enough to the soil surface to be classified as Histosols. The remaining non-Entisol profile exhibited a cambic B horizon and was classified as an Inceptisol. This particular profile was located within 4 m of the mainland and may have been a submerged upland soil.

All of the 82 profiles in the Entisol order met the criteria for an aquic suborder. The aquent suborder requires saturation for extended periods and indications of reduction (such as Munsell chroma of 2 or less). At the next level of Soil Taxonomy, three great groups of Entisols were recognized in Sinepuxent Bay, those being (in descending hierarchal order), Sulfaquents, Psammaquents, and Fluvaquents. The order in which great groups key out is based largely on the interpretive significance of soil characteristics. Sulfaquents are Aquents which have sulfidic materials within 50 cm of the soil surface. The determination that sulfidic materials were present in some subaqueous soils (for the purposes of classification) was based on the analysis of a subaqueous soil profile (Demas et al., 1996) where the pH of horizons with pyrite levels of >0.25% fell from about 7.8 to < 4.0 after moist-incubation. Psammaquents are Aquents that are composed primarily of sand size particles (having no soil horizon textures finer than loamy fine sand). The classification of subaqueous soils in this great group is based on field texture designations and particle size analyses. Fluvaquents are Aquents which exhibit an irregular decrease in organic carbon content with depth in the profile. In terrestrial situations Fluvaquents are commonly found on floodplains where buried surfaces are common due to the deposition of new surficial material during flood events. Subaqueous soils which were classified as Fluvaquents typically had a buried surface horizon with increased organic carbon levels within 1.25 m of the soil surface.

Two subgroups, typic and sulfic, were used in the classification of the mineral subaqueous soils. To meet the sulfic subgroup criteria Fluvaquents must have sulfidic materials within 50-100 cm of the soil surface. The majority of Psammaquents and Sulfaquents within the site fell within the typic subgroup. The particle size family was also crucial to evaluating landform composition. Particle size families of the subaqueous soils of Sinepuxent Bay included sandy, coarse loamy (>15% sand and <18% clay), fine-loamy (>15% sand and >18% clay), and fine-silty (<15% sand and >18% clay). Table 5-1 shows the subgroup and particle family classification of the subaqueous soils examined and the frequency with which they occurred in each of the seven major Sinepuxent Bay landforms .

Of the 10 profiles described in the Mid-Bay Shoal, 60% had sandy loam or loam textured horizons and sulfidic materials within the particle-size control section (25-100 cm), resulting in a their classification as coarse-loamy Typic Sulfaquents. In 3 of the 4 soils classified as sandy Typic Sulfaquents, the "heavy" textured sulfidic horizon

Table 5-1. Soil taxonomic classifications and composition of each of the seven major landforms identified in Sinepuxent Bay. Textural family abbreviations include s (sandy), co-lo (coarse-loamy), fi-lo (fine-loamy), fi-si (fine-silty), and lo (loamy).

Landform Name	**Classification (*Soil Taxonomy*)**	**% of each component**
Mid-Bay Shoal	co-lo, Typic Sulfaquents	60
	s, Typic Sulfaquents	40
Overwash Fans	Typic Psammaquents	100
Barrier Island Flats	co-lo, Sulfic Fluvaquents	67
	Typic Psammaquents	22
	co-lo, Typic Sulfaquents	11
Shallow Mainland Coves	Typic Psammaquents	73
	co-lo, Typic Endoaquents	27
Deep Mainland Coves	fi-si, Typic Sulfaquents	72
	lo, Terric Sulfihemist	7
	fi-lo, Sulfic Fluvaquents	7
	lo, Terric Sulfisaprists	7
	co-lo, Typic Halaquept	7
Transition Zones	Typic Psammaquents	58
	s, Typic Sulfaquents	19
	co-lo, Sulfic Fluvaquents	15
	co-lo, Typic Sulfaquents	4
	co-lo, Haplic Sulfaquents	4
Central Basin	fi-si, Typic Sulfaquents	100

occurred above 25 cm. The occurrence of sulfidic materials at or near the soil surface in 90% of the profiles would be the major soil attribute affecting soil interpretations for such activities as submersed aquatic vegetation (SAV) restoration or dredge disposal.

The Overwash Fans landform was extremely uniform, soil profile descriptions were very similar, and all were classified as Typic Psammaquents. Six of the 11 profiles (55%) had 3 chroma or greater surface horizons. Some of these horizons may have been inadvertently included with subsurface horizons early in the study. The presence of 3 chroma surface horizons (indicating it is oxygenated) could have implications for the feasibility of SAV restoration or other facets of benthic ecology.

The soils of the Barrier Island Flats were dominantly classified as coarse-loamy Sulfic Fluvaquents, and typically had a buried silt loam or loam surface horizons (Agb) containing sulfidic materials within 50-100 cm of the soil surface. In 67% of the profiles the sulfidic buried surface horizons occurred within the particle size control section (25-100 cm). In 11% of the soils, the buried sulfidic surface horizons occurred below 100 cm and thus, were outside of the control section. The presence of the Agb horizons with sulfidic materials has important implications for dredge disposal activities due to the possibility of acid-sulfate weathering. The sulfidic materials would be of less importance to benthic ecological interpretations because these materials occur well below the rooting zone of SAV or burrowing zone of benthic organisms such as clams.

The most distinctive attribute of the subaqueous soils of the Shallow Mainland Coves was the presence of Munsell colors of 3 or greater within the subsoil (in 87% of the profiles). Six profiles (40%) had surface and/or subsurface horizons with textures of sandy loam or loam. In four profiles the "heavy" textured horizon extended slightly into the particle-size control section. Although soil classification was effected by the depth to which the finer surface textured material extended, the absence of sulfidic materials and presence of 3 chroma substrata would have a greater influence on interpretations. The dredging and disposal of materials from these subaqueous soils would pose a reduced threat of acid-sulfate weathering, while the presence of high chroma colors in the profiles may be particularly favorable for rooting of SAV or burrowing benthic organisms such as clams and tubeworms.

High organic carbon levels, sulfidic materials, and silty soil textures were the most significant attributes of the subaqueous soils of the Deep Mainland Coves and Central Basin. Buried histic epipedons occurred in 47% of the profiles. In 2 subaqueous soil profiles, the organic horizons occurred at a depth shallow enough to meet the criteria for classification as Histosols. Five subaqueous soil profiles would be classified as Thapto-histic Sulfaquents, an implied subgroup not presently included in *Keys to Soil Taxonomy* (1996). Environmental hazards associated with dredge disposal would be significant due to the presence of sulfidic materials. The feasibility of SAV restoration would be limited in these soils by the high organic carbon levels and lower diffusion of oxygen into the surface horizons due to the silty textures. The 2 profiles that were classified in the coarse-loamy particle size family were located in the shallower margins of the landform adjacent to the mainland where a thin veneer of sand had been deposited. Although the sandier surface horizons might enhance SAV rooting, the sulfidic materials below would remain a significant limitation for dredge disposal activities.

The Transition Zones were dominated by subaqueous soils which were classified as Typic Psammaquents. The minor components, many of which contained sulfidic materials, were typically found in landscape positions near or at the boundary to landforms with similar soil characteristics. Thus, the transitional nature of the subaqueous soils on the margins of this landform is evident in their classification. While the majority of the subaqueous soils would not pose severe hazards for SAV rooting or dredge disposal, these interpretations could be significantly affected by the presence of sulfidic materials in the minor components of the landform.

The relative homogeneneity (taxonomically) of each landform provides the basis upon which soil series, phases and mapping units could be developed. Although initial soil delineations were drawn using the seven major landforms, additional analysis of the subaqueous soil characteristics of each landform could be used to help refine these delineations and provide more cartographic detail.

Development of Subaqueous Soil Series

In making a detailed soil survey, relatively homogeneous mapping units are delineated by using landforms as the basis for drawing delineations or soil boundaries. *Soil Taxonomy* interfaces with soil survey through the use of taxonomic groupings to name the soil mapping units. While subgroups or family level classifications are occasionally utilized, the soil series (the lowest category in *Soil Taxonomy*) is most frequently used in the naming of soil map units. Following the determination of the dominant soils on each landform, there was a need to develop soil series both to accommodate the soils fully within *Soil Taxonomy* and also to be able to use the series names for the development of soil mapping units.

In *Keys to Soil Taxonomy* (Soil Survey Staff, 1996) the category immediately above the series level is the family, which is differentiated according to 4 criteria: (i) particle-size class, (ii) temperature class, (iii) mineralogical class, and (iv) reaction class. In table 5-1, taxonomic classifications were presented which only include the particle-size class. To fully address subaqueous soil classification, the remaining 3 family level classes should be defined prior to developing soil series for the naming of mapping units.

The temperature class (regime) for the subaqueous soils of Sinepuxent Bay is difficult to categorize due to a lack of direct measurements of soil temperature at the prescribed depth of 50 cm. But, there are other data which could help place them into an appropriate temperature regime. Soil temperature data from Assateague Island indicates a borderline mesic/thermic (15° C) regime, with average yearly soil temperatures ranging from 14.8-15.2° C (USDA-NRCS, unpublished data). The mesic/thermic boundary along the east coast of the United States was originally conceived as the northern limit for the production of cotton (Smith, 1983). In Sinepuxent Bay, the dominant vegetation, eelgrass (*Zostera marina*), is near its southern limit of growth and widgeon grass (*Ruppia maritima*) is near its northern limit of growth (Day et al., 1989). These two ancillary facts suggest a mesic temperature class for the subaqueous soils of Sinepuxent Bay. Future research projects could help in determining temperature class through direct observational data and evaluation of the appropriate depth at which subaqueous soil temperature should be recorded for interpretive purposes.

The mineralogical class of each subaqueous soil is also difficult to infer without analytical data. There are however, limited mineralogical data from Assateague Island soils in Maryland and Virginia. Soils of the dunes, back-dunes, and tidal marshes with sandy and coarse-loamy particle-size classes exhibit a borderline mixed/siliceous condition of 87-95% resistant minerals (USDA-NRCS, unpublished data). Along the mainland, the fine-loamy and fine-silty mineral portions of tidal marsh and upland soils were found to have mixed mineralogy (USDA-NRCS, unpublished data). Based on the assumption that the subaqueous soils of Sinepuxent Bay would have mineralogical properties similar to nearby upland soils in the same particle size classes, sandy and coarse-loamy soils were classified as siliceous the fine-loamy and fine-silty soils were classified in mixed families.

Of the four reaction classes (calcareous, allic, acid, and non-acid), the two which would most often pertain to subaqueous soils are acid and non-acid. Measurements of pH ranging from 7.8-8.4 in one subaqueous soil profile (Demas et al., 1996) and other pH data from Sinepuxent Bay (Wells et al., 1996) suggest that a reaction class of non-acid would be most appropriate for the subaqueous soils of Sinepuxent Bay. A non-acid reaction class is not surprising considering the overwhelming influence of ocean saltwater in the bay.

Having established family classes, the next step towards the naming of map units is the development of soil series. Soil series further define the differences within a family that affects the soil's use. Series criteria can include soil properties used as criteria at higher levels of *Soil Taxonomy,* other soil characteristics such as the range of colors or soil texture, or the expression of characteristics or unique horizons which occur above or below the defined depths of the family level control section (usually 25-100 cm). Thus, the series control section can include soil properties from the surface to a depth of up to 2 m. Table 5-2 shows the proposed names and family level classifications for the six subaqueous soil series of Sinepuxent Bay.

Table 5-2. Soil series proposed for Sinepuxent Bay, MD survey area. Mineralogy and temperature classes based on mineralogy and temperature data from nearby terrestrial areas.

Soil Series Name	Soil Classification
Fenwick	siliceous, mesic Typic Psammaquents
Newport	siliceous, mesic Typic Psammaquents
Sinepuxent	coarse-loamy, siliceous, mesic non-acid Typic Sulfaquents
South Point	fine-silty, mixed, mesic non-acid Typic Sulfaquents
Tizzard	coarse-loamy, siliceous, mesic non-acid Sulfic Fluvaquents
Wallops	siliceous, mesic Typic Psammaquents

Although three of the series were classified as Typic Psammaquents, they differ markedly within the series control section. The proposed Fenwick soil series has colors of 3 chroma or greater in surface horizons, has firm to very firm consistence below 25 cm, and exhibits low levels of organic carbon. The Newport soil series differs from the Fenwick series in having colors of 3 chroma or greater and 0-5% coarse fragments in their substrata horizons. The Wallops soil series differs from the Fenwick and Newport soils in having Munsell chromas of 2 or less throughout the profile.

The remaining 3 proposed subaqueous soil series differ at higher categories of *Soil Taxonomy*. The Sinepuxent soil series has sulfidic materials within 50 cm of the surface; textures of sandy loam, silt loam, or loam within the particle-size control section; and typically exhibits 4 or more discontinuities. The South Point soil series is the only fine-silty soil identified in Sinepuxent Bay. In addition, this series commonly has a buried histic epipedon 60-190 cm below the soil surface, sulfidic materials within 50 cm of the surface, and exhibit the highest organic carbon contents of the site. The Tizzard series has a buried mineral surface (Agb) and sulfidic materials 50-100 cm below the soil surface. In addition, surface horizon Munsell chroma colors range up to 3.

Subaqueous Soil Series Phases

In Sinepuxent Bay soils, surface texture is an important phase, particularly because of its affect on SAV, and therefore it will be utilized in naming the mapping units. Excluding the nearly vertical cuts adjacent to the mainland and main channel, slopes in Sinepuxent Bay are nearly level (< 1.0%). Thus, a more critical phase distinction for estuarine applications might be water depth (which could provide information concerning light attenuation, the degree of wave agitation, and the energies associated with tidal and wind generated currents). The mapping units developed for Sinepuxent Bay therefore reflect these two phases, surface texture and water depth.

To help in determining appropriate map unit surface texture phases, a map was developed showing the surface texture of each soil profile described in Sinepuxent Bay. To determine the map unit water depth phase, the bathymetric data was utilized (figure 5-1). The 13 map units developed for Sinepuxent Bay are shown in table 5-3. Each map unit represents a unique portion of the landform on which they occur. For example, although the Newport soil series occurs on the Shallow Mainland Coves landform, the two coves which represent this landform have different dominant surface textures. To delineate this difference, two mapping units were developed with different surface texture phases (loamy sand and sandy loam).

The soil survey legend (table 5-3) and surface texture distribution data were used to generate a subaqueous soil survey of Sinepuxent Bay, MD (figure 5-2). Map units were correlated by landform and delineated accordingly. Map unit delineation was enhanced by photo-interpretation of the ortho- and infra-red photography. For example, the delineation of the map unit developed for the Overwash Fans adjacent to Assateague Island was clearly discernible on the infra-red photography as the boundary between bright, tan colored curvilinear features and more dark blue deep water areas. The placement of other map unit boundaries was similarly enhanced. In areas of deeper water, where photographic features were difficult to discern, delineations were based more on bathymetry and other data such as surface texture distribution and geomorphic position.

Table 5-3. Subaqueous soil survey mapping legend for Sinepuxent Bay, MD.

Subaqueous Soil Survey Legend
Sinepuxent Bay, Maryland

April, 1998

Map Unit Symbol	Map Unit Name
FeA	Fenwick sand, 0.2 to 0.5 m depth
NeB	Newport loamy sand, 0.2 to 1.0 m depth
NpB	Newport sandy loam, 0.2 to 1.0 m depth
SiB	Sinepuxent loamy sand, 0.5 to 1.0 m depth
SnB	Sinepuxent sandy loam, 0.5 to 1.0 m depth
SoC	South Point sand, 0.5 to 1.5 m depth
SpD	South Point sandy loam, 1.5 to 2.5 m depth
SwD	South Point silt loam, 1.5 to 2.5 m depth
TiC	Tizzard sand, 0.5 to 1.5 m water depth
TzC	Tizzard loamy sand, 0.5 to 1.5 m depth
WaC	Wallops sand, 0.5 to 1.5 m depth
WpC	Wallops loamy sand, 1.0 to 1.5 m depth
WsC	Wallops sandy loam, 1.0 to 1.5 m depth

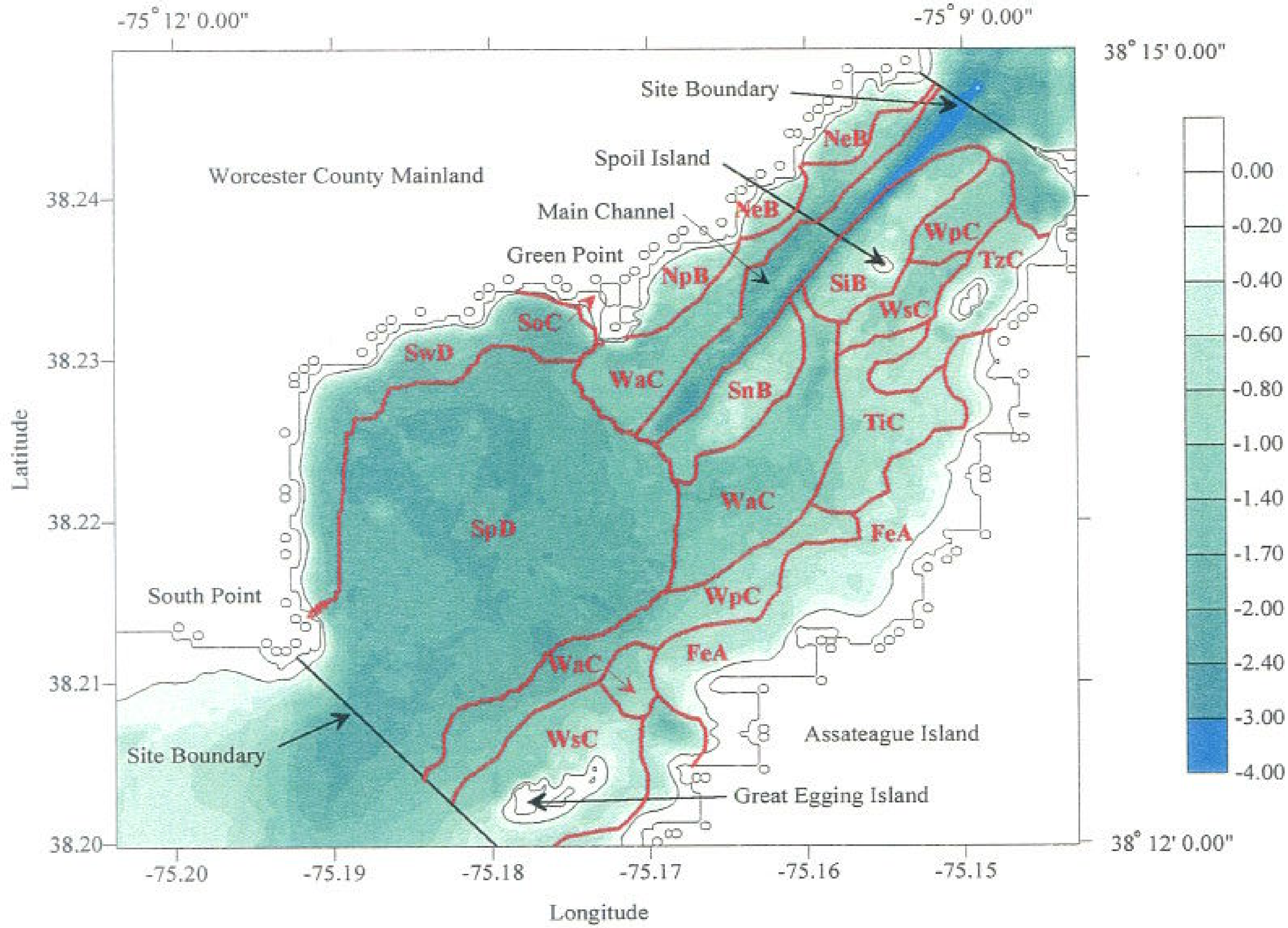


Figure 5-2. Subaqueous soil survey of Sinepuxent Bay (depth in meters below MSL)

CONCLUSIONS

The map generated in this study may be one of the first soil surveys produced utilizing pedological techniques in a permanently submersed estuarine environment . *Keys to Soil Taxonomy* (Soil Survey Staff, 1996) was found to be sufficiently detailed to develop 6 unique soils series. Soil correlation procedures in the *Soil Survey Manual* (Soil Survey Division Staff, 1993b) were also found to be adequate for the development and delineation of soil mapping units. The approach utilized in this study to classify and delineate subaqueous soils helps to establish an initial mapping protocol for the development of subaqueous soil resource inventories.

This study demonstrates the feasibility of conducting a subaqueous soil survey through the application of accepted pedological techniques, and in particular the soil-landscape paradigm (Hudson, 1992). Therefore, the notion of systematic variation inherent in the soil-landscape paradigm strongly suggests that the present (geological) approach to sediment mapping be modified to incorporate pedological concepts and techniques for the development of subaqueous soil resource inventories. The benefits of utilizing this approach include i) a significant increase in the level of detail (map scales of 1:12,000) in comparison to present sediment map scales (1:62,500 or smaller), ii) the 3-dimensional nature of soil maps versus the more 2-dimensional nature of the majority of present surficial sediment maps, iii) the possibility this approach could be applied to other similar shallow water coastal estuarine habitats, and iv) the use of subaqueous soil maps to further understand ecological relationships such as the distribution and vitality of SAV or the potential environmental hazards associated with dredging.

It is hoped that future applications of this approach ultimately will document enough subaqueous soil data to begin to address taxonomic concerns raised by this study. Temperature and mineralogy data would be helpful in confirming the family level classes associated with subaqueous soils. Additional field and analytical data could also enhance the way subaqueous soils are classified using *Keys to Soil Taxonomy* (Soil Survey Staff, 1996). Buried organic horizons found in the Deep Mainland Coves suggest that a Thapto-histic subgroup is needed within the Sulfaquents great group. Other modifications might include defining a subaqueous soil particle-size control section for benthic ecological interpretations or the development of "subaquic" subgroups or great groups in the Entisol order. It is also possible that subaqueous soils may be unique enough to justify the development of a soil order. This is not out of the realm of possibility considering the recent addition of a new soil order for permafrost soils (Gelisols). If frozen water is now considered to be order level criteria, it is possible that permanent submersion by liquid water might also warrant the addition of a subaqueous soil order to *Soil Taxonomy*.

CHAPTER VI

SUBAQUEOUS SOIL-SUBMERSED AQUATIC VEGETATION RELATIONSHIPS

INTRODUCTION

The importance of submersed aquatic vegetation (SAV) in estuarine ecosystems is of particular significance due to their role as shelter sites and nursery areas for juvenile finfish and shellfish (Sculthorpe, 1967). In Chesapeake Bay the reduction of standing stock of SAV has had major environmental and economic impacts (Kemp et al., 1984; Hurley, 1990; Chesapeake Bay Program, 1991). Although there have been increases or expansions of SAV beds (Orth et al., 1993), efforts to restock areas have not been entirely successful (Stevenson et al., 1993).

The reduction in SAV cover in Chesapeake Bay in the 1970's provided the impetus for intensive research into the causes for their decline. The results of these studies were summarized in *Chesapeake Bay Submerged Aquatic Vegetation Habitat Requirements and Restoration Targets* (Chesapeake Bay Program, 1992). The five factors effecting SAV growth were found to be suspended solids, chlorophyll a, light attenuation (Kd), dissolved inorganic nitrogen (DIN), and dissolved inorganic phosphorus (DIP). Minimum habitat requirements were therefore based on the levels of these five water quality parameters under which SAV could flourish. In addition to water quality parameters, it was also suggested that the decline of SAV resulting from a depletion of naturally available seed stocks (Rybicki and Carter, 1986), might be a critical factor in SAV restoration.

The focus on the impact of water quality conditions on SAV growth resulted in extensive documentation from both field and controlled laboratory experiments. The concentration on water quality is understandable considering that, at the time, water quality conditions were the dominant problem in Chesapeake Bay. Because of this, less attention was given to sediment characteristics that could effect SAV growth. Nevertheless, studies were conducted that indicated some sediment attributes could impact SAV significantly.

The sensitivity of SAV to sediment characteristics was evaluated in a number of ways and results indicated that four sediment attributes played a role in SAV growth and production. Surface texture (particle size) was implicated in part due to its control of oxygen diffusion. Plants which could transfer sufficient oxygen to their roots were less impacted by finer particle sizes than other SAV (Barko et al., 1991). Hurley (1990) noted that different species of SAV seemed to occur on specific suites of particle size classes. For example, eelgrass (*Zostera marina*) was typically found on "sandy" substrates while hydrilla (*Hydrilla verticillata*) was found on "silt to muddy" substrates. Also, the root:shoot ratio varies significantly in these species (Stevenson, 1988) suggesting that poorly rooted species (e.g. hydrilla) may depend on finer grained soils which have inherently higher phosphorus levels. Organic carbon content was also found to effect the growth of SAV. As organic carbon increased to levels above 5-10%, SAV production decreased (Barko and Smart, 1986). The presence of sulfides in the sediment has a deleterious effect on SAV roots, at times reaching levels toxic to the plant (Armstrong, 1975; Barko et al. 1991; Goodman et al., 1995). Another attribute found to impact SAV was bulk density. In a fashion analogous to terrestrial systems, high bulk density appeared to effect the rooting depth of SAV (Barko et al., 1991). Although now established as controlling factors in SAV production, the effects of sediment characteristics were studied almost exclusively under controlled laboratory conditions.

The difficulty in assessing the impact of sediment characteristics on SAV under natural conditions in the field was, and is, exacerbated by the lack of sufficiently detailed sediment maps. Because sediment maps typically portray individual characteristics, to gain a more holistic view of the their relationship to SAV growth, numerous maps would need to be overlain simultaneously along with SAV distribution. In addition, the use of different units of measurement or subjective terminology on sediment maps would necessitate data normalization prior to any analysis.

Recent work in Sinepuxent Bay, Maryland has indicated that the value of sediment maps to ecological research could be significantly increased by a change in mapping methods and concepts (Demas et al., 1996). Through the application of a pedological approach, it was shown that shallow water sediments that support rooted, flowering vegetation would be better viewed as subaqueous soils, incorporating the concept of soil as a medium for plant growth and the soil-landscape paradigm as a mapping tool (Demas et al., 1996; Chapters IV and V).

The objectives of this study were therefore to evaluate SAV biomass production and distribution in relation to subaqueous soil attributes and subaqueous soil map unit delineations.

MATERIALS AND METHODS

Water Quality, Nutrients and SAV Biomass Analyses

The site selected for this study was a 1,300 ha portion of Sinepuxent Bay, Maryland. Sinepuxent Bay is a shallow (< 5 m) coastal estuary bounded to the east by Assateague Island and to the west by the Worcester County mainland. Atlantic Ocean tides influence water column attributes significantly, entering to the north through the Ocean City Inlet and from the south through the Chincoteague Inlet. Tidal fluctuations typically range from 0.5-0.75 m (U.S. Dept. of Interior, unpublished data; Wells et al., 1996). Water quality conditions in Sinepuxent Bay have historically met the minimum habitat requirements set forth by the Chesapeake Bay Program (Boynton et al., 1996). In addition, increases in the areal extent of SAV beds in Sinepuxent Bay and Chincoteague Bays have also been recently documented (Orth et al., 1993).

Six SAV biomass sampling sites were selected based on landscape position, bathymetry, subaqueous soil surface characteristics, and the results of terrain analysis (Demas and Rabenhorst, 1998, in press). The locations of the SAV biomass/water quality sampling sites and subaqueous soil map units are shown in figure 6-1. Biomass measurements were made quarterly from June 1996 to October 1997. Aboveground and belowground SAV biomass were determined by extraction of three 0.1 m^2 cores from the soil, separation of roots and shoots, and drying at 60° C in a forced air oven.

Water samples for nutrient concentrations (including nitrate, nitrite, ammonium, and phosphate) at each site were filtered in the field through a Whatman GFC glass-fiber filter. Both filtrate and filters were placed on ice and kept frozen until analyzed. Dissolved and total nutrient analyses were made on a Technicon Auto-Analyzer II

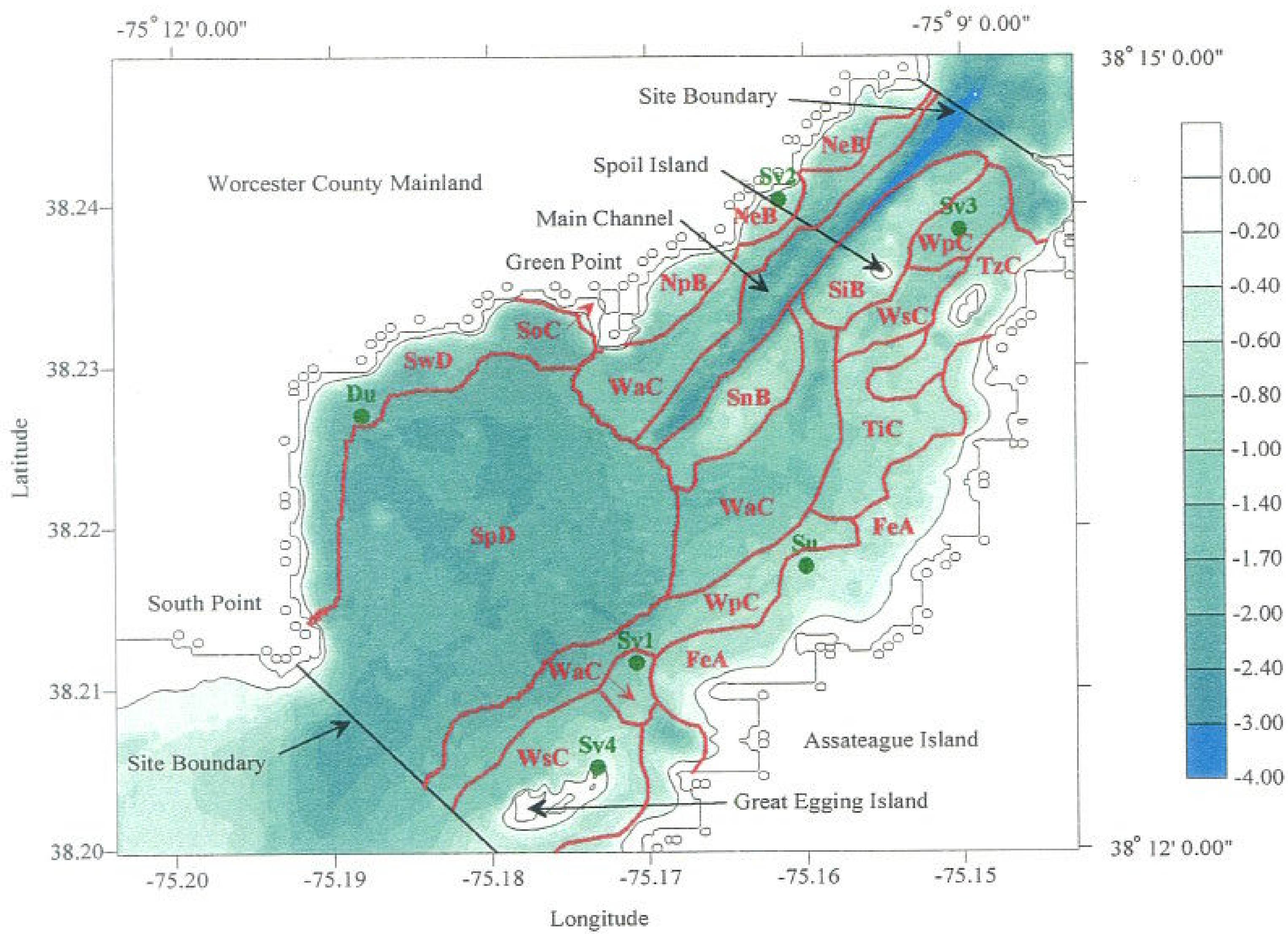


Figure 6-1. SAV biomass/water quality sites in Sinepuxent Bay (depth in meters below MSL)

system. Chlorophyll *a* concentrations were determined fluormetrically (Parsons et al., 1984) on a Turner fluorometer (model 111). Total suspended solids were determined using a modified gravimetric method (Banse et al., 1963). Salinity, temperature and dissolved oxygen were measured in the field using a Hydro-Lab auto-analyzer. Light extinction coefficients were determined by measuring photosynthetically active radiation (PAR) at depths of 5-10 cm below the water surface and at the subaqueous soil surface with a Li-Cor LI-1000 datalogger equipped with a LI-1925a underwater quantum sensor.

Subaqueous Soil Analyses

A detailed bathymetric map of the 1,300 ha site was generated based on over 23,000 geo-referenced depth data collected with a Rockwell PLGR+ GPS unit, Raytheon DE-719cm marine research fathometer, and Geolink XDS software. Terrain analysis resulted in the identification of seven major landform types within Sinepuxent Bay based on bathymetry, slope, landscape configuration, and geomorphic setting (Chapter III).

A total of 85 subaqueous soil profile descriptions were recorded, of which 75 were performed in the field, 9 were done in the laboratory, and one was described based on data reported by Wells et al. (1996). Morphological descriptions of all profiles followed the guidelines set forth in the *Soil Survey Manual* (Soil Survey Division Staff, 1993b). Representative pedons were sampled using a vibracoring device and 7.6 cm aluminum pipe during the summer and fall of 1996. The soils were sampled by horizon, placed in nitrogen sparged plastic bags, sealed and kept in a freezer until all sulfide analyses were completed. Particle size analyses were performed utilizing a modified pipette method (Kilmer and Alexander, 1949) wherein samples were dialyzed prior to analysis for the removal of salts. The procedure of Cornwell and Morse (1987) was utilized for AVS and CRS analyses. Organic carbon was determined using the procedure of Rabenhorst (1988), while total carbon was determined by combustion at 1050° C (Campbell, 1992). Calcium carbonate-carbon was calculated by difference between total carbon and organic carbon.

Additional analyses of micro- and macro-nutrients were performed to determine the general fertility of the subaqueous soils at each SAV biomass site. Micronutrient contents (B, Cu, Mn, and Zn) were analyzed using the methods of Bingham (1982) and the University of Delaware Soil Testing Staff (1991). Macronutrients (P_2O_5, K_2O, and Ca) were determined using a Technicon Auto-Analyzer following the procedures of Mehlich (1953) and Flannery and Markus (1980). Total N was determined by combustion (Campbell, 1992).

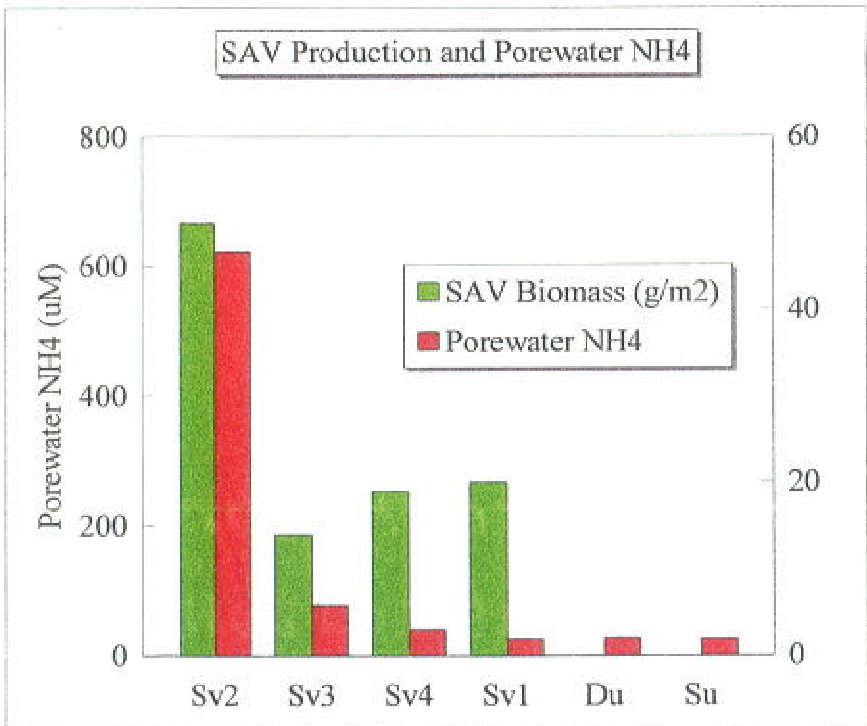
A subaqueous soil survey map was produced utilizing soil mapping units representing 13 phases of six subaqueous soil series. Map units were correlated by landform and delineated accordingly. Procedures for soil survey correlation followed those presented in the *Soil Survey Manual* (Soil Survey Division Staff, 1993b).

RESULTS AND DISCUSSION

A review of data associated with the five water quality parameters essential to SAV survival indicated that during the sampling period, all five parameters were met with the exception for occasional increases in total suspended solids (TSS) and light extinction (Kd). However, the increased TSS (and associated decrease in available light) occurred shortly after the passing of a tropical storm. The remaining data for chlorophyll *a*, DIN, and DIP were well within the established acceptable ranges. The measurements of the five water quality parameters, salinity, temperature, and dissolved oxygen were relatively uniform across the site (Merrell et al., 1997).

SAV biomass data from the six locations indicated production varied across the site, ranging from 0-50 g/m2. Because water quality parameters were highly similar at the six sampling sites, no relationship was found between SAV biomass production and variation in water quality conditions (Merrell et al., 1997). Also of interest was the finding that the greatest SAV production occurred adjacent to the mainland. This is in opposition to the prevailing view that SAV production in coastal estuaries is highest adjacent to the barrier islands. Porewater sulfide data indicated that sulfide content was at toxic levels at one of the sites (Dv) where there was no SAV production. All other sites had similar relatively low porewater sulfides. Porewater ammonium data (figure 6-2) indicated that while five of the sites had similar levels, the site with the highest SAV biomass production (Sv2) had ammonium levels nearly ten times greater. Thus, the interpretation of standard data associated with SAV research could explain the variation in SAV production at only two of the six sites.

Figure 6-2. Porewater ammonium levels in the rooting zone and SAV production at the six SAV biomass sampling sites.



The lack of vegetation at site Dv was likely a result of the toxic effects of high porewater sulfides and the extremely high production at site Sv2 could be linked to the substantial quantity of ammonium available to the roots.

To help further understand why SAV production varied in Sinepuxent Bay, data from subaqueous soil analyses were evaluated from all of the biomass sites. Table 6-1 shows the subaqueous soil mapping unit and significant subaqueous soil attributes at each of the six SAV biomass sites. The highest SAV production occurred on Newport loamy sand, 0.2-1.0 m water depth. The Newport soil at this site (Sv2) exhibited high chroma matrix colors in the substrata horizons. It also had the highest total nitrogen content in the subsoil (figure 6-3) of the 4 vegetated sites. A potential explanation for the increased N and high chroma colors in the substrata horizons is the possibility that groundwater from the mainland may be intruding into the site at depths shallow enough for contact with SAV roots.

No SAV production occurred at site Dv which was located on South Point silt loam, 1.5-2.5 m water depth. Organic carbon levels in the surface horizon of this map unit were the highest recorded for the site (figure 6-4). The high porewater sulfides are related to the microbial breakdown of organic matter in the soil surface (Merrell et al., 1997). So, although sulfides are the toxic component at this site, the high subaqueous soil organic carbon content is their probable source. Figure 6-5 shows a general trend of decreasing SAV production with increasing organic carbon content.

In addition to site Dv, no SAV production was recorded for site Su located on Fenwick sand, 0.2-1.0 m water depth. The Fenwick soil at this site is dominantly composed of sandy barrier island overwash materials. These materials are known to be

Table 6-1. SAV biomass production, subaqueous soil map unit, and selected subaqueous soil characteristics for each of the six SAV sampling sites.

SAV Site	Biomass (g/m^2)	Subaqueous Soil Mapping Unit	Selected Subaqueous Soil Attributes
Sv1	20	Wallops loamy sand, 1.0-1.5 m depth	Moderate fertility, intermediate levels of sulfides, organic carbon
Sv2	50	Newport loamy sand, 0.2-1.0 m depth	High fertility, low organic carbon, possible groundwater intrusion
Sv3	14	Wallops sandy loam, 1.0-1.5 m depth	Moderate fertility, intermediate levels of sulfides, organic carbon
Sv4	19	Wallops loamy sand, 1.0-1.5 m depth	Moderate fertility, intermediate levels of sulfides, organic carbon
Su	0	Fenwick sand, 0.2- 0.5 m depth	Dense sands, low fertility
Dv	0	South Point silt loam, 1.5-2.5 m depth	High organic carbon, high sulfides, high n-value

Figure 6-3. Total N content in the upper 50 cm of the subaqueous soils at the six SAV biomass sampling sites.

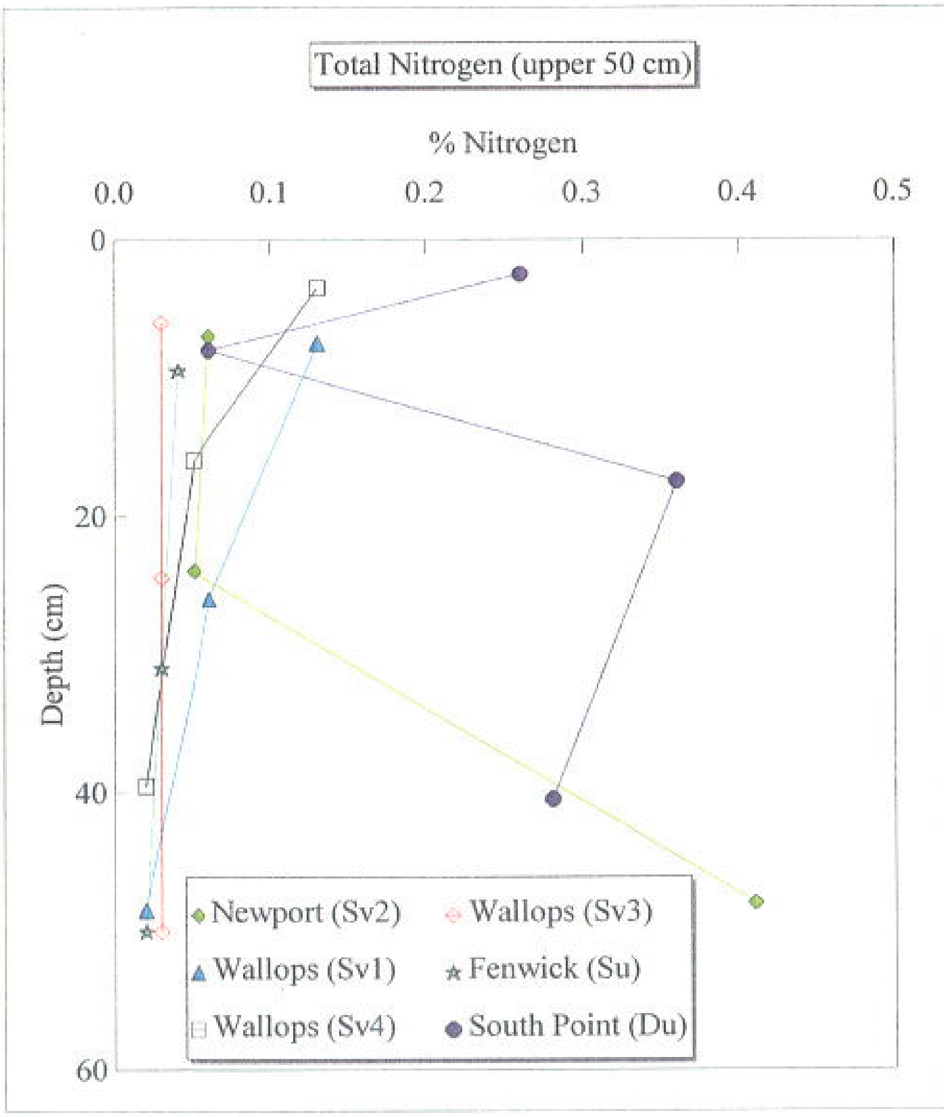


Figure 6-4. Organic carbon content in the upper 50 cm of the subaqueous soils at each of the six SAV biomass sampling sites.

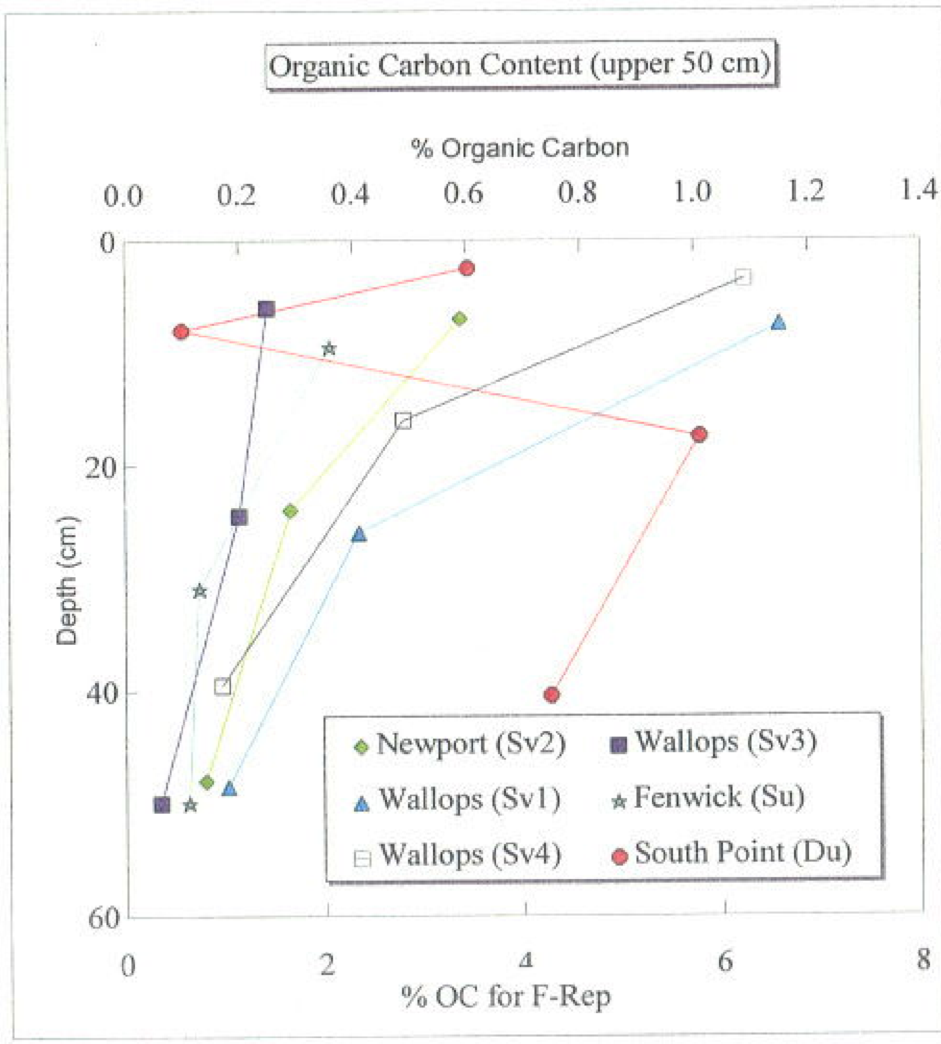
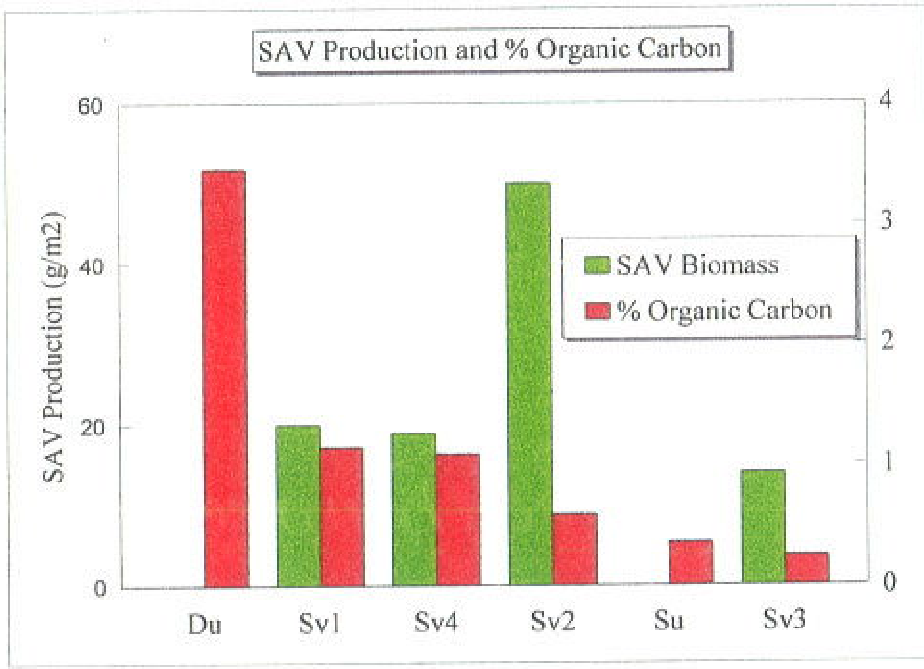


Figure 6-5. Subaqueous soil organic carbon content and SAV biomass production.



mainly quartz, and therefore inherently infertile. Subaqueous soil analytical data indicated that this site was low in both macro- and micro-nutrients. In addition, morphological descriptions indicated a firm (and sometimes very firm) consistence, inferring that these materials were much denser than other soils in Sinepuxent Bay. The low soil fertility and difficulty in roots penetrating the dense sands may be the reason that SAV do not occur on this mapping unit (Merrell et al., 1997). This finding opposes the generally accepted view that SAV production is high adjacent to barrier islands.

At the three remaining sites (Sv1, Sv3, and Sv4), SAV production was not significantly different, ranging from 14-20 g/m2. These three sites were located on two different map unit phases of the Wallops soil. The subaqueous soils at these sites exhibited intermediate levels of organic carbon compared to other soils within Sinepuxent Bay. Although SAV production in areas of the Wallops soil appeared to be significantly different than that found on the Fenwick, Newport, and South Point soils, it is difficult to determine from the limited data set if subaqueous soil characteristics were responsible for the variation.

CONCLUSIONS

The results of this study indicate that the determination in previous studies that water quality dramatically effects SAV growth and survival was a major, but incomplete, accomplishment. Controlled studies indicating that substrate characteristics could effect SAV were not included in the minimum habitat requirements put forth by the Chesapeake Bay Program (Chesapeake Bay Program, 1992). In addition, relationships between SAV and substrate characteristics were difficult to determine given the concepts, methods, and approach taken in the acquisition, interpretation, and cartographic presentation of sediment data.

Through the application of a pedological approach to the analysis and mapping of subaqueous soils, SAV production and distribution could be related to subaqueous soil attributes and distribution. The interdisciplinary approach to evaluating SAV-subaqueous soil relationships applied in this study shows that SAV production and distribution is not related exclusively to water quality. The results suggest that subaqueous soil characteristics such as organic carbon content, fertility, geomorphic setting, and bulk density may need to be considered along with existing SAV habitat requirements, but precise limits have not yet been determined. The results also suggest that the development of subaqueous soil resource inventories for shallow water estuarine ecosystems is cricial to our understanding of the relationships between benthic flora and fauna and the subaqueous soils on which they depend.

CHAPTER VII

CONCLUSIONS

This study demonstrated that available technology could be utilized to efficiently produce bathymetric maps with sufficient detail to perform terrain analysis such as that performed in terrestrial situations. The development of a bathymetric map is analogous to the development of contour maps from digital elevation data. The terrain analysis results showed that landforms could be identified in a subaqueous environment.

The examination of morphological and analytical data indicated that pedogenic processes are active in shallow water sediments, and therefore they would be better viewed as subaqueous soils. Evidence was presented which illustrated Simonson's (1959) pedogenic processes of additions, losses, transfers, and transformations occur in subaqueous soils.

Landscape and landform analyses demonstrated that soil properties systematically vary across the subaqueous landscape. Subaqueous soil characteristics were also shown to be in part a function of the state factors of soil formation (Jenny, 1941; Jenny, 1980). These relationships provided the basis from which a subaqueous soil-landscape model could be developed. The soil survey presented in this study was an example of a way that the soil-landscape paradigm (Hudson, 1992) could be applied in a subaqueous environment.

The evaluation of water column attributes, nutrient data, and submersed aquatic vegetation (SAV) biomass data indicated that subaqueous soil properties affected the growth and vitality of SAV more than water quality in Sinepuxent Bay. Organic carbon, soil density, fertility level, and sulfide content may be controlling factors in SAV production and should be considered for inclusion in the SAV Habitat Requirements (Chesapeake Bay Program, 1992).

While the results of this study illustrate that it is possible to utilize a pedological approach and mapping protocol in subaqueous environments, it also points to many unanswered questions. Soil fertility experts could begin to examine the relationship between subaqueous soil fertility and SAV growth and distribution. Soil physicists might further examine subaqueous soil stability, density, and diffusion processes. Soil mineralogists might examine in more detail the transformations and mineral suites that occur in subaqueous soils. Soil chemists could provide more data on the types of substances produced through bio-transformation, pedogenic, and diagenic processes. The possibilities for future research are numerous.

This study also suggests that other disciplines may benefit from understanding the role subaqueous soils play in estuarine environments. Benthic ecologists might consider relating benthic organism populations to subaqueous soil distribution to help further understand and enhance the contributions of Sanders (1958) and Rhoads (1974). Estuarine botanists might be able to more fully understand the factors controlling the distribution and vitality of SAV through examining their relationship to subaqueous soil properties and subaqueous soil distribution. The subaqueous soils data in this study could be utilized in SAV replanting efforts underway in the Maryland Coastal Bays, Delaware Inland Bays, and Chesapeake Bay. Estuarine biologists might be able to utilize subaqueous soil resource inventories to identify potential and existing clam, crab and oyster habitat areas; and the possible identification of present or potential pfiesteria cyst residence sites. Possible applications of subaqueous soil surveys by environmental specialists might include the identification of areas with potential dredge disposal problems due to acid-sulfate weathering, the identification and protection of potential SAV habitat, and the identification of areas for the creation of estuarine habitats such as coastal bird nesting islands or restocking of clam, oyster or SAV beds.

The development of subaqueous soil resource inventories could be significant to many environmental and ecological applications. The interdisciplinary nature of this study demonstrates that pedologists, in tandem with estuarine ecologists and coastal geomorphologists, could make a significant contribution in understanding and solving the problems associated with estuarine degradation. If we are to enhance and restore our estuaries, especially in relation to SAV growth and survival, the widespread development of subaqueous soil surveys should be seriously considered for incorporation into estuarine restoration and resource inventory programs.

CHAPTER VIII

EPILOGUE

The results of this study impacts the most fundamental aspect of pedology - the concept of soil. Although subaqueous soils support rooted, submersed aquatic vegetation, this in and of itself may not be sufficient to warrant their inclusion in the concept of soil. The growth of lichen, algae and other plants on the surface (or in cracks) of rocks does not mean rocks are soil. While the ability to support higher plants is a critical *function* of soil, especially in terms of mankind's reliance on soil for crop production, to define soil based solely on the concept of soil as a medium for plant growth would be so broad that everything from living animals to the open water of the earth's oceans would be included. A more fundamental aspect of how soil is defined is the pedological concept of soil as a natural body composed of mineral and organic material that changes in response to climate and organisms. These changes are referred to as soil genesis.

The process of soil change, or pedogenesis, is the foundation upon which the discipline of pedology rests. By relying on a more quantitative definition of soil, soil science limits itself almost exclusively to the study of pedogenically altered materials. If altered by soil genetic processes, a material can be considered soil even if it can not support higher plants. Although some pedologists have proposed taxonomic systems which have included subaqueous soils that support higher plants, the historical view that permanently submersed materials are non-soil has held sway for over 100 years.

The evidence presented in this study, that pedogenic processes alter shallow water sediments, establishes them as subaqueous soils. The official revision of the pedological definition of soil in *Soil Taxonomy* to include subaqueous soils could have philosophical implications that will ultimately strengthen the concept of soil. To define soils exclusively as pedogenically altered material is unsatisfactory in the sense that it does not recognize the critical role of soils in both agrarian and non-agrarian ecosystems. To define soil exclusively as a medium for plant growth is even more unsatisfactory. The inclusion of subaqueous soils recognizes, accepts, and strengthens the dual nature of the pedological definition of soil. Thus, if the material in question can support higher plants *and* has been pedogenically altered, there is no doubt that the material is soil.

In addition, the results reaffirm the conceptual accuracy of the soil-landscape paradigm (Hudson, 1992). The systematic variation of soil properties across the landscape is integral to pedologists' ability to map soils. It is a critical component of terrestrial soil survey projects and is even more so in a subaqueous environment, where remote sensing "removes" the veil of water to reveal the subaqueous landscape. Thus, regardless of the name one wishes to apply to subaqueous materials, the applicability of the soil-landscape paradigm provided the basis from which a mapping protocol was developed for the inventory of subaqueous resources. The development of a rudimentary subaqueous soil-landscape model could help efforts to restore degraded estuaries and protect environmentally sensitive areas. If we continue to work in tandem with other disciplines we will ensure that the hopes we have in our hearts will someday come true and the tide will indeed rise again!

Appendix

Morphological descriptions of subaqueous
soil profiles examined in
Sinepuxent Bay, Maryland

Abbreviations Used in Soil Morphological Descriptions

Horizon Nomenclature:

Based on accepted master horizon and suffix notations in the *Soil Survey Manual* (Soil Survey Division Staff,1993b) and *Keys to Soil Taxonomy* (Soil Survey Staff, 1996).

USDA Textural Class: From the *Soil Survey Manual* (Soil Survey Division Staff, 1993b)

S (sand), cS (coarse sand), fS (fine sand), LS (loamy sand), LfS (loamy fine sand), SL (sandy loam), fSL (fine sandy loam), vfSL (very fine sandy loam), SCL (sandy clay loam), L (loam), SiL (silt loam), SiCL (silty clay loam), CL (clay loam), MkSiL (mucky silt loam), Mk (muck), Mpt (mucky peat).

Redoximorphic Features (Conc.): From the *Soil Survey Manual* (Soil Survey Division Staff, 1993b)

f1f (few, fine, faint), f1d (few, fine, distinct), f2d (few, medium, distinct), f2p (few, medium, prominent), f3d (few, coarse, distinct), f3p (few, coarse, prominent), c1f (common, fine, faint), c1d (common, fine, distinct), c2f (common, medium, faint), c2d (common, medium, distinct), c3d (common, coarse, distinct).

Structure: From the *Soil Survey Manual* (Soil Survey Division Staff, 1993b)

sg (single grain), m (massive), 1msbk (weak, medium, subangular blocky).

Consistence: From the *Soil Survey Manual* (Soil Survey Division Staff, 1993b)

l (loose), vfr (very friable), fr (friable), fi (firm)

n-Value: From the *Soil Survey Manual* (Soil Survey Division Staff, 1993b)

Values based on "squeeze test": 0.8 (material flows with difficulty between fingers when squeezed), 0.9 (material flows with some difficulty between fingers when squeezed), 1.0 (material flows easily between fingers when squeezed).

Roots: From the *Soil Survey Manual* (Soil Survey Division Staff, 1993b)

1vf (few very fine), 2vf (common very fine), 3vf (many very fine), 1f (few fine), 2f (common fine), 3f (many fine)

Boundary: From the *Soil Survey Manual* (Soil Survey Division Staff, 1993b)

a (abrupt), c (clear), g (gradual)

PROFILE A-1 38° 14' 26.50" N, 75° 8' 57.11" W
coarse-loamy, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
A	0-4	S	10YR 3/3					3	sg	vfr		1f-1vf	c
2Cg1	4-15	L	N 2/			5	7.5YR 3/3	2	m	fr	0.9		a
3Cg2	15-40	S	N 3/	5Y 4/1	f2f			1	sg	vfr			g
4Cg3	40-48	SL	5Y 2.5/1					1	m	fr	0.9		c
4Cg4	48-72	LS	5Y 3/1	5Y 4/2	f3d			1	m	vfr			a
5Cg5	72-82	cS	5Y 5/1			2	10YR 2/1	20	sg	l			g
5Cg6	82-100	cS	5Y 4/1	N 3/	f3d				sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/20/96

15% cover widgeon grass (*Ruppia maritima*)
Numerous tubeworm burrows (casts) at 15 cm
Periwinkle shell at 75 cm

PROFILE A-3 38° 14' 5.17" N, 75° 9' 24.05" W
sandy, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
A	0-2	LS	10YR 3/3						m	vfr	0.7	2f-2vf	a
2Cg1	2-15	SL	5Y 2.5/1	5Y 4/1	f2d			3	m	fr	0.8-0.9	1f-2vf	g
3Cg2	15-30	LS	2.5Y 2/1	5Y 4/1	c2d			1	m	vfr	0.7	1vf	c
3Cg3	30-55	S	5Y 3/1	2.5Y 2/1	f1f				sg	l			a
3Cg4	55-90	S	5GY 5/1						sg	l			c
4Cg5	90-102	fS	5Y 5/1						sg	vfr			c
5Cg6	102-125	S	5Y 3/1	N 3/	f1f	2	7.5YR 3/2	3	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/20/96

80% cover widgeon grass (*Ruppia maritima*) and eelgrass (*Zostera marina*), mixed bed
Polychaetes numerous in 3Cg3 horizon
Few pockets of N 2/ loam in 4Cg4 horizon

PROFILE A-4 38° 13' 57.46" N, 75° 9' 32.01" W

coarse-loamy, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-2	LS	5Y 3/2						m	vfr	0.7	3f-2vf	a
2Cg1	2-28	L	5Y 2.5/1	5Y 4/1	f2d				m	fr	0.8-0.9	2vf	c
3Cg2	28-48	S	5Y 3/2	5Y 5/1	c2d	3	10YR 3/2	10	sg	l			a
4Cg3	48-68	fS	5Y 4/1	N 3/	f2d			2	m	vfr			a
4Cg4	68-78	fSL	5GY 3/1						m	fr	1.0		a
5Cg5	78-88	S	5Y 3/1	N 3/	f2d			5	sg	l			a
6Cg6	88-95	L	5Y 3/2	5Y 4/1	f1f	2	7.5YR 2/2	4	m	fr	0.7-0.8		c
6Cg7	95-112	L	5GY 3/1			2	10YR 2/2		m	fr	1.0		g
6Cg8	112-132	L	N 3/	5GY 3/1	c1f			2	m	fr	1.0		a
7Cg9	132-140	S	5Y 5/1					1	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/20/96

85% cover eelgrass (*Zostera marina*)
Few pockets clay loam in 6Cg6 horizon, possible old surface
Few thin (1-2 cm) bands N 2/ silt loam in 4Cg3 horizon

PROFILE A-5 38° 14' 13.14" N, 75° 9' 27.51" W

coarse-loamy, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Conc.	Organic Fragments (%)	Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-8	S	5Y 3/2					5	sg	vfr		1f-1vf	c
2Cg1	8-47	SL	5GY 3/1	5Y 4/1	f1f			1	m	fr	0.7-0.8	1vf	c
3Cg2	47-95	S	5Y 3/1	5Y 5/1	f2d			10	sg	l			g
4Cg3	95-130	vfSL	N 3/			3	10YR 3/2	2	m	fr	0.7-0.8		

REMARKS: Profile description by G. Demas and S. Demas, 7/30/92

55% cover eelgrass (*Zostera marina*)
Possible old surface at 95 cm
Few pockets N 2/ silt loam in 3Cg2 horizon

PROFILE A-6 38° 14' 13.14" N, 75° 9' 27.51" W
Sample S93MD047-058
coarse-loamy, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-15	LS	N 3/						m	vfr		2f-2vf	c
Cg1	15-25	LS	N 4/	5Y 4/1	f1f			2	m	vfr			c
2Cg2	25-43	L	5GY 4/1	5Y 5/1	f1f				m	fr	1.0		a
3Cg3	43-91	S	5Y 4/1						sg	l			g
4Cg4	91-103	LfS	N 4/						m	vfr			c
4Cg5	103-135	LfS	5Y 4/1					30	m	vfr			

REMARKS: Profile description by G. Demas, M. Rabenhorst, and J. Burns, 7/22/93

90% cover widgeon grass (*Ruppia maritima*) and rooted algae
Few clams present near surface

PROFILE A-7 38° 13' 36.04" N, 75° 9' 55.07" W

sandy, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-3	SL	10Y 4/1						m	vfr	0.9	3f-3vf	a
2Cg1	3-18	L	N 2.5/	10Y 4/1	f2d			15	m	fr	0.9	2f-1vf	c
3Cg2	18-34	LS	10Y 3/1			3	5YR 3/2	20	m	vfr		1vf	c
3Cg3	34-60	S	N 4/			3	5YR 3/2	30	sg	l			c
3Cg4	60-70	S	N 4/	5Y 3/2	f1d	10	5Y 3/2	25	sg	l			c
4Cg5	70-150	S	10Y 4/1						sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 6/16/97

50% cover eelgrass (*Zostera marina*)
Filamentous algae covering SAV shoots
Periwinkle shell at 70 cm

PROFILE A-8 38° 13' 42.41" N, 75° 9' 47.64" W
sandy, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-10	SiL	10Y 3/1						m	vfr	1.0	1f-1vf	a
2Cg1	10-25	SL	10GY 3/1	N 2/	f2d	2	10YR 3/2		m	fr	0.8		g
3Cg2	25-65	S	10GY 3/1					15	sg	l			g
3Cg3	65-95	S	5Y 5/1	N 2/	f2d			5	sg	l			c
3Cg4	95-107	LS	10Y 4/1					3	m	vfr			a
4Cg5	107-130	L	5GY 4/1					3	m	fr	1.0		c
5Cg6	130-170	LS	5GY 4/1			1	2.5Y 3/3	2	m	vfr			c
5Cg7	170-200	S	10Y 5/1	N 2/	f1d			5	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 6/16/97

80% cover widgeon grass (*Ruppia maritima*) and eelgrass (*Zostera marina*), mixed bed
Numerous tubeworm burrows (casts) in 2Cg1 horizon
Periwinkle shell at 55 cm

PROFILE A-9 38° 13' 48.12" N, 75° 9' 42.22" W

sandy, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-3	SiL	10Y 2.5/1						m	fr	1.0	3f-3vf	a
Cg1	3-22	SiL	N 3/			2	2.5Y 3/2		m	fr	1.0	2f-2vf	c
2Cg2	22-35	LS	10GY 3/1						m	vfr		1f	c
2Cg3	35-97	S	10GY4/1					2	sg	l			g
2Cg4	97-150	S	5GY 4/1					2	m	vfr			

REMARKS: Profile description by G. Demas and K. Merrell, 6/16/97

85% cover widgeon grass (*Ruppia maritima*)

PROFILE A-Rep 38° 14' 15.82" N, 75° 9' 12.53" W
Sample S97MD047-002
sandy, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-3	S	5Y 2.5/1						sg	vfr		2f-1vf	a
Cg1	3-27	S	5Y 3/1						sg	vfr		1vf	c
2Cg2	27-46	LS	10Y 4/1	N 3/	bands	4	2.5Y 3/3		m	fr	0.8-0.9		a
3Cg3	46-53	S	N 5/						sg	vfr			a
4Cg4	53-81	fS	5Y 5/1	N 2/	f1f				m	fr			c
4Cg5	81-126	fS	5Y 4/1						m	fr			c
5Cg6	126-150	S	N 5/	5Y 3/1	f1d				sg	l			a
6Cg7	150-157	fS	5Y 4/1						m	vfr			

REMARKS: Profile description by G. Demas at time of core extrusion, March 1997

50% cover eelgrass (*Zostera marina*)
Few thin (1-2 cm) bands of N 3/ silt loam in 2Cg2 horizon
Surface littered with shells

PROFILE B-1 38° 12' 34.95" N, 75° 10' 11.54" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
A	0-3	S	10YR 3/3						sg	fi			a
Cg1	3-25	S	N 2/	5Y 5/2	f2d				sg	fi			g
Cg2	25-47	S	5GY 3/1					2	sg	fi			g
Cg3	47-58	S	5Y 3/1						sg	fr			g
Cg4	58-95	S	5GY 3/1					1	sg	fr			g
Cg5	95-105	S	5Y 3/1			10	7.5YR 3/2	20	sg	fi			

REMARKS: Profile description by G. Demas and K. Merrell, 8/20/96

3% cover widgeon grass (*Ruppia maritima*)
Few pockets N 3/ loam (n-value 1.0) in Cg3 horizon
Auger refusal, dense sands

PROFILE B-2 38° 12' 37.33" N, 75° 10' 9.03" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
A	0-2	fS	5Y 4/3					30	sg	fi			a
2Cg1	2-6	S	N 2/	2.5Y 3/3	f1p			8	sg	fi			c
2Cg2	6-33	S	5Y 4/1					2	sg	fi			c
3Cg3	33-60	fS	5Y 5/1	N 3/	c1d			3	m	fi			

REMARKS: Profile description by G. Demas and K. Merrell, 8/20/96

0 % vegetative cover
Auger refusal, dense sands

PROFILE B-3 38° 12' 39.76" N, 75° 10' 6.71" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
A	0-2	fS	5Y 4/3						sg	fi			a
2Cg1	2-22	S	5Y 3/1	2.5Y 4/2	f1p			2	sg	fi			g
2Cg2	22-75	S	5Y 3/1	5Y 5/1	f2p				sg	fi			c
2Cg3	75-92	S	5Y 5/1	5Y 2/2	c2d				sg	fi			a
2Cg4	92-100	S	N 3/	5Y 3/1	f3p	3	10YR 3/2	3	m	fr			

REMARKS: Profile description by G. Demas and K. Merrell, 8/20/96

1% cover widgeon grass (*Ruppia maritima*)
Periwinkle shell at 18 cm
Few pockets 5Y 2/2 silt loam (n-value 1.0) in Cg2 horizon
Possible buried surface at 92 cm

PROFILE B-4 38° 12' 26.52" N, 75° 10' 19.07" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-2	S	5Y 2.5/2						sg	fr		2f-3vf	a
Cg1	2-43	S	5Y 4/1	N 2/	c2d			1	sg	fr		1vf	g
Cg2	43-102	S	N 4/			2	7.5YR 3/3	1	sg	fr			g
2Cg3	102-120	fS	5GY 4/1			5	10YR 4/6		m	fr			g
3Cg4	120-135	S	5Y 4/1	5GY 3/1	c2f			10	sg	fi			

REMARKS: Profile description by G. Demas and K. Merrell, 8/20/96

100% cover unidentified algae
Auger refusal, dense sands

PROFILE B-5 38° 12' 40.08" N, 75° 9' 58.45" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-8	S	5Y 3/1						sg	fr		2f-3vf	a
Cg1	8-25	S	N 2/						sg	fi		1vf	a
Cg3	25-73	LS	5Y 3/1	N 5/	f1d				m	fi			c
Cg4	73-100	S	10Y 4/1			2	10YR 3/2	2	m	fi			

REMARKS: Profile description by G. Demas and K. Merrell, 9/9/96

Many garnet grains in Cg3 horizon
Auger refusal, dense sands

PROFILE B-Rep 38° 12' 25.19" N, 75° 8' 57.18" W
Sample S97MD047-004
Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-19	fS	N 3/					1	sg	vfr			c
Cg1	19-43	fS	10Y 3/1	N 4/	f1d				sg	fr			c
2Cg2	43-71	S	5Y 5/1						sg	fi			c
2Cg3	71-115	S	N 6/					15	sg	fi			a
3Agb	115-152	LfS	5Y 4/1			15	7.5YR 3/3	5	m	fi			

REMARKS: Profile description by G. Demas at time of core extrusion, March 1997

1% cover eelgrass (*Zostera marina*)

PROFILE C-1 38° 14' 25.13" N, 75° 8' 53.51"

sandy, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-2	S	5GY 5/1						sg	l		1f-1vf	a
Cg1	2-9	SL	N 2/			2	2.5Y 2/2	1	m	fr	0.8		g
Cg2	9-50	LS	5Y 4/1	N 2/	f2d			10	m	fr			a
Cg3	50-74	S	5Y 5/1	N 3/	f3d			5	sg	l			a
2Cg4	74-100	cS	5GY 6/1	N 3/	f3d			5	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/21/96

50% cover algae (dominant) and some eelgrass (*Zostera marina*)
Possible A-C landscape transitional area
Periwinkle shell at 100 cm
Common green medium sand grains in Cg3 horizon
Near Sv3 biomass site

PROFILE C-2 38° 14' 18.05" N, 75° 8' 59.44" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-4	S	2.5Y 4/2					10	sg	1			a
Cg1	4-18	S	N 2/	2.5Y 3/2	f1p			5	sg	1			g
Cg2	18-50	S	5Y 2.5/2	5Y 3/2	f1f			4	sg	1			a
Cg3	50-68	S	5Y 5/1	N 4/	f3d	10	10YR 2/1	3	sg	1			c
Cg4	68-80	S	N 6/	N 3/	f3p			2	sg	1			

REMARKS: Profile description by G. Demas and K. Merrell, 8/21/96

1% cover eelgrass (*Zostera marina*)
Numerous tubeworm colonies, sea anenomies, and juvenile crabs at surface
Finely ground shells in Ag horizon

PROFILE C-3 38° 14' 5.43" N, 75° 9' 10.45" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
A	0-3	S	2.5Y 3/3					2	sg	l			a
Cg1	3-45	S	2.5Y 3/1	5Y 4/1	f2f			2	sg	l			a
Cg2	45-58	S	5Y 5/1	N 3/	c3p				sg	l			c
Cg3	58-65	LS	5Y 5/1	N 3/	c3p				m	vfr			c
2Cg4	65-100	cS	5GY 3/1	2.5Y 3/2	f2d			5	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/21/96

0% vegetative cover

Many fine garnet grains and finely ground shells in 2Cg4 horizon

PROFILE C-4 38° 14' 5.46" N, 75° 9' 18.14" W

coarse-loamy, Sulfic Fluvaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Conc.	Organic Fragments (%)	Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-4	LS	2.5Y 4/2	10YR 5/6	f1p			5	sg	l		1vf	a
Cg1	4-28	S	N 2/	2.5Y 5/3	f2p	1	10YR 2/1		sg	l			a
Cg2	28-52	S	5Y 4/1	N 3/	f2p			5	sg	l			g
Cg3	52-85	LS	5Y 4/1					1	m	vfr			c
2Cg4	85-110	SL	5Y 4/1	2.5Y 5/1	f2f	1	7.5YR 3/2	2	m	fr	0.8		a
3Ab	110-130	L	5GY 4/1			5	7.5YR 3/2	10	m	fr	1.0		

REMARKS: Profile description by G. Demas and K. Merrell, 8/20/96

10% cover eelgrass (*Zostera marina*) dominant, widgeon grass (*Ruppia maritima*), and algae; clumpy mixed bed
Polychaetes present in Cg1 horizon
Periwinkle shell at 110 cm

PROFILE C-5 38° 14' 13.14" N, 75° 8' 51.52" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Conc.	Organic Fragments (%)	Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-8	LS	N 3/						m	vfr		2f-3vf	a
Cg1	8-36	S	5GY 4/1	N 5/	f2d	2	7.5YR 3/2	1	sg	1		1vf	g
Cg2	36-68	S	5G 5/1	N 2/	f1p			15	sg	1			a
2Cg3	68-110	cS	N 5/	5GY 3/1	c2d			20	sg	1			

REMARKS: Profile description by G. Demas and K. Merrell, 9/13/96

70% cover eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*), some algae, mixed bed
Orange sponges, isopods, razor clam present at surface
Few pockets N 3/ sandy loam Cg2 horizon
5% gravel in 2Cg3 horizon
Oyster shell at 55 cm

PROFILE C-7 38° 14' 5.34" N, 75° 9' 10.77" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-3	S	2.5Y 5/2						sg	l			a
Cg1	3-23	S	N 3/					2	sg	l			c
Cg2	23-85	S	N 4/					8	sg	l			g
Cg3	85-110	S	10Y 5/1	N 3/	c2d			2	sg	fi			

REMARKS: Profile description by G. Demas and K. Merrell, 6/18/97

0% vegetative cover
Common pockets N 3/ sandy loam at 105-110 cm
Auger refusal, dense sands

PROFILE C-Rep 38° 14' 18.61" N, 75° 8' 57.18" W
Sample S97MD047-009
sandy, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-7	SL	5Y 3/1						m	vfr	0.9	2f-2vf	a
ACg	7-25	S	5Y 3/2	N 2/	f2d			1	sg	l			c
Cg1	25-54	S	N 4/						sg	l			g
Cg2	54-91	S	10Y 5/1					4	sg	fi			

REMARKS: Profile description by G. Demas at time of core extrusion, March 1997

50 % cover eelgrass (*Zostera marina*)
Vibracore refusal, dense sands

PROFILE D-1 38° 14' 25.06" N, 75° 9' 40.69" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-8	L	2.5Y 4/2	N 2/	c3d				m	fr	0.9	2f-2vf	a
Cg	8-22	S	2.5Y 3/2	N 3/	f2d			5	sg	l		1vf	a
2C1	22-78	S	2.5Y 3/3	N 3/	f1p				sg	l			g
2C2	78-110	S	5Y 4/4	10YR 4/1	c2d				sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/21/96

65% cover eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*), mixed bed
Clams present near surface
Polychaetes present in Cg horizon
Few pockets N 3/ sandy loam in Cg horizon
Possible groundwater intrusion at 78 cm

PROFILE D-2 38° 14' 22.58" N, 75° 9' 44.96" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-10	SL	2.5Y 4/2						m	vfr	0.9	2f-2vf	a
Cg1	10-24	LS	5Y 3/2	2.5Y 4/2	f2d				m	vfr	0.8	1vf	c
Cg2	24-55	S	5Y 4/2	N 3/	c2d	1	7.5YR 3/2	5	sg	l		1vf	a
C3	55-70	LS	5Y 5/3	N 3/	f1p			2	m	vfr			g
C4	70-78	LS	5Y 5/3	N 3/	f1p			2	m	vfr			g
C5	78-100	cS	2.5Y 5/6	2.5Y 4/2	f2f				sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/21/96

90% cover widgeon grass (*Ruppia maritima*) and eelgrass (*Zostera marina*), mixed bed
Clams present near surface
Polychaetes present in Ag and C3 horizons
Few pockets N 2/ sandy loam in Cg1 horizon
Possible groundwater intrusion at 78 cm

PROFILE D-3 38° 14' 17.48" N, 75° 9' 48.08" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-4	L	2.5Y 4/2	N 2/	c2d				m	fr	0.9	2f-3vf	a
Cg1	4-18	SL	5Y 3/1	5Y 4/1	f1f				m	fr	0.8	1f-2vf	c
Cg2	18-38	S	5Y 4/2	N 4/	f1d	2	7.5YR 3/3	20	sg	l		1vf	c
C3	38-88	S	2.5Y 5/3			1	7.5YR 3/2		sg	l			a
2C4	88-115	cS	5Y 5/4	2.5Y 3/1	f2p				sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/21/96

50% cover eelgrass (*Zostera marina*)
Clams present near surface
Possible groundwater intrusion at 88 cm
1% gravel in 2C4 horizon

PROFILE D-4 38° 14' 21.70" N, 75° 9' 45.48" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-18	LS	5Y 2/1						m	vfr		2f-1vf	c
Cg1	18-38	S	5Y 4/2	2.5Y 5/6	f1p			5	sg	l			c
C2	38-53	S	2.5Y 4/3	10YR 2/1	f3f				sg	l			c
C3	53-100	S	10YR 5/6	2.5Y 4/2	f2d				sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/12/96

100% cover widgeon grass (*Ruppia maritima*)
Near Sv2 biomass site
Possible groundwater intrusion at 53 cm

PROFILE D-5 38° 14' 28.37" N, 75° 9' 33.73" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-6	LS	5Y 4/2						m	vfr		1f-1vf	c
Cg1	6-38	S	N 2/	5Y 3/2	c2d				sg	l		1vf	c
Cg2	38-67	S	N 3/					3	sg	l			a
Cg3	67-88	LS	5Y 4/1			2	7.5YR 3/2	40	m	vfr			c
2Cg4	88-115	cS	5Y 4/1	N 2/	f1p			2	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 9/9/96

20% cover eelgrass (*Zostera marina*)

PROFILE D-6 38° 14' 20.26" N, 75° 9' 41.61" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-3	LS	5Y 3/2					1	m	vfr		3f-1vf	a
Cg1	3-20	S	N 2.5/	5Y 3/2		4	7.5YR 3/2	5	m	l		2f-1vf	c
Cg2	20-85	LS	10Y 3/2						m	vfr		1vf	a
C3	85-130	S	2.5Y 3/3					2	m	l			

REMARKS: Profile description by G. Demas and K. Merrell, 6/17/97

1% cover eelgrass (*Zostera marina*)
Periwinkle shell at 73 cm
Few pockets N 2/ sandy loam in Cg1 horizon
Possible groundwater intrusion at 85 cm

PROFILE D-7 38° 14' 17.87" N, 75° 9' 44.79" W

coarse-loamy, Typic Endoaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-3	LS	5Y 4/2						m	vfr		3f-3vf	a
Cg1	3-48	SL	10Y 2.5/1	N 2.5/	c2d				m	fr	0.9	2vf	g
Cg2	48-82	LS	10Y 3/1						m	vfr			g
Cg3	82-108	LS	5GY 5/1	N 2/	c1d	4	7.5YR 3/2		m	vfr			a
C4	108-150	S	2.5Y 5/3	10Y 4/1	c3p			15	m	l			

REMARKS: Profile description by G. Demas and K. Merrell, 6/17/97

40% cover eelgrass (*Zostera marina*)
Periwinkle shell at 85 cm
Few pockets 5GY 3/1 sandy loam in Cg3 horizon
Possible groundwater intrusion at 108 cm

PROFILE D-Rep 38° 14' 22.05" N, 75° 9' 46.16"
Sample S97MD047-003
Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-14	LS	N 3/						m	vfr		2f-2vf	a
Cg1	14-34	S	10Y 4/1	N 2/	c2d			3	sg	l		1f-1vf	g
Cg2	34-95	S	2.5Y 5/2						sg	l			c
C3	95-115	S	2.5Y 4/3						sg	l			c
2C4	115-135	fS	2.5Y 5/3						m	vfr			c
2C5	135-142	fS	2.5Y 5/3	2.5Y 6/2	f2d				m	vfr			

REMARKS: Profile description by G. Demas at time of core extrusion, March 1997

80% cover eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*), mixed bed
Clams present near surface
Tubeworm burrows (casts) present in Ag horizon
Possible groundwater intrusion at 95 cm

PROFILE E-1 38° 13' 56.06" N, 75° 10' 30.69"

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
A	0-4	L	2.5Y 3/3						m	fr	0.9	2f-2vf	a
Cg1	4-18	LS	N 2/	2.5Y 3/1	c1d			1	m	vfr		1vf	c
C2	18-32	S	5Y 3/3	5Y 5/1	f2d				sg	l			g
C3	32-60	S	5Y 3/3	2.5Y 5/6	f1p	3	10YR 2/1		sg	l			c
Cg4	60-72	S	N 4/	2.5Y 4/3	f2d				sg	l			c
Cg5	72-92	S	5Y 4/2	5Y 5/4	c2d				sg	l			a
2C6	92-100	cS	5Y 5/4	2.5Y 3/1	c2d				sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/22/96

60% cover eelgrass (*Zostera marina*)
Possible groundwater intrusion at 92 cm

PROFILE E-2 38° 14' 5.41" N, 75° 10' 7.24" W

coarse-loamy, Typic Endoaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-6	L	N 2/						m	fr	1.0	2f-2vf	c
Cg1	6-33	SL	N 2/	2.5Y 4/2	f2p				m	fr	0.8	2vf	c
C2	33-63	S	2.5Y 4/4	N 2/	f1p				sg	l			a
2C3	63-72	cS	5Y 4/4					1	sg	l			c
3C4	72-98	S	10YR 4/3						sg	l			g
3C5	98-128	S	2.5Y 4/3						sg	l			g
4Cg6	128-145	fS	2.5Y 4/2	N 3/	c2p				sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/22/96

30% cover eelgrass (*Zostera marina*)
Clams present near surface
Tubeworm burrows (casts) in Ag horizon
Common garnet fine sand grains in 4Cg6 horizon
Possible groundwater intrusion at 33 cm

PROFILE E-3 38° 14' 9.01" N, 75° 9' 58.76" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-2	L	2.5Y 4/2						m	fr	1.0	2f-2vf	a
Cg1	2-18	SL	N 3/					2	m	fr	0.8	2vf	g
C2	18-37	S	10YR 3/3						sg	l		1vf	g
C3	37-55	S	2.5Y 4/3	N 3/	c1d	2	7.5YR 3/3	1	sg	l			g
Cg4	55-68	S	2.5Y 4/2	5GY 3/1	m2d			2	sg	l			c
C5	68-100	S	2.5Y 4/3	N 3/	c2d			3	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/22/96

40% cover eelgrass (*Zostera marina*)
Many clams present near surface
Adjacent unvegetated surface horizon 2.5Y 4/3 sandy loam
Red polychaete worms present in Ag and Cg1 horizons
Possible groundwater intrusion at 68 cm

PROFILE E-4 38° 14' 9.18" N, 75° 10' 2.62" W

coarse-loamy, Typic Endoaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Conc.	Organic Fragments (%)	Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
A	0-3	SL	2.5Y 4/3						m	fr	0.9	3f-3vf	a
Cg1	3-28	SL	5Y 3/1						m	fr	0.9		c
C2	28-50	S	2.5Y 4/3	5GY 4/1	f2d	2	7.5YR 3/2	3	sg	l			g
C3	50-95	S	10YR 3/3						sg	l			c
C4	95-110	S	10YR 4/3	N 6/	c2d				sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 9/13/96

70% cover eelgrass (*Zostera marina*)
Periwinkle shell at 37 cm
Possible groundwater intrusion at 50 cm

PROFILE E-5 38° 14' 8.53" N, 75° 10' 8.79" W

coarse-loamy, Typic Endoaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-4	S	5Y 4/2	N 2/	f1p				sg	l		3f-3vf	a
Cg1	4-13	SL	N 2/						m	fr	0.9		a
C2	13-32	SCL	10YR 5/4	N 6/	c2d				m	fr	0.8		a
Cg3	32-52	LS	10YR 4/2	7.5YR 5/8	c2d				m	vfr			g
C4	52-105	S	2.5Y 5/4	5Y 4/1	c2d				sg	l			g
C5	105-120	S	2.5Y 3/3						sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 9/13/96

80% cover widgeon grass (*Ruppia maritima*)
Amphidods present in Ag and Cg1 horizons
Possible buried surface at 13 cm
Possible groundwater intrusion at 52 cm

PROFILE E-6 38° 14' 7.06" N, 75° 10' 3.70" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-6	LS	5Y 4/2	N 2/	c2d				m	vfr		3f-3vf	a
Cg1	6-30	LS	10Y 4/1	N 3/	f1p	3	10YR 2/2		m	vfr		2f-2vf	g
Cg2	30-75	S	10Y 4/1	N 3/	c2d			5	m	l			a
Cg3	75-120	S	5Y 5/2	N 2/	c2p			1	m	l			

REMARKS: Profile description by G. Demas and K. Merrell, 6/17/97

25% cover eelgrass (*Zostera marina*)
Few pockets 10Y 3/1 sandy loam in Cg2 horizon
Coarse sand content increased 110-120 cm
Periwinkle shell at 45 cm

PROFILE E-Rep 38° 14' 7.15" N, 75° 10' 8.09" W
Sample S97MD047-007
Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
A	0-13	S	2.5Y 3/3						sg	1		2f-2vf	a
2C1	13-33	fS	5Y 4/3	5Y 3/1	c2d				m	1		1vf	c
2C2	33-78	fS	5Y 5/3	5Y 4/2	f1d			2	m	1			c
2C3	78-97	fS	5Y 5/3					2	m	1			c
3C4	97-119	S	5Y 5/3						sg	1			c
3C5	119-140	S	2.5Y 5/3	5Y 4/2	c2d				sg	1			

REMARKS: Profile description by G. Demas at time of core extrusion, March 1997

35% cover eelgrass (*Zostera marina*)
Possible groundwater intrusion at 78 cm

PROFILE F-1 38° 13' 52.44" N, 75° 10' 59.53" W

coarse-loamy, Typic Halaquept

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-6	S	2.5Y 4/2	N 2/	f1p	10	10R 2.5/2	12	sg	l		1f-1vf	c
Cg1	6-12	S	N 2/	2.5Y 4/2	c2d			5	sg	l			a
ACb	12-28	SL	2.5Y 4/4	2.5Y 4/2	f2d			2	m	fr			c
2Bwb	28-45	L	2.5Y 5/6	5Y 5/1	c1p				1sbk	fr	0.7		c
2C3b	45-58	S	2.5Y 5/4	5Y 3/1	f2d				sg	l			a
3C4b	58-100	cS	2.5Y 6/6	2.5Y 4/2	f1f				sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/22/96

3% cover eelgrass (*Zostera marina*), clumpy
Tubeworms and seasquirts present in Cg1 horizon
Red worms present in ACb horizon
Core taken on sideslope adjacent to marsh, possible upland submerged soil (2Bwb horizon)

PROFILE F-2 38° 13' 53.61" N, 75° 10' 55.59" W

fine-loamy, Sulfic Fluvaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-6	SL	2.5Y 4/2			6	7.5YR 3/3		m	vfr			c
Cg1	6-38	S	5Y 2.5/1	N 2/	f3p	15	7.5YR 3/3		sg	l			a
Oab	38-62	Mk	10YR 2/1			30	10YR 3/2						c
2Cg2	62-72	SiL	N 2/			20	2.5Y 3/3		m	fr	0.9		g
2Cg3	72-88	L	5Y 5/2			5	10YR 3/3		1msbk	fr	0.8		c
2Cg4	88-105	CL	5GY 6/1	2.5Y 4/2	c2d	8	7.5YR 3/2		1msbk	fr	0.7		

REMARKS: Profile description by G. Demas and K. Merrell, 8/22/96

0% vegetative cover
40% silt loam mineral material in Oab horizon
5% pockets stripped sand grains in 2Cg3 horizon
Red worms present Ag horizon

PROFILE F-3 38° 13' 53.98" N, 75° 10' 55.16" W

coarse-loamy, Terric Sulfisaprist

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
A	0-6	fS	10YR 3/3						sg	l			a
2Cg1	6-23	S	5Y 5/1						sg	l			c
Oab	23-70	Mk	10YR 2/1			25	7.5YR 6/6						c
3Agb	70-80	SL	10YR 3/2			10	2.5Y 5/3		m	fr	0.8		c
3Bwgb	80-100	L	2.5Y 5/2			10	2.5Y 6/6		1msbk	fr	0.7		

REMARKS: Profile description by G. Demas, K. Merrell, and B. Nichols, 8/12/96

0% vegetative cover
Possible submerged upland marsh (3Bwgb horizon)

PROFILE F-4 38° 13' 53.23" N, 75° 10' 50.66" W

fine-silty, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-18	SiL	10Y 3/1			30	2.5Y 5/3		m	fr	1.0		c
Cg1	18-85	SiCL	10Y 3/1						m	fr	1.0		a
Oeb	85-140	Mpt	10YR 3/1										c
Oab	140-150	Mk	10YR 2/1										

REMARKS: Profile description by G. Demas and K. Merrell, 6/19/97

35% cover eelgrass (*Zostera marina*)

PROFILE F-5 38° 13' 53.29" N, 75° 10' 53.73" W
fine-silty, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-6	S	10YR 2/1						sg	l			c
Cg1	6-25	SL	10Y 4/1	N 2/	c2d	3	10YR 3/3	4	m	fr	0.8		a
2Cg2	25-48	SiL	N 3/						m	fr	1.0		c
Oeb	48-72	Mpt	7.5YR 3/2										g
Oab	72-100	Mk	N 2/			25	2.5Y 5/6						

REMARKS: Profile description by G. Demas and K. Merrell, 6/19/97

0% vegetative cover

PROFILE F-6 38° 13' 52.67" N, 75° 10' 58.62" W

fine-silty, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-8	S	10YR 3/1	N 2/	f1d				sg	l			a
Cg1	8-30	L	10Y 3/1					2	m	fr	0.9		c
2Cg2	30-63	SiL	10B 4/1						m	fr	1.0		a
Oeb	63-93	Mpt	10YR 3/2			10	2.5Y 5/3						c
Oab	93-120	Mk	N 2/										

REMARKS: Profile description by G. Demas and K. Merrell, 6/19/97

0% vegetative cover

PROFILE G-1 38° 12' 12.24" N, 75° 10' 22.81" W
sandy, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-10	L	10YR 2/2						m	vfr	1.0	2f-2vf	c
Cg1	10-25	LS	5Y 4/1					5	sg	l			g
Cg2	25-150	S	5Y 7/2						sg	f			

REMARKS: Profile description by G. Demas and B. Nichols, 7/22/94

80% cover widgeon grass (*Ruppia maritima*)
Clams present near surface

PROFILE G-2 38° 11' 56.40" N, 75° 10' 24.03" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-18	S	10YR 3/2	10YR 4/3	c3d				sg	l		2f	c
Cg1	18-50	S	2.5Y 4/2					5	sg	f			c
2Cg2	50-100	cS	10YR 5/1	2.5Y 4/2	f3d			3	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/12/96

40% cover eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*)
Near Sv3 biomass site
Few pockets coarse sand in Cg1 horizon

PROFILE G-3 38° 12' 13.71" N, 75° 10' 41.03" W

coarse-laomy, Sulfic Fluvaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-3	S	5Y 4/2	2.5Y 4/4	f1d				sg	l		2f-3vf	c
Cg1	3-25	S	N 2/	2.5Y 4/3	f2d			3	sg	l		1vf	g
Cg2	25-65	S	N 2/	5GY 4/1	f2d			3	sg	l			g
Cg3	65-80	S	N 3/	2.5Y 5/4	f1p			5	sg	l			a
2Agb	80-90	SL	5G 3/1			2	10YR 3/3	10	m	fr	0.8		a
2ACgb	90-110	S	5GY 3/1	5Y 5/1	f3d	1	10YR 2/1	30	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 9/9/96

60% cover eelgrass (Zostera marina)
Finely ground shells in Cg2 horizon
Few pockets 5G 3/1 sandy loam in Cg3 horizon
Pelicans present on nearby pilings

PROFILE G-4 38° 12' 15.91" N, 75° 10' 30.75" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-3	LS	2.5Y 4/2						m	vfr		3f-3vf	a
Cg1	3-38	S	N 3/	5Y 3/2	f2d	2	10YR 3/2	3	sg	l		1f	c
Cg2	38-65	LS	5Y 3/1					3	m	vfr			g
Cg3	65-95	S	10Y 4/1			5	2.5Y 3/3	3	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 9/9/96

80% cover widgeon grass (*Ruppia maritima*) and eelgrass (*Zostera marina*), mixed bed
Periwinkle shell at 80 cm
Common garnet grains in Cg3 horizon

PROFILE G-5 38° 12' 10.85" N, 75° 10' 22.16" W

coarse-loamy, Sulfic Fluvaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-4	S	5Y 3/2						sg	l		2f-2vf	a
Cg1	4-28	LS	5GY 3/1					5	m	vfr		1vf	c
2Agb	28-65	SL	N 3/			5	7.5YR 3/2		m	fr	0.9		g
2Cg2	65-90	S	5Y 3/1	N 4/	f2d	3	N 2/		sg	l			a
2Cg3	90-105	LS	10Y 4/1						m	vfr			a
2Cg4	105-120	S	N 5/					10	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 9/9/96

100% cover eelgrass (*Zostera marina*)
Tubeworms present in Ag horizon
Periwinkle shell at 80 cm
Few pockets 5GY 3/1 silt loam (n-value 1.0) in 2Cg3 horizon

PROFILE G-6 38° 12' 9.78" N, 75° 10' 47.73" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-3	S	5Y 4/2						sg	l		2f-2vf	a
Cg1	3-22	S	N 2/	5Y 4/2	c2d	4	2.5Y 4/4	8	sg	l		1vf	c
Cg2	22-85	S	10G 3/1	N 2/	f1d			15	sg	l			c
Cg3	85-100	S	5GY 5/1					20	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 6/17/97

25% cover widgeon grass (*Ruppia maritima*)
Periwinkle shell at 45 cm
Tubeworms present in Cg1 horizon
Finely ground shells in Cg2 horizon

PROFILE G-7 38° 12' 5.21" N, 75° 10' 47.36" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Conc.	Organic Fragments (%)	Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-3	LS	5Y 3/2			15	7.5YR 3/3		m	vfr		2f-2vf	a
Cg1	3-18	S	10Y 2.5/1	N 2/	c2d			2	sg	1		1vf	g
Cg2	18-68	S	10Y 2.5/1			3	2.5Y 3/2		sg	1			g
Cg3	68-95	S	5GY 5/1					4	sg	1			c
2Cg4	95-110	cS	5GY 5/1					20	sg	1			

REMARKS: Profile description by G. Demas and K. Merrell, 6/17/97

40% cover eelgrass (*Zostera marina*)

PROFILE G-8 38° 12' 4.12" N, 75° 10' 40.86" W

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-15	LS	N 2.5/			15	7.5YR 3/3	1	m	vfr		1f-1vf	a
Cg1	15-30	SL	N 3/			5	7.5YR 3/3	3	m	fr		1vf	c
Cg2	30-45	L	N 3/			2	2.5Y 3/3	5	m	fr	0.9		c
Cg3	45-90	S	10Y 4/1					10	sg	l			g
Cg4	90-130	LS	10Y 4/1	N 3/	c2f	2	2.5Y 3/3	5	m	vfr			

REMARKS: Profile description by G. Demas and K. Merrell, 6/17/97

40 % cover eelgrass (*Zostera marina*)
Common pockets N 5/ sand in Cg2 horizon
Few pockets 5GY 5/1 loam in Cg3 horizon
Periwinkle shells (2) at 110 cm

PROFILE G-Rep 38° 12' 14.15" N, 75° 10' 18.83" W
Sample S97MD047-005
sandy, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-15	SL	10Y 3/1	N 2/	c2d	3	7.5YR 3/2	1	m	fr	0.8	1f-1vf	a
Cg1	15-37	LS	5GY 4/1	10Y 3/1	f2d				m	vfr			c
Cg2	37-60	S	10Y 4/1					3	sg	l			g
Cg3	60-135	S	N 5/					5	sg	l			

REMARKS: Profile description by G. Demas at time of core extrusion, March 1997

50% cover widgeon grass (*Ruppia maritima*)

PROFILE H-2 38° 13' 53.67" N, 75° 8' 10.43" W

coarse-loamy, Sulfic Fluvaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
A	0-6	S	5Y 4/3					1	sg	l		1f-1vf	a
Cg1	6-32	S	N 2/	5Y 3/1	f1d				sg	l			c
Cg2	32-65	S	5GY 4/1	N 3/	f3f			3	sg	l			a
2Agb	65-78	L	5GY 3/1			10	7.5YR 3/2	20	m	fr	0.9		c
2Cg3	78-100	LS	5Y 4/1			5	7.5YR 3/3	5	m	vfr			

REMARKS: Profile description by G. Demas and K. Merrell, 8/23/96

40% cover widgeon grass (*Ruppia maritima*)
Periwinkle shell at 70 cm
In 2Cg3 horizon, majority of organic fragments at 85-90 cm

PROFILE H-3 38° 13' 49.83" N, 75° 9' 11.42" W
coarse-loamy, Sulfic Fluvaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
A	0-8	S	5Y 4/3					1	sg	l		1f-1vf	a
Cg1	8-42	S	N 2/	5Y 3/1					sg	l			c
Cg2	42-78	S	5GY 4/1	N 3/					sg	l			a
2Ab	78-90	L	N 3/			10	7.5YR 4/6	20	m	fr	0.9		c
2Cg3	90-105	LS	5GY 3/1	N 2/	f2p	2	7.5YR 4/6	5	m	vfr			g
2Cg4	105-120	S	5Y 5/1	N 2/	c2d	1	2.5Y 5/3	1	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/23/96

50% cover widgeon grass (*Ruppia maritima*)
Juvenile blue crabs present in seagrass clumps
Oyster shell at 60 cm

PROFILE H-4 38° 13' 51.29" N, 75° 9' 4.01" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-4	LS	N 2/						m	vfr		2f-3vf	a
Cg1	4-58	S	5Y 4/1	N 3/	f1d			2	sg	l			c
2Cg2	58-105	fS	5GY 4/1	10Y 3/1	f1d	2	10YR 3/3	4	m	vfr			a
3Ab	105-115	SiL	5Y 4/1	N 6/	f2p	5	7.5YR 4/6		m	fr	0.9		c
3Cg3	115-120	L	5GY 4/1	10YR 3/2		10	10YR 5/6		m	fr	0.9		

REMARKS: Profile description by G. Demas and K. Merrell, 9/13/96

100% cover widgeon grass (*Ruppia maritima*)
Mudworms present at surface
Many woody fragments in 3Ab and 3Cg3 horizons
Few pockets N 3/ loam in Cg1 horizon
10YR 3/2 features in 3Cg3 horizon are banded

PROFILE H-6 38° 13' 43.53" N, 75° 9' 14.63" W

coarse-loamy, Sulfic Fluvaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Conc.	Organic Fragments (%)	Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-18	S	10Y 4/1	N 3/	f1d				sg	l		2f-2vf	c
Cg1	18-72	S	N 4/	N 2/	c2d			4	sg	l			c
Cg2	72-90	S	10Y 5/1						sg	l			a
2Agb	90-120	L	5GY 4/1			3	10YR 2/2		m	fr	1.0		a
2Cg3	120-150	LS	10Y 3/1						m	vfr			

REMARKS: Profile description by G. Demas and K. Merrell, 6/18/97

40% cover widgeon grass (*Ruppia maritima*)

PROFILE H-7 38° 13' 41.30" N, 75° 9' 14.98" W

coarse-loamy, Sulfic Fluvaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-6	LS	10Y 3/1			3	7.5YR 3/2		m	vfr		3f-3vf	a
Cg1	6-30	S	10Y 3/1	N 2.5/	c1f	2	7.5YR 3/2		sg	l		1vf	c
Cg2	30-65	S	5GY 4/1			1	7.5YR 3/2		sg	l			c
Cg3	65-95	S	5GY 5/1						sg	l			g
2Agb	95-135	L	5GY 4/1			5	10YR 3/2		m	fr	0.9		c
2Cg4	13150	SL	5GY 4/1						m	fr	0.8		

REMARKS: Profile description by G. Demas and K. Merrell, 6/18/97

20% cover eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*), mixed bed
Periwinkle shell at 95 cm
Organic fragments in Ag and Cg1 horizon eelgrass (*Zostera marina*) blades

PROFILE H-8 38° 13' 36.35" N, 75° 9' 15.51" W

coarse-loamy, Sulfic Fluvaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-6	L	10Y 3/1	N 2/	c3p				m	fr	0.8	2f-2vf	a
Cg1	6-15	SL	N 2/	10Y 3/1	f2d	5	10YR 2/2		m	fr		2f	c
Cg2	15-40	S	10Y 3/1						sg	l		1vf	g
Cg3	40-88	S	10Y 3/1	N 2/	c2d				sg	l			g
2Agb	88-118	SL	5GY 4/1			10	7.5YR 3/3		m	fr			c
2Cg4	118-150	L	5GY 4/1						m	fr	0.8		

REMARKS: Profile description by G. Demas and K. Merrell, 6/18/97

40% cover eelgrass (*Zostera marina*)
Few pockets N 2/ sandy loam in Cg3 horizon

PROFILE H-Rep 38° 13' 39.90" N, 75° 9' 12.91" W
Sample S97MD047-006
coarse-loamy, Sulfic Fluvaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-6	fS	2.5Y 5/2						sg	l		1f-1vf	a
Cg1	6-21	fS	5Y 4/1					3	sg	l			c
Cg2	21-56	fS	5GY 3/1					5	sg	l			a
2Agb	56-106	SL	5Y 4/1			4	10YR 3/3		m	fr	0.8		c
3Cg3	106-170	fS	5GY 3/1						sg	l			

REMARKS: Profile description by G. Demas at time of core extrusion, March 1997

20% cover eelgrass (*Zostera marina*)

PROFILE I-1 38° 13' 53.16" N, 75° 10' 50.91" W
fine-silty, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	SiL	0-6	2.5Y 3/2						m	fr	1.0		c
Cg1	SiL	6-14	N 3/						m	fr	0.9		a
Cg2	SiCL	14-88	5Y 4/1			50	2.5Y 3/4		m	fi	0.9		g
Cg3	SiC	88-120	5Y 4/1			5	2.5Y 3/3		m	fi	0.9		

REMARKS: Profile description by G. Demas and K. Merrell, 8/22/96

10% cover eelgrass (*Zostera marina*)
Tubeworms present in Ag horizon

PROFILE I-2 38° 14' 0.72" N, 75° 10' 35.14" W

fine-silty, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-24	MkSiL	2.5Y 4/2			50	7.5YR 3/3		m	fr	0.9		c
Cg1	24-41	SiL	10YR 4/2			30	10YR 3/3		m	fr	0.9		c
Cg2	41-55	SiL	5GY 4/1						m	fr	0.9		a
Cg3	55-100	SiCL	5Y 4/1						m	fi	0.8		

REMARKS: Profile description by G. Demas and K. Merrell, 8/22/96

0% vegetative cover
Algae and shells with orange sponge infection at surface
Tubeworms present in Ag horizon
Three 1-2 cm bands of 10YR 3/2 silt loam with 20% organic fragments in Cg2 horizon
Periwinkle shell at 56 cm

PROFILE I-3 38° 12' 0.69" N, 75° 10' 35.30" W

fine-silty, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Conc.	Organic Fragments (%)	Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-32	SiL	5Y 4/1			40	2.5Y 4/3		m	fr	0.9		a
C1	32-46	SiL	2.5Y 3/3			60	2.5Y 4/3		m	fr	0.9		g
Cg2	46-65	SiL	5Y 4/1			50	7.5YR 4/4		m	fr	0.9		c
Ab	65-81	MkSiL	10YR 3/3			80	10YR 3/2		m	fr	0.9		c
Cg3	81-100	SiL	5GY 4/1			40	10YR 3/3		m	fr	0.9		

REMARKS: Profile description by G. Demas and K. Merrell, 8/22/96

0% vegetative cover
Few bands of 5Y 4/1 silt loam in Ab horizon

PROFILE I-4 38° 14' 0.49" N, 75° 10' 39.39"

fine-silty, Terric Sulfihemist

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-10	MkSiL	10Y 3/1						m	fr	0.9		a
Oe	10-90	Mpt	7.5YR 3/2										g
Oa	90-112	Mk	10Y 4/1										c
Agb	112-138	MkSiL	10Y 2.5/1			30	2.5Y 3/3		m	fr	1.0		c
Oeb	138-150	Mpt	7.5YR 3/2										

REMARKS: Profile description by G. Demas and K. Merrell, 6/19/97

0% vegetative cover
20% silt loam mineral material in Oe and Oeb horizons
35% silt loam mineral material in Oa horizon

PROFILE I-5 38° 13' 58.65" N, 75° 10' 42.18"

fine-silty, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-30	SiL	10Y 3/1						m	fr	1.0		a
Oe1	30-44	Mpt	7.5YR 3/2										a
Cg1	44-67	MkSiL	10Y 4/1			25	2.5Y 4/3		m	fr	1.0		g
Oe2	67-110	Mpt	10YR 3/1										c
Cg2	110-160	SiL	10Y 4/1			30	10YR 2/2		m	fr	0.9		c
Oeb	160-188	Mpt	7.5YR 3/2										a
2Cg3b	188-200	SiL	5GY 3/1						m	fr	0.9		

REMARKS: Profile description by G. Demas and K. Merrell, 6/19/97

0% vegetative cover

PROFILE I-6 38° 13' 57.19" N, 75° 10' 44.75" W

fine-silty, Typic Sulfaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-25	L	10Y 3/1						m	fr	1.0		c
Cg1	25-34	MkSiL	10Y 3/1			20	2.5Y 5/4		m	fr	1.0		a
Oa	34-46	Mk	10YR 2/2										c
Cg2	46-74	SiL	10Y 3/1			10	10YR 2/2		m	fr	1.0		a
Oeb	74-90	Mpt	7.5YR 3/2										a
Cg3b	90-150	SiL	10GY 4/1			20	2.5Y 5/6		m	fr	1.0		

REMARKS: Profile description by G. Demas and K. Merrell, 6/19/97

0% vegetative cover

PROFILE I-7 38° 13' 54.84" N, 75° 10' 46.41" W

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Conc.	Organic Fragments (%)	Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-10	S	5Y 4/2			4	10YR 3/2		sg	l		1vf	a
2Cg1	10-68	SiL	10Y 4/1			30	2.5Y 5/6		m	fr	1.0		c
2Cg2	68-90	SiCL	10B 3/1						m	fi	1.0		c
2Cg3	90-110	SiCL	10Y 4/1			25	2.5Y 5/4		m	fi	1.0		c
Oab	110-132	Mk	10YR 2/2										a
3Cg3b	132-150	SiCL	10B 4/1						m	fi	1.0		

REMARKS: Profile description by G. Demas and K. Merrell, 6/19/97

30% cover eelgrass (*Zostera marina*)

PROFILE J-1 38° 12' 48.04" N, 75° 9' 51.52" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-3	LS	5GY 4/2						m	vfr		1f-3vf	c
Cg1	3-44	S	5GY 5/1	N 2/	f2d				sg	l		1vf	g
Cg2	44-68	S	5Y 5/1	N 3/	f2d			10	sg	l			g
Cg3	68-90	S	N 5/	5GY 3/1	f2d			2	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/30/96

99% cover eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*), mixed bed
Razor clams present at surface

PROFILE J-2 38° 12' 50.24" N, 75° 9' 49.76" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-3	LS	5Y 4/2					2	m	vfr		2f-3vf	a
Cg1	3-22	S	5Y 4/1					2	sg	l		1vf	g
Cg2	22-61	S	5GY 4/1					1	sg	l		1vf	a
Cg3	61-70	S	5Y 3/1	N 5/	f3p			10	sg	l			c
Cg4	70-100	S	5Y 6/1	N 3/	c2d			2	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/30/96

99% cover widgeon grass (*Ruppia maritima*)
Red polychaete worms present at surface
Oyster shell at 61 cm
Coarse sand increase, garnet grains, and finely ground shells in Cg4 horizon

PROFILE J-4 38° 13' 2.74" N, 75° 9' 43.83" W
Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Conc.	Organic Fragments (%)	Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-4	LS	2.5Y 4/2					2	m	vfr		2f-2vf	a
Cg1	4-14	S	N 2/	5Y 4/2	f2d				sg	l		1vf	g
Cg2	14-48	S	5GY 3/1	5Y 4/3	f1f			2	sg	l			c
Cg3	48-88	S	N 6/	N 3/	f2p			3	sg	l			c
Cg4	88-110	S	5Y 4/1	N 6/	f3p	2	7.5YR 3/3		sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/30/96

95% cover widgeon grass (*Ruppia maritima*)
Clams present at surface
Common garnet grains in Cg3 horizon

PROFILE J-5 38° 13' 12.71" N, 75° 9' 34.35" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-4	LS	2.5Y 4/2					2	m	vfr		2f-2vf	a
Cg1	4-17	S	N 3/	N 2/	f1f			1	sg	l		1vf	g
Cg2	17-50	S	5Y 5/1	N 2/	c2p	2	10YR 3/2		sg	l			c
Cg3	50-78	S	5GY 4/1	5Y 5/1	c2f	1	7.5YR 3/4	3	sg	l			c
Cg4	78-100	S	N 4/	N 3/	c2f			1	sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/30/96

99% cover eelgrass (*Zostera marina*)
Periwinkle shells at 60 and 90 cm

PROFILE J-6 38° 13' 27.29" N, 75° 9' 27.51" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				`Color	Conc.	(%)	Color						
Ag	0-3	LS	2.5Y 4/2						m	vfr		2f-3vf	a
Cg1	3-41	S	N 2/	2.5Y 4/2	f2p	2	10YR 3/4	2	sg	l		2vf	c
Cg2	41-68	LS	N 4/			4	7.5YR 3/2	1	m	vfr			c
Cg3	68-89	LS	5GY 3/1	5Y 3/2	f2d	4	7.5YR 3/2		m	vfr			a
Cg4	89-100	S	5Y 5/1	N 3/	c2d	2	7.5YR 3/2		sg	l			

REMARKS: Profile description by G. Demas and K. Merrell, 8/30/96

95% cover eelgrass (*Zostera marina*)
Amphipods present at surface
Organic fragments in Cg2 horizon eelgrass (*Zostera marina*) blades
High fine sand content in Ag horizon

PROFILE J-Rep 38° 13' 10.10" N, 75° 9' 38.19" W
Sample S97MD047-008
Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-12	fS	5Y 5/2	5Y 2.5/1	f1d				sg	l			a
Cg1	12-37	fS	N 2/	5GY 4/1	f2p				sg	l			c
Cg2	37-91	fS	5Y 4/1						sg	l			g
Cg3	91-114	fS	5Y 3/1						sg	l			c
Cg4	114-130	fS	5Y 4/1						sg	l			

REMARKS: Profile description by G. Demas at time of core extrusion, March 1997

10% cover eelgrass (*Zostera marina*)

PROFILE K-1 38° 12' 50.07" N, 75° 9' 42.15"

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Conc.	Organic Fragments (%)	Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
Ag	0-10	S	5Y 4/2	N 2/	f3d			3	m	vfr		1vf	c
Cg1	10-28	S	5Y 3/2					3	m	fi			c
Cg2	28-40	S	N 4/						m	fi			g
Cg3	40-55	S	5Y 5/1						m	fi			

REMARKS: Profile description by G. Demas and K. Merrell, 6/16/97

10% widgeon grass (*Ruppia maritima*)
Auger refusal, dense sands

PROFILE K-3 38° 12' 57.47" N, 75° 9' 26.53" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
Ag	0-3	S	5Y 4/2						m	vfr			a
Cg1	3-21	S	5Y 4/1	N 2/	f2d				m	fi			c
Cg2	21-38	S	5Y 4/1						m	fi			c
Cg3	38-55	S	5Y 5/1					5	m	fi			

REMARKS: Profile description by G. Demas and K. Merrell, 6/16/97

0% vegetative cover
Auger refusal, dense sands

PROFILE K-4 38° 13' 1.26" N, 75° 9' 21.84" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features Color	Redoximorphic Features Conc.	Organic Fragments (%)	Organic Fragments Color	Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
A	0-5	S	5Y 4/3						m	fr			a
Cg1	5-36	S	10Y 3/1						m	fi			c
Cg2	36-55	S	10Y 5/1					5	m	fi			

REMARKS: Profile description by G. Demas and K. Merrell, 6/16/97

0% vegetative cover
Oyster shell at 45 cm
Auger refusal, dense sands

PROFILE K-5 38° 13' 8.70" N, 75° 9' 17.60" W

Typic Psammaquent

Horizon	Depth (cm)	USDA Texture Class	Matrix Color (moist)	Redoximorphic Features		Organic Fragments		Shells (%)	Structure	Consistence (moist)	n-Value	Roots	Boundary
				Color	Conc.	(%)	Color						
A	0-6	S	5Y 4/3						m	vfr			a
Cg1	6-28	S	5Y 3/1						m	fi			c
Cg2	28-45	S	10Y 4/1	N 3/	f2f				m	fi			c
Cg3	45-58	S	10Y 5/1					2	m	fi			

REMARKS: Profile description by G. Demas and K. Merrell, 6/16/97

0% vegetative cover
Auger refusal, dense sands

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