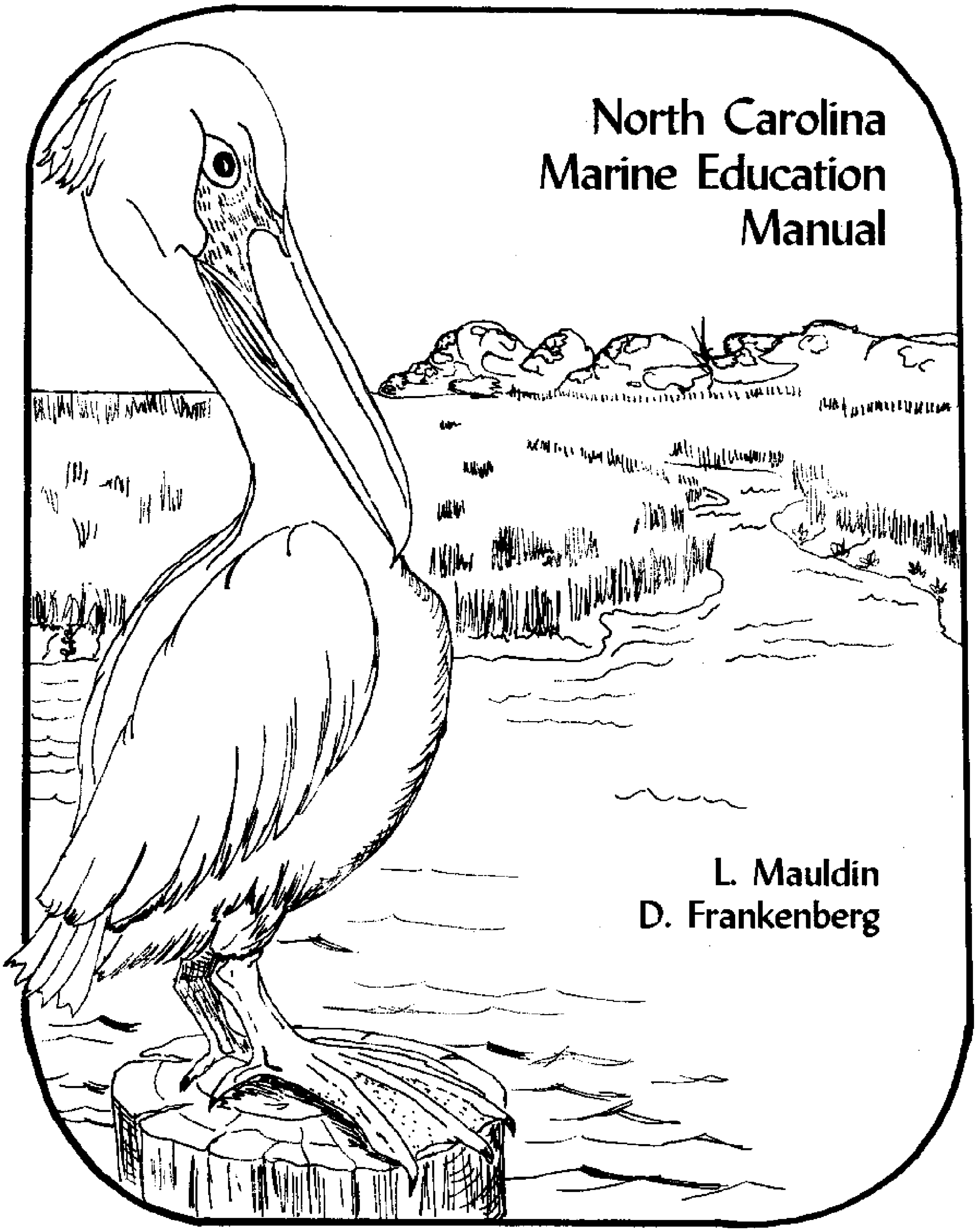
Unit One
Coastal Geology

North Carolina Marine Education Manual



L. Mauldin
D. Frankenberg

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August, 1978

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NORTH CAROLINA MARINE EDUCATION MANUAL

UNIT ONE

COASTAL GEOLOGY

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UNC Chapel Hill

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Unit 1 Coastal Geology

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The North Carolina Marine Education Manual is a collection of teaching materials generated by North Carolina public school teachers and university professors under a University of North Carolina Sea Grant College project entitled "Man and the Seacoast." Dr. Dirk Frankenberg is the principle investigator; the Resource Unit Development Committee project directed by Dr. William Rickards of North Carolina State University assisted with material production. The manual is designed to help middle school teachers put marine perspectives into their lessons. The activities can be modified for higher or lower grades.

This manual consists of separate units which cover environmental aspects of the coast such as geology, ecology, and seawater interactions and motions. Additional units cover facets of coastal communities and economics, history, anthropology, art, folklore, and literature. An appendix provides information on keeping aquaria, state and federal agencies, field trip guides, and film company addresses.

We wish to acknowledge the cooperation we have received from other marine education projects, North Carolina Marine Resource Centers, North Carolina Department of Public Instruction, National Marine Education Association, and many people who have contributed suggestions and opinions. Especially we wish to thank those people whose enthusiasm and contributions made this project possible -- the following North Carolina teachers:

<u>1977 "Man and the Seacoast" teachers</u>

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The North Carolina Marine Education Manual developed through the interaction and involvement of people interested in marine education. UNC Sea Grant would like to continue the involvement by inviting your opinions and suggestions for topics and activities. In this way, we can remain responsive to your needs with new additions to the manual.

Please address your comments to: UNC Sea Grant College Program
Marine Education Specialist
North Carolina State University
105-1911 Building
Raleigh, NC 27650

INTRODUCTION

The purpose of the Marine Education Manual is to provide educational materials that can be used to supplement existing curricula. We have found that students often have an inherent interest in the ocean. We hope that many students will be stimulated by marine oriented materials to learn not only about the ocean, but also about the general scientific phenomena that make the ocean explicable. Thus we hope these materials will prove helpful in teaching science through demonstration of general science concepts using marine examples.

The first unit of the Marine Education Manual provides marine oriented materials in Geology and Geography. These materials specifically focus on North Carolina, but all are adaptable to other areas. Unit One contains materials designed to supplement program features of North Carolina's course of study plans in Earth and Space for the Intermediate Grades and Earth Science for the Middle School/Junior High levels. We have included materials on large scale tectonic forces of continental drift (Part A). We also look at the development of North Carolina's coastal plain and at the wind and water movements that shape the barrier islands and sounds (Part B). For each topic, we have included a resource section that contains information on films, free materials, and books. However, the background reading provided for each topic is designed to provide enough information to work through suggested activities with students.

Table 1 provides a summary of the activities presented in Unit One in relation to the recommended program features of the North Carolina state curriculum guide (Course of Study for Elementary and Sceondary Schools K-12, 1977, pages 139-148). Program features include knowledge/content objectives. The objectives have been generalized into broad catagories to simplify the table. Process skill is a term used to include observing, classifying, using numbers, inferring, interpreting data, controlling variables, experimenting, and formulating models. Manipulative skills include using instruments, calibrating, and constructing. Supplemental skills of organizational, creative, and communicative ability include those which tend to develop an investigation: recording, comparing, planning, inventing, discussing, reporting, writing, graphing, and criticizing. We hope this table will make it easier to insert these activities into lesson plans.

Table 2 lists goals accompanied by behavioral objectives for "Coastal Geology". These are to help you present this material to your students.

The activities in this Marine Education Manual are suggestions of ways in which information on North Carolina's fascinating coast can be transferred to the classroom. Simulation is the name of the game. Most activities in this unit involve constructing and manipulating models. A valuable part of model-making is discussing how models relate to real situations. Only the framework of activities is described because we feel that teachers will want to modify them to suit their particular grade or class level. Specific equipment is minimal leaving maximal need for inventiveness and enthusiasm. We hope these activities will generate an understanding of what is happening on the North Carolina coast.

TABLE 1. Correlation of Activities with Some Skills and Program Features Recommended by the North Carolina Department of Education.

Activity	Process Skills	Manipulative Skills	Organizational Skills	Creative Skills	Communicative Skills	Measurement Systems
Making Ocean Basins	X	X				
Tectonic Puzzle	X	X		X	X	
Contour/Profiles						X
Seek and Find Words	X					
Cross Word Puzzle	X	X				
Explore Sediments	X	X	X	X		
Coring Layers	X	X	X	X		
Making Fossils	X	X	X			
Time Line					X	X
Seek and Find Words	X					
Sand Spit Process	X	X	X	X		
Island System Model	X	X		X		
Coast Geography	X					
Scallop Shield				X		
Maps and Charts	X	X	X	X		
Face of a Dune	X	X				
Beach Sands	X	X		X	X	
Identify Sands	X	X	X	X	X	
Island Model	X	X		X		
Sediment Layers	X	X		X	X	
Siltation Rates	X	X	X	X	X	X
Microsediments	X	X		X		
Estuarine Layers	X	X		X	X	
Marsh Parts			X			

TABLE 2

Goals and Behavioral Objectives

I. To present the tectonic origin of North Carolina's geologic structure and the subsequent effect in which erosion and sedimentation shaped the coastal plain and continental shelf.

Concept 1: North Carolina's physical features are a result of plate tectonics, weathering, and sediment deposition.

Behavioral Objectives: Upon completion of this concept, the student should be able

1. To show how crustal plates move to form and close ocean basins.

2. To draw contour lines from a marine depth chart and locate continental shelf, slope, and ocean basin.

Concept 2: Sediment layers in coastal landforms preserve records of past sea level changes and sediment movement.

Behavioral Objectives: Upon completion of this concept, the student should be able

1. To explain the source of sediment from coastal plains and explain how scientists investigate sediments.

2. To show how fossils are formed and identify two fossils found in North Carolina.

II. To describe the present coastal environmental features of barrier islands, sounds, and estuaries, and to indicate dynamic processes effecting these features.

Concept 1: Barrier islands develop when the ocean shapes coastal sands.

Behavioral Objectives: Upon completion of this concept, the student should be able

1. To make a model of a barrier island and show how longshore transport can change its shape.

2. To identify at least two types of sedimentary particles found in North Carolina sands.

Concept 2: Barrier island ecology is an interaction of beaches, dunes, maritime forests, and marshes.

Behavioral Objectives: Upon completion of this concept, the student should be able

1. To name and locate two inlets and three islands of North Carolina.

2. To describe how sand dunes form and move.

Concept 3. Estuarine systems develop in sheltered waters during periods of rising sea level.

Behavioral Objectives: Upon completion of this concept, the student should be able

1. To identify the following parts of a barrier island/ estuarine system: beach, dunes, maritime forest, marsh, sound, and river.

2. To describe clues indicating whether a coastline is submerging or emerging.

Concept 4: North Carolina's estuarine system is large and linked together by circulation of brackish water.

Behavioral Objectives: Upon completion of this concept, the student should be able

1. To recognize a marine chart, read depths, and be able to plot a route for a ship leaving a port using navigational symbols.

2. To predict where to find the saltiest and freshest water in an estuary.

Unit I. North Carolina's Coast and Waters

Part A. North Carolina's Place in Global Geology

Concept 1. North Carolina's physical features are a result of plate tectonics, weathering, and sediment deposition.

a. Background Reading

North Carolina's physical features are derived from events in global geology, i.e. plate tectonics. North Carolina is now on the trailing edge of the North American plate, but was once on the leading edge of an earlier plate during a period of plate collision that formed the Appalachian Mountains. North Carolina only became part of the trailing edge when two plates of crustal material "drifted" apart about 185 million years ago. Recent science texts provide useful information on the general theory of plate tectonics: the theory that has revolutionized earth science during the last twenty years. These texts do not provide much local information on the geology of North Carolina. North Carolina is, however, an excellent example of tectonically derived geology because it contains examples of early plate collisions and mountain building (the Appalachians), early sedimentary basins (the Durham Jurassic basin), and coastal plain features that preserve a record of changing sea level along a sedimentary coastline.

The major points needed to provide background for use of North Carolina examples are as follows:

1. A general understanding of plate tectonic theory;

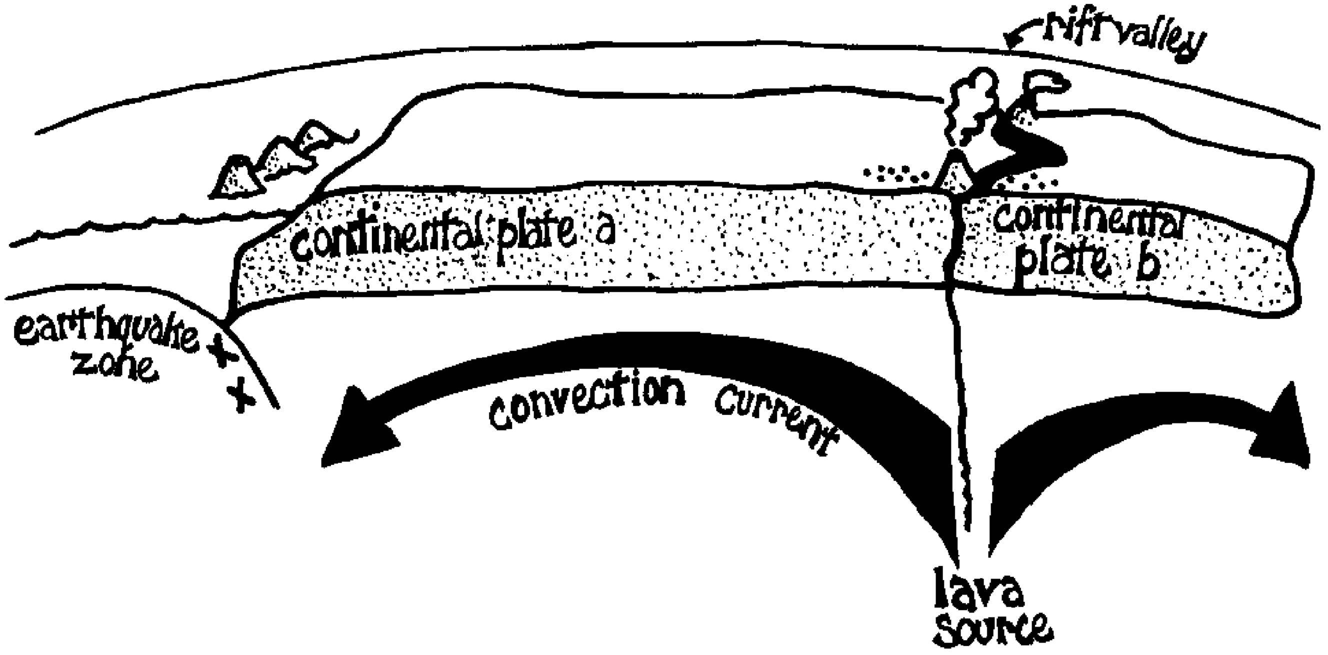
2. An understanding that North Carolina has developed on the trailing edge of a moving plate of crustal material; and

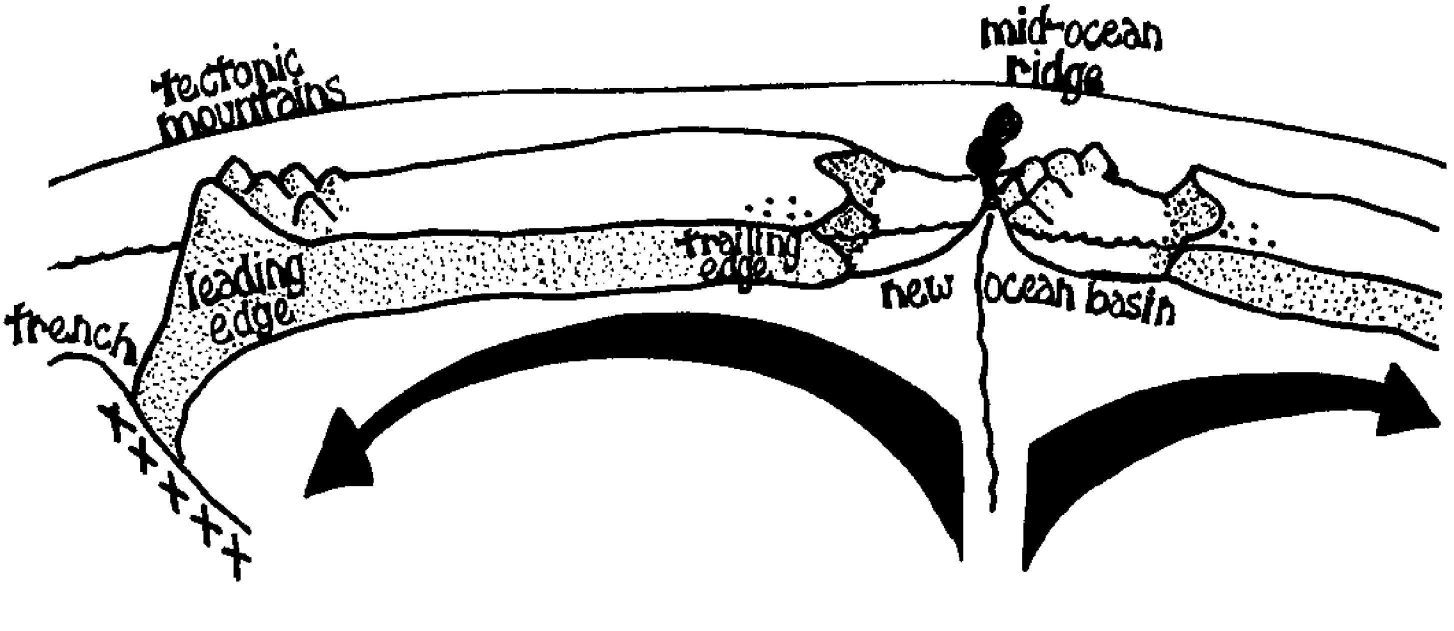
3. An understanding of the reasons for, and geologic implications of, the rise and fall of sea level against North Carolina's coast.

A general description of plate tectonic therory is beyond the scope of this material, but can be derived from geology science texts and from articles such as the January, 1973 issue of National Geographic (Volume 143, number 1, pages 1-53). A useful quote describing the general features of plate tectonics can be found on page 7 of Samuel W. Matthew's 1973 lead article in National Geographic:

> Geologists' "new view of the earth is of continents drifting majestically from place to place, of mountains and island chains forming like rumples in rugs pushed together, of oceans opening and closing.

Figure 1


rift valley
continental plate a
continental plate b
earthquake zone
convection current
lava source


mid-ocean ridge
tectonic mountains
trailing edge
leading edge
trench
new ocean basin

The earth's seemingly rigid crust, these geologist say, actually consists of a crazy quilt of great rafts, or "plates", that are much like huge ice floes jostling about on a frozen sea. From 30 to 100 miles thick, the plates slowly move, carrying the continents and ocean basins with them.

Sliding over a hot, semiplastic layer below, the rigid plates grind and crush together, causing earthquakes and volcanic eruptions. They crack, usually in the ocean basins where they are thinnest, and the pieces move apart. In the cracks molten rock wells up and solidifies, like new ice forming. Along other edges the plates are just as steadily destroyed. They bend downward, forming the deep oceanic trenches, and slide beneath an opposing plate or edge of a continent to be consumed within earth's interior." (S.W. Matthew. This Changing Earth, National Geographic 1973 (1) page 7. (Figure 1)

North Carolina science teachers can use the physical features of the state to lend interest to the tectonic theories. Some of the following inquiries can be discussed using tectonic explanations.

1. How did North Carolina get its western mountains?

Part of NC formed the floor of an ancient sea basin. The collision of the two plates forced the sedimentary layers to buckle and fold resulting in jagged mountain peaks similar to the Rockies. These peaks have eroded down to produce the present Appalachian Mountains.

2. If the rock forming the Appalachians was orginally the sea floor, why are few fossils found in North Carolina's mountains?

Basically, the initial collision of the two plates occurred close to North Carolina (the leading edge). The deformation stress was so intense that the sedimentary layers, including the fossils, were altered by metamorphism.

3. Why is the coastal plain so flat?

The coastal plain is a result of the erosional sediment from the Appalachians. For over 200 million years, sediment has washed down the rivers and deposited in the ocean. These layers eventually built up a wide, gently sloping plain which extends from the "fall line" to the edge of the continental shelf. Since the coastal plain was formed after the plates collided and after much of the subsequent spreading of the Atlantic Ocean basin, it is considered the trailing edge of the American plate.

Once the general design of the plate tectonic theory is understood, it is relatively easy to place geologic features of North Carolina in relation to plate movements. The mountains of North Carolina are now thought to have originated in a collision between two ancient plates that preceeded formation of the Atlantic Ocean. As the Atlantic Ocean developed by spreading of the Mid-Atlantic Ridge, the ocean basin widened and the slow process of weathering, erosion and deposition began to form the sediment that now comprises the coastal plain and continental shelf. (Figure 2)

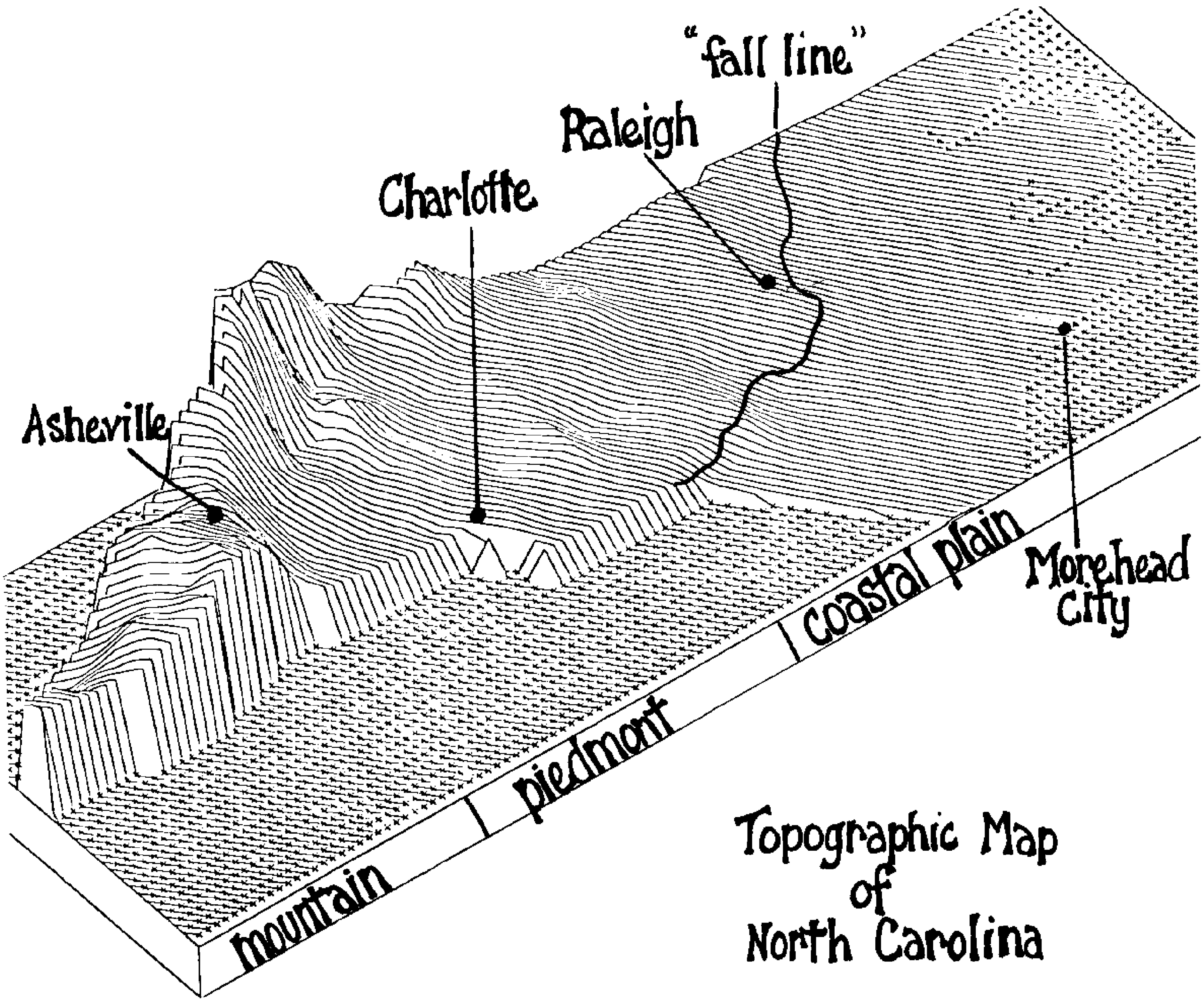

"fall line"
Raleigh
Charlotte
Asheville
Morehead City
mountain
piedmont
coastal plain
Topographic Map of North Carolina

Figure 2

b. Vocabulary

Appalachians - the mountains of North Carolina resulting from plate collision. These mountains are made of metamorphic material deformed by the stress of being on the leading edge of colliding plates.

Bathymetric - deep water measurements

Coastal Plain - a strip of land of indefinite width that extends from the sea shore inland to the first major change in terrain features. In NC, it consists of sedimentary material and has been inundated by the sea.

Continental Shelf - the sea floor adjacent to a continent extending from the low water mark to the change in slope, usually about 600 ft. (200 m, 100 fathoms).

Continental Slope - the ocean bottom between the continental shelf and the deep sea floor

Contour line - a line on a chart connecting points of equal elevation or depth

Fall Line - separates the Piedmont from the coastal plain region, marked by a change in topography such that rivers have waterfalls at this point.

Plate Tectonics - the theory of global dynamics in which the earth's surface is divided into individual plates which move in response to processes in the upper mantle. The plate margins are the sites of considerable activity. This theory supports the idea of "continental drift".

Rift - the split of a plate of crustal material

Sea Level - The boundary between land and sea water. Sea level varies in relation to the rise and fall of the land and with alteration of the ocean basin and volume of water.

Sonar - "Sound Navigation and Ranging", a technique using underwater sound and echoes for determining water depth and location of underwater features.

Trailing Edge - that side of a plate which does not collide with another plate

c. Activities

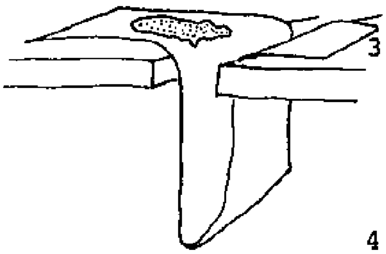
How Did the Atlantic Ocean Get Here - Plate Tectonics

1. Objective: To simulate the mid-Atlantic Ridge and discover how ocean basins spread.

2. Teacher Preparation: Each pair of students should have a sheet of paper (possibly a large piece of newsprint), a work surface such as two desks pushed closely together; a crayon or pencil.

3. Procedure:
   1. Fold the paper in half. Insert it between the two desks (or, if desks are not available, two even stacks of books may be used). Refer to Figure 3.
   2. Crease part of the left side and fold it over on the desk. Label this part "North America". You might even want to locate North Carolina. Crease part of the right side and fold it over on the other desk. Label it "Africa". This simulates the single joined continent before it breaks up (perhaps you could mention Pangaea).
   3. Slowly start to pull each half from the center. This represents the rift or split of the super-continent. As the rift becomes wider, color it blue. This represents the oceanic basin. (Figure 3)
   4. Pull the rift out further and color the new part blue. The Atlantic Ocean is continuing to widen. The place where the rift begins is in the mid-Atlantic Ridge - a chain of volcanic mountains extending north of Iceland and south of Africa.

Figure 3



4. Discussion:
   1. What does this activity tell about the age of the rocks close to the Mid-Atlantic Ridge and near the continents? (young nearest Ridge)
   2. The Mid-Atlantic Ridge, as the name implies, is very near the middle of the ocean. From this activity can you explain this? (ocean formed either side)
   3. Where does the material which flows out of the rift originate? (mantle of earth)
   4. Where do you think the most volcanic activity occurs - near North Carolina or near the Mid-Atlantic Ridge? Why? (Mid-Atlantic Ridge)

c. Activities

Plate Tectonic Puzzle

1. Objective: To demonstrate that the earth's crust consists of moving plates whose positions have changed over time and that North Carolina's geological features are traceable to this process.

2. Teacher Preparation: Cut out the continental puzzle pieces given on the following page. These can be mounted or laminated for longer use. Supply the students with the time line of Pangaea to the present day continental arrangement (or convert to transparencies for overhead projection). (Figure 4)

3. Procedure:
   1. Locate the continental shapes in their present-day positions on a globe.
   2. Locate and name the continents on the map of Pangaea. The shapes of these will not correspond exactly since the pieces are continents and the map shows continental blocks (this includes the continental shelf which extends underwater from shore).
   3. Move the puzzle pieces into the Pangaea arrangement and begin to move them, step by step, to their present-day locations, following the drifting pattern given on the time line. (Figures 5, 6, 7)

4. Discussion:
   1. As you make each move, describe how the continents drifted, approximate direction, rotation, attachments, eventual position.
   2. What mountain range was formed when India "crashed" into Asia? From the diagrams, can you say something about the age of these mountains? (The Himalayas, less than 65 million years old)
   3. Look at the approximate position of North Carolina on the map of Pangaea. If mountains are formed as plates collide, when might the Appalachians have formed? (When Pangaea was formed, more than 225 million years ago)
   4. In the map of our present day arrangement of continental blocks, the edges of these blocks do not look like our present coastlines. Give a reason for this. (Sea level is now higher than the edge of the blocks,continental shelf is often a better outline to match.)
   5. Which type of coastline does NC have? Leading or trailing edge of a plate block? (Trailing edge.

Clues are that there is a flat, sedimentary coastal plain. Leading edges are characterized by mountain ranges.)

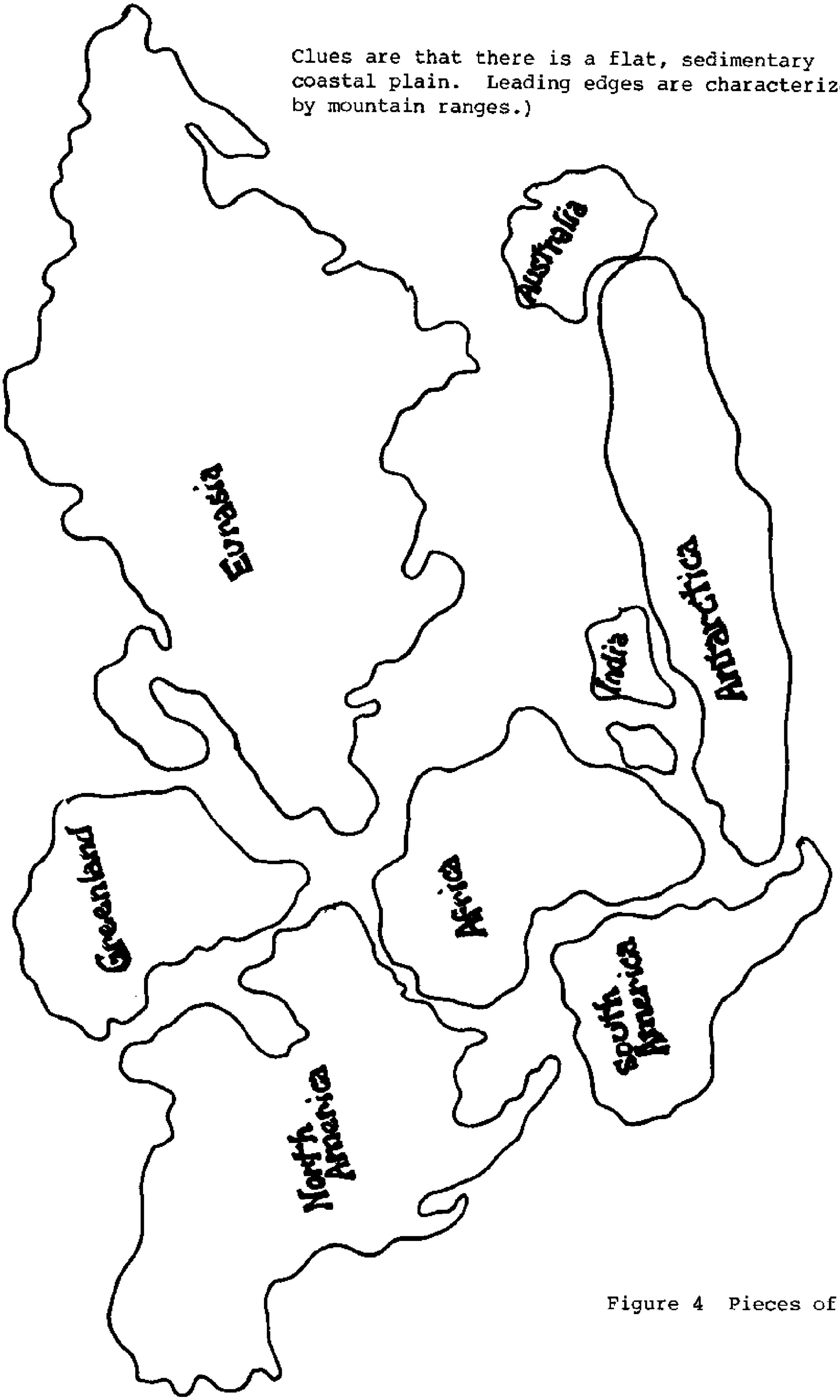


Figure 4 Pieces of Puzzle

Fig. 5. Crustal Plate Movement beginning 225 million years ago
End of Paleozoic Era and beginning of Mesozoic Era.

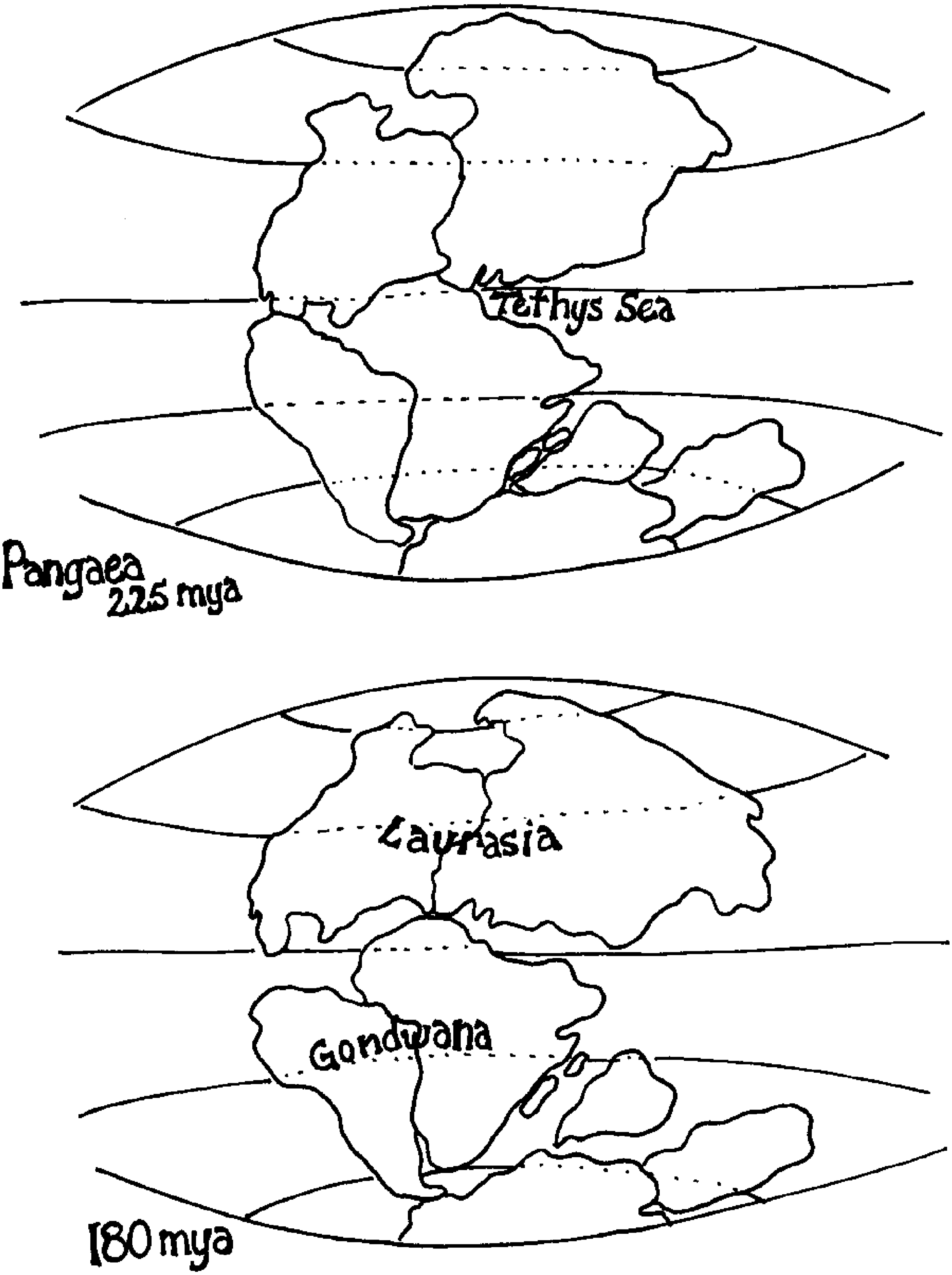
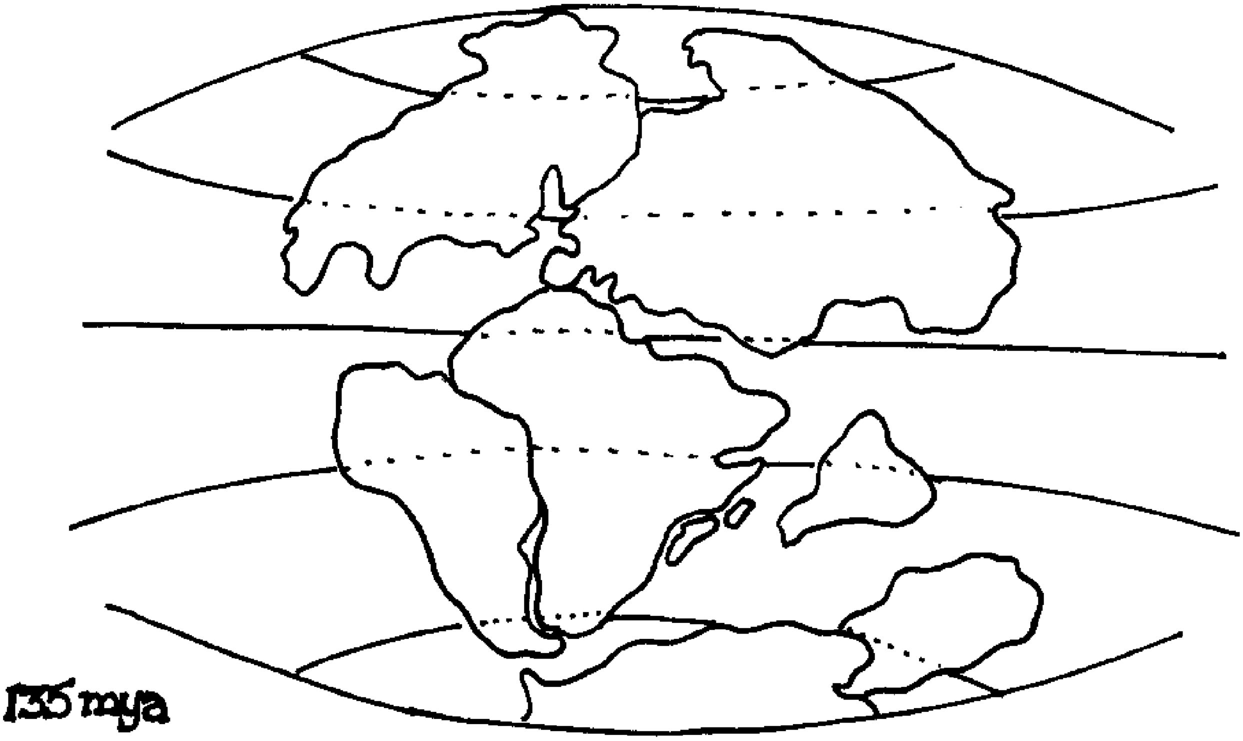


Fig. 6. Mesozoic Movement.



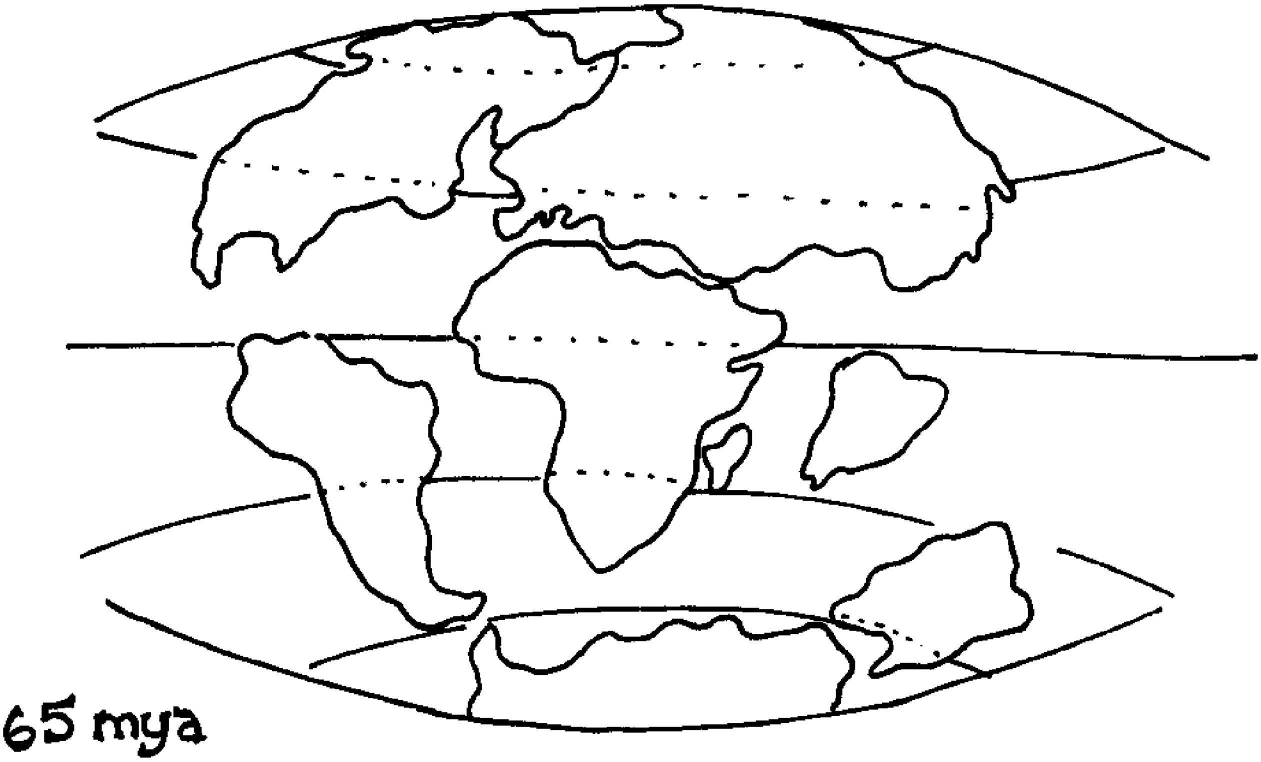
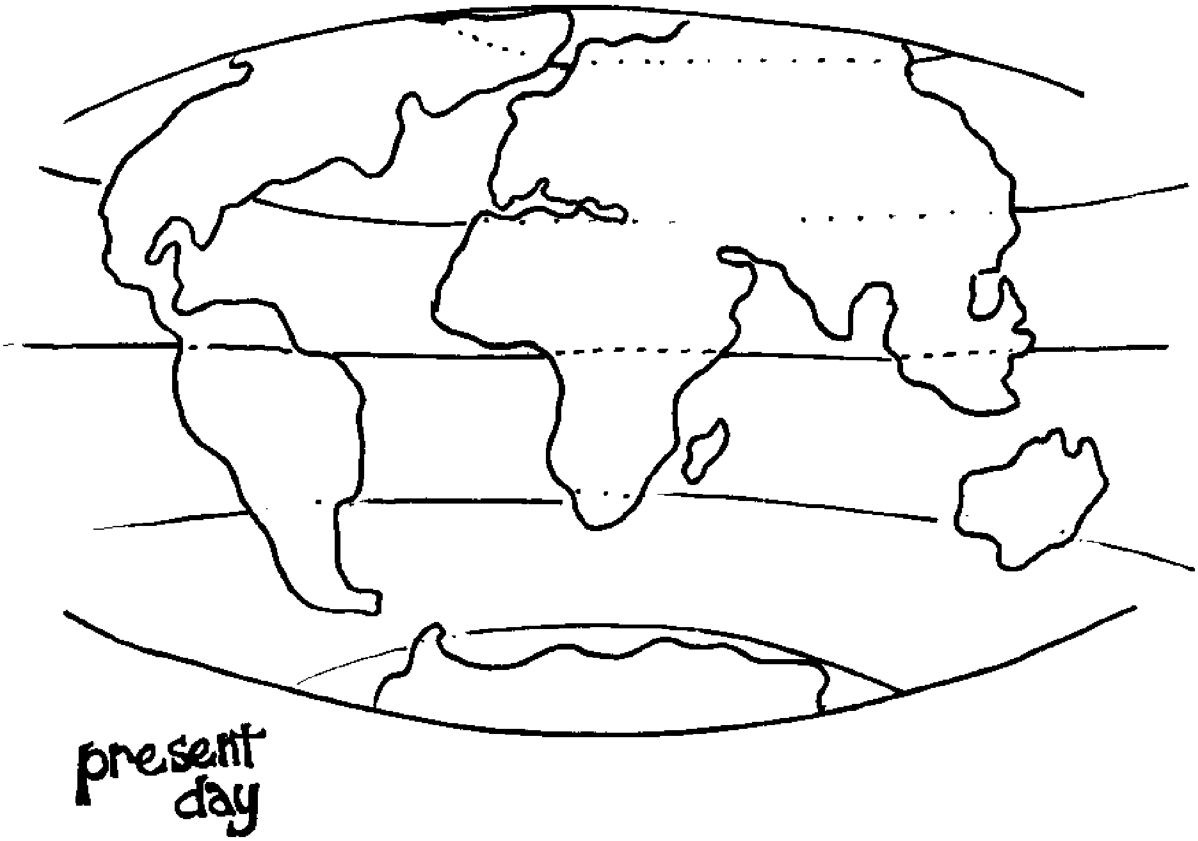


Fig. 7. Present Crustal Configuration.



c. Activities

Bathymetric Contouring - North Carolina's Continental Shelf

1. Objectives:
   1. To make a contour map.
   2. To make a profile map.
   3. To identify the continental shelf and slope.

   Information on ocean depth (Bathymetric data) from soundings relates facts on the structure and features of the ocean floor. Soundings are measurements of the water depth, now usually determined by a technique of echo sounding called "SONAR". During the 1800's and earlier, soundings were made by dropping a knotted line over the side of the ship and measuring the length of line needed to reach the bottom. Some of the words on a chart may be new to students.

   a. fathom: a unit of depth measurement - it is equal to 6 feet or about 2 meters.

   b. Mean low water: the depth of the water level during the average low tide.

   c. contour map (topographic): contour lines are drawn connecting points of equal depth. Contour lines provide us with an idea of the bottom landscape or "seascape". (Note: When contour lines of equal intervals are drawn, the closer they are together, the steeper the slope; the further they are apart, the gentler the slope).

   d. profile map: the side view of the seascape - showing the ups and downs.

   e. continental shelf: an extension of the coastal plain, i.e., it consists of similar material.

   f. continental slope: extending seaward of shelf with steep topography relative to the flat shelf and sea floor, often cut by canyons. It extends down to the continental rise and the ocean basin. (Figure 8)

2. Teacher Preparation:
   1. Provide each student with a bathymetric chart with depths marked on it. (Figure 9) and a profile graph (Figure 10).
   2. Yellow, red and blue crayons.

3. Procedure:

1. Look carefully at the chart of the waters off the coast of North Carolina. The numbers on the chart represent the depth of the water in fathoms (1 fathom = 6 feet) at mean low water.

2. Note that water depth increases from the shoreline. With your finger, trace the 20 fathom depth along the shore from Cape Fear to Cape Hatteras. Notice that it is sometimes quite close to the shore and sometimes is further out marking the presence of shoals and shallow water.

3. With a pencil (in case you make a mistake the first time) - draw a solid line connecting the areas which would be 20 fathoms deep. This line is called a contour line.

4. With a pencil, draw four more contour lines for depths of 50 fathoms, 100 fathoms, 1,000 fathoms, and 2,000 fathoms.

5. The continental shelf is relatively shallow and may be defined by being less than 100 fathoms. Color the continental shelf yellow.

6. The continental slope is quite steep and the water depths increase rapidly in a short distance. It gradually becomes the continental rise and ocean basin. Color the area between 100 - 1,000 fathoms red. Color the ocean floor blue.

4. Discussion:

1. What might be a disadvantage to using a knotted rope to take soundings of the depths? What might be a disadvantage in using "SONAR"? What would be the advantages of "SONAR"?

2. Discuss the importance of bathymetric contouring as it relates to navigation and commercial fishing.

3. What relation is there between water depth and the position of the capes?

4. What advantages would accrue to a state with a wide continental shelf?

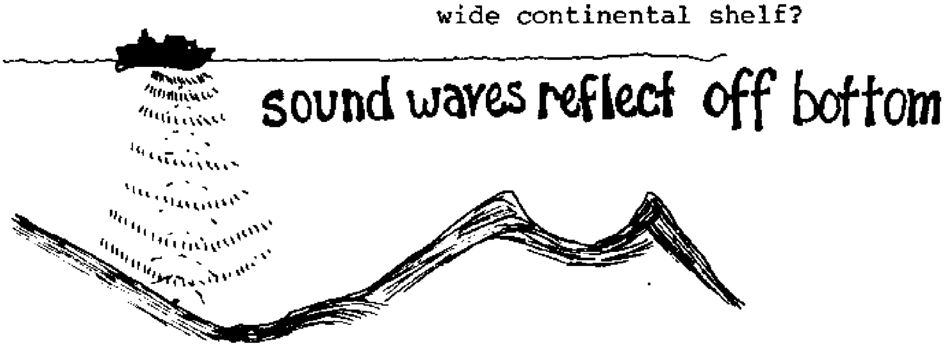
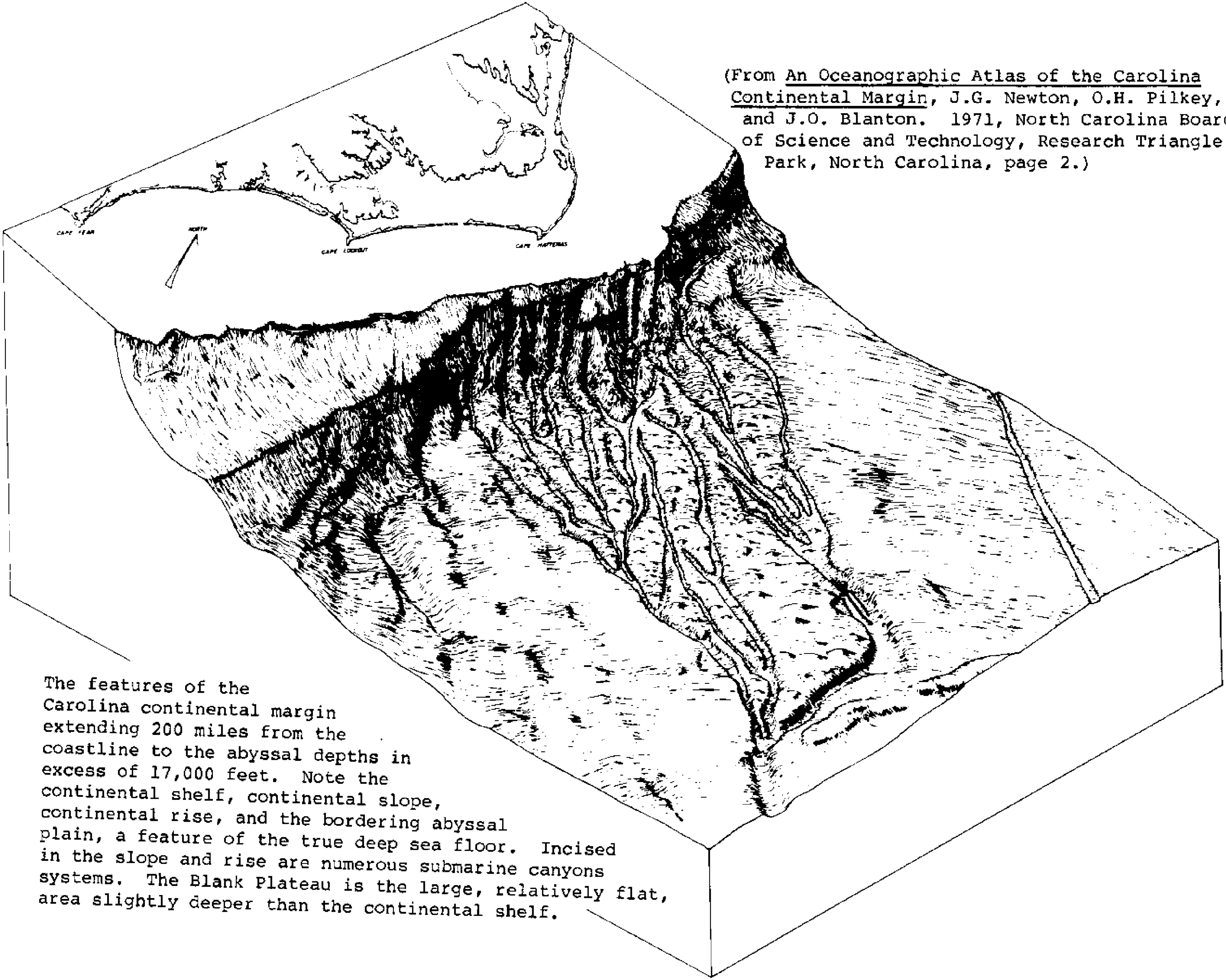


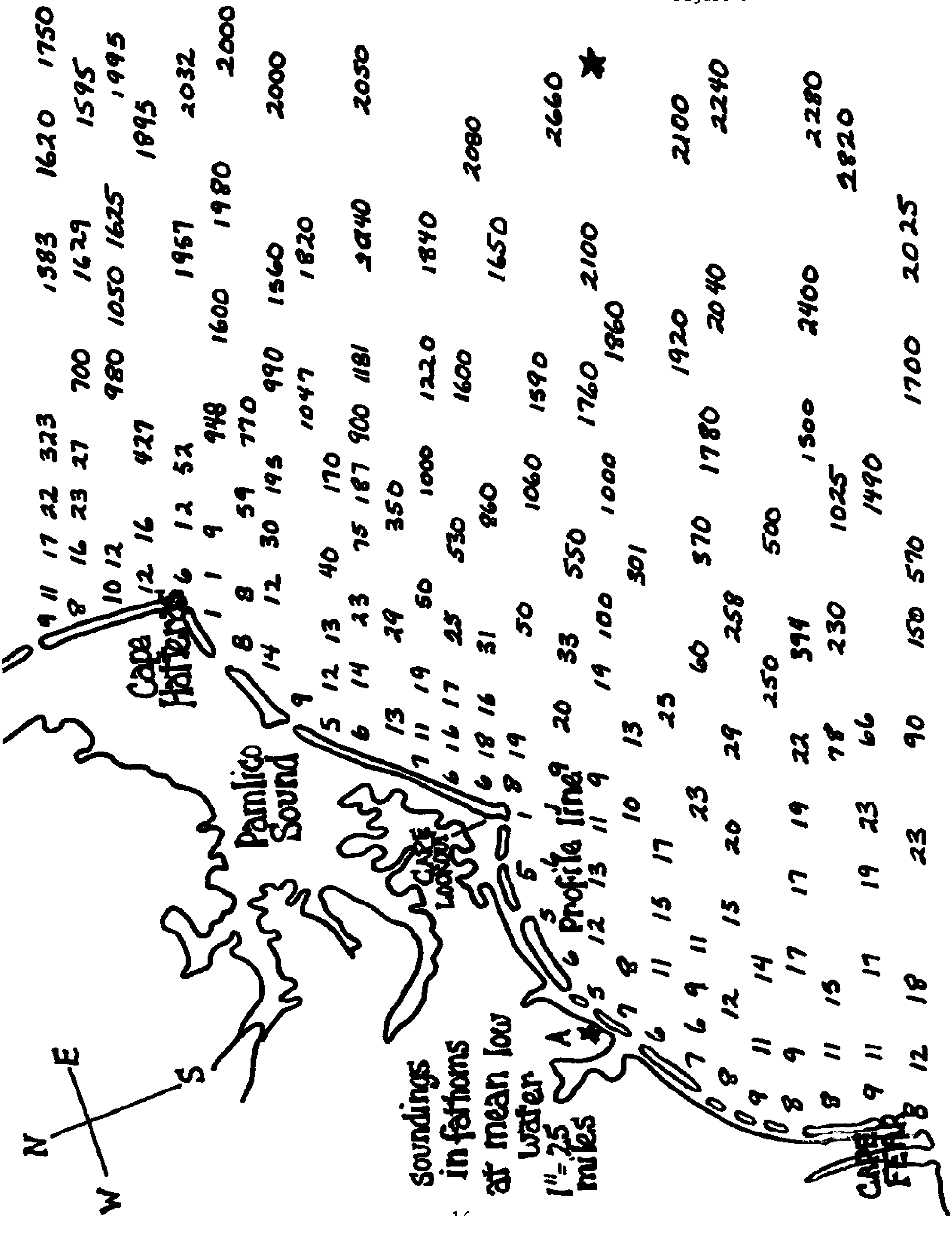
Figure 8

(From An Oceanographic Atlas of the Carolina Continental Margin, J.G. Newton, O.H. Pilkey, and J.O. Blanton. 1971, North Carolina Board of Science and Technology, Research Triangle Park, North Carolina, page 2.)



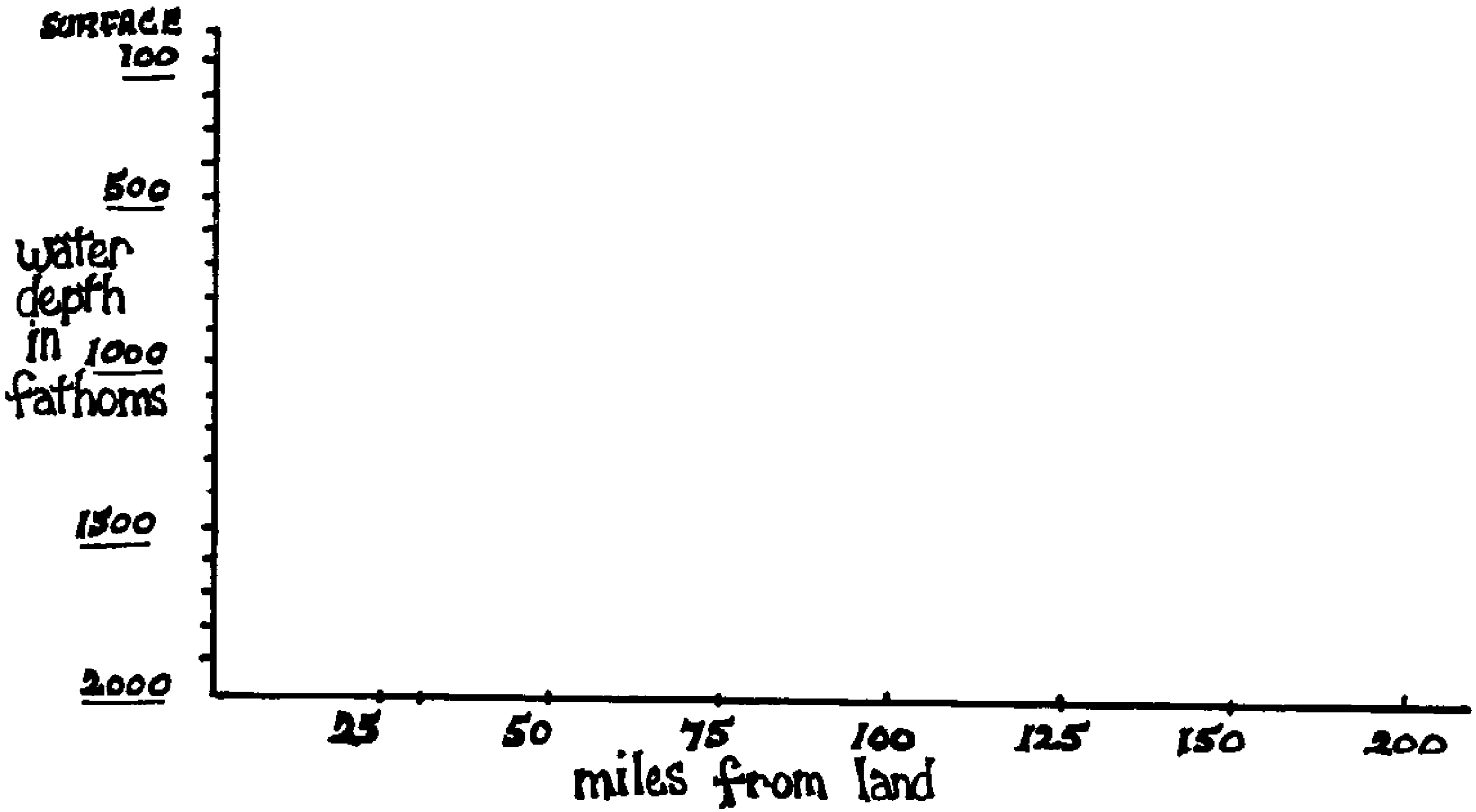
The features of the Carolina continental margin extending 200 miles from the coastline to the abyssal depths in excess of 17,000 feet. Note the continental shelf, continental slope, continental rise, and the bordering abyssal plain, a feature of the true deep sea floor. Incised in the slope and rise are numerous submarine canyons systems. The Blank Plateau is the large, relatively flat, area slightly deeper than the continental shelf.

Figure 9



Soundings in fathoms at mean low water
1" = 25 miles
N
E
S
W
Cape Hatteras
Pamlico Sound
Cape Lookout
Profile line
A
Cape Fear

Figure 10



Profile Chart of North Carolina's Continental Shelf and Slope

1. Label the shelf and slope
2. The deepest part shown is ____ fathoms or ____ feet.
(6 feet = 1 fathom)

Find the hidden words

there are 17 words or phrases hidden away for you to find

```
F Z B A L A M O T L A Q O P
W O U M A P I E D M O N T X F
E F X C D P Z O L P S L E O B C K O
R W F L E A D I N G E D G E J O R P
I M L N G L A J N H I K Z I R A F K
X I U A E A R T H Q U A K E O S Z M
L D M E M C E I D O T H U J N T B A
T O S Y O H F S M A R K I L I A N Z
V C O N T I N E N T A L S H E L F B
S E Q C U A Q A I W I N H I C P G U
L A V A G N U L K P L A T E H L X L
R N F K H S O E H T I W H J E A S K
O R I F T I P V J R N O I R K I E H
F I E C Y J H E B E G K C H T N P O
P D O F A L L L I N E T R O A E K N
E G L B K F H J P C D M U P I M J Z
L E R O S I O N F H G B S L H U O P
M P C R A O T I L T E C T O N I C S
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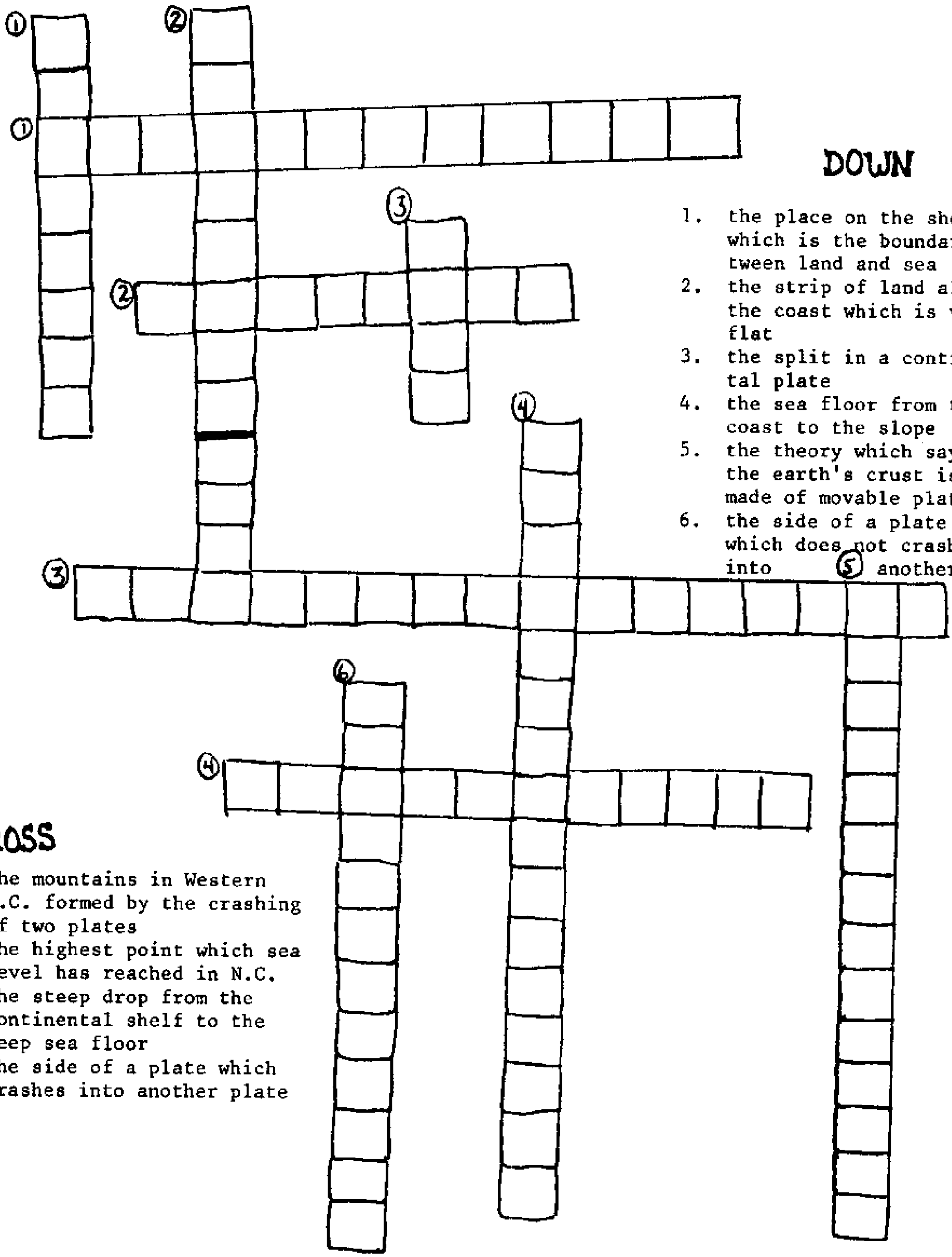


ACROSS

1. the mountains in Western N.C. formed by the crashing of two plates
2. the highest point which sea level has reached in N.C.
3. the steep drop from the continental shelf to the deep sea floor
4. the side of a plate which crashes into another plate

DOWN

1. the place on the shoreline which is the boundary between land and sea
2. the strip of land along the coast which is very flat
3. the split in a continental plate
4. the sea floor from the coast to the slope
5. the theory which says the earth's crust is made of movable plates
6. the side of a plate which does not crash into another one.

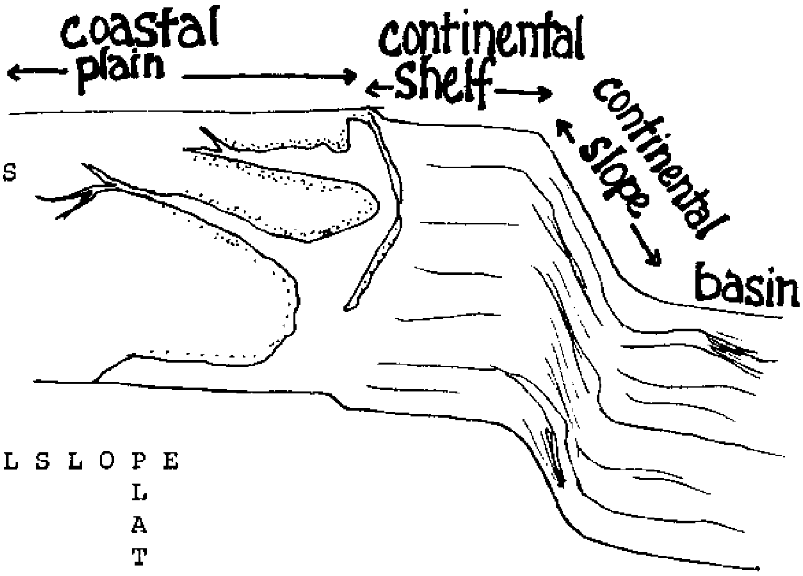
c. Activities

Answer Sheet For Word Games

1. Vocabulary hidden in the hidden-word game

earthquake	coastal plain
plate	fall line
crust	erosion
trench	piedmont
tectonics	sea level
mid-ocean ridge	rift
trailing edge	Appalachians
leading edge	continental shelf
lava	

2. Crossword Puzzle

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S     C
E     O
A P P A L A C H I A N S
L     S
E     T       R
V   F A L L L I N E
E     L       F
L     P       T
      L         C
      A         O
      I         N
  C O N T I N E N T A L S L O P E
                I           L
            T   N           A
            R   E           T
        L E A D I N G E D G E E
            I   T           T
            L   A           E
            I   L           C
            N   S           T
            G   H           O
            E   E           N
            D   L           I
            G   F           C
            E               S
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d. Resources to Use

Films - See appendix for addresses

1. The Land Beneath the Sea (MN-10280): 25 min., color, free loan, Department of the Navy.

2. In the Beginning: 28 min., free loan, U.S. Geological Survey.

3. This Land: 39 min., free loan, Shell Film Library.

4. Continental Drift: 10 min., color, National Film Board of Canada.

5. Sea Patterns, Sea Cycles: "Exploring the Ocean Floor" - 6 sound filmstrips. Cypress Publishing Co. 1763 Garden Avenue, Glendale, CA 91204.

Printed Material

1. Pamphlets available from the U.S. Department of the Interior, U.S. Geological survey. Up to 50 free.

   "Glaciers - A Water Resource"; "Geological Times"; "Landforms of the U.S."; "Our Changing Continent"; "The Great Ice Age".

2. Pamphlets from Encyclopedia Britannica:

   "Earth and Geology" (one free, others 25¢)

3. Placemats - Laminated Charts of North Carolina Coastal Waters available from DEE GEE's, Morehead City, NC $1.25 per mat and 50¢ postage; 10% discount on orders over 25.

4. Project COAST Activity Packet, #302 - Sea Floor Spreading. $2.00

References

1. ISCS. 1972. Probing the Natural World: Part 3. Crusty Problems. Silver Burdett: General Learning Corporation, Morristown, NJ, pp. 1-24. Available for $5.95, excellent explanation of continental drift.

2. Alexander, Tom. 1975. "A Revolution called Plate Tectonics Has Given Us a Whole New Earth". Smithsonian, 5(10):30-39.

3. Dietz, Robert S. and John C. Holden. 1970. "The Breakup of Pangaea". Scientific American, October, 223(4):30-41.

4. Matthews, Sam. 1973. "This Changing Earth". National Geographic, 143(1):1-38.

5. Tailing, Don and Maureen. 1971. Continental Drift. Doubleday and Co., Inc., New York.

Concept 2. Sediment layers in coastal landforms preserve records of past sea level changes and sediment movement.

a. Background Reading

The coastal plain and continental shelf of North Carolina, and the east coast of the United States in general, consists of sediments eroded from the land and limestones formed beneath the sea. The sediments came largely from weathering of rocks in the mountains and on the Piedmont plateau. The limestones originated in shallow seas by processes similar to those occurring near the Bahamas today (deposition of calcium carbonate from corals or algae and subsequent hardening). Thus, both land and ocean processes have contributed to North Carolina's coastal plain. The coastal plain extends from the "fall line", running across North Carolina more or less in the location of U.S. Highway 1 (Henderson, Raleigh, Sanford, Southern Pines) to the shoreline. Coastal material continues to the edge of the continental slope 150-300 miles offshore. Almost 10,000 vertical feet of sediment is at the present shoreline, but this layer of material gets thinner inland toward the "fall line" and seaward toward the deep sea floor.

The sedimentary layers that make up North Carolina's coastal plain and continental shelf have been deposited during the last 100 million years. Unfortunately, the record is not continuous because layers of sediment have been removed during periods of high sea level.

The reasons for the rise and fall in sea level are varied and include the following: (1) differences in the size of ocean basins caused by expansion and contraction of midocean spreading centers (centers with rapid spreading rates occupy larger volumes of ocean basins than do centers with slow spreading rates, and (2) differences in the volume of available water created by freezing and melting of the polar ice caps. In some periods when the ocean basins were small and the volume of water was high, sea level rose to flood the entire coastal plain of North Carolina. In other periods when the ocean basins were large and large volumes of water were frozen into the ice caps, sea level fell to expose all of what is now the continental shelf. One can find fossils of terrestrial animals, such as mastodons, up to hundreds of miles off the present shoreline of North Carolina. During periods of high sea level, limestone formed and sediments at the edge of the continent were reworked and redeposited. During periods of low sea level, new sediments were deposited on top of the limestone and reworked material. Thus, if we dig into the North Carolina coastal plain we find a discontinuous record of ancient marine environments.

An excellent example of sedimentary deposition is found at the Texas Gulf Corporation's open pit phosphate mine in Aurora. Extending to depths of 40 feet are the light yellow, recent sediments no older than 15,000 years. Beneath this layer gray "Yorktown" sediments deposited two to five million years ago extend to about 80 feet; and, further down, the darker grey, phosphate-rich Pungo River sediments deposited five to eight million years ago reach 80-120 feet below the current land surface. The phosphate-rich sediments are now thought to have been deposited when the area was at the edge of the continental shelf and covered by 300 to 600 feet of sea water. Most of these sedimentary layers contain abundant marine fossils that offer mute testimony to the marine origins of eastern North Carolina.

The upper layers of coastal plain sediments in North Carolina are covered with unconsolidated "surficial deposits" ranging between two and thirty feet in thickness. Although the origin of these deposits is unclear, they are probably fluvial (river), possibly with some soil horizons (regolity) scattered throughout. These "surficial deposits" overlie the older rock formations that are described below.

Three different sediment layers formed during the Cretaceous Period (145 million years ago to 65 million years ago) are represented in the southeastern part of North Carolina. These three formations (Middendorf, Black Creek, and Peedee) reflect rising sea level along the east coast of the United States. (Figure 11b). Middendorf sediments are fluvial, Black Creek sediments are estuarine, and Peedee sediments are marine. As sea level rose, these environments moved westward. Thus, estuarine sediments were deposited over fluvial, marine sediments over estuarine, etc. This shoreward progression is recorded in Cretaceous formations of southeastern North Carolina. (Figure 11b).

Recent deposits are exemplified by the estuaries at the coast of North Carolina. These sediments collect in the restricted waters behind the barrier islands. Few sediments currently escape this trap, suggesting that eventually sounds behind the barrier islands will be completely filled in with sediments. (Table 1).

The economic assets of coastal plain sediments can be divided into three major areas: phosphate mining, sand and gravel mining, and limestone quarrying. These operations contribute significantly to the economy of the county in which they are located and the sediments constitute a major portion of the mineral assets of North Carolina.

Phosphate ore is mined from open pits by the Texas Gulf Corporation near Aurora on the Pamlico River. Drag lines are used to remove upper layers, exposing the phosphate rich rock from the Pungo River Formation of the Miocene Epoch, approximately 80-120 feet below the surface. The phosphate ore is processed for use in fertilizer.

Sand and gravel are mined by several companies for local use.

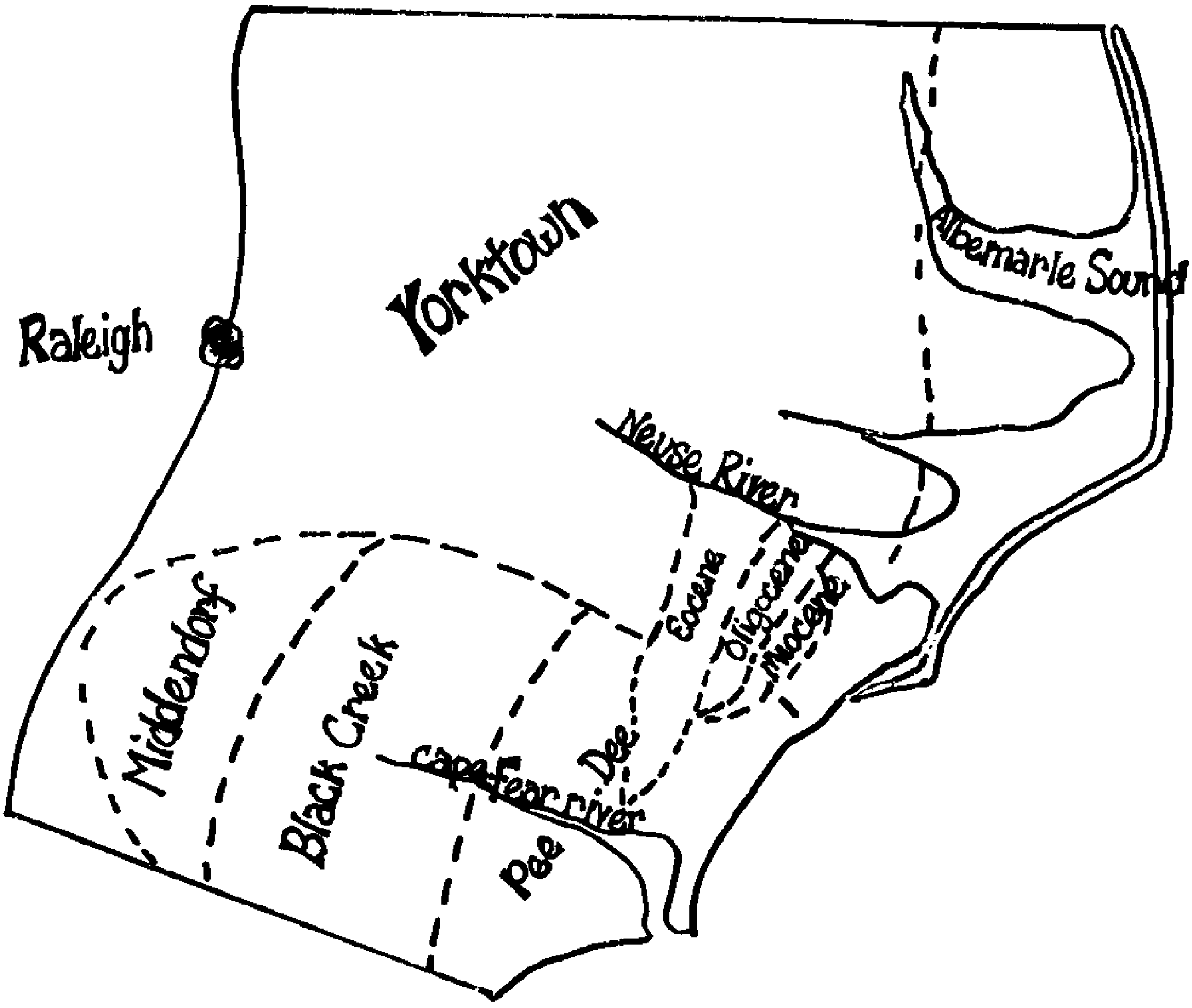
Limestone is mined by Martin-Marietta Aggregates near Castle Hayne. The hard Eocene limestone from the Castle Hayne formation is used in paving and building. The open pit exposes the limestone which is blasted out. Close by, Ideal Cement Company mines softer limestone called micrite (limestone composed of mud-sized grains of carbonates) which is used for portland and masonry cement. Ideal Cement Company removes micrite from the level above the harder limestone layer mined by Martin-Marietta. The harder limestone acts as the floor for mining equipment.

Another mineral with long range potential is monazite. Monazite is a heavy, igneous mineral which eroded, washed to ancient beaches, and b came part of some sedimentary sand layers. Monazite is a source for thorium which would be important if breeder nuclear reactors develop as an energy source.

Two other coastal resources are being considered for utilization: ancient oyster shells and peat. Albemarle Sound has great quantities of buried oyster shells which could be dredged and processed into a high grade lime. First Colony Farms Corporation is researching techniques to extract peat (a fuel source) from pocosins and freshwater swamps.

Location of geologic formations on the Coastal Plain

Figure 11.



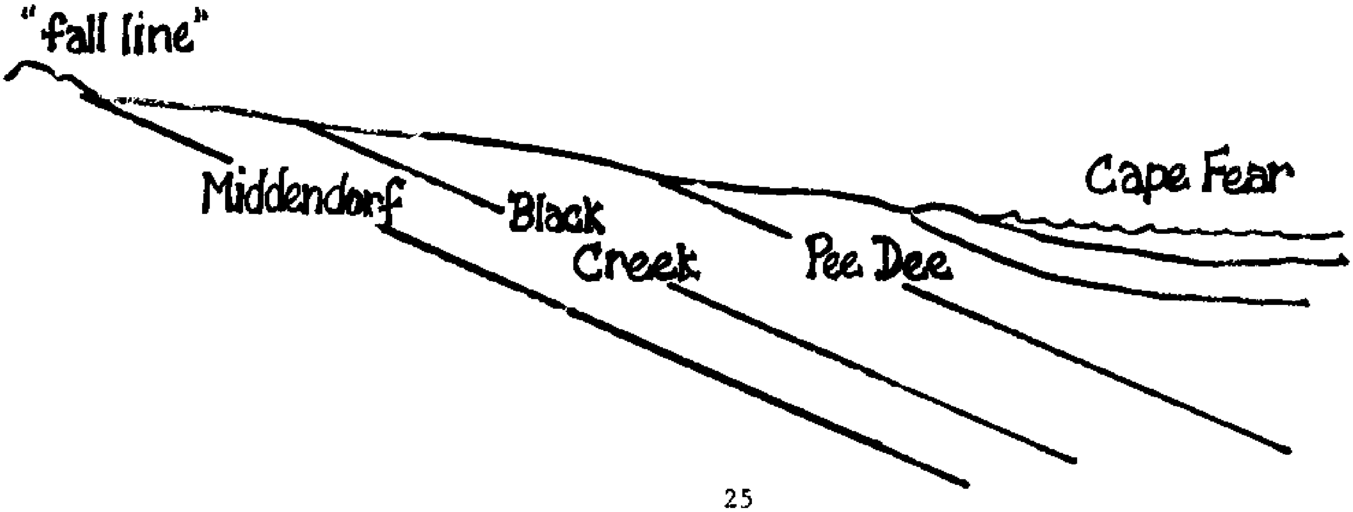


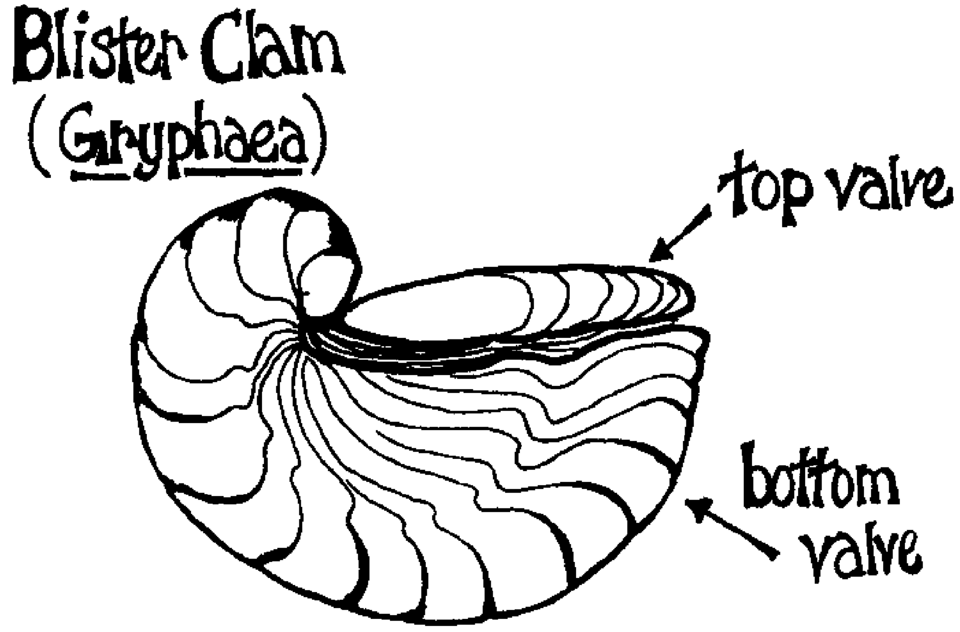
Table 1. Geologic Formations on the Coastal Plain of North Carolina showing materials, some fossil locations, and sediment origin. Figures 12, 13, and 14 illustrate several index fossils. (Information adapted from communication with Dr. Walter Wheeler, UNC-CH)

Unit/Formation	Material Type	Fossils	Location
Mesozoic Cretaceous (ca 145-65 million years ago)			
Lower Cretaceous Cape Fear	Marine mud/sand	No fossils	Below Fayetteville; follow river by boat and look at banks. Cumberland Co., relatively unimportant formation
Upper Cretaceous Middendorf (Tuscaloosa)	Fluvial, lenses of sand and clay, unconsolidated	Poor fossils	Southern Pines, Sanford, Fayetteville in road cuts. Important formation found at the railroad cut at Spring Lake, Rt 87, north end of Fort Bragg
Black Creek	Fluviomarine, estuarine bays unique stratification of laminated clean sand and clean dark clay. Some amber and pyrite.	Full of both lignitized and petrified wood (coastal forest). Has holes bored by marine shipworms. Found the jaw of Mosasaur, giant marine dinosaur, and a terrestrial lizard, Gohgosaurus. Remains of crocodiles present.	Elizabethtown area on Cape Fear River. 10 miles SE of Fayetteville, 1 1/2 miles from county line off Rt. 87.

Unit/Formation	Material Type	Fossils	Location
Upper Cretaceous Pee Dee	Marine, muddy sand	Many shells of coiled oysters Exogyra and thick shelled oyster Ostrea pratti and echinoids. A very few ammonites	Rt. 141 bridge over Cape Fear River near Rigelsville. Suffleton, NE of Goldsboro. Martin-Marietta Quarry, 4 miles east of Castle Hayne (crushed rock).
(Rocky Point Member)	Alternating sand-limestone and sand.		
Cenozoic - Tertiary			
Paleocene (ca 63-58 mya) Beaufort Formation		Brachiopod, Olenoothyris, blister clam, Gryphaea vesicularis	Found in deep wells, exposed in spoils of channelization. On Mosely Creek off Neuse River 10 miles NE of Kinston on county line of Craven and Lenoir. Only spot in state.
Eocene (58-36 mya) Castle Hayne Formation	Fine lined lime mud-micrite (cement) limestone	Many fossils, sea urchins	Ideal Cement Co. quarry 5 miles east of Castle Hayne. Also found on beach in groins as great rocks at Ft. Fisher. Town of Maple Hill.
Oligocene (36-22 mya) Trent Formation	Sandy-limestone and limestone	Fairly many fossils one spot has a mass of barnacle plates	Along Trent River from New Bern to Trenton
Miocene (22-6 mya) Lower Belgrade Beds		Molds of clams, barnacles, giant oyster, Crassostrea gigantissima	Belgrade quarry of Martin-Marietta, north abuttment of railroad bridge across Trent at Pollacksville US 17.
Mid. Pungo River	Commercial phosphate, sand		Subsurface only, except in Texas Gulf Pit

Unit/Formation	Material Type	Fossils	Location
Pliocene (6-2 mya) Yorktown or Duplin Formation	Marine sands	Some fossils, coral thickets	Exposed on Chowan River near Albemarle sound. Near Edenton on Meherrin River. Best known at Magnolia Well, Magnolia. Also near Cape Fear River. (Sir Charles Lyell, 1840's). Usually under 40 ft. of surface sediment.
Cenozoic-Pleistocene (2,000,000-6,000 years ago)			
Lower Pleistocene Croatan Formation to N Waccamaw Formation to SE		Panope - geoducks	Best along the south bank of Neuse, SE of New Bern. Also, Old Dock, Columbus Co. Town Creek, Brunswick Co., Walker's Bluff, Lower Cape Fear River
Talbot Formation or Flanner Beach Formation	Marine	Dinocardium, Rangia, corals	Croatan National Forest campsite
Pamlico		Fossils less than 120,000 years old	Deep ditches in coastal plain. Intracoastal Waterway near Carolina Beach and housing developments.
Surficials	Fluvial deposits with some soils which are dominantly sandy with strongly developed A and B soil horizons.		Scattered over everything, 2-30 feet deep

Figure 12


Blister Clam
(Gryphaea)
top valve
bottom valve

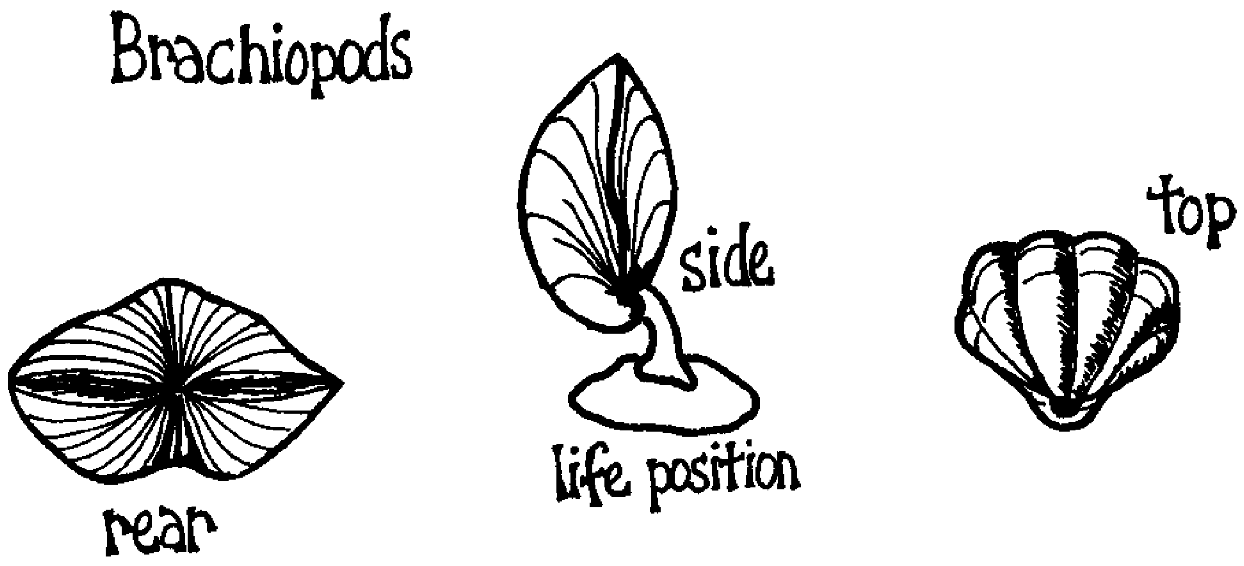
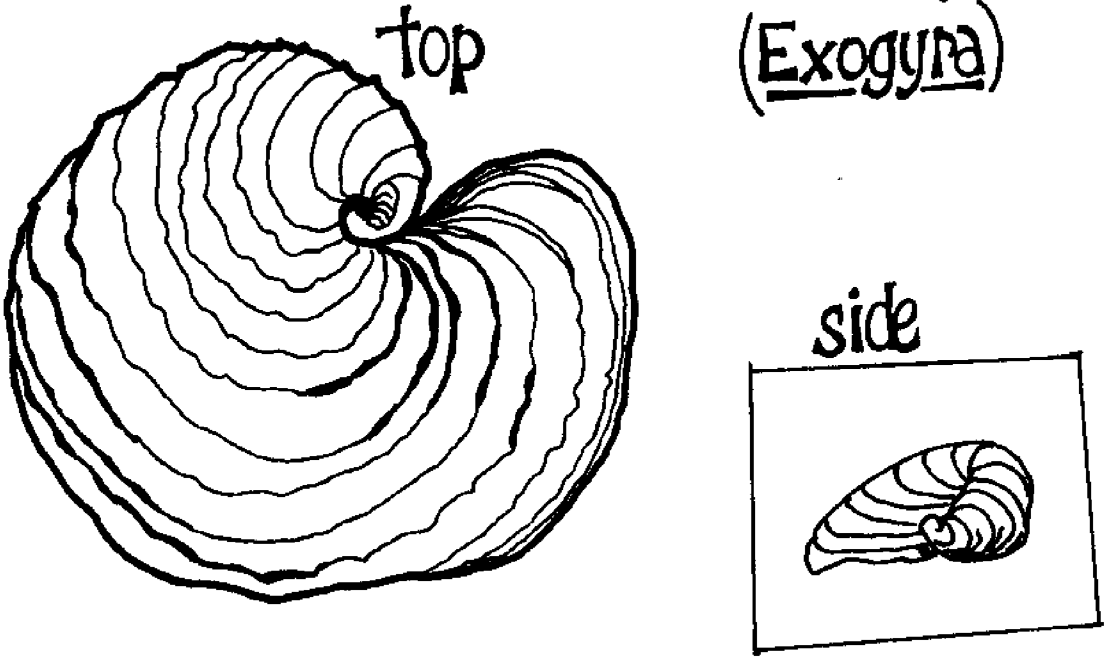

Brachiopods
side
life position
top
rear

Figure 13


coiled oyster
(Exogyra)
top
side

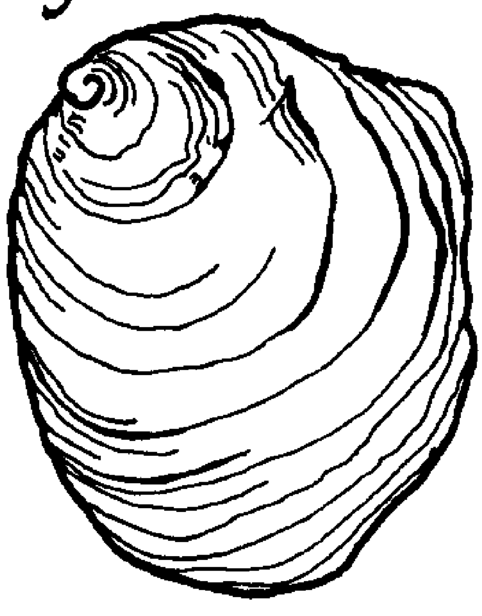
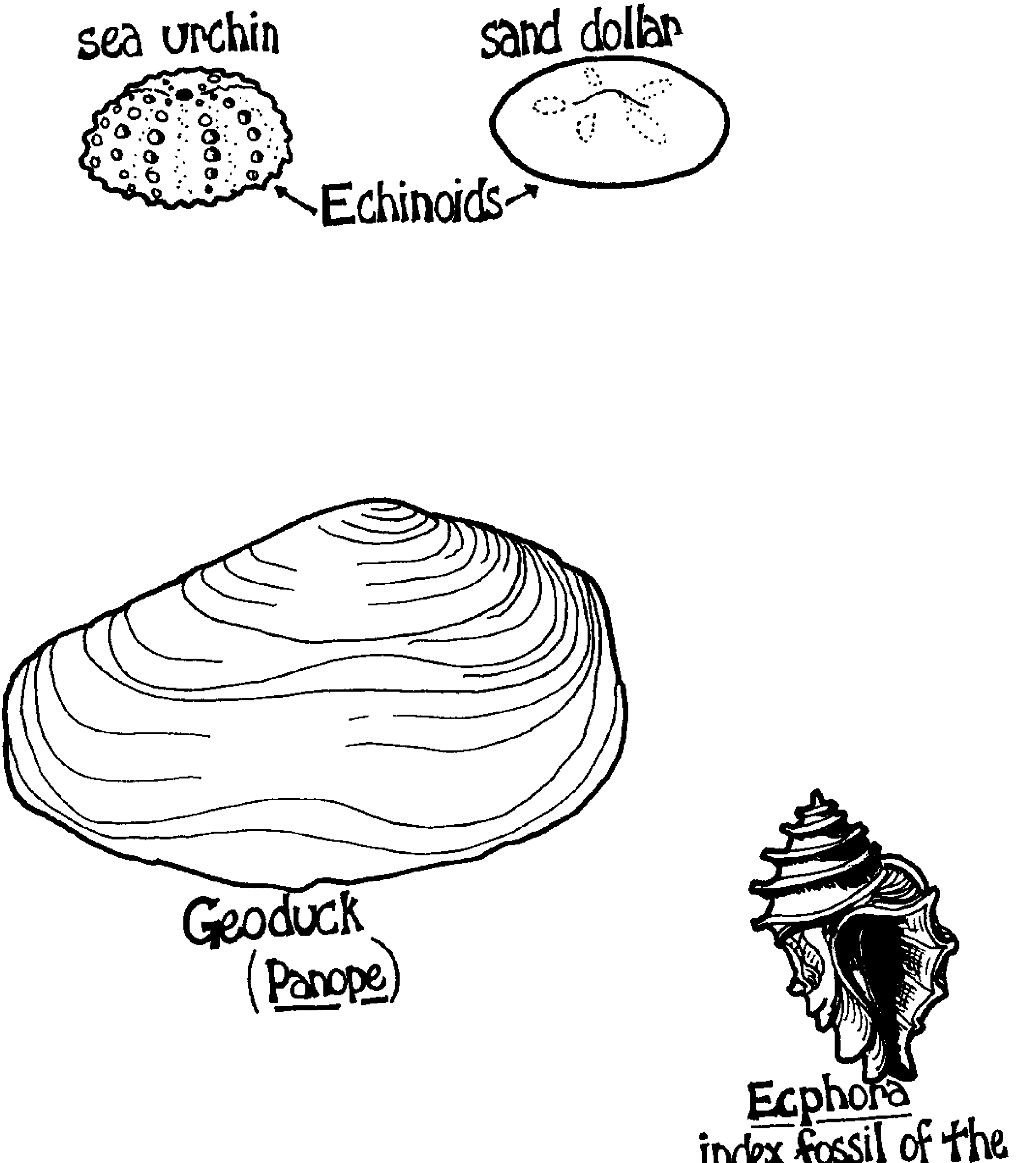

thick-shelled oyster
(Ostrea pratti)

Figure 14



sea urchin
sand dollar
Echinoids
Geoduck
(Panope)
Ecphora
index fossil of the
Yorktown Formation

b. Vocabulary

Coring - the process of recovering sediment samples by driving a hollow tube into the sediment layers.

"Fall-Line" - separates the Piedmont from the coastal plain region, usually marked by a change in topography such that rivers have waterfalls at this point.

Fluvial - having to do with rivers

Fossil - the natural preserved evidence of past life which can exist in the form of molds, tracks, burrows, actual shells or bones, reliefs, and mineralized remains

Limestone - a sedimentary rock made of calcium carbonate (fizzes with dilute HCl) formed where calcareous skeletons are cemented by $CaCO_3$.

Sediment - particles of organic and inorganic matter that accumulate in unconsolidated form.

Surficial deposits - the sediments covering the underlying rock layers which make up the coastal plains, probably deposited by river. These surficial deposits obscure the lower layers except at man-made or river cuts or outcrops.

c. Things To Do

Exploring Recent Sediments

1. Objectives: 1. To simulate sediments layers.

   2. To experiment with a sampling technique of coring.

   3. To try to interpret cores; e.g., source, organisms.

2. Background

All things in sea water, whether a particle of dust blown from land, a decaying piece of marsh grass, or a shark, eventually end up on the sea floor. So scientists turn to the sediments to study ocean history.

Supposing you could dive down to the bottom beneath the ferry landing at Ocracoke Island, what might you find? tin can, silt, sand, decomposing papercups. Some things decay too quickly to become part of the sediment. Particles are characteristic of shallow water while other particles are found only on deep bottom areas of the ocean floor. So you can see, sediment composition depends on where you collect.

What's in sediment? Sediment collects as particles "rain" down to the bottom. In North Carolina, sediment is predominantly composed of sand: sand eroded from inland mountains. Then, depending on where you collect, you will find different additions. For example, beach sediments often contain broken shells (carbonates) while marsh sediments have more decayed plant material - think of the black, smelly mud of the marsh.

How do we collect sediments? Scientists often try to punch a pipe into the sediments and keep the inside or core. Coring keeps sediments in the order in which they were deposited. This core may be just a few feet long from a gravity corer (the weight on the pipe pushing it into the "mud") to a thousand feet long from a drilled core (similar to well drilling).

3. Teacher Preparation:

   1. For each team of students or class demonstration, collect some containers of different colored "dirt", e.g. clay, mud, colored sands, ground up shells, ground up leaves, glitter. Two more containers to hold layers of sediment - milk

cartons for example. Several plastic straws or disposable pipettes with tips cut off. Glass stirring rods; pencil (core pushers).

2. Organize teams composed of two sets of students: one to make sediment layers and one to core the sediment and analyze. Competition can be organized to see which team analysis is most correctly interpreted.

3. Procedure:

1. One set of students with the "sediment" and containers makes up two different sediment layers in the containers.

2. Record the order and their interpretation of how the layers got there.

3. Saturate the layers with water.

4. The second set of students are the scientists and have their straw "corers". Push the corer into the container, hold the top tight with fingers, and extract the "core". Using the stirring rod or pencil, push the sediments out one end onto a creased sheet of paper.

5. Now comes the analysis. Record the number and make-up of the sediments, and perhaps make some attempts at the environment of the samples - quiet, marshy areas, beach sediments with shells.

4. Discussion:

1. Where do sediments come from? Most from land erosion; some from sea deposition of calcium carbonate which makes limestone.

2. What might cause the layers of sediments to be different? Different type of deposited material due to source or position, e.g., river sediment first drops out sand, then silt.

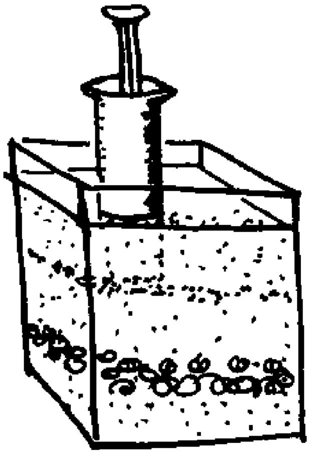
3. What are some problems that scientists might have in taking cores and in interpreting them? Technical problems of too much sand or rock. Also, some layers will be absent if these have been exposed to erosive forces during low sea level periods.

c. Things To Do

Coring the Sound

1. Objectives:
   1. To understand that today's estuarine sediments are a product of materials brought by rivers from different upland sources over a long period of time.
   2. To experiment with one method of studying sediments - coring.
   3. To be able to identify simulated sedimentary layers by observing characteristics of color, texture, etc.

2. Teacher Preparation:
   1. Prepare a stream table for each group (one can use a roast pan, line a shoe box with plastic, etc. The object is to have a watertight container with an overflow opening. The box is set on an angle.)
   2. Prepare three types of "sediment". You can spray paint sand different colors, use sand which is already colored, or use materials with differing textures, i.e. clay, crushed shells, sand, crushed rocks.



   3. A source for water flow is needed - a rubber hose from a faucet or an elevated container with a rubber hose as a siphon with a "pinch clamp" regulator.
   4. A waste water catcher for the overflow.
   5. One syringe with the end cut off so the cylinder has a uniform diameter.

3. Procedure:
   1. Set the water table box on a rather steep angle (30^{o}).
   2. Arrange the three sources of sediments at the upper end.
   3. With the rubber hose, slowly water down one pile of sediment so that it collects in the lower angle of the box. Then, proceed to repeat this process with the second and third piles of sediment, allowing the sediment to form layers in the bottom angle. (Note: If you use materials with differing textures or weights, wash the heaviest down first for best results.) Enough sediment should be used so that the layers accumulate up to the overflow hole.

4. Take the syringe, draw the plunger partially back, insert it carefully into the layers, withdrawing the plunger as needed. When it hits bottom, pull the syringe "corer" carefully from the layers (hopefully, the vacuum will keep the sediment layers in place). Either observe the layers within the syringe or extrude the layers into a creased sheet of paper for analysis.

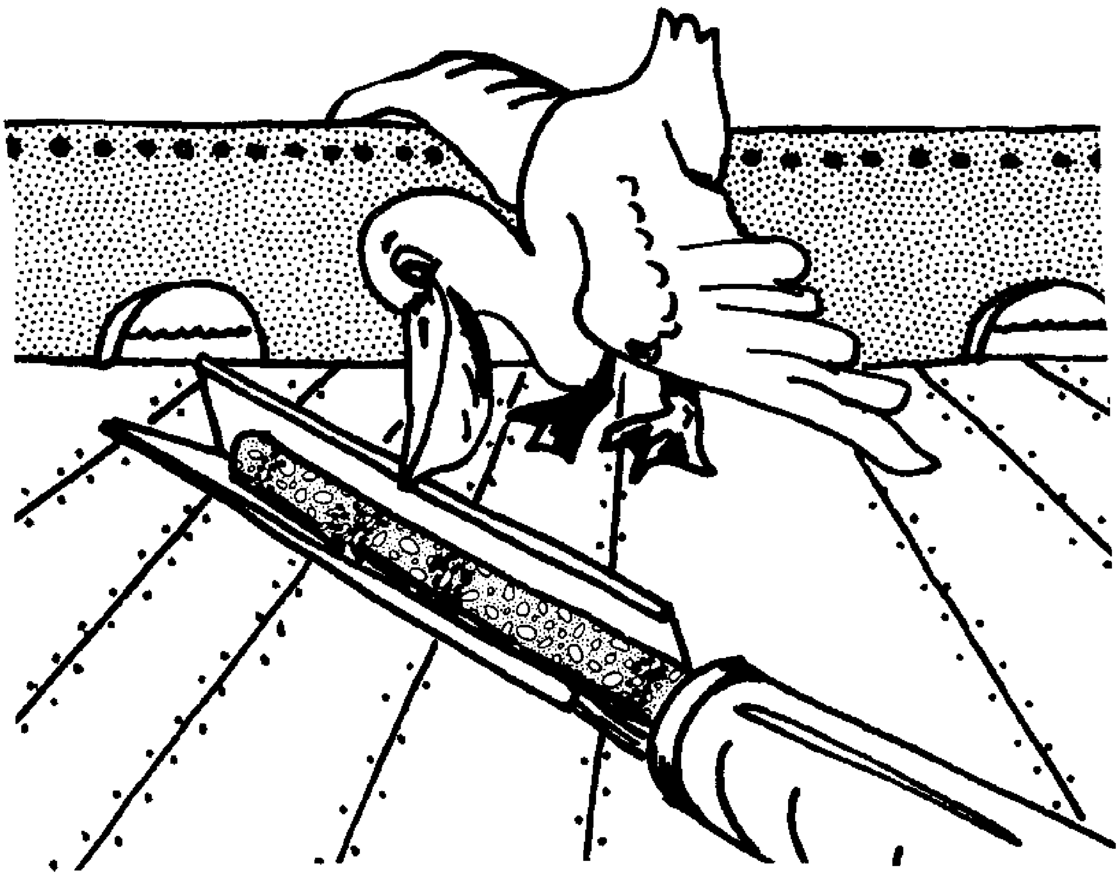
5. Record the analysis.

4. Discussion:

1. Why do you think that rivers might carry different sediment types at different times in geologic history? Sediments from glaciers, mountains, volcanos, swamps may have flowed out with rivers.

2. If the rubber hose represents the river flow, what does the angle of the box which collects the sediment represent? Angle of land.

3. Why are cores a useful tool in determining the history of the coastal area? Scientists have learned to interpret the layers in a core in relation to environmental conditions.



c. Things to Do

Making Marine Fossils

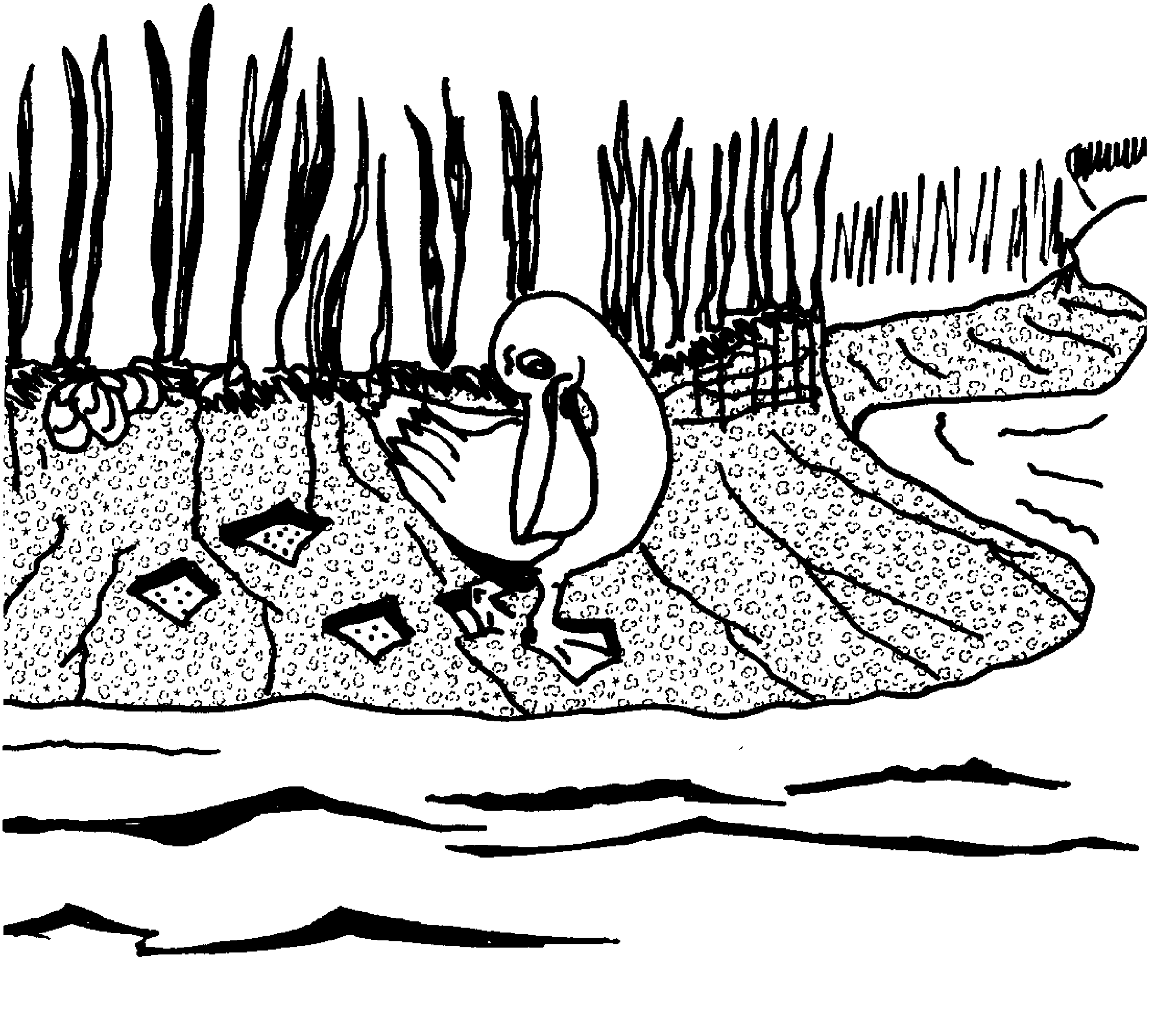
1. Objective: To construct fossils of the imprint and mold-types fossils

2. Teacher Preparation:
Plaster of Paris (molding material which will harden); Modeling Clay; Vaseline; Small pan, paper cup or plate; Some "fossil material" like shells, twigs, bones, etc.

3. Procedure: To make an imprint fossil:
   1. Mix up a batch of Plaster of Paris with water to form a thick mixture.
   2. Pour the mixture into a cup or plate container until it is about an inch thick.
   3. Coat the "fossil" with vaseline to prevent sticking and place it in the partially hardened Plaster of Paris.
   4. Let it continue to harden and then remove the object.

   To make a mold fossil:
   1. Put the modeling clay into a container.
   2. Press the solid object into the clay - you may wish to make a pattern.
   3. Lift the object out carefully.
   4. Into this depression, pour the Plaster of Paris and water mixture.
   5. Let it harden, then take it carefully out of the clay.

4. Discussion:
   1. What do you think happened to the real animal or plant which leaves an imprint or mold fossil? (decays)
   2. In order for a marine fossil to be formed, what do you think the surface of the bottom has to be like? (Experiment with some natural materials like solid rock, gravel, fine clay, sand.) (mud, sand)



3. What would have to happen to Pelican Pete's mud marks for them to become fossil imprints? (Depression must fill with mud, other layers of sediments deposit on top of marsh bank in rising sea level; then all layers lithify or become sedimentary rock.

c. Things to Do

Making a Coastal Plain Time Line

1. Objectives:
   1. To be able to see the amount of time needed to form what is called our coastal plain.
   2. To become familiar with the period and epochs of geologic history. Figure 15.
   3. To review the fossils found in North Carolina.

2. Teacher Preparation:
   1. Provide a continuous roll of paper or string with tags. This line is based on a 30-meter length, but could be modified for shorter spaces. Provide students with a copy of time chart presented in the background reading (Table 2) and a centimeter ruler.
   2. The time line provides measurements; this could be worked out by students as a math exercise.

3. Procedure:
   1. Roll out 30 meters of paper or string. The beginning of the roll is the base of Cretaceous. We have left out a lot of time if you look on a complete geologic history chart. The time is 145,000,000 years before the present (BP).
   2. At each section, write in the Period and Epoch and indicate what marine life was present in North Carolina's waters.

4. Discussion:
   1. What is the period in which we are now living? Recent.
   2. Do a little library research. How long has man been on the time line you have created? Mark that spot.
   3. Discuss what types of organisms may have been living in the past and yet their fossilized remains are absent.
   4. On the time line, mark the points when the barrier islands might have formed. Pleistocene.
   5. Compare this time line to one which includes all eras - e.g. Paleozoic Era, Mezozoic Era, and Cenozoic Era.

5. Important Points:

1. Recent History (last 6,000 years) occupies only 1/8 cm out of 3,000 cm.

2. Cretaceous Period occupies over half the time line.

3. Man occupies only a small part of time. Cavemen were Pleistocene, earliest evidence is from Pliocene.

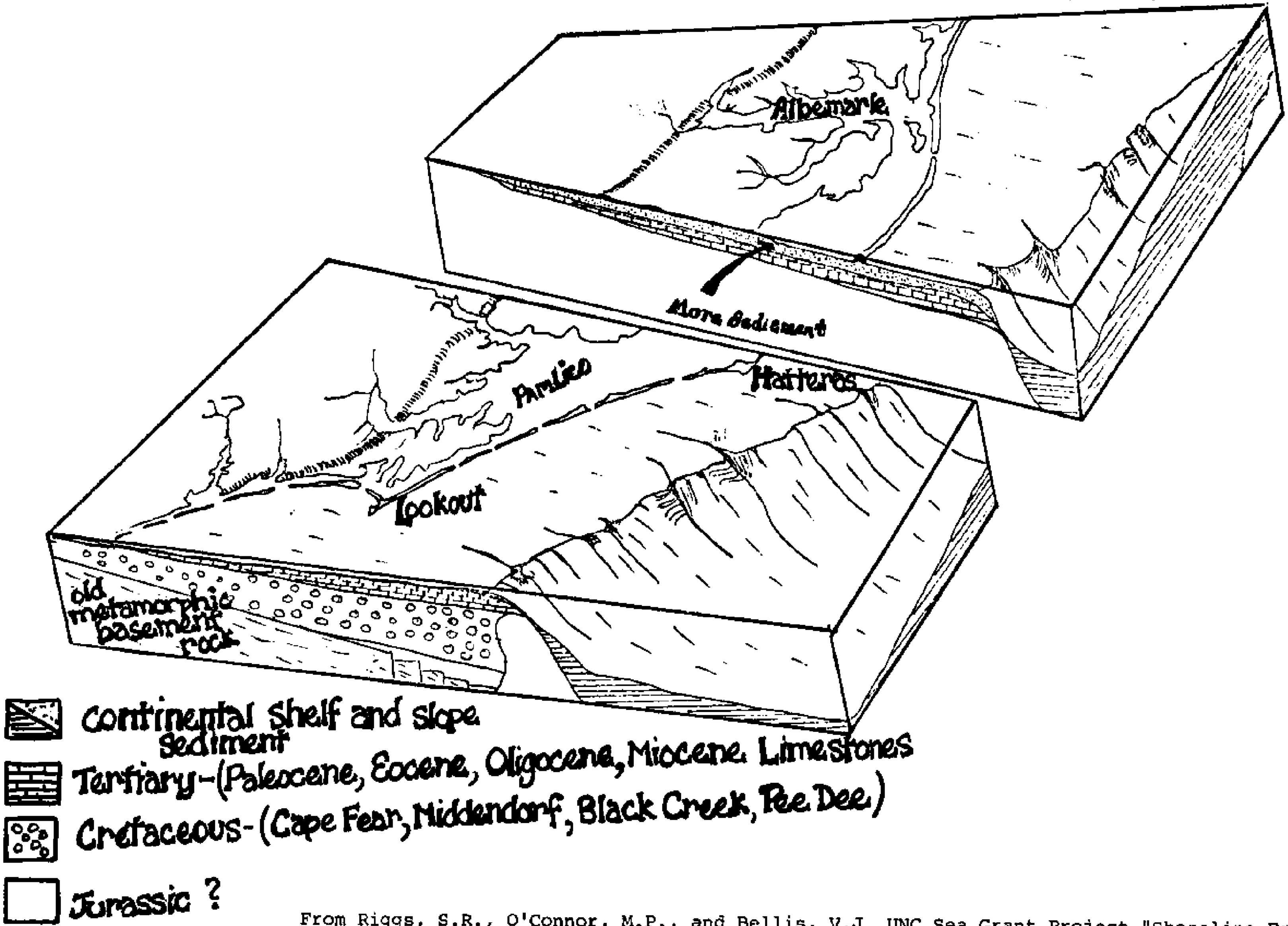
(Table 2) Time Chart

PERIOD	LENGTH OF PAPER	YEARS BEFORE PRESENT
Recent	1/8 cm	0 NOW
Pleistocene	29.5 m	6,000
Tertiary		
Pliocene	28.75 m	2,000,000
Miocene	25.5 m	6,000,000
Oligocene	22.5 m	36,000,000
Eocene	18 m	58,000,000
Paleocene	17 m	65,000,000
Cretaceous		
Base of Cretaceous	0 m	145,000,000

Scale 48,000 years = 1 centimeter

Figure 15

Comparison of sediments north of Cape Hatteras and south of Cape Lookout



From Riggs, S.R., O'Connor, M.P., and Bellis, V.J. UNC Sea Grant Project "Shoreline Erosion and Acretion -- A Process Response Classification of Estuarine Shore Zone Environments of North Carolina.

Find the hidden words

there are 10 words or phrases hidden away for you to find

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F Z B A L A M O T L A Q O F
W O U M A S E D I M E N T O F
E F X O L O Z O L P S L E S B C K O
R W F L E U D K N O E Q G S J O R P
I M L N G L A J N H I K Z I R A F K
X I U A E Z R H H Q B A K L O S Z M
L D V E M C E I D O T H U J N T B A
T O I Y O H F S M A R K I L I A N Z
V C A N T I N E N X C L A Y O L F B
S E L C U A Q A I W I N H I C P G U
L O V A G N U L K P L U T E H L X L
R N F K M I N E R A L W H J E A S K
O R Q F T I P V J R Y O I R K I E H
F I E C Y J H E B E P K C H T N P O
P D O F A L L L I N E T R O A E K N
E G L B K F H J P C D M U P I M J Z
L I M E S T O N E H I B S L H U O P
M P C R C O R I N G E O T P N L C S
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c. Things To Do

"Where is the Word?" -- A Review

Objective: To review the terminology of this section on sediments

Teacher Preparation:
Duplicate the "Seek and Find" game on the preceeding page and the definition blanks. You can fold the page to eliminate the answers.

Procedure: Search for the ten hidden words in the jumble of letters, then match them with these definitions.

1. Collecting long tubes of sediment involves this process __________
2. The preserved remains of past life __________
3. Dirt, sand, and mud that drop on the bottom __________
4. The boundary between land and sea surface __________
5. The very flat land between the coast and Piedmont __________
6. A sedimentary rock made of calcium carbonate precipitated in deep water __________
7. The highest point to which the sea has risen __________
8. Having to do with rivers __________
9. Very fine particles of sediment __________
10. What chemical compounds rocks are made of __________

CORING

FOSSILS

SEDIMENT

SEA LEVEL

COASTAL PLAIN

LIMESTONE

FALL LINE

FLUVIAL

CLAY

MINERALS

d. Resources to Use

<u>Films</u> - See appendix for addresses of distributors

1. History Layer by Layer: 23 min.; color; McGraw Hill.

2. The Fossil Story: color; free loan; Shell Film Library.

<u>Printed Material</u>

1. Geologic Map of North Carolina: Available from the Department of Conservation and Development, Raleigh, NC.

2. Newton, J., Orrin Pilkey and Jack Blanton. 1977. <u>The Oceanographic Atlas of North Carolina</u>. Write to : NC Board of Science and Technology, Research Triangle Park, NC 27709. $4.64.

<u>References</u>

1. ISCS. 1972. Probing the Natural World: 3: Crusty Problems. Chapter 7: The Formation of Layered Sediments, pp. 52-57. Recommended highly.

2. Shephard, Francis P. 1968. <u>The Earth Beneath the Sea</u>. Athenium, NY. Revised paperback edition.

3. U.S. Bureau of Mines. 1973. Mineral Yearbook. Available in some university libraries; also available from the Superintendent of Documents; U.S. Government Printing Office, Washington, D.C. 20402

Part B. Coastal Environmental Systems

Concept 1. Barrier islands develop when the ocean shapes coastal sands.

a. Background Reading

North Carolina's coastal shoreline is characterized by three types of environments: the mainland with its rivers and fringing marshes; the sounds; and the barrier islands. These 3 areas are interrelated by water which both exchanges sediments and organisms and mixes salinity and nutrients in the system. These coastal features have often changed due to inlet shifts, sediment deposition and erosion, and sea level fluctuations. In order for us to effectively manage the coastal area, it is important for us to understand some of the processes which shape this river-sound-island system.

The open sea meets North Carolina at landforms that geologists call barrier islands. The most prominent of these are the Outer Banks, extending from the Virginia border to Cape Lookout, but barrier islands continue southward along the coast to the South Carolina border. These islands absorb the sea's energy and thereby shelter inshore waters and the mainland coast.

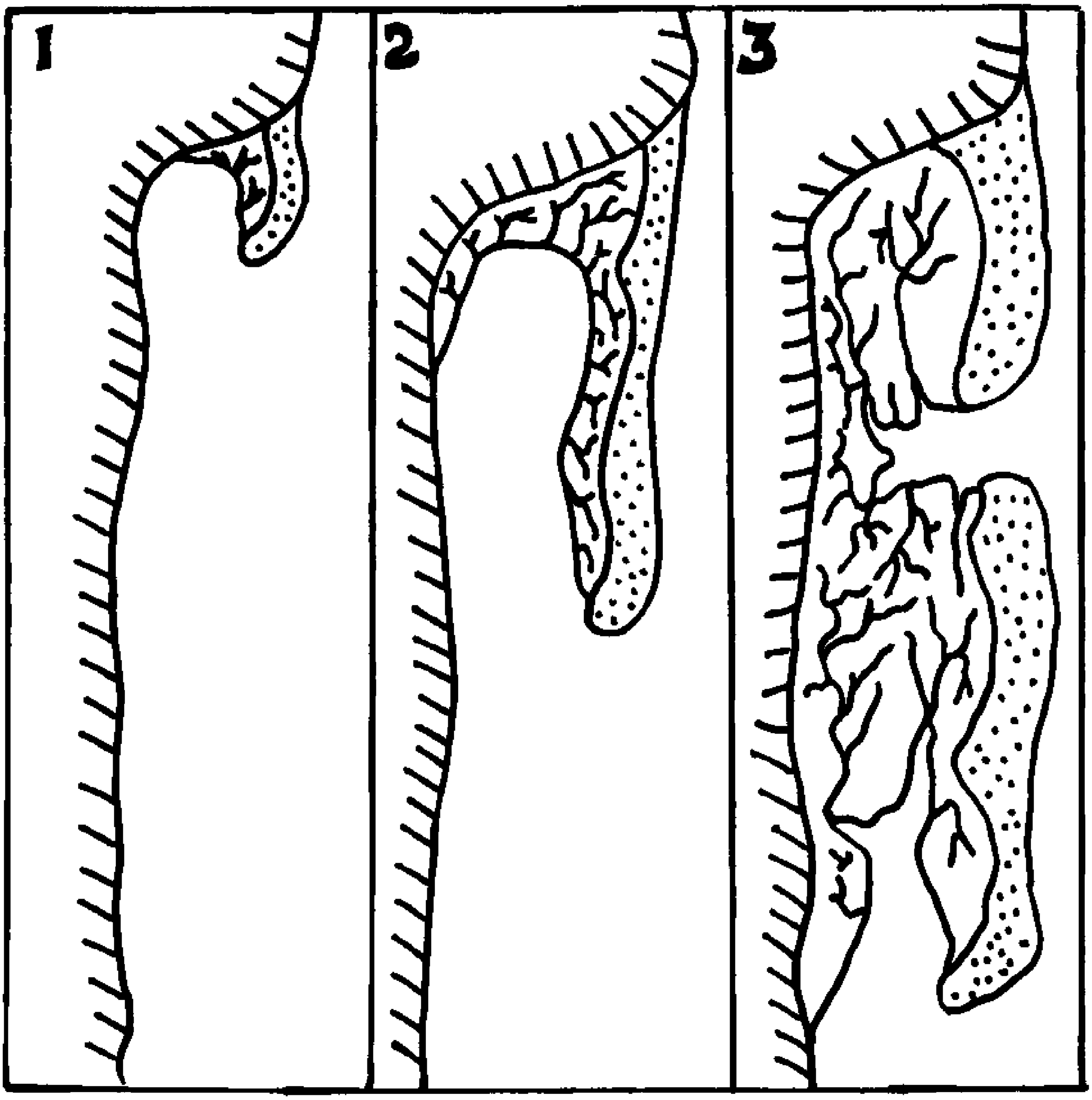
Much of the energy from ocean waves and winds dissipates as it moves the sands of the barrier islands. In absorbing the ocean's forces, barrier islands can become destabilized and migrate. Thus, barrier islands are dynamic and constantly changing. During calm weather these changes are restricted to alterations of beach steepness, and transfer of fine sands to dune areas, but, during storms, alterations can involve beach and dune erosion, island flooding by wave overwash, and inlet migration and formation. These storm-induced alterations can devastate structures built by man.

Origins

Scientists agree that barrier islands are a normal feature of sedimentary coastlines, but several different hypotheses have been formulated to explain the origin of North Carolina's Outer Banks. The existence of these multiple hypotheses demonstrates the evolving nature of science and might be used to show how human creativity is involved in scientific development. Three hypotheses are outlined here. All are based on analyses of cores through barrier islands, sand movement patterns, sea level history, and other oceanographic data.

1. The earliest theory, proposed by DeBeaumont in 1845, is the idea of an off shore bar created by breaking waves depositing sediment when they lost energy. As sediment accumulates, a shallow underwater bar forms and, if sea level falls, the bar becomes a narrow island seaward of an inshore body of water.

Figure 16



SPIT THEORY OF BARRIER ISLAND FORMATION:
1. Erosion of headland creates elongating spit down current;
2. Marsh development and further elongation of spit;
3. Spit breaks and forms an island. (From Hoyt, 1967)

Godfrey and Godfrey, Barrier Island Ecology of Cape Lookout National Seashore and Vicinity, North Carolina, Nat. Park Service Scientific Monograph Series, #9, 1976, page 9.

2. The elongate spit hypothesis suggests that the Outer Banks developed from sediments carried south by longshore currents to be deposited in a long sand finger. This finger, or elongate spit, is assumed to have grown across open water, gradually enclosing lagoons or "sounds" as North Carolinians call them. When storms or currents breached this spit, inlets formed, leaving isolated land pieces as barrier islands. (Figure 16)

3. The coastal ridge theory suggests that dune ridges on the edge of the shore were cut off by rising sea level, with isolated ridges becoming barrier islands and the flooded areas behind becoming sounds.

Unfortunately, none of these simple theories adequately explains all of North Carolina's Outer Banks. Most geologists seem to agree that something like the following sequence of events may have taken place.

The initial barrier islands of North Carolina were probably formed from off shore bars on the continental shelf at a low sea level stand several thousand years ago. Sediments brought down rivers were built up by wind and wave action to form a typical mainland beach. With the onset of a worldwide warming trend, sea level began to rise as melting glaciers released huge quantities of water into the ocean. As sea level rose, lower-lying areas behind the beach were flooded, detaching the coastal ridge from the mainland and forming an ancestral barrier. The present Outer Banks are most likely the result of 1) extensive modification and migration of the "primary barriers" formed around 4,000 years ago when sea level rise decelerated, and 2) addition and extension of "secondary barriers" through spit elongation and off shore bar emergence. Approximately 60% of the Outer Banks from Virginia to Cape Lookout are thought to be "secondary barriers". The extent, direction, and rate of barrier island modification and migration depend upon the response of islands to varying hydraulic climates and sediment inputs and are critical processes in the barrier island system as a whole.

Processes

Because barrier islands absorb ocean energy they are dynamic land forms that change constantly in response to environmental changes. These changes fall into three general categories although details differ on different islands.

1. Longshore Transport: Ocean waves usually approach barrier islands at an angle to the beach. As these waves break they move water and sand grains along the beach in the direction of their travel. This process transports sand along a beach and may deposit it at one end of the island, thereby extending that end. If this deposition diminishes the size of a natural inlet between islands, tidal currents running through the inlet may erode the non-deposition

side to create serious erosion problems. As an example, Fort Macon on the east side of Bogue Bank is faced with such a problem and breakwaters have had to be built to protect the fort from destruction. Thus longshore transport has resulted in a situation in which Fort Macon must be protected physically from the inlet it was built to protect militarily. Over geologic time (10's of thousands of years) longshore transport of sediment from north to south along North Carolina's continental shelf may even account for the difference in thickness of sediment cover of the lower Tertiary limestone north and south of Cape Lookout (Figure 15).

2. Inlet Migration: The processes of longshore transport described above can result in migration of inlets along the length of a barrier island. Geologists now know that Shackleford Banks have been completely reworked by inlets that have migrated up and down its length throughout its history. The process results from longshore sediment transport which fills part of an inlet with sediment causing tidal currents to concentrate and erode the opposite bank. Inlet migration can also reverse direction when wave direction changes. Thus, barrier island inlets are inherently unstable and directly effect the stability of the barrier islands.

3. Washover: Sediment particles move along barrier islands under almost all wave conditions. During periods of high tides and waves, sea water may wash over the barrier island carrying sediment from the beach side to the sound side. Evidence of washover occurrence can be found on all North Carolina barrier islands, although the frequency and extent of these events seems to be higher on islands running north/south than on those running east/west. Most geologists consider washover events as essential to preserve barrier islands through geologic time. The Outer Banks have maintained themselves by migrating coastward via washover as sea level has risen during the past 15,000 years.

Washover sediments and shoreward migration of barrier islands are practical concerns to anyone building a permanent structure on a barrier island. Beach erosion and loss of housing are major concerns to barrier island property owners. Thus efforts have been made to "stabilize" these inherently unstable landforms. In Cape Hatteras National Seashore, "stabilization" to protect state Highway 12 involved erection of fences to trap sand on the dunes before it could blow over the road. These fences have changed the profile of the Outer Banks by creating relatively tall continuous dunes with few washovers in areas characterized previously by low discontinuous dunes with many washover areas. The ultimate environmental impact of this change can not yet be evaluated. (Figure 18)

Fig. 18

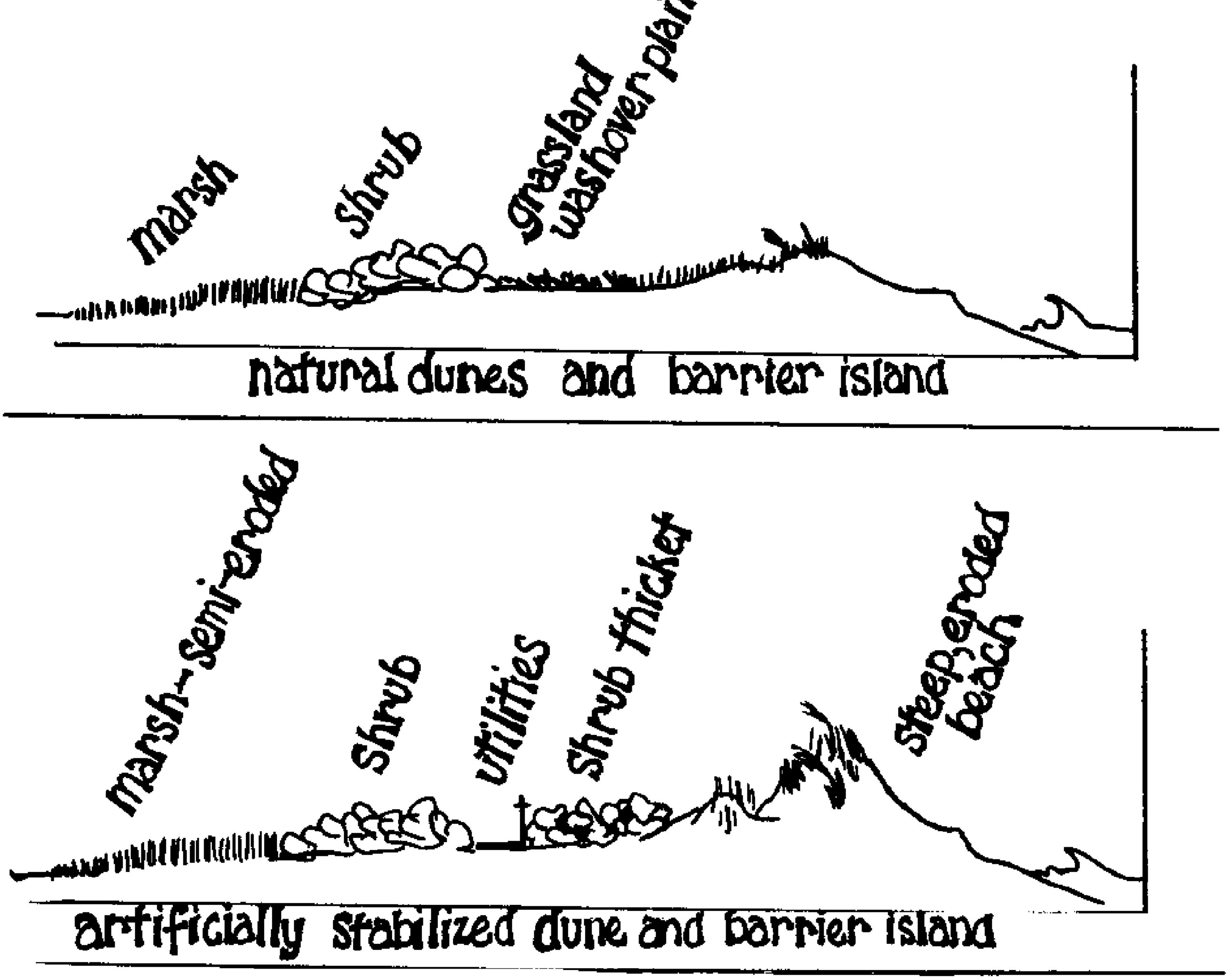
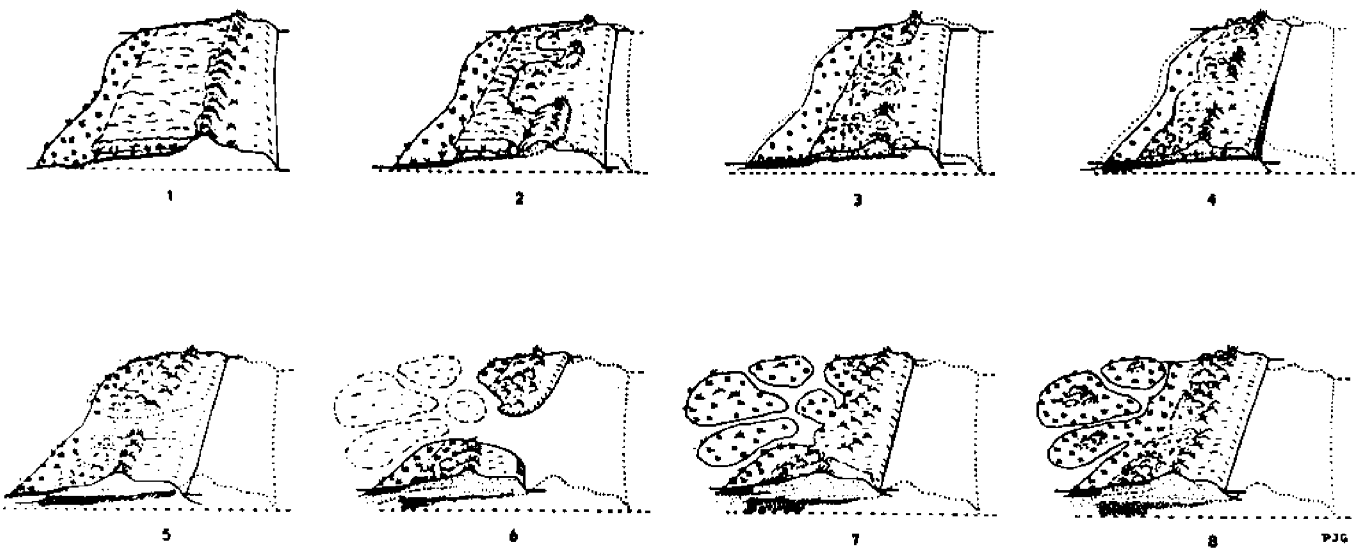


Figure 19. Diagrammatic Summary of Barrier Island Migration



1. Typical barrier island with ocean front berm, dunes, maritime forest, and sound-side marsh.

2. Storms and slightly rising sea level knock the dunes back into the maritime forest.

3. Overwash of much of the island results in retreating dunes and higher marsh.

4. Continued storms and overwash result in erosion and retreat of the front of the barrier island so that maritime forest is exposed on ocean side. Original marsh area is covered by overwash sand.

5. New dunes form on either side of an overwash.

6. Inlet opens and typical tidal delta appears behind.

7. Inlet closes and marsh area extends to delta area.

8. Island stabilizes for a time with new dune line (over old marsh area), maritime forest growing behind dunes, and expanding salt marsh.

(Modified from Godfrey, P.J. and M.M. Godfrey. 1976. Barrier Island Ecology of Cape Lookout National Seashore and Vicinity, North Carolina. National Part Service Scientific Monograph Series No. 9. $2.40)

b. Vocabulary

Barrier Island - elongated island of sand separated from the mainland by a body of water.

Breakwater - a sea wall of rock, concrete, etc., to absorb the impact of waves and thus protect the shore behind it.

Dunes - mounds of sand built by the force of the wind.

Estuary - the place where a river meets the sea.

Hydraulic climate - type, direction, and force of waves, tides, and currents.

Inlet - opening between barrier islands.

Jetty - a structure built to influence currents in order to maintain channel depths or protect the entrance to harbors or entrap sediment being carried by longshore transport (also called groins).

Longshore Current - the current in the surf zone moving parallel to shore generated by waves breaking at an angle with the shoreline.

Marsh - area of soft wet land periodically flooded by the tide, typically found in a low energy area behind an island or in estuaries.

Off-shore Bar - a submerged mound of sand.

Sound - lagoon-like body of water between the mainland and island.

Spit - a small point of land projecting into the water from the shore.

Washover - the phenomenon of the sea breaking over or through an island and depositing sediment on the sound side.

c. Things to Do

Investigating A Sand Spit Process

1. Objectives: To build a spit to simulate actual processes on the Outer Banks.

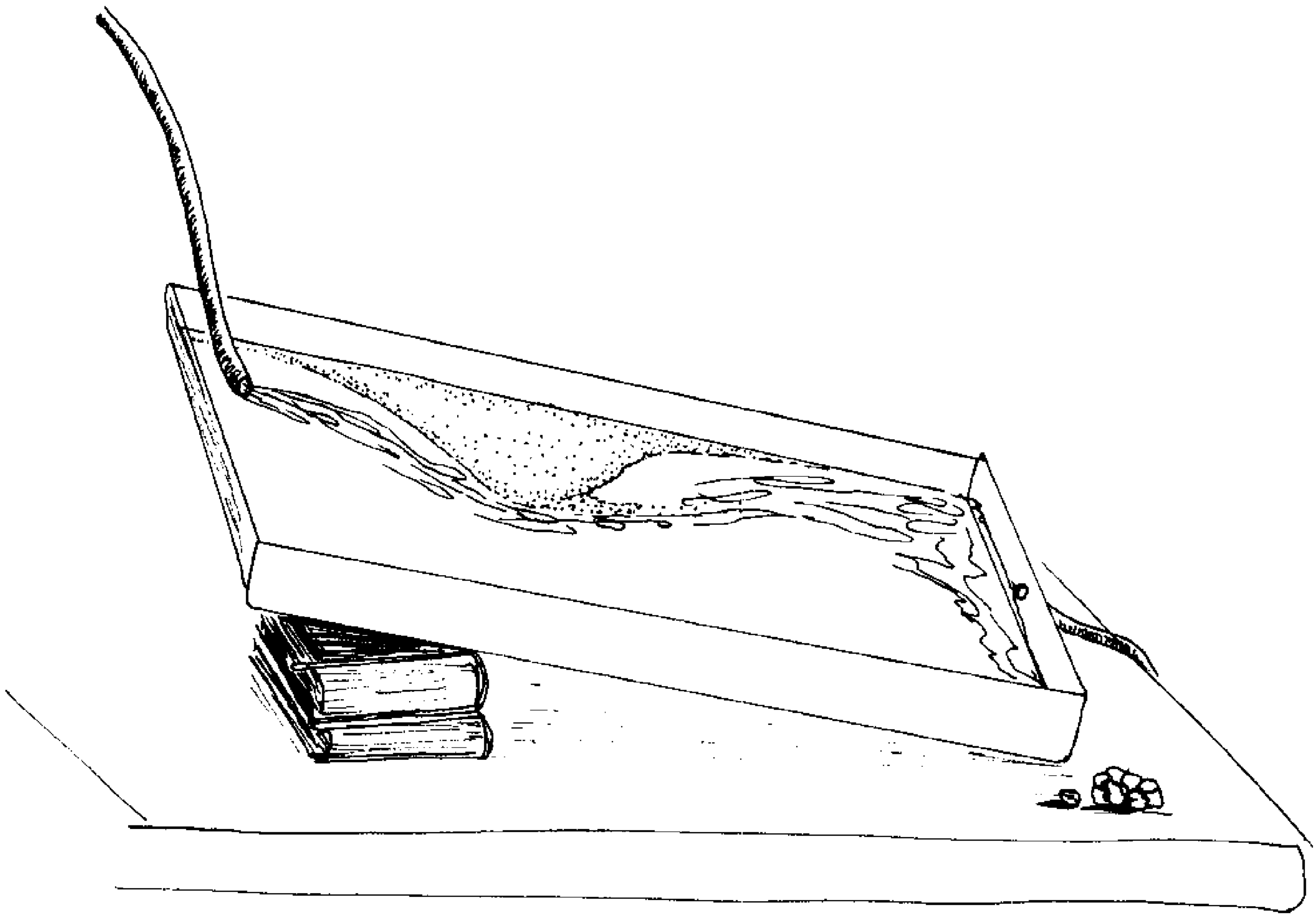
2. Teacher Preparation:
   1. Provide each group with a stream table or shallow tray.
   2. Provide sand, a squeeze bottle (source of water flow -- could come from siphoning a bucket of water or from a faucet).
   3. Provide place for waste water.

3. Procedure:
   1. Make a sand model of a shoreline with an angle.
   2. Raise the upper end of the tray slightly with a board or book.
   3. Fill the tray with 1-2 inches of water, just so it touches the shoreline.
   4. With the squeeze bottle or hose from faucet, start a very gentle flow of water past the angle of sand. This represents a "longshore current".
   5. Observe carefully the movement of sand particles.
   6. Continue the flow until a small extension of sand is formed - the spit.
   7. With sketches, record the steps in spit formation.
   8. For variation, ask some students to be engineers whose job is to prevent the flow of sand -- perhaps it is filling an imaginary harbor -- and to control the sand flow. Experiment with objects such as gravel, metal strips, etc. Record the results.

4. Discussion:
   1. What starts the flow of sand in nature? (Long shore current induced by waves hitting shore at an angle.)
   2. What kind of land forms could initiate spit formation? (Headlands, capes, any projection of land.)

3. Discuss the effect of sand spit formation on man's development, island shape changes, and shoaling.

4. Discuss sources of the sand that forms spits. (Most sand in North Carolina originally came from glacial deposits transported from New York and New England areas by long shore currents. Some sand is derived from erosion of mountains and carried by rivers.)



c. Things to Do

Model-Making Of The Barrier Island System

1. Objectives:
   1. To review some of the topographic features of the coastal regions.
   2. To investigate the processes of erosion and deposition from the mainland and the windblown transportation of sand on the barrier islands.

2. Teacher Preparation: For each group working with this model, provide one large tray with shallow sides (cookie sheet), Plaster of Paris, a bit of dirt and sand, a small fan (blowing by mouth can substitute), ice, map of North Carolina, and crayons.

3. Procedure:
   1. Using a road map for reference, sketch an area of the coastal system on the tray: include part of the mainland, a river, a sound, and barrier islands.
   2. Using a thick mixture of Plaster of Paris and water, build up the outlines of coastal features. Be sure to have some slope in the mainland section.
   3. Allow the whole model to dry completely. You may wish to color in the land areas.
   4. Process 1: Erosion and Sedimentation
      - a. Fill up the tray so that water fills up the "sound" and "ocean".
      - b. Place some dirt or clay on the mainland.
      - c. Using a running hose, a container of water or a faucet to simulate river runoff, slowly wash the dirt into the sound.
      - d. On a sheet of paper, sketch the model and record the areas of deposition of the sediment.
      - e. Repeat this investigation using crushed ice piled on the mainland and allowing it to melt, thus simulating glaciers.
   5. Process 2: Wind Erosion and Deposition
      - a. Fill up the tray so that water fills in the "sound" and "ocean".

b. Place some fine sand on the barrier island.

c. Place a fan or a healthy, hearty blowing person on the seaward side of the model island.

d. Blow the sand for approximately five minutes. Observe its movement over the island and its deposition on the far side. Record the deposition on the far side. Record the deposition patterns on a sheet of paper having a sketch of the model.

4. Discussion: 1. Discuss the effect of both processes on the "sound". (Both put sediments in shallow sounds.)

2. Discuss the various ways these processes could affect the shape of the land as well as the water depth. (Produces spits, inlets, and, depending on currents, shoals. Both processes cause sounds to become shallower.)

c. Things to Do

Where Are The Barrier Islands And Sounds?

1. Objectives:
   1. To be able to locate some of the major islands, sounds, bays, inlets and towns.
   2. To be able to discuss the significance of the position of the towns and forts in relation to the coastal features.

2. Teacher Preparation:
   1. For each team, have a blank map of the North Carolina coast and a road map. If possible obtain a Landsat photo or aerial photo of the areas (see resources). Figure 18.
   2. Crayons; small rulers to gauge distances.

3. Procedure:
   1. Using the road map and the blank, fill in the following locations:

Atlantic Ocean

<u>Sounds</u>

Albemarle Sound

Pamlico Sound

Core Sound

Bogue Sound

Roanoke Sound

Currituck Sound

<u>Islands</u>

Bodie Island

Hatteras Island

Ocracoke Island

Bogue Banks

Smith Island

<u>Rivers</u>

Cape Fear River

Chowan River

Pamlico River

Neuse River

New River

<u>Inlets</u>

Oregon Inlet

Hatteras Inlet

Ocracoke Inlet

Beaufort Inlet

Bogue Inlet

New River Inlet

Corncake Inlet

<u>Towns</u>

Manteo

Morehead City

Swan Quarter

Wilmington

Fig. 20 Student Map

2. Answer the following questions:

   a. Off the North Carolina coast there are many long, thin islands. These are called barrier islands. What do you think the word "barrier" means as used in this name? Break or bar between ocean and mainland.
   Be prepared to discuss with the class the meaning of the word "barrier".

   b. Some of the barrier islands are large; some are very small. Find the largest island and write its name here: Hatteras Island.

   c. Ocracoke (ō-cra-coke) island is located at about the middle of the North Carolina coast. Find Ocracoke Island on the map. Using the scale of the map, determine the length of Ocracoke Island. Measure it in miles and in kilometers. Fill in the blanks: Ocracoke Island is about (17) miles long or (30) kilometers long.

   d. Between the barrier island and the mainland are bodies of water. These bodies of water are called sounds. More properly they are called lagoons, but most people in North Carolina call them sounds. Pamlico (Pam-li-co) sound is the largest sound in North Carolina. Part of it lies between Ocracoke Island and the mainland. Measure the distance between Ocracoke Island and the mainland (Bluff Point) (you will need the scale again). Ocracoke Island is (25) miles or (38) kilometers from the mainland by way of the shortest distance.

   e. Between the barrier islands are gaps where water runs into and out of the sounds. These gaps are called inlets. How many inlets can you count along the North Carolina coast? There are (22) inlets on my map.

   f. Did you find more inlets north of Hatteras or south of Hatteras? South.

   g. What is the name of the inlet that separates Ocracoke Island from Hatteras Island? Hatteras Inlet.

   h. The barrier islands are made of sand. Where do you think this sand came from? North-mountain erosion and glacier deposits. See if you can guess how the barrier islands may have formed. Be prepared to discuss your theory with the class and your teacher.

i. The barrier islands have two sides. One side faces the ocean and the other side faces the sound. On Ocracoke Island, is the town of Ocracoke located on the ocean side or the sound side of the island? The town of Ocracoke is on the (sound) side of the island.

j. Most of the barrier islands lie in a north-south direction. Can you find any that lie in an east-west direction? Name one of these islands. (Note: If the island does not have a name, write the name of a city located on the island.)
A barrier island lying in an east-west direction is (Shackleford Banks near Beaufort, Atlantic Beach).

k. What differences are there between barrier islands that run north to south and those that run east to west? (North South are longer).

l. How do barrier islands help protect the sound and mainland from the ocean and bad weather? (Absorb impact of heavy winds and waves).

c. Things to Do

Scallop Shield

1. Objective: To gain insight into the student's view of the coast.

2. Teacher Preparation: Construction paper, and water colors or crayons.

3. Procedure: Instruct students to draw a scallop shell. Section it off into six equal sections. Have students illustrate the answers to the following questions.

   The last time you went to the beach, or if you went to the beach . . .

   1. You stay in a (a) mobile home; (b) motel; (c) tent; (d) camper; (e) other

   2. What animal represents the beach to you?

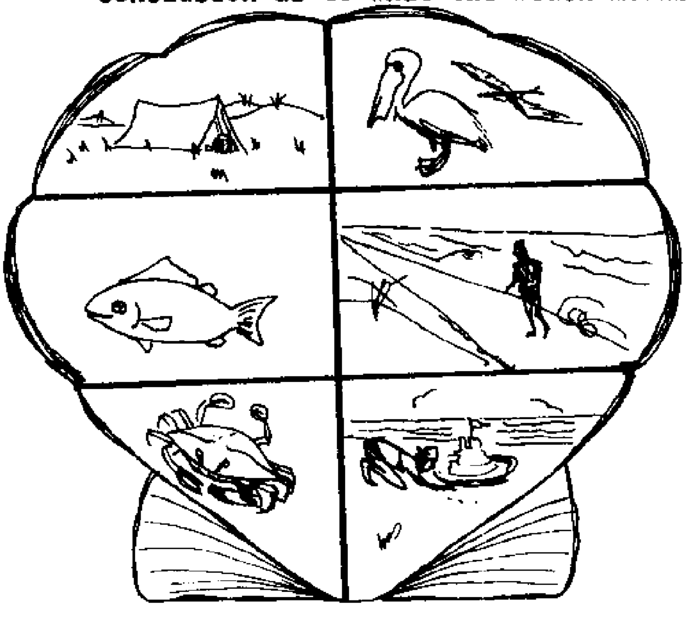
   3. What would you bring back with you?

   4. What would you most enjoy about your trip?

   5. What is your favorite seafood?

   6. What was your favorite activity at the beach?

   Encourage discussion of how each child views the beach. Some may come to play miniature golf or ride skateboards. Some may come to collect shells or watch birds. Try to have each child come to a conclusion as to what the beach means to him.



c. Things to Do

What is the Difference Between Map and Chart?

1. Objectives:
   1. To be able to compare a chart and a map.
   2. To be able to determine channels and shoals by using water depths.
   3. To be able to locate navigational marks. Figure 20.

2. Teacher Preparation:
   1. To familiarize the students with the coastal region, have the students do the activity working with a road map.
   2. Have one chart for each team. This activity is geared to use the U.S. Coast Guard Chart 11545 on Beaufort Inlet and Core Sound. Each student should have a blank chart of the area.
   3. Have tracing paper, crayons and a ruler available.

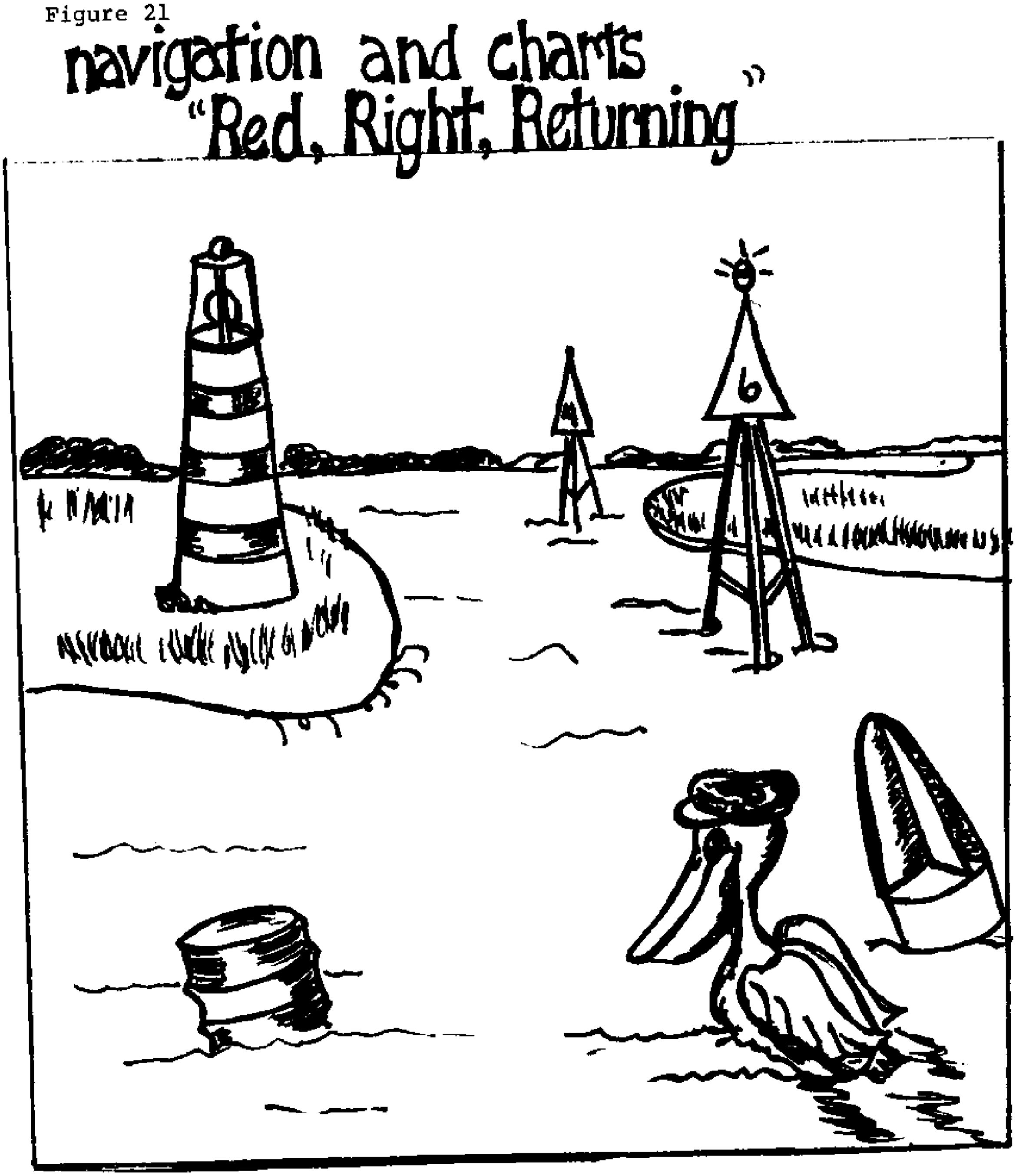
3. Procedure: Spread out the chart and locate answers to the following questions:
   1. Notice the colors on the chart. What is represented by beige? (land) by green? (marsh) by blue? (water) by white?
   2. Look at the water depths. Are they in meters or feet (feet)
   3. What is the average depth for Core Sound? How wide is it?
   4. Why is the sound so shallow? Make some guesses.
   5. On the insert of Lookout Bight, locate the jetty. What is the sand formation which formed behind the jetty called? How do you think it got there?
   6. Locate Cape Lookout lighthouse. Discuss some currents and possible erosion occurring there.
   7. With tracing paper over the chart, determine a route for a ship going from the coastal water into the NC State Port Terminal. Then chart a route from the Port Terminal to Marshallsberg.
   8. Locate North River. Why do you suppose that the area between Harkers Island and Beaufort

is so full of mud flats and marshes? (Sediment from river is trapped).

9. Discuss some of the differences and similarities between a chart and a map (use, design, symbols).

10. Locate information on the Intracoastal Waterway. Where does it pass through North Carolina?

Figure 21



c. Things To Do

Find Your Way In

Objective: Use navigational aids to plot a boat's route to a marina.

Teacher Preparation: Duplicate page and have students plot their way in.

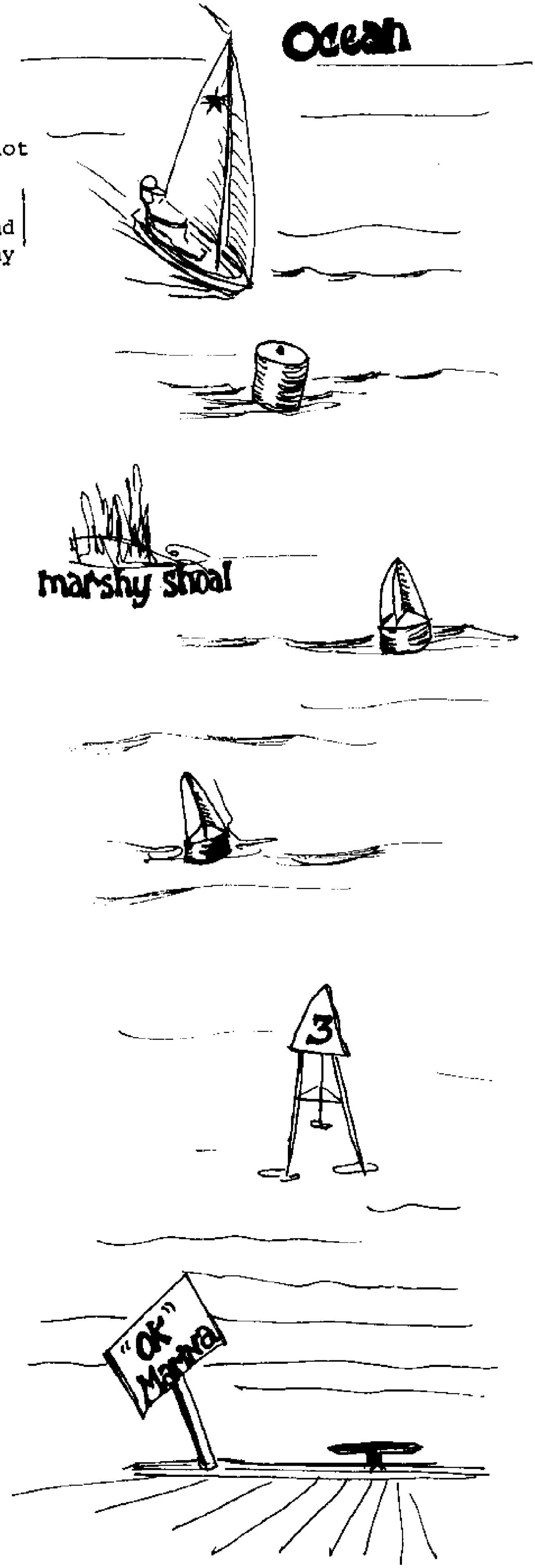
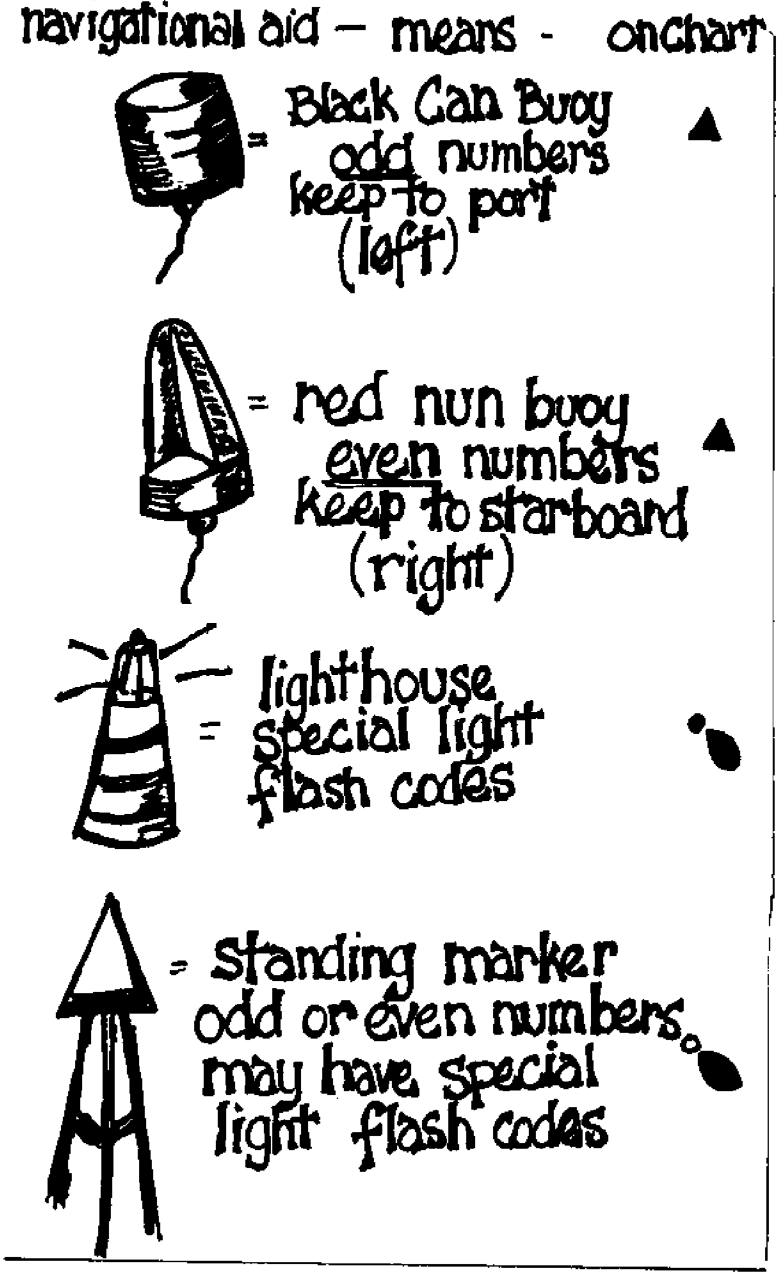


Figure 22



Standard Rule: "Red to the right when returning from ocean."

c. Resources to Use

Films - See appendix for addresses of distributors

1. Boque Inlet - Study of Inlet Shifts: 5 min., N.C. Coastal Resources Commission, Raleigh, NC.

2. The Beach, A River of Sand: 20 min., color; 16 mm., Encyclopedia Britannica.

3. Water Bound: Our Changing Outer Banks: 18 min., color; UNC-Sea Grant, N.C.S.U., Raleigh, NC.

Printed Material - See appendix for addresses

1. Charts available from U.S. Department of Commerce, NOAA, National Ocean Survey, Rockville, Maryland 20852.

2. Baker, Simon. 1977. "The Citizen's Guide to North Carolina's Shifting Inlets". Sea Grant Publication Number - UNC-SG-7705.

3. Cleary, W.J. and P.E. Hosier. 1978. New Hanover Banks: Then and Now. UNC Sea Grant UNC-SG-77-14. $2.00.

4. Pilkey, O., Orrin Pilkey, Sr., Robb Turner. 1975. How to Live with an Island; A Handbook to Bogue Banks, NC. NC Science and Technology Research Center Research Triangle Park, NC 27709. $2.75.

5. Pilkey, O., W.J. Neal, O. Pilkey, Sr. 1978. From Currituck to Calabash: A Guide to North Carolina's Barrier Islands. Science and Technology Research Center, Research Triangle Park, NC 27709.

6. "Know Your Mud, Sand and Water". Sea Grant Publication Number UNC-SG-76-01. One copy free to NC residents; $1.25 for additional copies.

7. Langfelder, J. et al. 1974. Historical Review of Some of North Carolina's Coastal Inlets. Report #74-1. Available from the Center for Marine and Coastal Studies, NC State University, Raleigh, NC.

8. From Project COAST. #234 - Ecology of Sand Dunes. 50¢
   #240 - Beaches: A Geological Study. $1.50.

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1. Cairns, H. 1974. This Other Eden. Times Printing Co., Inc., Manteo, NC.

2. Corey, Jane. 1969. Exploring the Sea Coast of North Carolina. The Provincial Press, Raleigh, NC.

3. Godfrey, Paul. 1976. "Barrier Beaches of the East Coast". Oceanus (19): 27-30.

4. Hoyt, John. 1971. Field Guide to Beaches. Houghton Mifflin Co., Boston, MA., 46 pp.

5. MacNeill, Ben. D. 1958. The Hatterasman. John Blair Publishing Co., Winston-Salem, NC.

6. Shepard, Frances P. and Harold R. Wanless. 1971. Our Changing Coastlines. McGraw Hill Book Co., New York, NY, 597 pp.

7. Schwartz, M.L., ed. 1971. Barrier Islands. Dowden, Hutchenson, and Ross, Inc.

8. "Our Changing Atlantic Coastline". National Geographic, Dec. 1962, pp. 860-887.

9. Weedbee, Charles H. 1966. Legends of the Outer Banks. John Blair, Publ., Winston-Salem, NC.

Unit 1. North Carolina's Coast and Waters

B. Coastal Environmental Systems

Concept 2. Barrier island ecology is an interaction of beaches, dunes, maritime forests and marshes.

a. Background Reading

North Carolina's barrier island coastline supports an ever increasing tourist and recreational industry. People come to lie in the sand, swim in the surf, relax in motels or homes, and fish in the coastal waters. What people value is the natural beauty of the barrier island. To understand how to live with these islands, it is important to know their component parts and the interactions that characterize barrier island ecology. (Figure 20)

Barrier islands are the land's first line of defense against the ocean's energy. The islands absorb the energy of the ocean winds and waves, but their shapes are altered. Thus, a barrier island is a dynamic landform. Its sands are always moving, or ready to move, if sufficient energy is focused upon them. These sands are sometimes partially stabilized by plants, but their tenuous stability is easily disrupted by human development. To live with an island we must use it where it can tolerate use and avoid development where it is vulnerable. A transect across a barrier island from beach to salt marsh crosses habitats that are both tolerant and sensitive to human development. The biota give hints about the sensitivity of their habitats. Thus the barrier island provides a useful place to develop students' ability to observe natural history in action.

The Beach

Barrier island visitors recognize the beach as that portion of the oceanfront between high and low tide. Geologists have a somewhat more extensive definition which includes as "beach" that protion of the shore influenced by the effects of ordinary waves. This includes nearshore sand bars as well as the berm - a supra-tidal terrace of sand brought ashore by waves. Beaches are an accumulation of rock fragments subject to movement by ordinary waves. As such, beaches and beach sediments are in constant motion. A visitor can stand where waves are running up the beach and watch beach sediments sweep by his feet. Beaches can be composed of many materials. North Carolina's beaches are mostly quartz and fledspar from the weathering of granitic rocks. Beaches elsewhere may be black volcanic sands, white carbonate fragments, or pink coral. Also, beaches may be comprised of large cobbles rather than sand.

The most significant feature of beaches is sediment mobility. Sand moves along North Carolina's barrier islands as well as onshore and offshore. The direction of sand movement is a function of wave climate (wave height, direction and steepness) and the shape of the shoreline. Various structures can interfere with sand movement. If sand becomes trapped in one place and does not reach another protion of the beach, then that section is "starved" of its regular supply of sand and will erode. Thus, most attempts to "stabilize" beaches are really just methods of displacing a problem from one place to another.

The Dunes

Dunes and dune fields are formed by wind transport of sand and the growth of stabilizing vegetation. Sand moves by saltation, a process whereby sand lifted by wind energy bounces along a loose sand surface setting other grains in motion by its impact. The wind velocity necessary to initiate sand movement is known as the threshold velocity and is about 10 m.p.h.

Dry sand is transported back from the beach by onshore winds. Usually only the smallest grains of beach sand are moved, thus dunes are comprised of finer sand particles than the beaches. The fine sand particles move back to form mounds in which dune plants can take root. Tidal litter, detritus, left behind at the high water mark often provides the niche for the initation of plant growth necessary for dune formation. Vegetation that establishes itself at the high tide strand line or on a dune increases the accumulation of sand by reducing wind velocity at the sand surface. Plants, such as sea oats (Uniola paniculata) and American beach grass (Ammophila species), develop extensive root systems capturing moisture from rainfall and bind sand stabilizing the sand surfaces. These plants can be buried under blown sand and still put up new shoots. Thus they are superbly adapted to growing in the unstable dune environment.

Beach grass seedings will establish themselves on the shore or dune particularly after periods of heavy rainfall which provide sufficient moisture and stabilization for growth. Root fragments off toppled clumps of beach grass from eroded dune areas are a major means of reestablishing new embryo dunes. It is interesting to note that grass shoot elongation and branching occurrs in the spring, and creates a loose cluster of shoots in sand accreting areas and denser clusters in more stable areas. Embryo dunes, stabilized by plants, may coalesce to form a band of upward growing dunes.

Dunes may also migrate and shift their position frequently through continuous windward erosion and leeward deposition and occasional dune "blowouts". On the Outer Banks, you can find small, embryo dunes a foot in height capped by a stabilizing crown of sea oats and giant dunes like Kill Devil Hill over 100 feet high. The unvegetated dunes can grow to hugh proportions. Their mobility and height are a function of the wind strength. Jockey's Ridge at Nags Head and Bear Island have shifting dunes of notable size. On the other hand, vegetated dunes are fairly stable anchored by the complex root system of the plants.

Dune plant ecoloyg is influenced by an array of subtle and obvious environmental factors. Salt spray is an obvious factor in determining dune species, as some plants are well adapted to frequent spray and may even receive certain growth requirements in that form. Other factors influencing plant growth on dunes include dune surface orientation, stability, distance inland, and topography. Dune plants often live close to the limits of their tolerance. As a result they are susceptaible to human perturbation. There are numerous examples of stable, vegetated dunes that have become barren unstable dune fields through man's influence. These examples provide solid reason for protecting dunes from development, vehicular traffic, and even heavy foot traffic. Sand dune ecology is a product of delicate environmental balances. The fact that natural dune fields are constantly shifting, attests to the transient nature of individual dunes in this environment.

There are also man-made dunes on North Carolina's barrier islands. These Outer Bank coastal dunes were developed in the 1930's along Hatteras, Pea, and Bodie Islands. Formed along snow fences they are linear features equivalent to a sea wall. They were built to stabilize the sand, prevent washovers, and thus protect the island highway. Actually, these artificial dunes have caused increased erosion on the beach face and, by preventing the natural process of oceanic overwash, have halted barrier island migration thereby artifically introducing a temporary stability to the zone behind the dunes. The height of these man-made linear dunes provides protection from salt spray so that shrubs normally found in the rear of the island have spread seaward often forming impenetrable thickets 10-15 feet high.

The Maritime Forests

Some of North Carolina's barrier islands support a special forest type composed of salt tolerant components of the coastal evergreen forest. This maritime forest is dominated by live oak (*Quercus virginiana*), laurel oak (*Q. laurifolia*) and yaupon holly (*Ilex vomitoria*) with wax myrtle (*Myrica cerifera*), red cedar (*Juniperus virginiana*), red bay (*Persea borbonia*) and American holly (*Ilex opaca*) as associated species. The ground cover is usually partridge berry (*Micholia repeus*) with vines such as catbrier (*Smilax* spp) and poison ivy (*Rhus radieans*). The maritime forest is quite rare in North Carolina, being virtually restricted to wider portions of barrier islands. Excellent samples exist in Duck Woods, Nags Head Woods, Buxton Woods, Ocracoke Island, parts of Core Banks, Shackleford Banks, Bogue Island, Bear Island, and Smith Island. Much of the existing maritime forest is privately owned and subject to increasing development pressure.

The maritime forest is relatively tolerant to human development. The earliest settlements on the Outer Banks (Ocracoke, Portsmouth, Old Nags Head, Diamond City, etc.) were built in maritime forests as they are on relatively high ground and shelter inhabitants from temperature extremes. The maritime forest stabilizes shifting sands even more than dune plants and is also more efficient at retaining rainfall and nutrient materials from salt spray. The tree species have several interesting adaptations for their salty environment (thick, leathery salt tolerant leaves, physiological mechanisms for excreting excess salt, etc.). However, as Dr. Vincent Bellis, a biologist with East Carolina University, points out, the forest itself is a study in community adaptation. The outer canopy serves in water retention and as a heat shield which enables the absorptive root network to survive the drying summer winds. The forest root zone operates as a selective ion filter allowing excess amounts of sodium, chloride and magnesium ions to pass through while retaining most of the needed nutrients -- nitrogen, phosphorous, calcium and potassium. In summary, the maritime forest is specially adapted to its coastal, sandy habitat. It is reasonably tolerant of human development that does not deplete or pollute the fresh-water supply or open unnecessary holes in the forest canopy.

The Salt Marsh

The landward margin of North Carolina's barrier islands is usually fringed by salt marsh. These habitats are flat beds of salt-resistant vegetation that can be flooded by sea water. The periodicity and duration of flooding separates salt marsh plants into distinct zones. As one moves from the island towards the sound, one passes from areas of salt marsh edge shrubs (high tide bush *Baccharis halimifolia*, marsh elder *Iva frutescens*) and herbs (sea oxeye *Borrichia frutescens*) into one of the most rigorous environments on the barrier islands. These areas are flooded on the highest storm tides and are barren of plants as the occasional flooding simply leaves too much salt. These barren "salt pans" are often surrounded by the highly salt-tolerant succulent glass wort (*Salicornia* spp.) once used by colonists in pickling and still used by coastal residents to flavor salads.

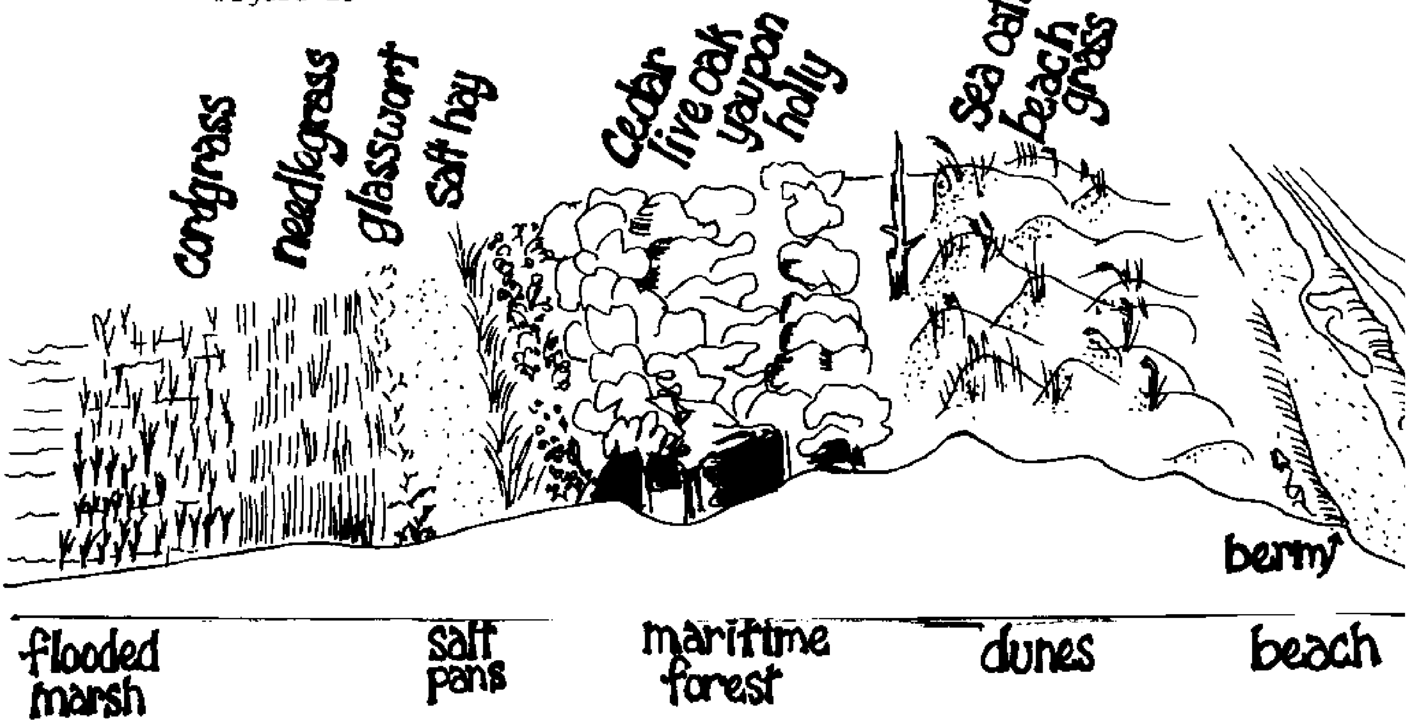
The major areas of salt marsh occur on lower land that is flooded regularly by tides. Marsh plant distributions reflect the flooding regime. So, in areas flooded by a few of the high tides each month, one finds salt hay (*Spartina patens*) and spike grass (*Distichlis spicata*). Further along where land is flooded by several of the month's highest tides one finds black needle rush (*Juncus roemerianus*) and finally, in areas regularly flooded by high tides, one finds the salt marsh cordgrass (*Spartina alterniflora*) occupying large flats extending to the edge of the sounds. This sharply demarcated salt zonation can be observed from bridges or coastal highways all along North Carolina's coastline and can be used as an interesting example of species distribution along an environmental gradient.

The salt marsh is relatively tolerant of human development although species change occurs whenever anything alters the tidal area. Usually such alterations result from sediment pressing down, or being piled on, the marsh surface. Careful observation can usually uncover where someone has unloaded sediment onto the marsh surface with resulting changes in zonation patterns.

Summary

(1) Barrier islands are naturally dynamic and change in width and length due to energy from waves, washovers, longshore currents, and deposition; (2) all island habitats interrelate, i.e., one cannot stabilize a dune without affecting the beach or the maritime forest; (3) barrier island plants and animals occupy environmentally rigouous habitats and have easily observable adaptations that allow them to colonize these areas. In many cases additional stresses on these species can destroy whole populations and thereby affect the ecological balance of the entire barrier island system.

Figure 23



b. Vocabulary

Adaptation - modifications of an organism which increase its survival chances.

Beach - that portion of the shoreline from the berm to the nearshore sand bars. It could be composed of sand, pebbles, shells, etc.

Berm - a terrace of sand found at the highest tide point where waves have either deposited sand or eroded a little cliff.

Biota - the living plants and animals in an area.

Blowout - for sand dunes it refers to the situation when winds move sand to create an unstable moving dune in an area previously stabilized by plants.

Dune - mound of sand.

Habitat - an ecological term to indicate a place where an organism lives or the place where one would go to find it; its "address".

Maritime Forest - the evergreen forest of salt tolerant trees and other plants that inhabits the back portions of barrier islands.

Overwash - a process whereby waves washing over an island carry sand from the seaside to the landside.

Saltation - the movement of sand by wind bouncing sand grains along a loose sand surface thus setting other grains in motion.

Tolerance - the amount of stress an organism can absorb and still survive. The maximum and minimum range in which an organism can survive is called the "limits of tolerance".

c. Things To Do

What We can Learn from the Face of a Dune

1. Objectives: 1. To investigate the processes which cause dunes.

2. To be able to identify the parts of a dune.

3. To investigate some methods for stabilizing dunes.

Winds with speeds over 10 m.p.h. can carry sand which can build dunes. The sand grains are rolled up the windward slope and, if there is enough energy, slip over the crest to the leeward side. Consequently, the windward side is a gentle slope and the leeward side is steep and is known as the slip face. Sand is deposited on the slip face. Thus, wind deposited layers of sediment are recognized by having angled layers. One can thus determine the direction of the winds in ancient sedimentary rock formed from cemented sand dunes.

Diagram:

2. Teacher Preparation: 1. One shoe box per team, taped to the edge of a table.

2. A small quantity of fine sand for each box.

3. Some matchsticks or plant pieces available.

3. Procedure: 1. The student is to act as the wind and blow the sand into a dune shape. By adding more sand to the source, a competition can be set up as to which team can blow up the highest dune.

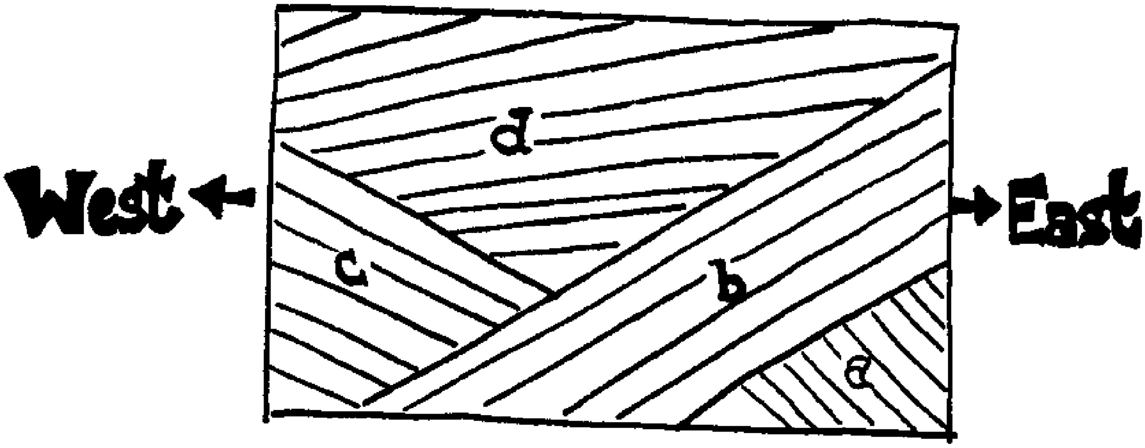
2. Draw and label the dune's shape in profile (side view).

3. Investigate different types of simulated dune stabilizers (matchsticks to be "fences" or plant pieces to be "planted beach grass") and note the effect on the dune movement.

4. Discussion: 1. What would conditions have to be for a beach dune to migrate or move inland? (Little to no vegetation to hold it, wind.)

2. How do beach stabilizers affect the height of a dune? (or what happens to sand grains when they hit a fence or plant)? (Make dune higher and steeper).

3. In the diagram below of a part of sedimentary rock, in what direction did the wind blow most of the time? (think of the slip face angle).



a - west wind

b - east wind

c - west wind

d - west wind

c. Things to Do

Exploring Beach Sands

1. Objectives:

   1. To investigate the properties of sand using scientific processes of observation, identification, classification, measurement, inference, etc. - hands - on exercise (adapted from Virginia Institute of Marine Science, Marine Education, Gloucester Point, Virginia).

   2. To draw some conclusions about the sand and where it is located.

2. Teacher Preparation:

   1. Prepare ahead of time two sandwich bags of sand for each pair. This sand should vary, perhaps only as much as one being wet and the other dry. However, you could get sand from a sand dune and from the surf, or you could get builder's sand and sand from a river or other combinations to enable comparison.

   2. Divide the class into groups of pairs.

   3. Have a number of stations set up where each pair can take their sand and investigate, manipulate, or measure. Some suggestions for equipment are as follows: magnets, jars with lids to test settling rates, scales for weight, oil or syrup, fresh and salt water to test buoyancy, settling, etc., hand lens or magnifying glass, straws, detergent, etc. Anything can be used which is available in the classroom.

3. Procedure:

   1. To each pair of students, hand out the two plastic bags of sand. Show all the students the stations and the materials for investigating this sand.

   2. Each pair is to use all senses to make observations on the sand. Record the observations - have sheets of paper for about 50 observations.

   3. First, observe the material as it is -- don't do anything to it. Touch it, taste it, rub it between your fingers, look at it very closely. Record these observations.

   4. Second, manipulate the material -- do things to it. Use the magnets, the jars, the types of liquids, blow it, try to break it, etc.

5. Third, measure it. Use weight, size, floatation, sinking, ability to hold water, etc.

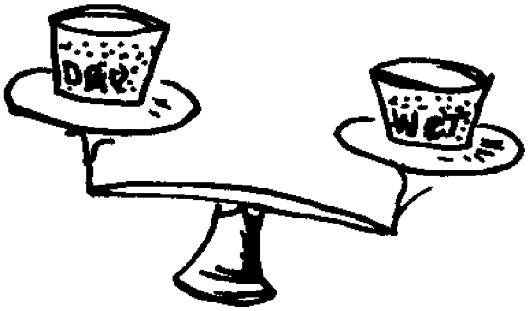
6. Note -- Do not use all your sand on one experiment.

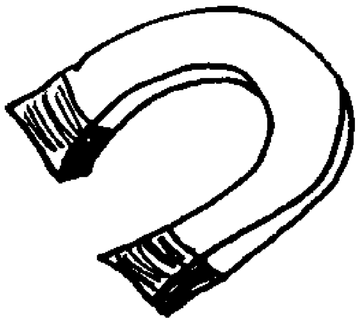
4. Discussion:

1. Bring the class together after 20 minutes for discussion. List the observations on the board.

2. List the differences between the sands and discuss how the students determined there was a difference.

3. Let the students make some hypotheses on where the sand originated. (Heavier sand stays in the surf, lighter sand is carried up to the dunes; sand with pieces of detritus and leaves or such might come from a river, pure sand is sorted already, etc.)





C. Things To Do

Identifying Sediment Contents of the Beach

1. Objectives:

   1. To learn to recognize an organism by looking at a fragment.

   2. To separate living from nonliving parts in sediment by visual identification.

   In the teacher explanation of this lab, emphasize that sediment which makes up the beaches, bottoms of sounds, and oceans may come from many sources. For example, the beaches of North Carolina consist of about 95% inorganic and 5% shellpeices north of Cape Hatteras and 75% inorganic (quartz and feldspar) and 25% shell south of Cape Hatteras. Further south near Miami Beach, Florida, the beach consists of about 50% inorganic and 50% shell. Actually, anything which does not decay will deposit in the sediment layers. Consequently, in analyzing sediment from different places, we can determine a lot about the plankton (floating plants and animals) and the benthos (bottom dwellers). The trick is to be able to identify the make-up of the sediment from the bits and pieces left from the whole animals and be able to separate these from bits of rock.

2. Teacher Preparation:

   1. Collect shells, dried starfish, sea urchins, crabs, coral, fish bones, fish scales, and similar types of marine organisms which would leave some "hard parts" when dead. The students can probably bring in enough samples for a class activity.

   2. Have some sand and clay brought in.

   3. Have dissecting scopes or hand lens available for students.

   4. Have some small cups for mixing up sediment; some tools for breaking up specimens.

3. Procedure:

   1. Have the students identify animal specimens available.

   2. Divide the classes into small groups with examples of the animals. Each group is to break the specimens into smaller and smaller parts. Make sure that the student can identify the specimen using the smaller pieces. Record the descriptions.

   3. Exchange the broken pieces so that students learn to recognize other specimens from pieces.

4. When the students feel familiar with their animals, have them look at sand and clay particles under the hand lens. Have them investigate how they would distinguish between the living parts and the nonliving parts based on their observations.

5. In the conclusion of this exercise, let the students test their skills by describing a mixture made by combining specific specimen pieces and sand in small cups. Depending on the type of class, the mixtures could be more complex and the identification could be handled in percentages rather than just descriptions.

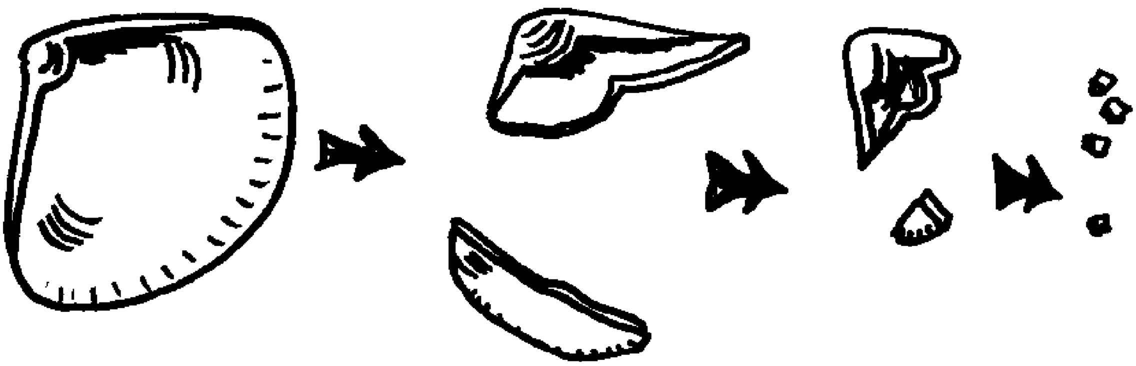
4. Discussion:

1. What would cause shells to break up? (Waves, current, wind, animals, weather).

2. What is the smallest size piece from which a student could identify the specimen?

3. What would be one hyptohesis to explain why there are less minerals or sand as we go to beaches further south? (Consider that the source of most quartz and feldspar sand comes from rivers carrying glacier materials several thousand years ago. As the glacier stopped about New Jersey, the amount of material just thins out as one goes south.)

4. What would be some reasons why a scientist would want to know the make-up of sediment? (Original source of materials, direction of transportation, mineral resource.)



C. Things To Do

Model of a Barrier Island

1. Objectives:
   1. To construct a model of a barrier island.
   2. To use the model to show some of the effects of salt spray on the island.

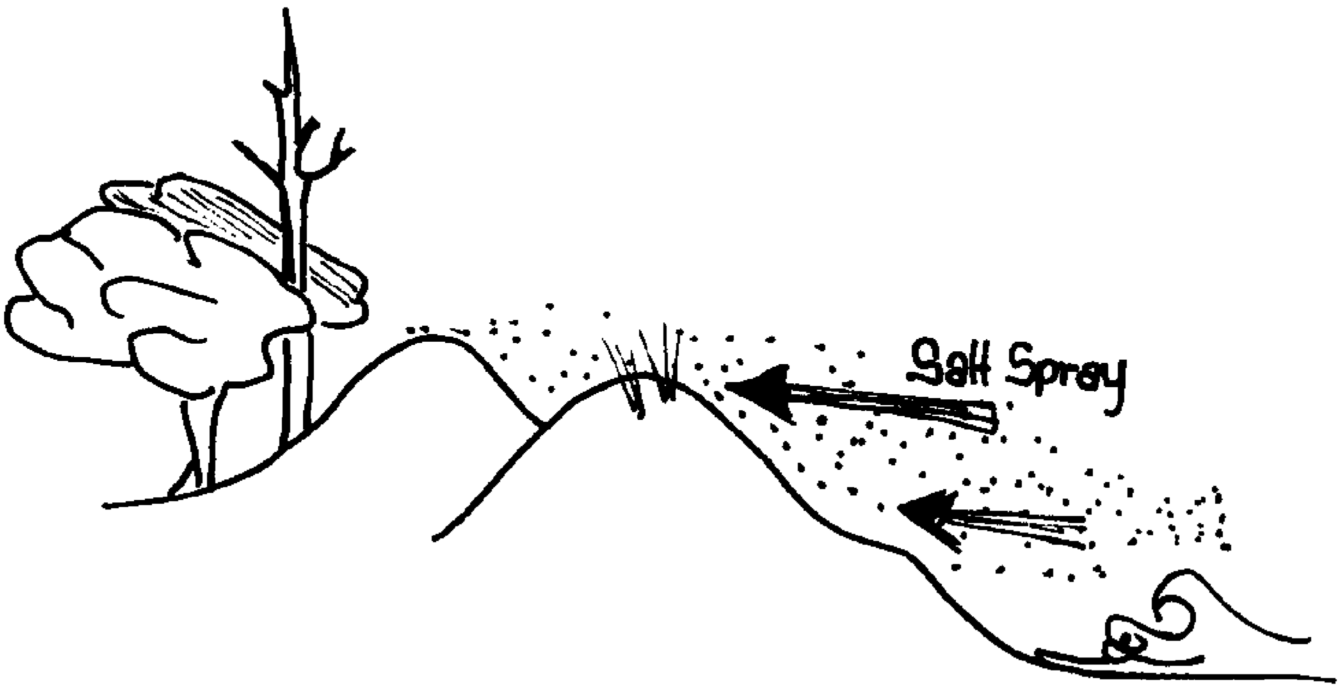
2. Teacher Preparation: Provide each group with a flat board or piece of cardboard; Plaster of Paris; small pieces of evergreen cedar or juniper; spray bottle filled with ink or can of spray paint.

3. Procedure:
   1. On the board, outline the shape of an island.
   2. Using a thick mixture of Plaster of Paris and water, build up the model so that it has a gently sloping beach, higher dunes, a lower area for the maritime forest, and a gently sloping marsh area (See Diagram).
   3. When the plaster is nearly dry, insert small pieces of cedar just so the tops are even with the dunes and some are quite a bit higher.
   4. Process: When the model is dry, investigate the salt spray over the island. Hold the spray no higher than the highest part of the beach area. Spray. Observe the area colored or wet. Hold the spray slightly higher and spray again. Again record the area colored or wet. (This would simulate normal salt spray coming from breaking waves and the sea breeze and also the effects of storms.)

4. Discussion:
   1. What part of the island absorbs most of the salt spray? (Dunes).
   2. What type of plants could grow on the dunes? What special adaptations to wind and salt are present? (Deep roots, tolerance to salt).
   3. Observe the effects of spray on the trees. What happened to the higher trees? Since salt can kill some plant leaves and stems, what would happen to the shape of the trees? (Trimmed by wind.)
   4. Discuss some of the places on the islands which would receive the least amount of salt spray and

why. How would this affect the plant and animal life? (Between dunes and back from beach. Less tolerant species can live here.)

5. For a further investigation, grow different types of plants in paper cups in the classroom. Once they have grown, divide them into groups and subject them to different amounts of salt spray (salt water in the spray bottle). Observe the effects on the plants.



d. Resources to Use

Films (Please see appendix for addresses of distributors)

1. Billion-Dollar Marsh: 44 min.; color; Time-Life.

2. Salt Marshes: Barrier between Sea and Land: 24 min.; color; Harper Row; Written by the authors of Life and Death of a Salt Marsh, John and Mildred Teal.

3. The Salt Marsh: A Question of Values: 22 min.; color; Encyclopedia Britannica.

The above three films are quite good to show both the ecological and management aspects of the marsh.

4. Birds of the Shore and Marsh: 14 min.; color; Coronet.

5. Succession from Sand Dune to Forest: 16 min.; Encyclopedia Britannica.

6. Birds of the Sandy Beach: 10 min.; color; B.F.A.

Printed Material

1. "Wildlife of Lakes, Stream, and Marshes". National Wildlife Federation, 1 copy free, others 10¢.

2. Sea Coast Plants of the Carolinas, for Conservation and Beautification. UNC-SG-73-06. Write UNC Sea Grant Office.

3. Silberhorn, Gene. 1076. Tidal Wetland Plants of Virginia. Ed. Series No. 19. Write to Virginia Institute of Marine Science, Gloucester Point, VA 23062. $3.00.

4. "Barrier Islands of Georgia" Poster. Department of Natural Resources, Atlanta, GA 30334. (Poster has two sides: one showing the geography of the Georgia islands and the other showing the transect biota across the island).

5. Pilkey, O., Orrin Pilkey, Sr., Robb Turner. 1975. How to Live with an Island; A Handbook to Bogue Banks, NC. Write to North Carolina Board of Science and Technology, Research Triangle Park. North Carolina 27709.

6. "Know Your Mud, Sand and Water". 1976. UNC-SG-76-01. Write North Carolina Sea Grant Office. One copy free, others 25¢.

7. Teal, M. and J. Teal. 1969. Life and Death of a Salt Marsh. Little, Brown and Comp., Boston, MA.

8. Project Coast activity packets. #230 - Marshes: Nature's Bounty. $5.70. #202 - Distribution of Salt Marsh Life. $1.10. (Please see appendix for address)

Man and the Sea Coast - Barrier Island Geology set of 30 slides with script. on loan. University of North Carolina Sea Grant Marine Education. North Carolina State University, Raleigh, NC.

Unit 1. North Carolina's Coast and Waters

B. Coastal Environmental Systems

Concept 3. Estuarine systems develop in sheltered waters during periods of rising sea levels.

a. Background Reading

Estuarine areas develop during periods of rising sea level in locations sheltered from the sea and characterized by the mixing of fresh water with sea water. Rising sea level traps and reworks sediment particles in sheltered coastal waters; keeps sediments from washing away; and produces environments in which fresh water/sea water mixing retains more sediment.

North Carolina has had a coastline for about 180 million years; but, in the past, the location of the coastline has been as far inland as Raleigh and as far seaward as the edge of the continental shelf. These changes have been brought about by changes in sea level. The amount of water present in the oceans depends upon the shape of ocean basins and the volume of liquid water on the earth's surface. During periods of colder climate, liquid water has been tied up in ice sheets that covered much of the surface of the earth; this phenomenon is known as continental glaciation. During a period extending from about one million to 12 or 15 thousand years ago, ice sheets have advanced at least four times in the northern hemisphere. At the time of maximum development, this vast ice sheet extended as far south as New York, Pennsylvania, Ohio, Illinois, Missouri, Kansas, Nebraska, and as far west as the Rocky Mountains, and was over a mile thick at its thickest spot. This quantity of ice moved countless tons of material thereby forming many geographic features of the northern United States. The glaciers also locked up large volumes of water causing the level of the sea to fall and expose large areas of land that had previously been submerged under the sea. During the last ice age much of the continental shelf lay exposed and presumably covered by cold, lowland marshes and swamps.

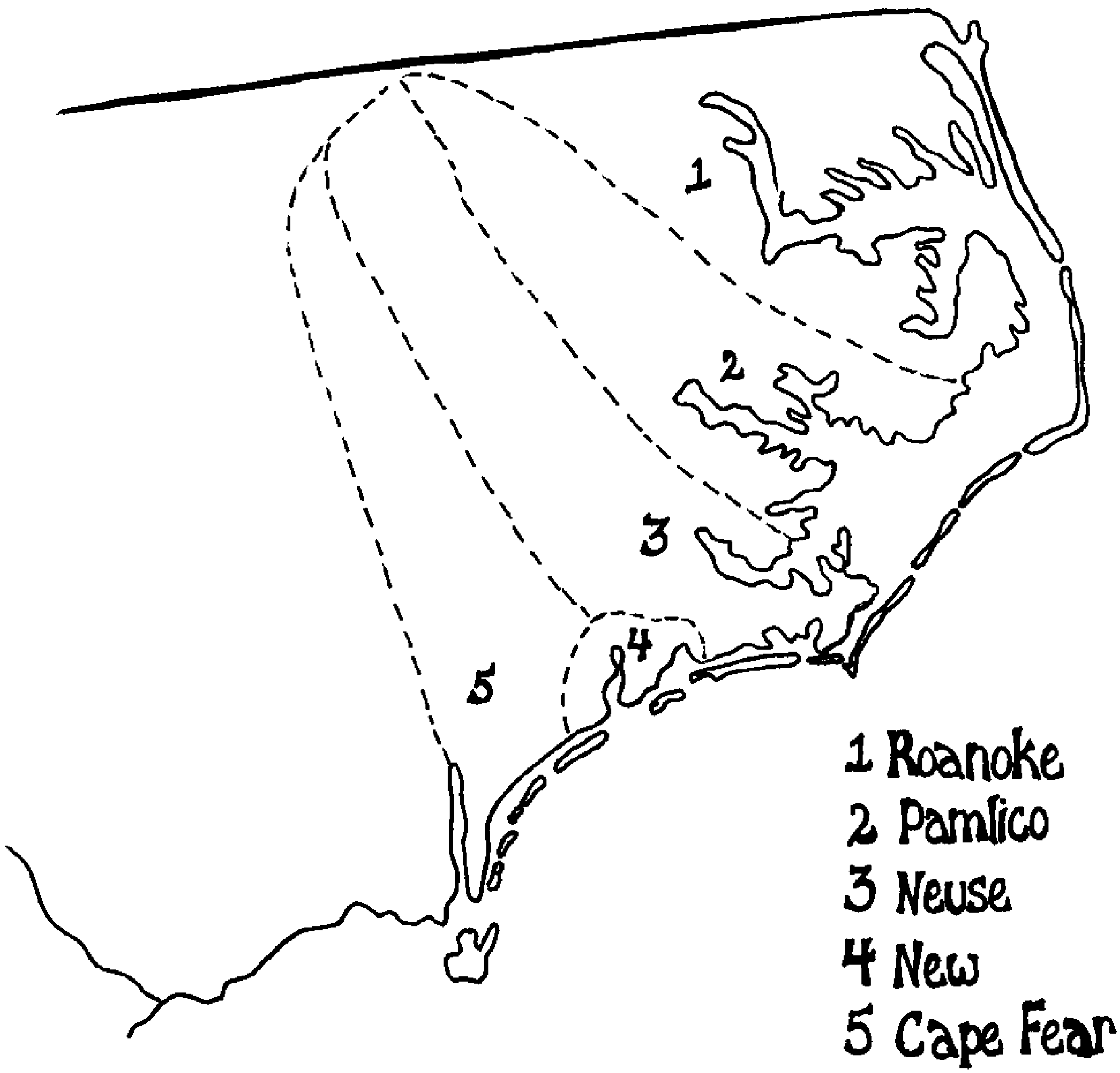
The maximum lowering of the oceans was about 350 to 500 feet below present sea level. This means that while an immense glacier occupied the middle of the country, the coastline was located as much as 300 miles seaward of its present position.

As the ice sheets melted however, sea level rose. When the ice sheets were smallest, sea level was 150 to 300 feet above its present position. Extreme high and low sea levels have occurred four times in the past million years. Lesser fluctuations in level have occurred more frequently in the same period. These sea level changes have left their record as coastal plain terraces of North Carolina.

North Carolina's barrier islands are thought to have been formed from sediments brought to the sea coast by rivers during periods when sea level was lower than it is at present. The theories of barrier

Figure 24

RIVER DRAINAGE SYSTEMS OF NORTH CAROLINA



island formation have been described elsewhere in these materials, but, once formed, the islands protected landward areas from the full force of the ocean's energy. During periods of rising sea level, sea water flooded low lying areas behind the islands to form sounds, lagoons and, in the river mouths themselves, estuaries. These protected waters provide a low energy trap for sediment particles moved seaward by rivers and landward by ocean waves and currents. Thus, these protected waters became increasingly shallow.

The rising sea level that flooded North Carolina's low lying coastal areas most recently resulted from melting of the last great North American ice sheet. The ice melted because the climate got warmer. This warming also caused changes in North Carolina's forests.

Studies of plant pollen and other fossils trapped in successive layers of peat in the Great Dismal Swamp indicate that cold weather forests of fir and spruce occupied uplands of Beaufort and Bertie counties less than 50,000 years ago. Gradual warming forced the spruce-fir forest to retreat northward and to higher elevations. Relics of this forest survive today on scattered mountain tops in the Smokies and Blue Ridge. With the warming trend, beech and maple replaced the conifers and then, in their turn, were replaced by oak and hickory. Pines occupied well drained sand beach ridges and vast areas within the hardwood forest cleared by fires.

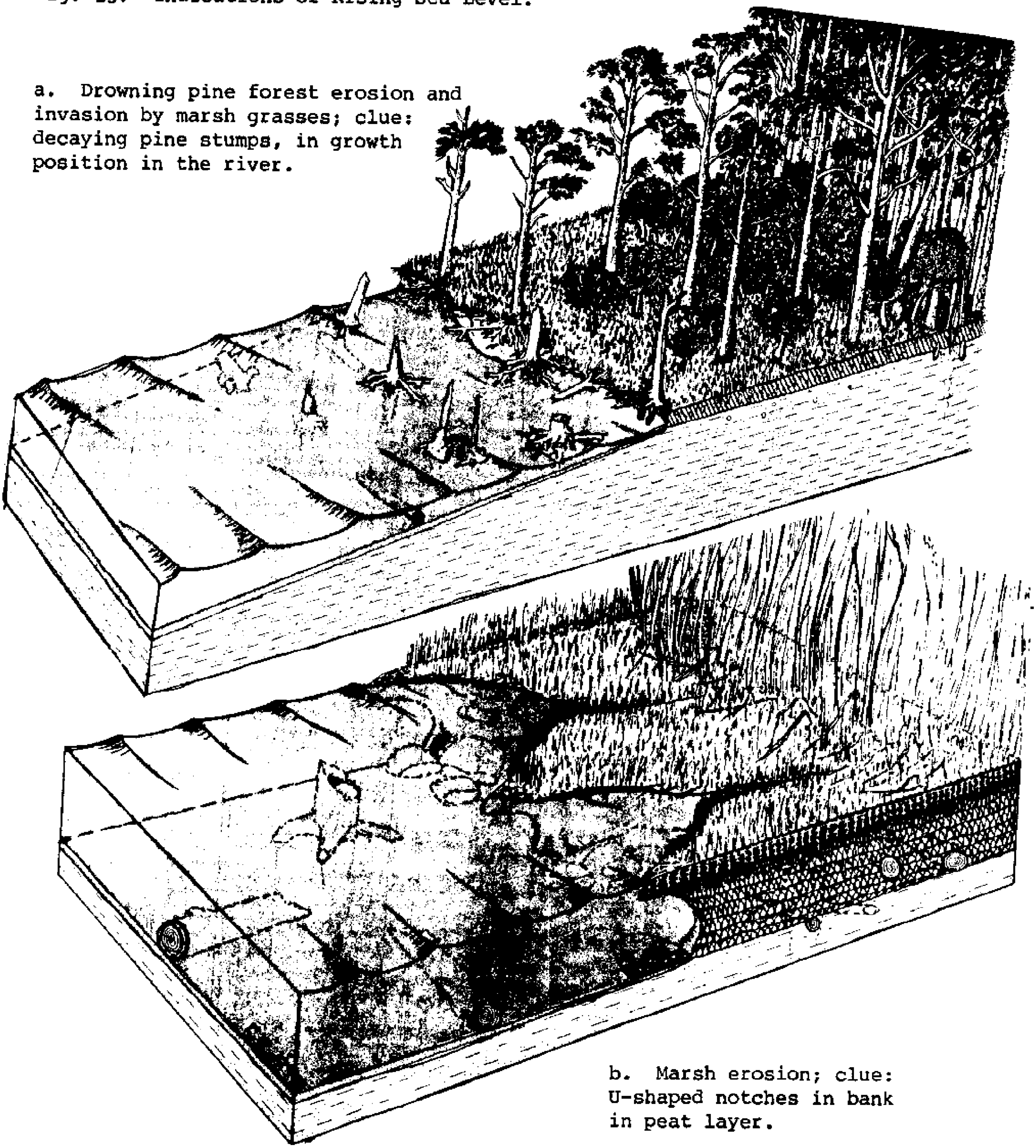
As this type of change occurred inland, the edge of the sounds and estuaries were being colonized by other plants. Marsh plants grew, but were often drowned by rising sea level. However, as more sediment was added at the edge of the sounds and as the rate of sea level rise decreased, salt marsh plants took hold to stay. Grasses began to grow where tides flooded the ground less than half of the time. Spartina alterniflora, a tall coarse grass, grew above mid-tide level while Spartina patens, a finely textured relative, grew near the high water level.

Rivers brought more sand down into the sheltered estuarine zone. Some was trapped in sand bars across inlets, but some settled about the stems and roots of Spartina. Gradually, as more sediment was trapped, the plants grew into new territory and marshes began to fill the sounds, lagoons and estuaries.

As sea level continued to rise, plant growth and trapped sediment raised the level of the marsh to keep step with changing sea level. Spartina patens grew well on layers of peat, accumulated from the roots and leaves of previous growth, and as sea water crept inland the marsh extended inland along with it. Freshwater grasses and shrubs were engulfed by rising salt water and were replaced by salt marsh grasses. Fresh water cypress swamps became flooded with sea water, and as the soil became soaked with salt, the cypress died and the salt marshes marched on to claim larger areas of what had been fresh water swamps. (Figure 25A)

The same drama occurred along creek banks and bogs. Usually the water in the creeks moved rapidly, eroding the curved edges of the

Fig. 25. Indications of Rising Sea Level.



a. Drowning pine forest erosion and invasion by marsh grasses; clue: decaying pine stumps, in growth position in the river.

b. Marsh erosion; clue: U-shaped notches in bank in peat layer.

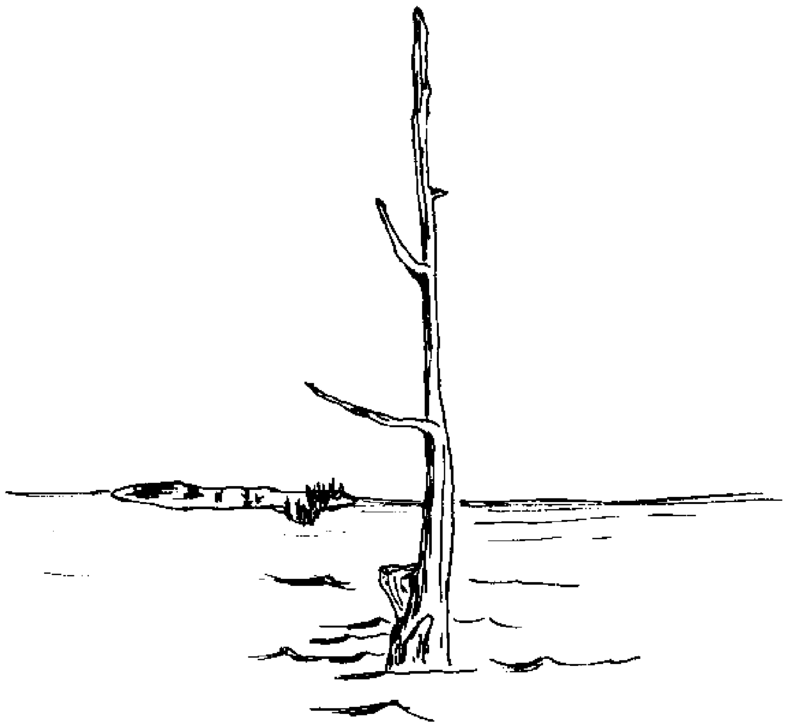
(Bellis, V.J., O'Connor, M.P., and Riggs, S.R. 1975. "Estuarine Shoreline Erosion in Albamarle-Pamlico Region of North Carolina." UNC Sea Grant Publication UNC-SG-7529.

creeks. This caused sediment to be deposited further along the creeks. Heavy rains helped to create channels in the marsh and in rivers. This allowed salt water to move inland where the process of marsh-building continued. (Figure 25B)

This marsh-building process has continued over thousands of years. North Carolina's northeastern coastal marshes have been inundated at the rate of six to twelve inches each century -- a five foot rise in sea level every thousand years.

How do we know this is happening? Huge cypress logs have been found buried under ten feet of salt marsh peat when highways were built. Geologists often find thick layers of fresh water peat under modern salt marshes, indicating that what is now a marsh was once a freshwater bog. Boaters in the North Carolina sounds often find submerged stumps and logs, the remains of ancient forests. Single cypresses still stand miles from the nearest land. Examination of early maps and navigation charts reveal that these logs and trees were once located on small islands that had been occupied by houses and orchards during North Carolina's colonial period. Batts Island, once located in Albemarle Sound, is an example where these events have taken place.

The struggle between land and sea continues. For example, Indian Island which lies about a mile offshore in the Pamlico River near South Creek has lost about 102 feet of shoreline between 1938 and 1970. At the present rate of erosion (3.2 feet per year) Indian Island can be expected to disappear in about 150 years.



b. Vocabulary

Continental Glaciation - a period of time during ice ages when much of the continent is covered by a huge sheet of ice.

Continental Shelf - a zone from low tide line to a depth where there is a marked increase of slope.

Glacier - a large mass of ice and snow that forms in areas where the rate of snowfall constantly exceeds the rate at which it melts. It moves slowly down a mountain slope or valley until it melts or breaks away.

Pleistocene Period - a period of time that began about 1,000,000 years ago which is characterized by ice sheets over Europe and North America.

Sediment - small bits of worn away rocks that are transported by wind and water.

Spartina - a hearty, salt tolerant grass.

Submergence - a process in which the coast is covered by the ocean due either to a rising sea level or coastal subsidence.

Terraces - a wide steplike feature; a relatively level surface bounded by a steep slope upward on one side and a steep slope downward on the other side.

c. Things To Do

Layering of Sediments

1. Objective: To observe how sediments settle in layers.

2. Teacher Preparation: About a pint of sand; Rock particles; Soil; tap water; Pail; Masking tape; Gallon jar; Spoon

3. Procedure:
   1. Mix one part each of sand, soil, and pebbles in the pail and add enough water to hold it together.
   2. Fill the gallon jar with water.
   3. Add 3-4 spoonfuls of mud mixture to the water and observe the sinking and layering of the particles.
   4. Observe which kind of particles form the bottom layer, next layer, etc.
   5. Set the jar aside and note changes which take place throughout the day. Tape may be applied to the outside of the jar, noting the time of day and height of the layers. More spoonfuls may be added to see how the layering is a continual process.

4. Discussion:
   1. How does this activity represent what may be happening in the estuaries when rivers and inlets deposit sediment (Figure 24)? (Shows where sediments are deposited.)
   2. If a geologist only finds very fine mud and silt in the estuary, what hypotheses could he make about the following:
      A. The river current - slow or fast? (Slow).
      B. Where could the heavier particles like sand be found? Upstream or downstream? (Upstream).

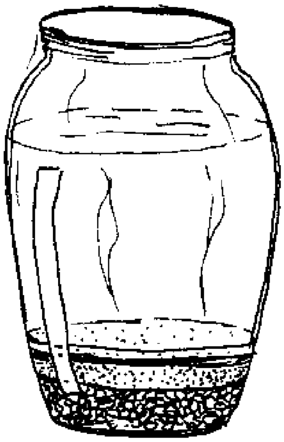


Figure 26

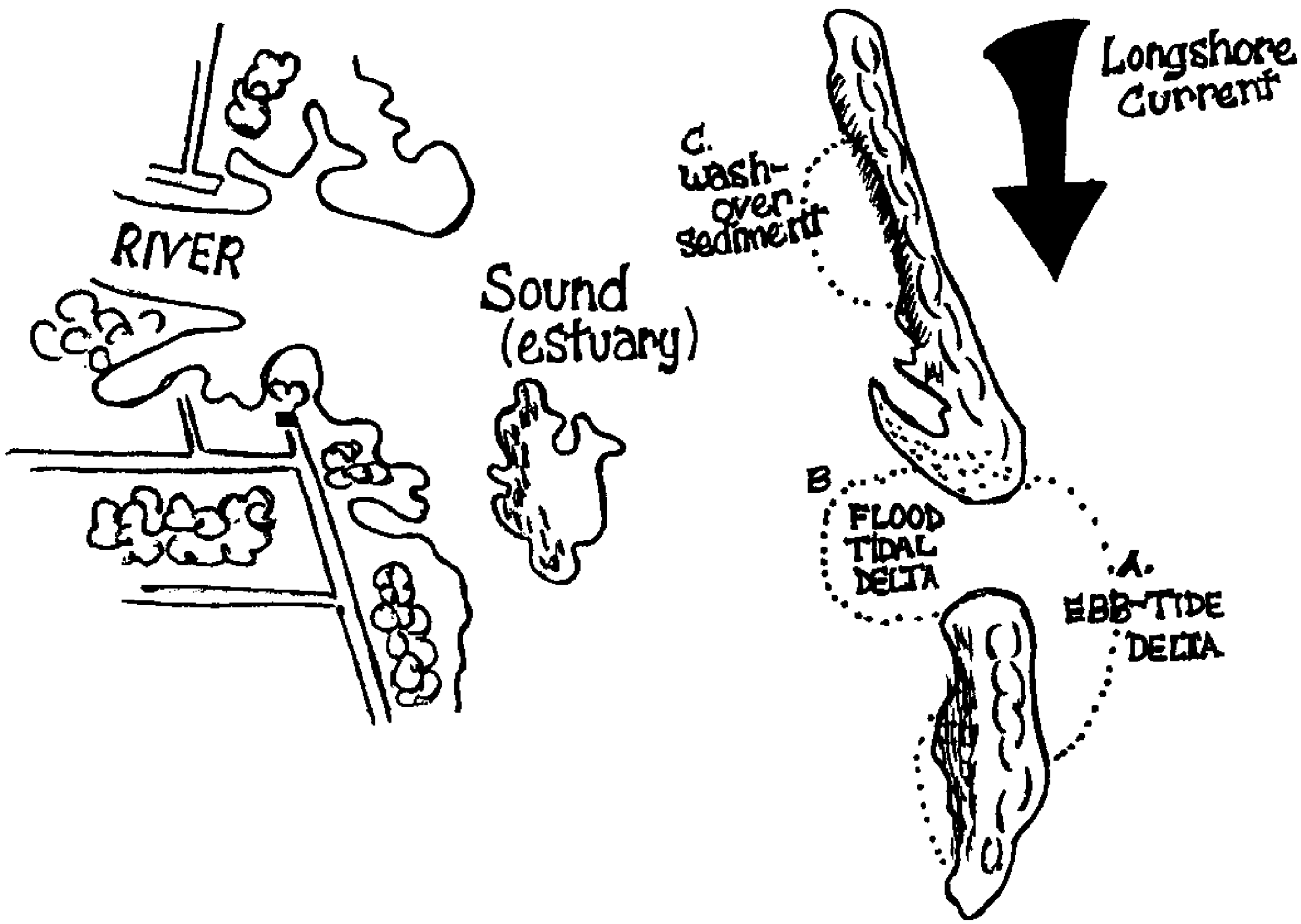
Depositional Patterns in an Estuary-Barrier Island System

A. Delta formed by the ebb tide flowing from the estuary. Note that it is being stretched southward by the longshore current.

B. Delta formed by the flood tide. Note that the spit is made up of sediment from this flood tide delta. Inlet migration and island lengthening occur in this fashion.

C. Washover sediment in the process of being colonized by marsh grasses. Lateral migration of the island occurs in this fashion.

The sound sediment is a combination of sea sediment washed in through inlets and sediment from rivers. As estuaries have flooded rivers via rising sea level, river flow is very slow and most of the river sediment has already been deposited before reaching the sound.



c. Things To Do

Siltation Rates

1. Objective: The students will observe how larger, heavier particles sink faster than smaller particles in water.

2. Teacher Preparation: About a pint of clean, fine grain sand and various sizes of pebbles; two clear containers; water; metronome/stop watch; paper/pencil/measuring tape.

3. Procedure:

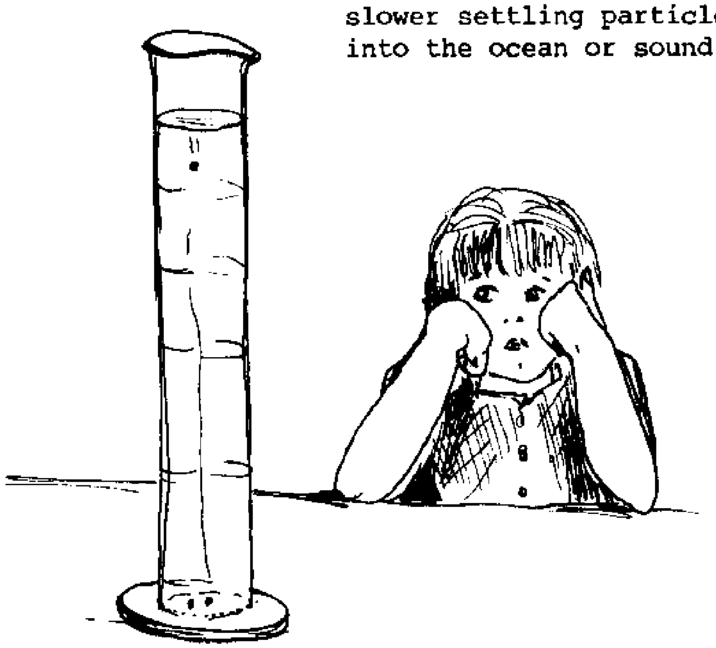
   1. Have children speculate as to which particles they believe will sink the fastest.

   2. If using a metronome, set it at approximately 1-2 second intervals. It is helpful if a student says "go-stop" to the beat of the metronome or pushing of the stop watch button.

   3. The students record the time it took for the particle to fall and record their observation. The particle should be drawn to size on their paper with the time recorded underneath.

   (It is helpful if the student wets his/her finger, puts the particle on it, and then at "go" touches his/her finger to the water's surface.)

4. Discussion: How would the rate of sinking effect sediment size at the mouth of a river? (Particles that sink fastest would be located closest to the river mouth, slower settling particles would be found further into the ocean or sound.)



c. Things to Do

Microsediments In Estuaries

1. Objectives:
   1. To observe sediment particles and perhaps some microfossils under the dissecting scope or low-power microscope.
   2. To realize that some areas once underwater will have microfossil remains.
   3. To locate some micro-organisms in marine or freshwater environments today and observe the shapes.

In a sediment sample the non-living parts will include particles of clay, salt, sand, and other eroded minerals. They have shapes and colors which can be observed and drawn. Also in the sediments are small organisms which once lived in the plankton (upper layer of the water) or on the surface sediment. These include foraminifera (mainly marine) and pieces of small snails, clams, and echinoderms. The most abundant marine fossils are the Foraminifera - "forams". Most foraminiferan shells are coiled like that of a tiny snail, and are made of calcium carbonate. Some examples are shown in Figure 27.

2. Teacher Preparation: Obtain sediment from the top centimenter of a marine habitat such as a marsh or mud flat. (One could order diatomaceous earth or prepared samples from a biological supply house.) Sediment from a freshwater pond or stream would contain many types of particles and some organisms also. Obtain some screen sieves to separate out the coarse material, aluminum foil to make drying dishes for samples, dissection scopes, microscopes, small paint brush for separating samples, and black paper for mounting samples for dissecting scope.

3. Procedure:
   1. Collect the sediment sample; separate out coarse material by washing the sample through a sieve and keeping the material passing through. Most clays should dissolve and wash out, leaving a fine collection of sediment particles in a dish or in finer sieves.

2. Dry small portions of the sediments in an oven or by air. Use the aluminum foil to hold separate samples.

3. Once dry, take a small paint brush, slightly wet the top, and transfer individual grains from the foil to a section of black paper stuck to a slide. Some may be transferred to clear slides for use with the compound microscope.

4. Observe and record the shape, color, and texture of some of the once living sediment particles. Observe, record and try to identify some of the organic particles using the identification pictures given here.

5. Place a drop of dilute HCl on the sample. This will cause any calcium carbonate or shell material to bubble and fizz.

4. Discussion:

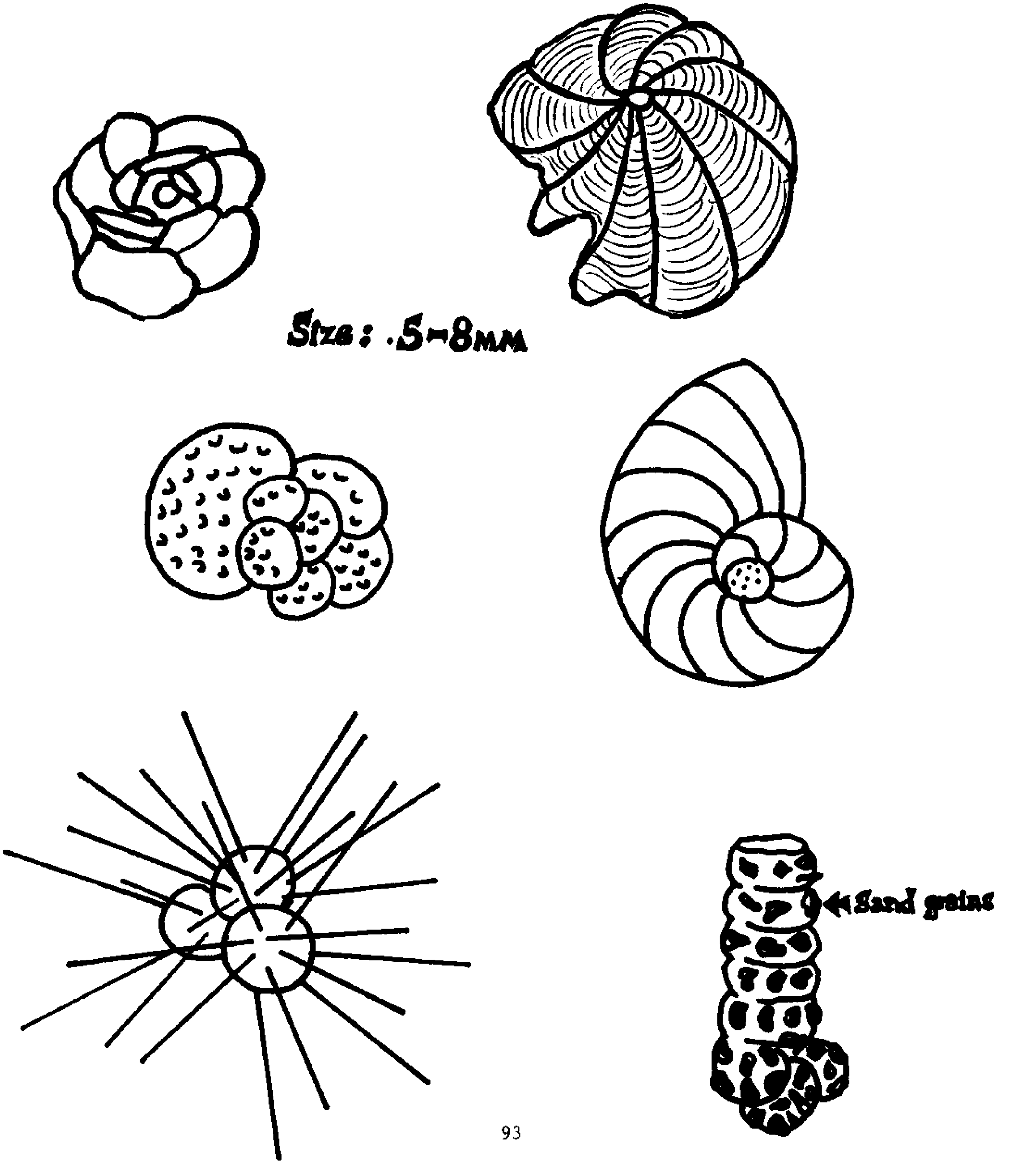
1. Discuss the types of sediment particles found in relationship to the habitat from which they came.

2. Use library books to explain how foraminiferans and diatoms are important to a food chain.

3. What would the presence of Foraminifera tell you about the origin of a sediment sample?

Figure 27

Foraminiferans often found in sediment



d. Resources to Use

Films

1. Crisis in the Estuary: 15 min; color; Milner-Fenwick, Inc.

2. Estuarine Heritage: 28 min; color; NOAA-free loan.

3. Estuary: 28 min; color; EPA-free loan; Modern Talking Pictures.

Printed Materials

1. "Estuary - What a Crazy Place". National Wildlife Federation, 1 copy free, other 25¢.

2. Pringle, Lawrence. 1973. Estuaries, Where River Meets the Sea. MacMillan Publishing Co., New York, NY. 50 pp. (Written for junior high students).

3. Reid, G. 1967. Ecology of Inland Waters and Estuaries. Reinhold Publishing Corp., New York, NY.

Unit 1. North Carolina's Coast and Waters

B. Coastal Environmental Systems

Concept 4. North Carolina's estuarine system is large and linked together by circulation of brackish water.

a. Background Reading

North Carolina has an irregular coastline. Numerous rivers and bodies of water indent the coast, and hundreds of fingers of land project out into the water. The open ocean coastline is a series of fringing islands. These sandy, off-shore beaches border the coast more or less continuously from Sandy Hook, New Jersey to Miami, Florida. Along our coast these off shore "banks" form barrier islands. This chain of islands is broken at several places by inlets of various sizes. At the northeastern end of our coast, the barrier islands are as much as 25 miles away from the nearest mainland. Broad, shallow sounds separate the two. At the southern end of our coast barrier islands lie close to the mainland and sounds disappear altogether. The sounds are bordered by flat grasslands known as salt marshes. Sounds, inlets, rivers, creeks, and salt marshes are known jointly as the North Carolina estuarine system.

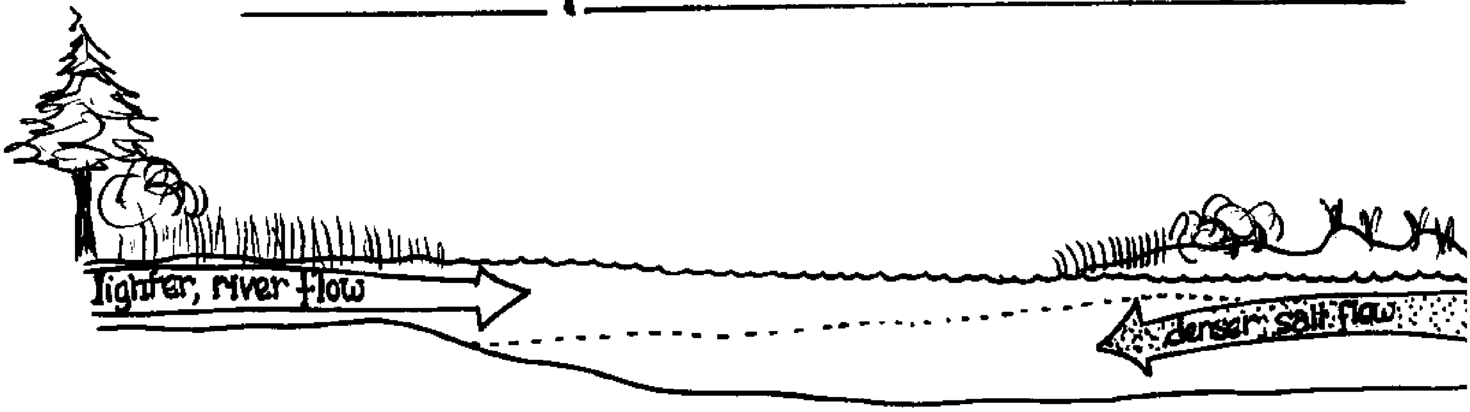
Estuaries themselves are defined as semi-enclosed coastal bodies of water having free connections with the open sea and in which sea water is measurably diluted by fresh water draining off the land. Thus, the term "estuary" is restricted to river mouths but general texts usually refer to the sounds of North Carolina as tidal estuaries. Estuaries can be divided into four basic types. These are: (1) coastal plain estuaries, or drowned river valleys, (2) bar-built estuaries, (3) estuaries produced by tectonic processes, and (4) fjords. Estuaries of the coastal plain and bar built type are found in North Carolina.

Coastal plain estuaries are found along coasts characterized by rising sea level. The circulation within these estuaries is related to river flow and tidal currents. River water being lighter than salt water flows out over the sea water, thereby extablishing two water layers separated by a density interface through which mixing occurs. The extent to which salt water intrudes into the estuary and the degree of mixing between salt and fresh water layers is controlled by tides and winds. The Cape Fear River mouth is North Carolina's best example of a two-layered coastal plain estuary.

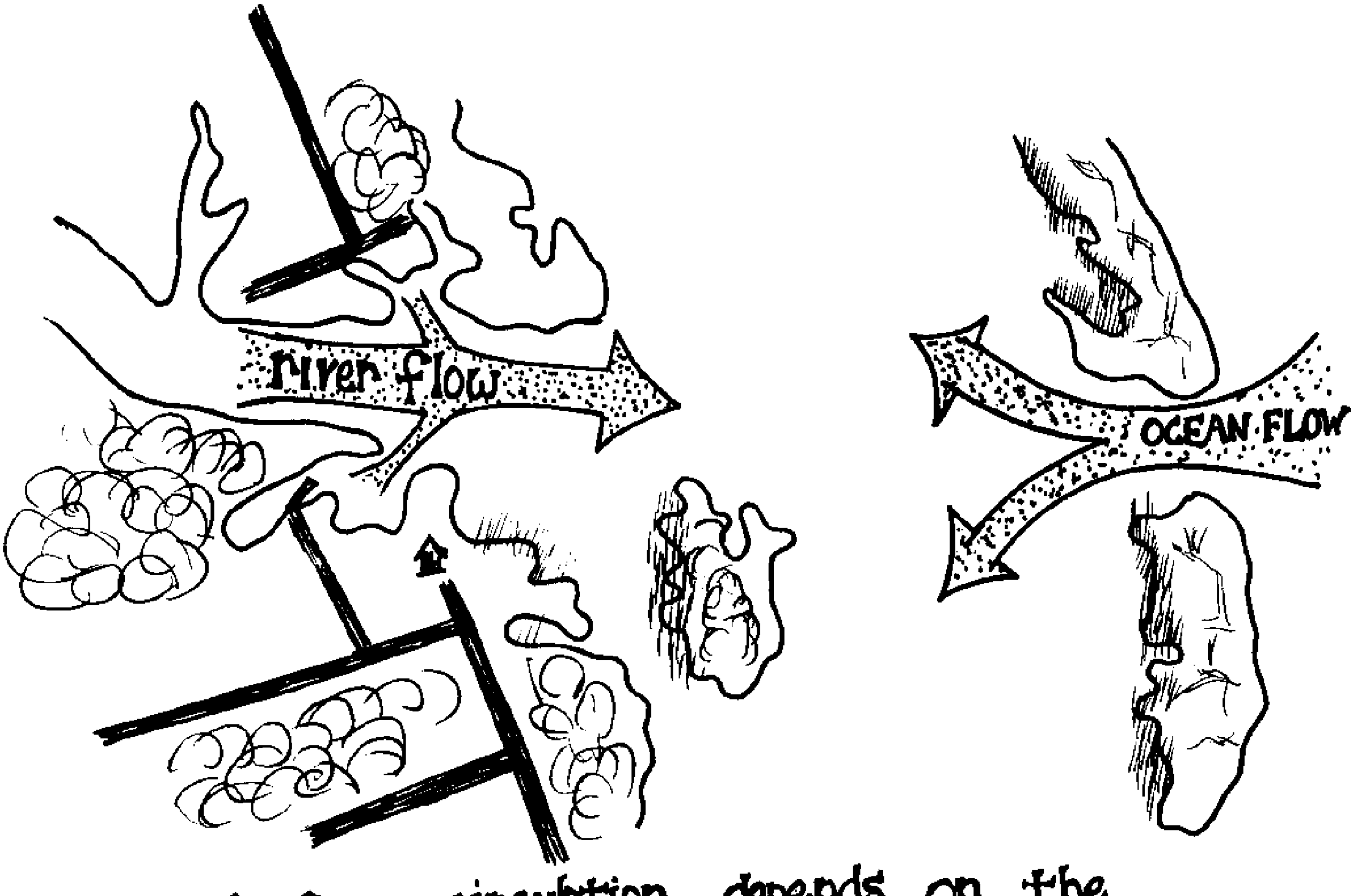
Many of the estuaries of North Carolina are bar-built estuaries. These estuaries form when sand carried by wave action accumulates in offshore bars and barrier islands enclose coastal water to form shallow estuaries. Currituck Sound is North Carolina's best example of such an estuary.

Figure 27

circulation patterns in the estuary system



vertical layering depends on density



Surface circulation depends on the direction of tidal flow

Fjords are inlets in the coastal areas of formerly glaciated valleys. They occur at latitudes above 38 degrees where Pleistocene glaciers carved their way to the sea.

Estuaries produced by tectonic processes occur where there has been earth movement by faulting, folding, or local subsidence or emergence of land.

The salt water found in North Carolina's estuarine system comes from the Atlantic Ocean. The fresh water comes from several major river systems. From north to south, the rivers emptying into the estuarine system are the Chowan, Roanoke, Pamlico, Neuse, and New. The Roanoke, Pamlico and Neuse Rivers drain both piedmont and coastal plain; the others drain only the coastal plain. The Cape Fear River differs from all others in that it flows directly into the ocean rather than to the landward edge of the estuarine system.

Inlets form the dynamic link between ocean and coastal sounds. Sea water is transported through inlets by tide and winds to mix with fresh water supplied by land runoff. The estuarine system is protected from high ocean energies; thus, such low energy environments as marshes, mud flats, oyster reefs, tidal creeks, and submerged grass beds can develop. (Figure 29)

Mud flats, oyster reefs, and grass beds are found within the shallow regions of the sounds. Marshes and tidal creeks are found bordering sounds.

Mud flats and oyster reefs can be located where they are permanently submerged or between high and low tide levels in the intertidal zone. Mud flats are formed in areas of fine sediment deposition which receives little current or wave action. (Figure 26). Oyster reefs are formed on a firm substrate when oysters (Crassostrea virginica) attach and provide additional substrate to which others attach forming a large cluster. Grass beds are formed in shallow areas where currents move slowly to provide a favorable habitat for growth of eel grass (Zostera marina). These beds are highly productive and may occupy large areas of North Carolina sounds.

Salt marshes are flat beds of salt resistant vegetation occurring in the intertidal zone bordering sounds, lagoons, and estuaries. Salt marshes are often classified into two basic groups, i.e. regularly and irregularly flooded marshes. Irregularly flooded marshes are those which are flooded at irregular intervals by storm and wind driven high tides. More than 100,000 acres of North Carolina marshes are irregularly flooded. These irregularly flooded marshes usually have sandy, firm bottoms and are drained by short, relatively unbranched, tidal creeks. Black needle rush (Juncus roemerianus) is the most dominant plant. It grows about three feet high and is very dense. During periods of heavy winter rain, irregularly flooded salt marshes may be covered with fresh water; during periods of high storm tides, they may be flooded with nearly full strength sea water; and during spring and early summer, they may become so dry that no standing water can be found. Regularly flooded salt marshes are those flooded by almost every normal high tide. There are about 58,000 acres of regularly flooded salt marshes in North Carolina. The bottoms of these marshes are soft and the marshes are drained by long, dendritically branched, tidal creeks.

North Carolina also has about 47,000 acres of coastal fresh water marshes that are rarely flooded with salt water. In general, the waters flooding these marshes are fresh to moderately brackish. Over one half of this type of marsh is found around Currituck Sound, North Carolina's northernmost sound.

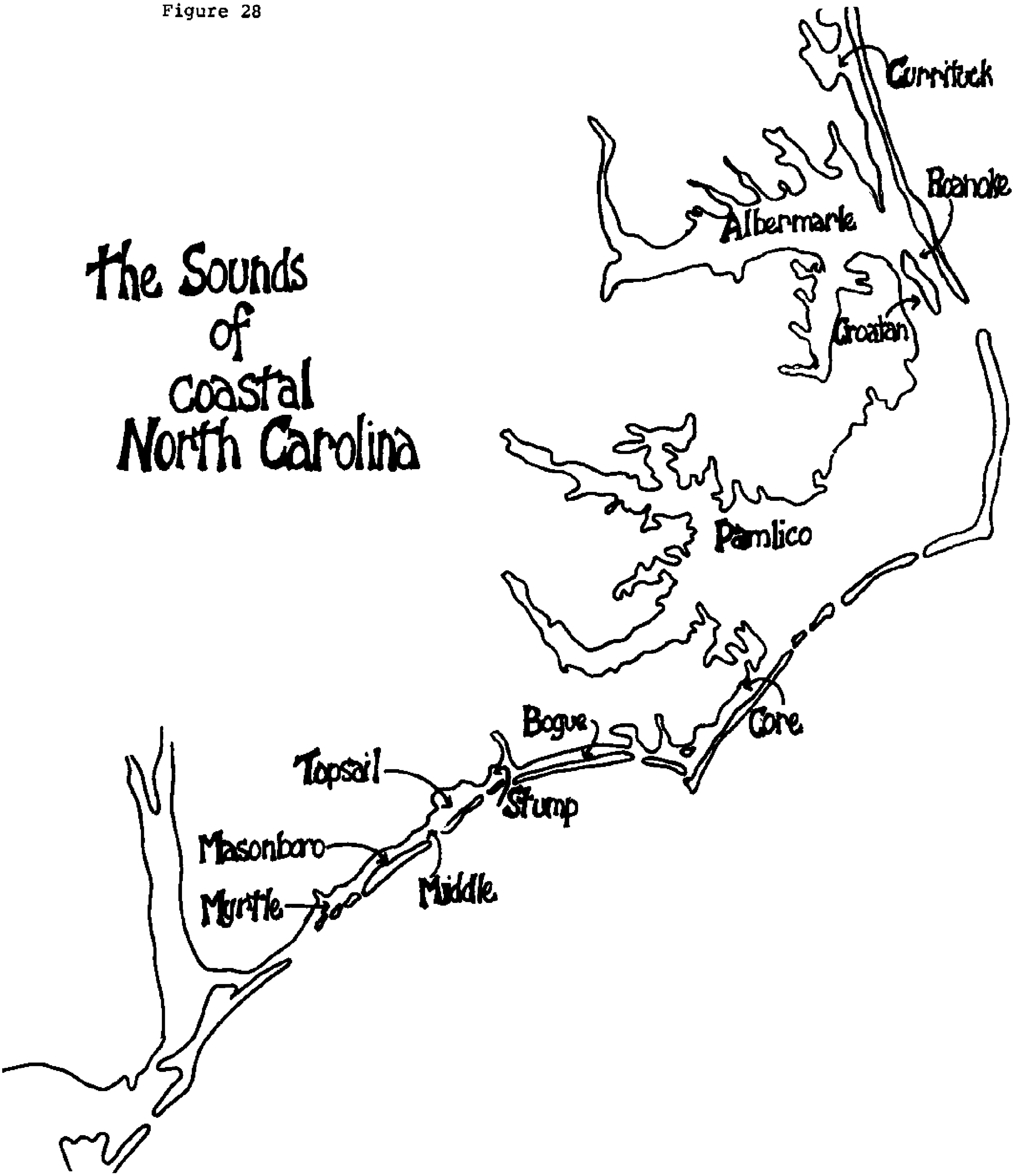
Marsh drainage creeks can be considered the life lines of the marsh. Sea water comes through inlets into the sounds, filling these creeks which thus serve as a conduit carrying water into the marsh. The distribution of marsh plants is usually in distinct zones controlled by tidal creeks fed by flooding regimes. Salt marsh cord grass (Spartina alterniflora) grows close to the banks of the creeks. As one moves further away from the tidal creeks, other plant species become part of the flora, another species of Spartina, S. patens (salt marsh hay), spike grass (Distichlis spicata), the black needle rush Juncus roemerianus and the succulent glasswort (Salicornia spp) are the most obvious of these. Their distribution is related to flooding frequency. At the upland border of salt marshes one sometimes finds a barren zone that is flooded only during the highest high tides. These areas are known as salt pans, and they often have soil waters that are two or three times as salty as sea water. Another feature sometimes found associated with marshes is a hammock. This is an elevated area covered with cedar and hardwood trees.

The estuarine system of North Carolina covers over 300 linear miles (480 kilometers). This actually forms thousands of miles of coastline and millions of acres of estuarine habitats.

There are twelve major sounds along the coast of North Carolina. These vary in size, shape, depth, and salinity. Most are shallow but differ in the amount of fresh water runoff that reaches them from the mainland. The plants and animals of these sounds vary due to the resultant differences in salinity regimes. (Figure 28)

Currituck Sound, the northernmost of the twelve named sounds in the state, is about 40 miles long, 3 to 4 miles wide, and less than 7 feet deep over most of its area. It is essentially a low salinity lagoon draining the bordering swamps and lowlands. It opens into the eastern end of Albemarle Sound to the south, while the Inland Waterway links it with Norfolk to the north and with the North River tributary of Albemarle Sound to the southeast. Its mouth is about 24 miles from Oregon Inlet, the nearest opening to the ocean; consequently, its waters are fresh to brackish and are notable for supporting water fowl, fresh water game fish, and such migrants to fresh water as striped bass and alewives.

Figure 28


The Sounds of coastal North Carolina
Currituck
Roanoke
Albermarle
Croatan
Pamlico
Core
Bogue
Topsail
Stump
Masonboro
Middle
Myrtle

Albemarle Sound has an east-west dimension of about 55 miles, averages about 7 miles wide, and has a rather level bottom about 18 feet deep. Eight rivers, including the Roanoke and Chowan, drain into it while it drains through Croatan and Roanoke Sounds into the upper part of Pamlico Sound. The Inland Waterway connects it with Currituck Sound to the northeast, and, by way of the Alligator River, with Pamlico Sound to the south. Albemarle is essentially a fresh water sound. It has proven to be an exceptionally favorable habitat for anadromous fishes (those that seek fresh water to spawn). The resulting fish migrations and the shallow, level bottom suitable for staking nets form the basis for the intensive fishery of the area.

Roanoke and Croatan Sounds parallel each other and extend south from eastern Albemarle into northeastern Pamlico Sounds. Roanoke Sound, just west of the offshore bar, is about 8 miles long, one half to 2 miles wide, and has a depth of only 1 to 3 feet over most of its area. Croatan Sound, west of Roanoke Island, is also about 8 miles long, but is 2 to 4 miles wide and generally 7 to 10 feet deep. This sound is important to the circulation and drainage from Albemarle to Pamlico Sound. Accordingly, it is a potential bottleneck for anadromous fishes entering Albemarle Sound. However, because of its high fresh water circulation, it has not been very productive of oysters.

Pamlico Sound is approximately 70 miles in its long northeast-southwest dimension and varies from 10 to 30 miles in width. In the basins the bottom is rather level with a depth of about 20 feet, but there are extensive shoals distributed as follows:

1. Completely around the shoreline grading into the extensive bordering marshes,

2. As flood tidal deltas at the four existing inlets,

3. Between the converging mouths of the rivers, particularly the two larger ones, the Neuse and Pamlico,

4. Extending northward from Ocracoke Inlet as Bluff Shoal. This shoal is created due to the deposition of suspended matter where waters draining from the north meet drainage from the southwest. Thus, the merged estuaries of the Neuse and Pamlico Rivers form one basin of Albemarle Sound while a second basin stretches northeast toward Roanoke and Croatan Sounds.

The salinity in Pamlico Sound varies with location. Sessile fishery forms are distributed accordingly: clams at the mouths of inlets and oysters along the inland shores.

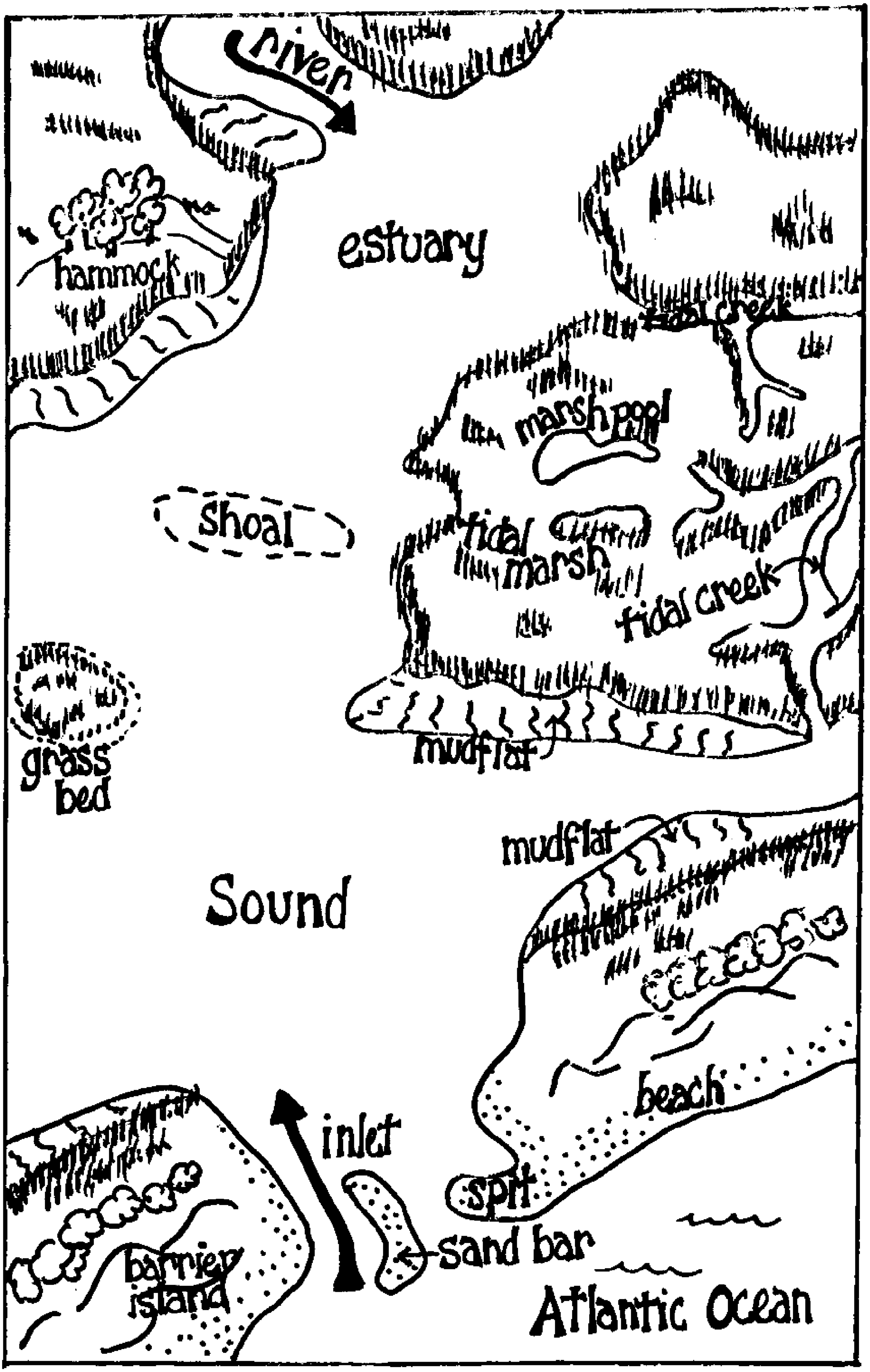
Core Sound begins at the southern part of Pamlico Sound and extends southwesterly about 36 miles to the vicinity of Beaufort, where it joins Bogue Sound, a sound that stretches to Swansboro, about 25 miles to the west. These sounds vary from 1 to 6 miles in width and are extremely shallow. Core Sound averages only 3½ feet deep and Bogue Sound about 2½ feet. There is considerable drainage from the surrounding lowland by way of marshes and small creeks. The North River and the Newport River form large arms of these sounds opposite Beaufort Inlet. The Inland Waterway cuts through to the Newport River from Pamlico Sound to Beaufort where it takes a westerly course through Bogue Sound. In addition to Beaufort and Bogue inlets, two other inlets (Okracoke and Hatteras) cut through the outer banks to connect Core Sound with the ocean.

Beaufort Inlet and the adjacent intersection of the sounds and "rivers" afford a terminal for coastal, inland-water, and land transportation which has resulted in the rise of Beaufort and Morehead City as fishing and sea ports.

Southwest from Bogue Inlet and extending to the mouth of the Cape Fear River (a distance of about 75 miles), the coast is fringed with numerous small, shallow lagoons interrupted by marshes. Streams and creeks of varying volume flow into these small lagoons and several small inlets connect them with the sea. The sizeable New River drains across the marshes between Bogue and Stump Sound and into the ocean by way of New River Inlet. The larger lagoons of this area are Stump, Topsail, Middle, Masonboro, and Myrtle.

There is very little open water between the Cape Fear River and the state line 32 miles to the west. The Inland Waterway, which has continued southward through the sounds and marshes mentioned above, is cut through marshes in this area and leads to Charleston, South Carolina, and eventually all the way to Brownsville, Texas.

Figure 29


river
estuary
hammock
tidal creek
marsh pool
shoal
tidal
marsh
tidal creek
grass
bed
mudflat
mudflat
Sound
beach
inlet
spit
sand bar
barrier
island
Atlantic Ocean

b. Vocabulary

Banks - another name for barrier islands, or offshore sandy beaches

Barrier Island - an island separated from the mainland by a narrow body of water or by a shallow, often marshy area

Delta - a level, fan-shaped deposit formed at the mouth of a stream entering a quiet body of water or where flooding tide carries sea water into coastal sounds

Estuarine System - an ecosystem that includes a marsh, an inlet or a source of salt or brackish water, a lagoon, and a source of fresh water, usually a drowned river

Estuary - a semi-enclosed coastal body of water having free connections with the open sea where sea water is measureably diluted by freshwater runoff

Hammock - a highly elevated area associated with marshes that contains hardwood trees

Inlet - an opening that connects the sounds or lagoons with ocean water

Irregularly Flooded Marshes - low areas along the coast that do not receive tidal waters on a regular basis

Lagoons - an area of quiet, shallow water between a barrier island and the mainland

Salt Marsh - an area of low, wet land covered with grasses and inundated by salt water frequently

Mud Flats - flat, compacted mud areas that are exposed between high and low tide levels; usually in shallow sound areas

Salt Barren Area - a small area beyond the high tide mark that receives salt water only at extreme high tides; the salt does not get washed away, so this leaves the area too salty for plants to grow

Sounds - the water found between a barrier island and the mainland

Regularly Flooded Marshes - a low land that receives salt water as the tides move in and out of the marsh

c. Things To Do

Let's Make An Estuary

Write the following geological terms in the order in which they occurred during the geological making of an esturay - marsh system.

1. estuary	1. ______________
2. volcanic activity	2. ______________
3. streams	3. ______________
4. glacier	4. ______________
5. warming trend	5. ______________
6. sand bar	6. ______________
7. storm	7. ______________
8. ice age	8. ______________
9. sediments	9. ______________
10. barrier island	10. ______________
11. inlet	11. ______________
12. ocean	12. ______________
13. rocks	13. ______________
14. weathering	14. ______________
15. mountain	15. ______________

P.S. Your answers may vary slightly from your neighbors'. Be ready to explain your sequence of events.

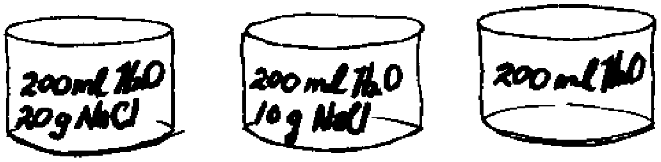
c. Things To Do

Stratification On An Estuary

1. Objective: To demonstrate how sea water is stratified into density layers with the denser, saltier layers at the bottom.

2. Teacher Preparation: 1,000 ml glass graduated cylinder or tall jar/ glass; salt; water; food coloring (3 colors).

3. Procedure:
   1. Mix three separate concentrations of salt water in three separate containers. The first concentration should be significantly more dense than the second. One of the beakers may contain only water. e.g.



   2. Add food coloring (different colors) to each beaker.

   3. Pour the more dense salt water mixture into the tall jar or graduated cylinder. Next, slowly pour the second most dense salt water mixture into the cylinder on top of the bottom layer, being careful that mixing does not occur. Finally, add the third layer of pure water. The column should contain three separate layers of different colors, demonstrating the stratification of sea water.

4. Discussion:
   1. Where would the top layer come from, the bottom layer? (top, river; bottom, sea)

   2. How would winds affect the stratifications? (mix up layers)

c. Things To Do

What Are The Marshes Made Of?

1. Objectives:
   1. To be able to label a diagram of a marsh with correct parts.
   2. To indicate the flow of water through a marsh estuarine system.

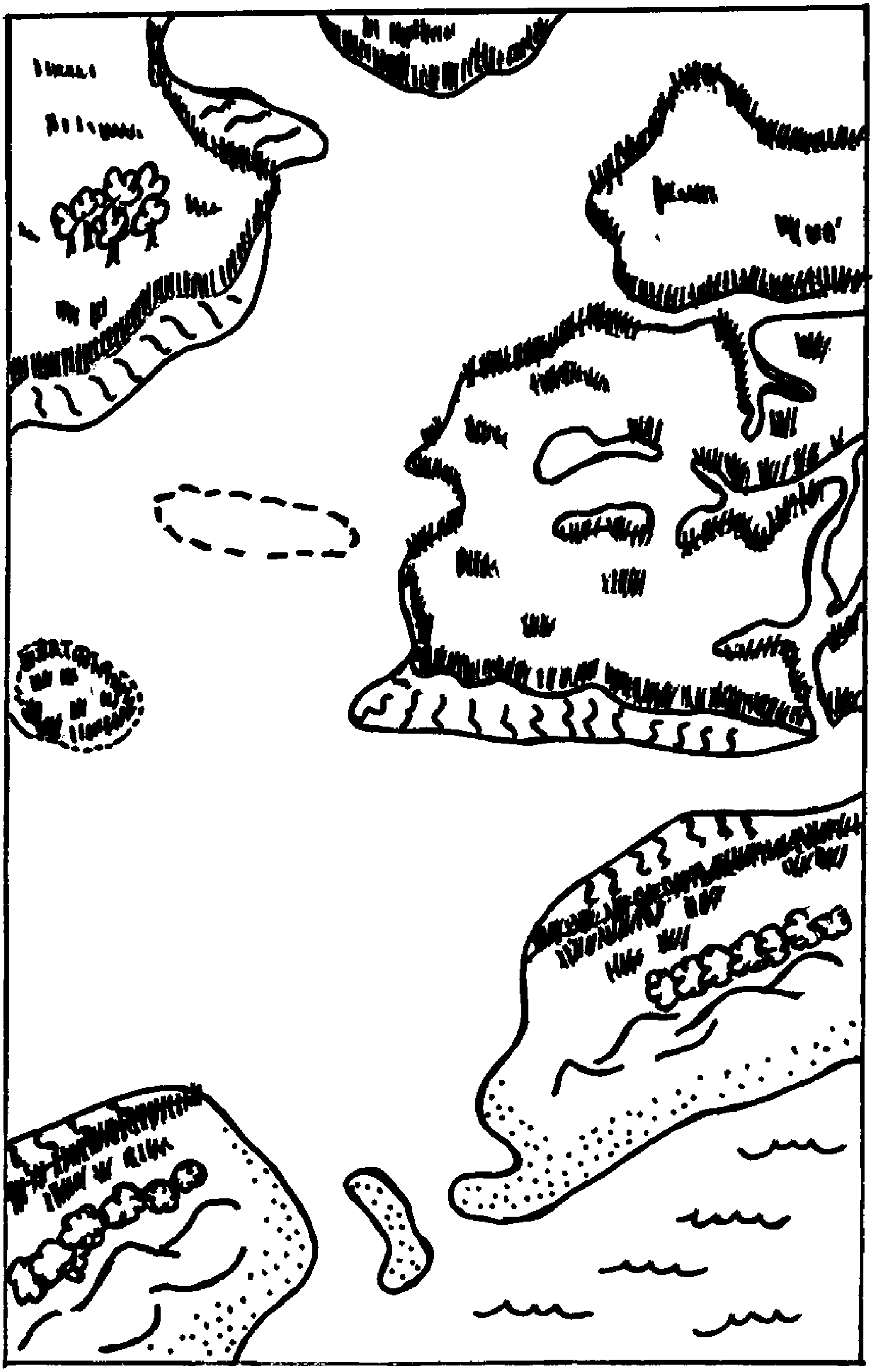
2. Teacher Preparation:
   1. Review the parts of a marsh and, if possible, show one of the films on marshes.
   2. Explain the circulation within a marsh by river flow and tidal currents.

3. Procedure:
   1. Label the diagram with the following parts:

      river; inlet; barrier island; spit; sand bar (above water); shoal (underwater); marsh; mud flat; maritime forest; hammock (island of trees in a marsh); tidal creeks; estuary (sound); beach; grass flat (underwater); tidal pools.

   2. Using a blue crayon, draw arrows to show the flow of water at ebb tide (when it goes out). Using a red crayon, draw arrows to show the flow of water at flooding tide (when it comes in).

Fig. 30. Student chart of an estuary and marsh.



d. Resources To Use

Films

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3. Reid, G. 1967. Ecology of Inland Waters and Estuaries. Reinhold Publishing Corp., New York, NY.

4. Evan, S.M. and J.M. Hardy. 1970. Seashore and Sand Dunes. Heinemann Investigations in Biology. Heinemann Educational Books, Ltd. 5 S. Union St., Lawrence, MA 01843. $2.50. Good activities described.