Unit One

Coastal Geology

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Acknowledgements

The North Carolina Marine Education Manual is a collection of teaching materials generated by North Carolina public school teachers and university professors. It is designed to help middle school teachers put marine perspectives into their lessons. The activities can be modified for higher or lower grades.

The manual was created under a UNC Sea Grant project titled "Man and the Seacoast." Dr. Dirk Frankenberg was the principal investigator. The Resource Unit Development Committee, directed by Dr. William Rickards of North Carolina State University, assisted with material production.

This volume consists of separate units that cover environmental aspects of the coast such as geology, ecology and seawater. An additional unit covers facets of coastal history and anthropology. An appendix provides information on state and federal agencies, field trip guides and safety, film company addresses, and keeping aquaria.

We wish to acknowledge the cooperation we have received from other marine education projects, the N.C. Aquariums, the N.C. Department of Public Instruction and the National Marine Educators Association. We especially wish to thank the people whose enthusiasm and contributions made this project possible — the following North Carolina teachers:

1977 "Man and the Seacoast" teachers


1977 "Man and the Seacoast" staff

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1977 "Resource Unit Development Committee


1986 Contributors

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The North Carolina Marine Education Manual was 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, Box 8605, North Carolina State University, Raleigh, N.C. 27695-8605.
Introduction

This Marine Education Manual is designed 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 in this book, and that they will learn not only about the ocean, but also about the general scientific phenomena that make the ocean explicable. We also hope these materials will help teach 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 focus specifically 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.

Materials on large-scale tectonic forces of continental drift have been included. We also examine the development of North Carolina’s coastal plain and the wind and water movements that shape the barrier islands and sounds. For each topic, we have included a resource section that contains information on films, books and free materials. 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 Secondary Schools K-12, 1977, pages 139-148).

Program features include knowledge/content objectives. The objectives have been generalized into broad categories 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 those that 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 that 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 teachers may want to modify each lesson to suit their grade or class levels. 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 N.C. Department of Education.

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Table 2: Goals and Behavioral Objectives

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.

To describe the present coastal environmental features of barrier islands, sounds and estuaries, and to indicate dynamic processes affecting 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.
Geological Origins

Plate Tectonics

Two hundred million years ago, North Carolina looked different. The newly formed Appalachian Mountains stood tall and jagged. To the east stretched land and more land. There was no Atlantic Ocean. All of the earth’s crust was locked into a single continent, Pangaea, meaning “all lands.” North Carolina was once on the leading edge of a large plate that collided with another and formed the Appalachian Mountains. North Carolina became part of the trailing edge of the North American plate when two plates of crustal material “drifted” apart about 185 million years ago. The two plates drifted apart as the result of a great rift that split apart Pangaea and formed the Atlantic Ocean.

Current science texts provide useful information on the general theory of plate tectonics — the theory that has revolutionized earth science in the last 20 years. But these texts do not provide much local information on the geology of North Carolina.

North Carolina is an excellent example of tectonically derived geology. It contains examples of early plate collisions and mountain building (the Appalachians), an early rifting stage and sedimentary basins (the Deep River and Dan River Triassic basins), and coastal plain features that preserve a record of changing sea level along a passive continental margin.

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 the last 185 million years of North Carolina’s geologic record 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 theory is beyond the scope of this material, but it can be derived from geology science texts and from articles such as one in 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. Mathew’s article:

North Carolina’s physical features are a result of plate tectonics, weathering and sediment deposition.
Geologists’ new view of the earth is of continents drifting majestically from place to place, of mountains and island chains forming like ripples in rugs pushed together, of oceans opening and closing.

The earth’s seemingly rigid crust, these geologists 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.

“This Changing Earth,” *National Geographic*, 1973 (1) page 7. (Figure 1).

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

1. How did North Carolina get its western mountains?

Part of North Carolina 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 the present Appalachian Mountains.

2. If the rock forming the Appalachians was originally 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 more than 200 million years, sediment has washed down the rivers and deposited into the ocean. Those layers eventually built up a wide, gently sloping plain that 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.
Figure 1

Pre-Split

Post-Split
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 preceded 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.

4. What evidence is found in North Carolina of the great rift that split apart Pangaea to form the Atlantic Ocean?

The Deep River (Durham and vicinity, see 1985 Geologic map of North Carolina) and Dan River basins (Stokes and Rockingham counties, see 1985 Geologic Map) are part of a series of long, narrow depositional basins that stretch from North Carolina to Nova Scotia in a northeastwardly trend. These basins were formed by normal faults that developed on either side of the great rift during the Triassic Period.

In North Carolina, the rocks of the Triassic basins are composed of red, brown, purple or gray mudstones, sandstones and conglomerates that were deposited in marsh, lake and fluvial environments. Coal bed and black shales of the North Carolina Triassic basins have yielded abundant plant fossils that mirror remains of ancient ferns, cycads and conifers. Occasionally, freshwater bivalves and vertebrate fossils have also been found in Triassic rocks.
Vocabulary

Appalachians - the mountains of North Carolina resulting from plate collision. The metamorphic rocks of these mountains were deformed by the stress of being on the leading edge of colliding plates.

Bathymetric - deep ocean water contour measurements.

Coastal plain - a strip of land of indefinite width that extends from the seashore to the first major change in terrain features. In North Carolina, it consists of sedimentary rocks and has been inundated by the sea many times in geologic history.

Continental shelf - the sea floor adjacent to a continent extending from the low water mark to the change in slope, usually about 600 feet (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 or map connecting points of equal value, such as elevation or depth.

Fall line - an imaginary line or narrow zone that 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 that move in response to processes in the upper mantle. The plate margins undergo 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 or both.

Sonar - "Sound Navigation and Ranging" is a technique using underwater sound and echoes to determine water depth and location of underwater features.

Trailing edge - the side of a plate that does not collide with another plate.
How Did the Atlantic Ocean Get Here?
Plate Tectonics

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

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; and a crayon or pencil.

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 2.

2. Crease part of the left side of the paper 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 pull each half from the center. This represents the rift or split of the supercontinent. As the rift becomes wider, color it blue. This represents the oceanic basin. (Figure 2)

4. Pull the rift out farther 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.

Discussion
1. What does this activity tell about the age of the rocks close to the Mid-Atlantic Ridge and those near the continents? (young nearest Ridge)

2. The Mid-Atlantic Ridge, as the name implies, is very near the middle of the
ocean. After doing the activity, can you explain this? (ocean formed either side)

3. Where does the material that 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? (Mid-Atlantic Ridge) Why?

Plate Tectonic Puzzle

To demonstrate that the earth's crust consists of moving plates which change positions over time, and that North Carolina's geological features are traceable to this process.

Objective

Teacher Preparation

Cut out the continental puzzle pieces given on the following pages. Mount or laminate them for longer use. Supply the students with the changes of Pangaea through time to the present day continental arrangement (or you can convert to transparencies for overhead projection). (Figures 3-6)

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 that extends underwater from shore.)

3. Move the puzzle pieces into the Pangaea arrangement. Then move them, step by step, to their present locations, following the drifting pattern given on the time line. (Figures 4, 5, 6).

Discussion

1. As you make each move, describe how the continents drifted, their approximate directions, rotations, attachments and eventual positions.
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 the present arrangement of continental blocks, the edges of these blocks do not look like our present coastlines. Give a reason for this. (Sea level is higher now than the edge of the blocks. The continental shelf is often a better outline to match.)

5. Which type of coastline does North Carolina have? Leading or trailing edge of a plate block? (Trailing edge)
Figure 4. Crustal Plate Movement beginning 225 million years ago. End of Paleozoic Era and beginning of Mesozoic Era.

Pangaea

225 million years ago

180 million years ago
Figure 5. *Mesozoic Movement*

135 million years ago

65 million years ago
Figure 6. Present Crustal Configuration
Exploring the Depths

To simulate techniques for learning ocean depths.

Objectives

To make a transection showing depth and to construct a bottomland profile.

To understand how oceanographers map the ocean floors and to become aware of problems that they might encounter.

Teacher Preparation

For each team (up to five students/team), use one large container (trash can, wash bucket), wire screen, hardware cloth, ink, water, string, small fishing weights, graph paper, meter stick and odd non-floating objects.

In the bottom of each trash can, place an object to build a bottom shape (upturned bowl, tray, pile of rocks). Fill container with water; color with ink until you cannot see the object. Cover the container with wire screen. For younger children, mark a line across the screen with tape to give them a point from which to measure.

1. Assign roles to team members: measurer, recorder, grapher, sounder.

Procedure

2. Using weighted string, lower the line in the water until it hits "bottom." Mark the water point level on the string. The sounder gives the string to the measurer to obtain length. The recorder records depth and the point of transection. After all the measurements have been made across the screen, the points are graphed and a profile is made. (Several teams can do the same container and profiles can be compared.)

3. Once the measuring and graphing is completed, discuss how ships might have had problems with charting the ocean floor (currents, rope breaking, drifting ships, unsure of exact location) and what types of improvements have been made (Sonar, satellite navigation, LORAN C).
Bathymetric Contouring:  
North Carolina's Continental Shelf

Objectives
To make contour and profile maps.
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. Water depth is usually measured by a technique of echo sounding called sonar. Until the 1800s, 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.

Words to Know

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

mean low water: the depth of the water level during the average low tide.

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 farther they are apart, the gentler the slope.)

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

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

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 7).

Teacher Preparation
Provide each student with a bathymetric chart with depths marked on it (Figure 8) and a profile graph (Figure 9).

Students will also need yellow, red and blue crayons.
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 near the shore and sometimes farther out — marking the presence of shallows and shallow water.

3. With a pencil (in case you make a mistake the first time), draw a solid line connecting the areas that 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 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 to 1,000 fathoms red. Color the ocean floor blue.

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 9

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 for you to find.
Crossword Puzzle

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

DOWN
1. the mountains in western N.C. formed by the crashing of two plates
2. the highest point that 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 that crashes into another plate
Answer Sheet for Word Games

Hidden Word Game

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

Crossword Puzzle

**Down**
1. sea level
2. coastal plain
3. rift
4. continental shelf
5. plate tectonics
6. trailing edge

**Across**
1. Appalachians
2. fall line
3. continental slope
4. leading edge
Resources

Films
1. "Continental Drift": 10 min., color, National Film Board of Canada.
5. "This Land": 39 min., free loan, Shell Film Library.

Printed Materials
1. Hardbottom Distribution Map, UNC Sea Grant, Box 8605, N.C. State University, Raleigh, N.C. 27695-8605. $5. Depicts the flora and fish associated with the continental shelf in Onslow Bay, N.C. Also includes a map of the hardbottoms in the bay.
2. Pamphlets from Encyclopedia Britannica:
   - Earth and Geology (one free, others 25 cents)
   - Glaciers - A Water Resource; Geological Times; Landforms of the U.S.; Our Changing Continent; The Great Ice Age.

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4. Fodor, R.V. Earth in Motion: the concept of plate tectonics. 1978. 95 pgs. (Written for young students.)

Coastal Plain Sediments

The coastal plain and the continental shelf of North Carolina and the East Coast in general consist of sediments eroded from the land and limestones formed beneath the sea. The sediments largely came from rocks weathering in the mountains and the Piedmont plateau. These sediments formed sandstones, mudstones and conglomerates. In more recent deposits, they formed unconsolidated sands and clays.

The limestones originated chiefly 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" that runs 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 to 300 miles offshore. At Cape Hatteras, almost 10,000 vertical feet of sediment is present. This layer of sediment gets thinner inland toward the "fall line" and thickens seaward toward the deep-sea floor.

The sedimentary layers (strata) that make up North Carolina's coastal plain and continental shelf have been deposited during the last 100 million years.

During each advance and retreat of the sea, sediments were either added to (deposited) or removed (eroded) from the geologic record. In some instances, sediments deposited during one time period were reworked, through wave and current action, during a later time period.

The reasons for the rise and fall in sea level are varied. They include: (1) differences in the size of ocean basins caused by expansion and contraction of mid-ocean spreading centers. (Centers with rapid spreading rates occupy larger volumes of ocean basins than do centers with slow spreading rates.) (2) Differences in the volume of available water created by freezing and melting of the polar ice caps. The position of the shoreline may also change in response to the rise and fall of the land.

In some periods when the ocean basins were small and the volume of water was high, sea level rose enough to flood North Carolina's coastal plain. In other periods when the ocean basins were large and huge volumes of water were frozen into the ice caps, sea level fell and exposed all of the continental shelf.

Fossil hunters find evidence of terrestrial animals such as mastodons up to hundreds of miles off North Carolina's present shoreline. 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 redeposited on top of the limestone and reworked material. Thus, if we examine the rocks of the North Carolina coastal plain we find a discontinuous record of ancient marine environments.

Table 3 illustrates the vertical sequence of geologic formations found in eastern North Carolina. The formations are arranged chronologically and are similar to their natural position in the earth with the oldest formation at the bottom and the youngest formation at the top.

Rock types described in the table are very generalized. In nature, rocks within a formation often vary both laterally and vertically in thickness, composition, grain size and color. All of the formations listed, with the exception of the Pungo River Formation, are exposed at the surface somewhere in the coastal plain of North Carolina. Rock exposures (outcrops) are often found along river and creek banks, hillsides, highway cuts and quarries. Numerous outcrop localities are described in the references listed at the end of this unit.

The Pungo River Formation is exposed at the Texaspit Chemical Co.'s open pit phosphate mine in Aurora. Here, the Pungo River Formation occurs 80 to 120 feet below the current land surface and consists of dark gray, phosphate-rich sands, clays and limestones. These phosphate-rich sediments are 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.

The exposed Pungo River Formation at Texaspit and the overlying Yorktown and younger formations has yielded the most diverse assemblage of vertebrate fossils found in North Carolina. Fossils from this site include remains of sharks, skates, bony fish, alligators, whales, manatees, elephants, mastodons, horses and birds. (Enos and Carter, 1984) Abundant invertebrate fossils have also been found at this mine site.

The upper layers of coastal plain sediments in North Carolina are covered with unconsolidated "surficial deposits" ranging from several inches to hundreds of feet in thickness. Although the origin of these deposits is unclear, they are probably fluvial (river), possibly with some soil horizons scattered throughout. These "surficial deposits" overlie the older rock formations that are described in Table 3.

The oldest exposed coastal plain rocks were deposited in the Cretaceous Period. The Cretaceous deposits include the Cape Fear, Middendorf, Black Creek and Pee Dee Formations. The last three formations reflect rising sea level along the East Coast (Figure 10). In general, Middendorf sediments are fluvial, Black Creek sediments are estuarine, and Pee Dee 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 10).
Recent deposits are exemplified by the estuaries on North Carolina's coast. Sediments collect in the restricted waters behind the barrier islands. Few sediments escape this trap, suggesting that eventually sediments behind the barrier islands may eventually fill completely with sediments. (Table 3).

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

Phosphate ore is mined from the Texas Gulf pits near the Pamlico River. Workers use drag lines to remove upper layers, exposing the phosphate-rich rock from the Pungo River Formation of the Miocene Epoch. This formation is approximately 80 to 120 feet below the surface. The phosphate ore is processed for fertilizers.

Throughout the coastal plain, several companies mine sand and gravel for local use.

Limestone is also mined in several places, including areas near Wilmington and New Bern. The hard limestone blasted from the Castle Hayne and River Bend formations is used in paving and building. In places, there is also a "softer" limestone called micrite (limestone composed of mud-sized grains of carbonates) that is used for portland and masonry cement.

Another mineral with long-range potential is monazite, a heavy mineral that develops in igneous and metamorphic rocks. When eroded and washed to ancient beaches, it becomes part of some sedimentary sand layers. Monazite is a source for thorium and may be important if breeder nuclear reactors develop as an energy source. Other "heavy" minerals found in sedimentary sand layers are rutile and ilmenite. These two minerals are a source of titanium.

Two other coastal resources have been considered for utilization: ancient oyster shells and peat. Albemarle Sound has great quantities of buried oyster shells that could be dredged and processed into a high-grade lime. Scientists and engineers are researching techniques to extract peat (a fuel source) from pocosins and freshwater swamps.
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 that exists in the form of molds, tracks, burrows, actual shells or bones, impressions and mineralized remains.

Limestone - a sedimentary rock made chiefly of calcium carbonate (fizzes with dilute HCl) formed where calcareous skeletons are cemented by CaCO₃.

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

Surficial deposits - the sediments covering the underlying rock layers that make up the coastal plains, probably deposited by river. These surficial deposits obscure the lower layers except at outcrops or river or man-made cuts.
Location of Geologic Formations on the Coastal Plain

Figure 10
Table 3. Geologic formations on the Coastal Plain of North Carolina showing materials, some fossil locations, and sediment origin. Figures 11, 12 and 13 illustrate several index fossils. (Information adapted from communication with Dr. Walter Wheeler of the University of North Carolina at Chapel Hill.)

<table>
<thead>
<tr>
<th>Unit/Formation</th>
<th>Material Type</th>
<th>Fossils</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mesozoic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cretaceous</strong> (ca 145-165 million years ago)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Lower Cretaceous</em> Cape Fear</td>
<td>Marine mud/sand</td>
<td>No fossils</td>
<td>Below Fayetteville; follow river by boat and look at banks. Cumberland County, relatively unimportant formation.</td>
</tr>
<tr>
<td><strong>Upper Cretaceous</strong> Middendorf (Tuscaloosa)</td>
<td>Fluvial, lenses of sand and clay, unconsolidated</td>
<td>Poor fossils</td>
<td>Southern Pines, Sanford. Fayetteville in road cuts. Important formation found at the railroad cut at Spring Lake, Rt. 87, north end of Fort Bragg.</td>
</tr>
<tr>
<td><strong>Black Creek</strong></td>
<td>Fluvio- marine, estuarine bays unique stratification of laminated clean sand and clean, dark clay. Some amber and pyrite.</td>
<td>Full of lignitized and petrified wood (coastal forest). Has holes bored by marine shipworms. Found the jaw of Mosasaur, a giant marine dinosaur, and a terrestrial lizard, Gehyrosaurus. Remains of crocodiles present.</td>
<td>Elizabethtown area on Cape Fear River. Ten miles southeast of Fayetteville, 1.5 miles from county line off of Rt. 87.</td>
</tr>
<tr>
<td><strong>Pee Dee</strong> (Rocky Point Member)</td>
<td>Marine, muddy sand</td>
<td>Many shells of coiled oysters Exogyra and thick-shelled oysters Ostrea pratti and echinoids. A few ammonites.</td>
<td>Rt. 141 bridge over Cape Fear River near Riegelwood. Sufletton, northeast of Goldsboro. Martin Marietta Quarry, 4 miles east of Castle Hayne (crushed rock).</td>
</tr>
<tr>
<td>Unit/Formation</td>
<td>Material Type</td>
<td>Fossils</td>
<td>Location</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------------------------</td>
<td>----------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Cenozoic - Tertiary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paleocene (ca 63-58 mya) Beaufort Formation</td>
<td></td>
<td>Brachiopod, Olenoidyris, blister clam, Gryphaea vesicularis</td>
<td>Found in deep wells, exposed in spoils of channelization. On Mosely Creek off Neuse River, 10 miles northeast of Kinston on county line of Craven and Lenoir. Only spot in this state.</td>
</tr>
<tr>
<td>Eocene (58-36 mya)</td>
<td>Fine-lined lime mud-micrite (cement) limestone</td>
<td>Many fossils, sea urchins</td>
<td>Ideal Cement Company quarry 5 miles east of Castle Hayne. Also found on beach in groins as great rocks at Fort Fisher. Town of Maple Hill.</td>
</tr>
<tr>
<td>Oligocene (36-22 mya)</td>
<td>Sandy-limestone and limestone</td>
<td>Many fossils. One spot has a mass of barnacle plates</td>
<td>Along Trent River from New Bern to Trenton.</td>
</tr>
<tr>
<td>Mid. Pungo River</td>
<td>Commercial phosphate, sand</td>
<td></td>
<td>Subsurface only, except in Texaseulf pit.</td>
</tr>
<tr>
<td>Cenozoic-Pleistocene</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Pleistocene</td>
<td>Paknape - geoducks</td>
<td></td>
<td>Best along the south bank of Neuse River, southeast of New Bern. Also, Old Dock, Columbus County</td>
</tr>
<tr>
<td>Unit/Formation</td>
<td>Material Type</td>
<td>Fossils</td>
<td>Location</td>
</tr>
<tr>
<td>------------------------</td>
<td>---------------</td>
<td>----------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Lower Pleistocene</td>
<td>Marine</td>
<td>Dinocardium, Rangia, corals</td>
<td>Town Creek, Brunswick County, Walker's Bluff, Lower Cape Fear River</td>
</tr>
<tr>
<td>Talbot Formation or Flanner Beach Formation</td>
<td>Marine</td>
<td>Dinocardium, Rangia, corals</td>
<td>Croatian National Forest campsite</td>
</tr>
<tr>
<td>Punctico</td>
<td>Marine</td>
<td>Fossils less than 120,000 years old</td>
<td>Deep ditches in coastal plain, Intracoastal Waterway near Carolina Beach and housing developments.</td>
</tr>
<tr>
<td>Surficials</td>
<td>Pleuvial deposits with some soils that are dominantly sandy</td>
<td></td>
<td>Scattered. Found in soil 2 to 30 feet deep.</td>
</tr>
</tbody>
</table>
Figure 11

blistcr clam
(Grphaea)

brachiopods

rear

side
coiled oyster
*(Exogyra)*

thick-shelled oyster
*(Ostrea pratti)*
Figure 13

- sea urchin
- echinoids
- sand dollar
- geoduck (Panope)

*Ecphora*

index fossil of the Yorktown Formation
Exploring Recent Sediments

To simulate sediment layers.

To experiment with a sampling technique of coring.

To try to interpret cores: e.g., source, organisms.

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

What might you find if you dove to the bottom of the waters beneath the ferry landing at Ocracoke Island? Tin cans? Silt? Sand? Decomposing paper cups?

Sediment composition depends on where you collect. Some particles decay too quickly to become part of the sediment. Others are characteristic of shallow water, while some are found deep on the ocean floor.

What is sediment?

Sediment collects as particles "rain" down to the bottom. In North Carolina, sediment is predominantly composed of sand eroded from inland mountains. Depending on where you collect, you will find different additions. For example, beach sediments often contain broken shells (carbonates); marsh sediments have more decayed plant material. Think of the black, smelly mud of the marsh.

How do we collect sediments?

Scientists often punch a pipe into the sediments then keep the inside or core. Coring keeps sediments in the order they were deposited. A few feet of sample core can be taken by a gravity corer, where the weight of the pipe pushes it into the mud. A 1,000-foot sample can be obtained with a drilled core (similar to well drilling).

Teacher Preparation

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 like milk cartons to hold layers of sediment. Several plastic straws or disposable pipettes with tips cut off. Glass stirring rods; pencil (core pushers).
Organize teams composed of two sets of students: one to make sediment layers and one to core the sediment and analyze it. Competition can be organized to see which team analysis is most correctly interpreted.

**Procedure**

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

2. Record the order of the layers and the team's interpretation of how each layer 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, analyze the sample. Record the number and makeup of the sediments. Attempt to name the environment of the samples — quiet, marshy areas; beach sediments with shells.

**Discussion**

1. Where do sediments come from? Most sediments come from land erosion. Some come 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.
Coring the Sound

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.

Objectives

To experiment with one method of studying sediments— coring.

To be able to identify simulated sedimentary layers by observing characteristics of color, texture, etc.

Teacher Preparation

Prepare a stream table for each group using a roasting pan, a shoe box lined with plastic or any other watertight container with an overflow opening. Set the box at an angle.

Prepare three types of "sediment." You can spray paint sand different colors, use sand that is already colored, or use materials with differing textures, i.e. clay, crushed shells, sand, crushed rocks.

A source of water flow is needed. You can use a rubber hose from a faucet or an elevated container with a rubber hose as a siphon — with a "pinch-clamp" regulator.

A wastewater catcher for the overflow.

A syringe with the end cut off so that the cylinder has a uniform diameter.
Procedure

1. Set the water table box at a steep angle (30°).

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

2. If the rubber hose represents the river flow, what does the angle of the box that 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.)
Making Marine Fossils

Objective
To construct imprint and mold-type fossils.

Teacher Preparation
Plaster of Paris (molding material that will harden); modeling clay; petroleum jelly; small pan, paper cup or plate; some "fossil material" like shells, twigs, bones, etc.

Procedure
1. To make an imprint fossil:
   Mix up a batch of plaster of Paris with water to form a thick mixture.
   Pour the mixture into a cup or plate container until it is about an inch thick.
   Coat the "fossil" with petroleum jelly to prevent sticking. Place it in the partially hardened plaster of Paris.
   Let the mixture harden, then lift the object out.

2. To make a mold fossil:
   Put the modeling clay into a container.
   Press the solid object into the clay. You may wish to make a pattern.
   Lift the object out carefully.
   Pour the plaster of Paris and water mixture into this depression.
   Let it harden, then take it carefully out of the clay.

Discussion
1. What do you think happened to the real animal or plant that left imprint or mold fossils? (decays)

2. What do you think the surface of the bottom has to be like for a marine fossil to form? 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.)
Making a Coastal Plain Time Line

Objectives

To be able to understand the amount of time needed to form the coastal plain.

To become familiar with the periods and epochs of geologic history.

(Figure 14)

To review the fossils found in North Carolina.

Teacher Preparation

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. Give students a copy of the time chart printed here (Table 4) and a centimeter ruler.

The time line provides measurements. These could be worked out by students as a math exercise.

Procedure

1. Roll out 30 meters of paper or string. The beginning of the roll marks the base of the Cretaceous Period — 145 million years before the present. If you look on a complete geologic history chart, we left out a lot of time.

2. At each section, write in the period and epoch and indicate what marine life was present in North Carolina's waters.

Discussion

1. Which period do we live in now? (Recent)

2. Do a little library research. How long has man been on earth? Mark that spot on your time line.

3. Discuss what types of organisms may have been living in the past but have no fossilized remains today.

4. On the time line, mark the points when the barrier islands might have formed. (Pleistocene).

5. Compare this time line to one with all eras - e.g. Paleozoic and Mesozoic eras.
1. Recent History (the last 6,000 years) occupies only 1/8 cm out of 3,000 cm.

2. The Cretaceous Period occupies more than half of the time line.

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

---

**Table 4**

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>LENGTH ON PAPER</th>
<th>YEARS BEFORE PRESENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent</td>
<td>1/8 cm</td>
<td>0 NOW</td>
</tr>
<tr>
<td>Pleistocene</td>
<td>29.5 m</td>
<td>6,000</td>
</tr>
<tr>
<td>Tertiary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pliocene</td>
<td>28.75 m</td>
<td>2,000,000</td>
</tr>
<tr>
<td>Miocene</td>
<td>25.5 m</td>
<td>6,000,000</td>
</tr>
<tr>
<td>Oligocene</td>
<td>22.5 m</td>
<td>36,000,000</td>
</tr>
<tr>
<td>Eocene</td>
<td>18 m</td>
<td>58,000,000</td>
</tr>
<tr>
<td>Paleocene</td>
<td>17 m</td>
<td>65,000,000</td>
</tr>
<tr>
<td>Cretaceous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base of Cretaceous</td>
<td>0 m</td>
<td>145,000,000</td>
</tr>
</tbody>
</table>

**Time Chart**

*Scale: 48,000 years = 1 cm*
Hidden Word Game

Find the 10 words and phrases hidden in these letters.

FZBALAMOTLAQOFVIDC
WOUMASEDIMENTOFAXS
EFXOLOZOLPSLSBCKO
RWFLEUDKNOEQGSJORP
IMLNLAJNHKZIRAFK
XIUAEZRHHQBAKLOSZM
LDVEMCEIDOTHUJNTBA
TOIYOHFSMARKILIANZ
VCANTINENXCLAYOLFB
SELCUAQAIWINHIPTGU
LOVAGNULKPLUTEHLXL
RNFKMINERALWHJEASK
ORQFITYJRYOIRKIEH
FIECYJHEBEPKCHTNPO
PDFAALLLINETROAEKN
EGLBKFHPCDMUPIMJZ
LIMESTONEHIBSLHUOP
MPCRCORINGEOTPNLCS
"Where is the Word?" — A Review

**Objective**
To review the terminology of this section on sediments.

**Teacher Preparation**
Duplicate the "Hidden Word Game" on the preceding page and the definition blanks. You can fold this page to eliminate the answers.

**Procedure**
Search for the 12 hidden words in the jumble of letters, then match 10 of 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 the 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. Composed of very fine particles of sediment ________

10. The chemical compounds rocks are made of ________

**ANSWERS:**

1. CORING
2. FOSSILS
3. SEDIMENT
4. SEA LEVEL
5. COASTAL PLAIN
6. LIMESTONE
7. FALL LINE
8. FLUVIAL
9. CLAY
10. MINERALS

CARBONATES
DEPOSITS
Resources

Films

Printed Material

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Fossil Vertebrates


Fossil Invertebrates


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Continental Shelf Geology: Hardbottoms

Off the coast of Cape Fear, the continental shelf is criss-crossed with remnants of old river channels. The edges, or scarps, of these channels provide breaks in the sea floor's smooth topography.

When sea level was lower and the layers of the continental shelf were exposed, rivers like the Cape Fear cut channels through the rock. Some of these channels remain with high, jagged scarps. Others have been filled in or have weathered away completely.

These underwater cliffs have become the homes of many varieties of plants and animals. Schools of small bait fish circle over the scarps. Snappers and groupers hide in the cavities. Soft corals, sponges and seaweed coat the surfaces. These colorful, exciting marine communities are known to fishermen and divers as "hardbottoms.”

Hardbottoms are any hard surfaces, vertical scarps or eroded rock areas exposed on the sea floor that are composed of limestone, sandstone or consolidated clays. The scarps that bound hardbottoms range from a few inches to 25 feet or more in relief as in Onslow Bay. Continuous erosion of the scarps by biological or physical processes produces a rock rubble zone in front of the vertical or undercut scarp.

The formation of hardbottoms plays an essential part in the story of the development of the coastal plain and continental shelf.

North Carolina's coastal plain begins near I-95 (which runs from the Virginia border to South Carolina, bypassing Rocky Mount and Fayetteville) and extends eastward to the Atlantic Ocean. The geology of the land beneath the sea does not change; the continental shelf has the same sediment and layers as the coastal plain. In fact, much of the continental shelf was exposed during periods of lower sea level when glaciers absorbed much of the earth's water. Clues to this are peat beds and mastodon teeth found in water 50 to 100 feet deep. Alternatively, higher sea level during warming periods has covered the coastal plain up to Smithfield. Ancient sand dunes and marine fossils inland are evidence of the sea's migration over land.

Ancient geology also explains the differences in hardbottoms along the North Carolina coast. Hardbottoms are more common south of Cape Hatteras to the South Carolina shelf. Off of Cape Fear near Wilmington, a slight topographic rise called the Cape Fear Arch extends for miles into the continental shelf. This huge bulge of sediment uplifted the underlying sediment layers. Weathering and erosion exposed these layers of rock as wide, flat irregular bands bending around the arch. The bands are thinly covered with mobile sand. This area contrasts in the evenly sloping continental shelf north of Cape Hatteras. Here, thick sand...
covers much of the surface rock, and no arch pushes the rock layers upward.

These extensive, flat mesas are generally covered with varying thicknesses of highly rippled, moving sand and shell gravel. These moving sands scour the surfaces and prevent living plants and animals from attaching. This, in turn, limits the types and populations of fish that gather around the hardbottoms. Much of the continental shelf of Onslow Bay is like this.

The scarps of hardbottoms stand above the moving sands. Seaweeds, like brown Sargassum or green calcareous algae, attach to the edges of the limestone or clays. Soft corals and whip corals of pink, purple, white and orange, wave in the currents. Many boring animals dig crevices in the scarps that eventually make safe spots for groupers and spiny lobsters. The biological community is rich and diverse. The greater the relief, the more irregularities and surface area available for bottom organisms and associated fish. High relief scarps and rock rubble zones have high biological productivity.

Hardbottoms are similar to tropical coral reefs. Although frame-building reef corals are absent, many of the invertebrates and fish common to tropical reef systems are present. Four-eyed butterflyfish, red squirrel fish and blue damsel fish dart in and out of the nooks and crannies of the scarps. Juveniles and larvae travel north via the Gulf Stream and are carried inward by Gulf Stream eddies, storms and currents.

These fertile hardbottoms have been secret fishing spots of skillful navigators for years. They used compass settings, boat speeds and estimates of current speeds to help them calculate the whereabouts of hardbottoms. Now that marine electronics have become available to fishermen and divers, hardbottoms have become more accessible.

Most large boats are equipped with Loran receivers and depth recorders. Loran (Long Range Navigation) receivers pick up radio waves broadcast from towers onshore and, by comparing the signals, "plot" the position of the boat at sea. Using a set of marked coordinates, fishermen can locate a spot at sea, then later return to within 50 feet of that location. Depth recorders reveal the topography of the underwater surface and show schools of fish. These devices send sonic waves from the boat to the bottom and record the images on a screen.

If a boat traveled over part of Onslow Bay, a continuously recording fathometer would produce a chart showing several characteristic sizes and types of hardbottoms. The electric pulses sent from the boat's transducer reflect off the bottomland or schools of fish and back to the boat's transceiver. The difference in travel time of the electrical pulses produces a record of the bottom topography. Research boats, diving boats, and recreational and commercial fishing boats use fathometers to find new hardbottom areas.

Marine geologists have been exploring the part of the continental
shelf known as Onslow Bay. The bay lies between Cape Lookout and Cape Fear. Their investigations began as a search for phosphate ore deposits, which have huge economic potential. The discovery of the broad distribution of hardbottoms is just one of the results of their research.

Four types of hardbottom communities have been characterized so far. They vary in elevation, geologic age, form and structure, extent of exposure on the sea floor and richness of the biological community they support.

**High-relief hardbottoms** — The scarps are greater than 10 feet tall and may extend more than 25 feet. They consist of vertical limestone rock cliffs with an extensive rock rubble zone. The rubble was broken from the scarp by biological activity and physical forces. The resulting surface is a very irregular topography with extensive rocks and crevices. Such variance provides increased surface area for organisms to attach and more hiding places for benthic invertebrates and fish. These high-relief hardbottoms generally have the greatest biological productivity and the greatest diversity and abundance of organisms and associated reef fish. Usually, these are the largest hardbottoms on today’s sea floor. They are relatively young geologically — only tens of thousands of years old.

**Low-relief hardbottoms** — The scarps are less than 3 feet tall. Adjacent, highly rippled, mobile sandy bottom surfaces have little biological life. Low-relief hardbottoms have moderate biological productivity.

**Flat hardbottoms** — The little relief on this gentle slope is often covered with thin, scattered patches of mobile sand that prevent extensive development of biological communities. The sands accumulate from the top of the hardbottom, forming sand ramps into the topographic low-lying areas. These environments are characterized by low biological productivity.

**Topographic Lows** — These are the low-lying areas between rock scarps that are often composed of older deposits of dark, semi-hardened clay and sand. This bottom surface is not conducive for attached bottom organisms and contains only a few species of boring organisms that live below the surface. Also, mobile sand scours the bottom during storms and limits the life that can exist there. Following the storms, the sands are deposited and trapped in the lower areas on the slightly irregular clay surface.

Since sophisticated marine electronic equipment assists boaters in finding hardbottoms and, more importantly, in returning to them again, these biologically rich areas may be in danger of overexploitation. Reef fish of commercial and recreational importance such as sea bass, red snapper, silver snapper and grouper are territorial and long-lived. People who fish or dive in the shallower sites may eventually take all the fish. Then, it would take many years for new fish to move in and re-establish a stable community.
How Many Fish Can You Harvest?

Objective
To stimulate the mark-and-recapture technique for estimating populations of commercially important reef fish.

Materials Needed per Team of Five
- bag of dried beans
- two or three marking pens, paint, etc.
- measuring cup
- large bowl
- small bowl

Roles of Team Members
- counters (1 to 3 students)
- markers (1 to 3 students)
- recorder (1 student)
- calculator (1 student)

Procedure
1. Put the beans in the large bowl. This represents the total population of fish on a hardbottom.

2. Using the measuring cup, remove about half a cup of beans. This represents fishing effort in a certain period of time or fish caught with a trap on the bottom.

3. Count and mark these beans. This number is "T" = number marked in the pre-census period.

4. Return the beans to the bowl and mix.

5. Use the measuring cup again to remove a half a cup of beans.

6. Count the beans in the cup. This is "n" = number of marked fish caught in the census period.

7. Make a count of how many are already marked. This is the "t" = the
Number of marked fish in the census period.

8. Population Estimate Calculation

\[ N = \frac{T}{V/n} \]

- \( N \) = population estimate
- \( T \) = total count in second sample (step #6)
- \( V/n \) = total count in first sample (step #3)
- \( t \) = number marked in second sample (step #7)

9. Although it is not possible to check your estimate for error in field situations, it is possible with this experiment. Count the total number of beans available in the bowl.

\[
\frac{\text{Actual number of beans in bowl}}{\text{Number estimated in bowl}} \times 100 = \% \text{ error}
\]

1. If you were working for the National Marine Fisheries Service and were in charge of managing fish populations on hardbottoms, what information would you need?

2. What might be causes of error in the fish estimation technique?

**Hardbottoms Poster/Map** This four-color poster is a guide to the natural offshore reefs (hardbottoms) between Cape Lookout and Cape Fear. It shows the four types of hardbottom communities. Available for $5 from UNC Sea Grant, Box 8603, N.C. State University, Raleigh, N.C. 27695-8605.

**Discussion**

**References**
Coastal Environmental Systems

Barrier Island Geology

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 three areas are interrelated by water which exchanges sediments and organisms and mixes salinity and nutrients into the system. These coastal features have often changed due to inlet shifts, sea level fluctuations, sediment deposition and erosion. For effective coastal management, it is important to understand some of the processes that shape this river-sound-island system.

The open sea meets North Carolina at landforms that geologists call barrier islands. The most prominent ones make up the Outer Banks, which extend from the Virginia border to Cape Lookout. But barrier islands continue southward along the coast to the South Carolina border.

Barrier islands absorb the sea's energy and shelter inshore waters and the mainland coast. Much of the energy from ocean waves and winds dissipates as it moves the sands of these islands. In absorbing the ocean's forces, the islands can destabilize and migrate. Thus, the shape of barrier islands is 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 man-made structures.

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 they might be used to show how human creativity is involved in scientific development. The three hypotheses outlined here are based on analyses of cores through barrier islands, sand movement patterns, sea level history, and other oceanographic data.

1. One early theory suggests that an offshore bar is created by breaking waves depositing sediment when they loose 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 15: Formation of an island and the marsh behind it.

Spit Theory of Barrier Island Formation:
1. Erosion of headland creates an elongating spit down current;
2. Marsh development and further elongation of spit;
3. Spit breaks and forms an island. (From Hoyt, 1967).

2. The *elongate spit* hypothesis suggests that the Outer Banks developed from sediments carried south by longshore currents and 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 15).

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 agree that something like the following sequence of events may have taken place.

The initial barrier islands of North Carolina were probably formed from offshore bars on the continental shelf at a low sea level stand several thousand years ago. Sediments brought down rivers built up by wind and wave action formed 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, low-lying areas behind the beach were flooded. This detached the coastal ridge from the mainland and formed an ancestral barrier.

The present Outer Banks are most likely the result of 1) extensive modification and migration of the "primary barriers" formed about 4,000 years ago when sea level rise decelerated, and 2) the addition and extension of "secondary barriers" through spit elongation and offshore bar emergence. About 60 percent 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 they are critical processes in the barrier island system as a whole.

**Processes**

Because barrier islands absorb ocean energy, they are dynamic land forms that reflect environmental changes. These changes fall into three general categories. Details vary 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. Longshore transport can take sand along a beach and deposit it at one end of the island, extending it. If this deposition diminishes the size of a natural inlet between islands, tidal currents running through the inlet may erode the non-deposition side and create serious erosion problems.

   Fort Macon on the east side of Bogue Banks is faced with such a problem. Breakwaters had to be built to protect the fort from destruction. Now Fort Macon must be protected physically from the inlet it once protected militarily. The varying thicknesses of sediment cover of the
lower Tertiary limestone north and south of Cape Lookout may be explained by the longshore transport of sediment north to south along North Carolina's continental shelf over tens of thousands of years.

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 has been reworked completely by inlets that have migrated up and down the Banks. The process results from longshore sediment transport that fills part of an inlet with sediment and causes 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 affect the stability of the barrier islands. (Figure 17)

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 and carry sediment from the beach side to the sound side. Evidence of washover 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 essential to preserving barrier islands through geologic time. The Outer Banks have maintained themselves by migrating seaward 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. So efforts have been made to "stabilize" these inherently unstable landforms. In Cape Hatteras National Seashore, fences were erected to trap sand on the dunes before it blew over State Highway 12. These fences have changed the profile of the Outer Banks by creating tall, continuous dunes with few washovers in areas previously characterized by low, discontinuous dunes with many washover areas. The ultimate environmental impact of this change cannot yet be evaluated. (Figure 16)
Figure 16

natural dunes and barrier island

artificially stabilized dune and barrier island
Figure 17. Diagrammatic Summary of Barrier Island Migration

1. Typical barrier island with oceanfront 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 the 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 it.

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.

Vocabulary

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

**Breakwater** - a seawall of rock, concrete, etc., that absorbs the impact of waves and protects 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** - the opening between barrier islands.

**Jetty** - a structure built to influence currents and to maintain channel depths. Jetties can also 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. It is generated by waves breaking at an angle with the shoreline.

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

**Offshore Bar** - a submerged mound of sand.

**Sound** - a lagoon-like body of water between the mainland and an 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.
Investigating a Sand Spit Process

To build a spit simulating actual processes on the Outer Banks.

Provide each group with a stream table or shallow tray.

Provide sand and a squeeze bottle (source of water flow — it could come from siphoning a bucket of water or from a faucet).

Provide a place for waste water.

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 to 2 inches of water, just so it touches the "shoreline."

4. With the squeeze bottle or a hose from a 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. This represents the spit.

7. With sketches, record the steps in spit formation.

8. For variation, ask some students to be engineers. Their 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.
Discussion

1. What starts the flow of sand in nature?
   (Longshore 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 form spits.
   (Most sand in North Carolina originally came from glacial deposits transported from New York and New England areas by longshore currents. Some sand is derived from erosion of mountains and carried by rivers.)
Model-Making of the Barrier Island System

Objective

To review some of the topographic features of the coastal regions.

To investigate the processes of erosion and deposition from the mainland and the wind-blown transportation of sand on the barrier islands.

Teacher Preparation

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

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 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 on the seaward side of the model island or have someone blow from that direction.

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.

**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.)
Where are the Barrier Islands and Sounds?

To be able to locate some of the major islands, sounds, bays, inlets and towns.

To be able to discuss the significance of the position of the towns and forts in relation to the coastal features.

Objectives

Teacher Preparation

For each team, have a blank map of the North Carolina coast and a road map. If possible, obtain Landsat or aerial photos of the areas (see resources). Figure 18.

Provide crayons and small rulers to gauge distances.

Procedure

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

Atlantic Ocean

<table>
<thead>
<tr>
<th>Sounds</th>
<th>Inlets</th>
<th>Islands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albemarle Sound</td>
<td>Oregon Inlet</td>
<td>Bodie Island</td>
</tr>
<tr>
<td>Pamlico Sound</td>
<td>Ocracoke Inlet</td>
<td>Hatteras Island</td>
</tr>
<tr>
<td>Core Sound</td>
<td>Beaufort Inlet</td>
<td>Ocracoke Island</td>
</tr>
<tr>
<td>Bogue Sound</td>
<td>Bogue Inlet</td>
<td>Bogue Banks</td>
</tr>
<tr>
<td>Roanoke Sound</td>
<td>New River Inlet</td>
<td>Smith Island</td>
</tr>
<tr>
<td>Currituck Sound</td>
<td>Concan Inlet</td>
<td></td>
</tr>
<tr>
<td>Hatteras Inlet</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Towns

<table>
<thead>
<tr>
<th>Rivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manteo</td>
</tr>
<tr>
<td>Morehead City</td>
</tr>
<tr>
<td>Swan Quarter</td>
</tr>
<tr>
<td>Wilmington</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cape Fear River</td>
</tr>
<tr>
<td>Chowan River</td>
</tr>
<tr>
<td>Pamlico River</td>
</tr>
<tr>
<td>Neuse River</td>
</tr>
<tr>
<td>New River</td>
</tr>
</tbody>
</table>
Answer the following questions:

a. Off the North Carolina coast lie many long, thin islands called **barrier islands**. What do you think the word "barrier" means 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 small. Find the largest island and write its name here: **Hatteras Island**.

c. Ocracoke (o-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. Measure it in miles and in kilometers. Fill in the blanks: Ocracoke Island is about **17** miles long or **28** 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-ii-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. Is the town of Ocracoke located on the ocean side or
the sound side of Ocracoke Island? (sound side)

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 those 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 and 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)
Scallop Shield

To gain insight into the student’s view of the coast.

Construction paper and water colors or crayons.

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

The last time you went to the beach, did you...

1. 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 from the beach?
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 play miniature golf or ride skateboards. Some may collect shells or watch birds. Try to have each child come to a conclusion on what the beach means to him or her.

Objective

Teacher Preparation

Procedure

Discussion
What is the Difference Between a Map and a Chart?

Objectives
To be able to compare a chart and a topographic map.
To be able to determine channels and shoals by using water depths.
To be able to locate navigational marks.

Teacher Preparation
To familiarize the students with the coastal region, have the students do the activity with a topographic map.

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. (One source for the charts is the N.C. Maritime Museum in Beaufort, N.C.)

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 that formed behind the jetty called? How do you think it got there?

6. Locate Cape Lookout lighthouse. Discuss some currents and erosion that may occur there.

7. With tracing paper over the chart, determine a route for a ship going from the coastal water into the N.C. State Port Terminal. Then chart a route
from the Port Terminal to Marshallberg.

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 the river is trapped.)

9.
Discuss some of the differences and similarities between a chart and a topographic map (use, design, symbols). Trace the drainage patterns into some of the sounds or bays. Do they flow through urban or rural areas? What type of pollution could be current to the estuary?

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

Figure 19 Navigation and Charts "Red, Right, Returning"
**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.

**Figure 20**

<table>
<thead>
<tr>
<th>Navigational Aid</th>
<th>Navigational Symbol</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Can Buoy" /></td>
<td>▲</td>
<td>black can buoy odd numbers keep to port (left)</td>
</tr>
<tr>
<td><img src="image" alt="Nun Buoy" /></td>
<td>▲</td>
<td>red nun buoy even numbers keep to starboard (right)</td>
</tr>
<tr>
<td><img src="image" alt="Lighthouse" /></td>
<td>.</td>
<td>lighthouse special light flash codes</td>
</tr>
<tr>
<td><img src="image" alt="Standing Marker" /></td>
<td>◊</td>
<td>standing marker odd or even numbers may have special light flash codes</td>
</tr>
</tbody>
</table>
Standard Rule: "Red to the right when returning from ocean."
Resources

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

Printed Materials

2. Cape Hatteras Lighthouse (Grades 3-4). $5.50. Project Cape Dare County Schools, P.O. Box 640, Manteo, NC 27954.


References


Barrier Island Ecology

**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 islands. 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 21)

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 the area that can tolerate use and avoid development where the land is vulnerable. A transection of a barrier island from the beach to the salt marsh shows habitats that are tolerant and sensitive to human development. The biota give hints about the sensitivity of their habitats. For this reason, the barrier island provides a useful place to develop students' abilities to observe natural history.

**Beaches**

Barrier island visitors recognize the beach as the portion of the oceanshore between high and low tide. Geologists define "beach" as any part of the shoreline influenced by the effects of ordinary waves. This includes nearshore sand bars as well as the berm—a supratidal terrace of sand brought ashore by waves.

Beaches are an accumulation of sediments. They are subject to movement by ordinary waves and are in constant motion. Anyone can stand where waves run up the beach and watch beach sediments sweep by his feet. The beach can be composed of many materials. In North Carolina, the beaches contain mostly quartz and feldspar from weathering granitic rocks. Beaches elsewhere may be black volcanic sands, white carbonate fragments or pink coral. Also, beaches may be comprised of cobblestone 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 portion of the beach, then that section is "starved" of its regular supply of sand and will erode. Thus, most attempts to "stabilize" beaches are futile, displacing a problem from one place to another.

**Barrier island ecology is an interaction of beaches, dunes, maritime forests and marshes.**
Dunes and dune fields are formed by wind transport of sand and the growth of stabilizing vegetation. Sand moves by saltation, a process where sand lifted by wind energy bounces along a loose sand surface and sets other grains in motion by its impact. The wind velocity necessary to initiate sand movement, known as the threshold velocity, is about 10 m.p.h.

Onshore winds transport dry sand back from the beach. Since only the smallest grains of beach sand usually move, 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, or detritus, left behind at the high water mark often provides a niche for plant growth necessary for dune formation. Vegetation established at the high tide strand line or on a dune increases sand accumulation by reducing wind velocity.

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 seedlings grow quickly after periods of heavy rainfall which provide sufficient moisture and stabilization. Root fragments from beach grass clumps on dunes are a major means of establishing new dunes. Embryo dunes, stabilized by plants, may coalesce to form a band of upward growing dunes.

Dunes may also migrate and shift positions frequently through continuous windward erosion and leeward deposition. Storm waters occasionally break through a dune to form “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 huge 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 ecology is influenced by an array of subtle and obvious environmental factors. Salt spray is an obvious factor in determining dune species. 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 susceptible 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, vehicles and even heavy foot traffic.

There are also man-made dunes on North Carolina’s barrier islands.
Outer Bank coastal dunes were developed in the 1930s along Hatteras, Pea and Bodie islands. Formed along snow fences, they are linear features equivalent to sea walls. They were built to stabilize the sand, prevent washovers, and thus protect the island highway. 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 to 15 feet high. Actually, artificial dunes cause increased erosion on the beach face and, by preventing the natural process of oceanic overwash, have halted barrier island migration. Thus, the stability to the zone behind the dunes is artificial.

**Maritime Forests**

When barrier islands are wide enough, maritime forests can develop. Composed of salt tolerant components of the coastal evergreen forest, a 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 (*Michelia reidii*) with vines such as cat brier (*Simpiax spp*) and poison ivy (*Rhus radicans*). 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.

Maritime forests are restricted to wider, more stable 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 that does not deplete or pollute the freshwater supply or open unnecessary holes in the forest canopy. The earliest settlements on the Outer Banks such as Ocracoke, Portsmouth, Old Nags Head and Diamond City, were built in maritime forests. Thus the inhabitants were on relatively high ground, sheltered from storms and temperature extremes.

Tree species have interesting adaptations for their salty environment such as thick, leathery salt tolerant leaves, and physiological mechanisms for excreting excess salt. 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 that 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.
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. Salt marsh shrubs such as the high tide bush (Baccharis halimifolia) and marsh elder (Iva frutescens), plus herbs like sea oxeye (Borrichia frutescens) edge the upper high tide zone. Just below is a barren zone caused by too much salt in the sandy soil. These barren "salt pans" are often surrounded by the highly salt-tolerant succulent glasswort (Salicornia spp.) once used by colonists in pickling and still used by coastal residents to flavor salads.

Marsh plant distributions reflect the flooding regime. Large flats regularly flooded by salty high tides are occupied by salt marsh cordgrass (Spartina alterniflora). Where the shore is flooded by several of the month's highest tides one finds black needlerush (Juncus roemerianus). In areas flooded by a few of the high tides each month, salt hay (Spartina patens) and spike grass (Distichlis spicata) grow along the edge. The zones are sharply demarcated by slight elevation changes. Bridges provide a view of the species gradient. Salt marsh cordgrass is lowest and closest to the water. Black needlerush grows behind the cordgrass and closer to brackish creeks. Salt hay, then shrubs, mark the upper edge of the marsh system.

Salt marshes are now protected from degradation. They are valuable food sources for estuarine fish and invertebrates. They slow shoreline erosion by absorbing wave energy. Education has changed people's attitudes. Salt marshes were once considered smelly wastelands suitable only for dredge and fill operations. Now they are recognized as an important part of the coastal ecosystem.
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 rigorous 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 21

cordgrass
needles
grass
salt hay
live oak
pauopo holly
sea oats
beach grass
berm

flooded marsh    salt pans    maritime forest    dunes
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 - a mound of loose, wind-blown, granular material (generally 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.

Overtwash - 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.”
What We Can Learn From
The Face of a Dune

Objectives

To investigate the processes that cause dunes.

To be able to identify the parts of a dune.

To investigate some methods for stabilizing dunes.

Winds with speeds over 10 m.p.h. can carry sand that can build dunes. The sand grains are rolled up the windward slope and, if there is enough energy, climb 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 recognizable by having angled layers. One can thus determine the direction of the winds in ancient sedimentary rock formed from cemented sand dunes.

Teacher Preparation

Provide one shoe box per team and tape it to the edge of a table.

Have a small quantity of fine sand for each box.

Have some matchsticks or plant pieces available.

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 to see which team can blow up, or build, 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.
1. What would conditions have to be for a beach dune to migrate or move inland? (Little to no vegetation to hold in 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.)

Sedimentary Rock

```
West

a - west wind
b - east wind
c - west wind
d - west wind

East
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Exploring Beach Sands

Objectives

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).

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

Teacher Preparation

Prepare ahead of time two sandwich bags of sand for each pair of students that will be working together. This sand should vary, perhaps only as much as one being wet and one 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. Many other combinations will enable comparison.

Divide the class into groups of pairs.

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 that is available in the classroom.

Have sheets of paper available for students to write down observations.

Procedure

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

2. Each pair is to use each of their senses to make observations on the sand. Have them record 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, flotation, sinking, ability to hold water, etc.

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

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.)

Discussion
Identifying Sediment Contents of the Beach

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

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

In explaining this lab, teachers should emphasize that sediment which makes up the beaches, and bottoms of sounds and oceans may come from many sources. For example, the beaches of North Carolina consist of about 95 percent inorganic material and 5 percent shell pieces north of Cape Hatteras. South of Cape Hatteras, it's 75 percent inorganic (quartz and feldspar) and 25 percent shell. Further south near Miami Beach, Fla., the beach consists of about 50 percent inorganic and 50 percent shell. Actually, anything that 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 makeup of the sediment from the bits and pieces left from the whole animals and be able to separate these from bits of rock.

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

Have some sand and clay brought in for the class.

Have dissecting scopes or a hand lens available for students.

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

Procedure
1. Have the students identify animal specimens available.

2. Divide the class 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
4.
When the students have become familiar with their animals, let 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.

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 hypothesis 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 from several thousand years ago. Assuming the glacier stopped around 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 makeup of sediment? (Original source of materials, direction of transportation, mineral resource.)
Model of a Barrier Island

Objectives

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

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.

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 is 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, the sea breeze and the effects of storms.)

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 that 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 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.
Resources

Films

The first three films are excellent resources to show the ecological and management aspects of the marsh.

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

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

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

4. "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.

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


Printed Materials

1. "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.)


3. Man and the Sea Coast - Barrier Island Geology set of 30 slides with script, on loan. UNC Sea Grant Marine Education. North Carolina State University, Box 8602, Raleigh, NC.


6. Project CAPE, Dare County Schools, P.O. Box 640, Manteo, NC 27954. (A) A Guide to Field Trip Studies for the Coastal Environment, $3.50. (B) A Guide to Field Trip Sites in Coastal North Carolina, $2.50.
7. Schoenbaum, T. *Islands, Capes and Sounds.*


Estuarine Geology

Background Reading

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

North Carolina has had a coastline for about 180 million years. 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 on the shape of ocean basins and the volume of liquid water on the earth's surface.

During periods of colder climates, 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. From about one million to 12,000 or 15,000 years ago, ice sheets 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 and Nebraska. It spread as far west as the Rocky Mountains and was over a mile thick in parts. This quantity of ice moved countless tons of material, forming many geographic features of the northern United States. The glaciers also locked up large volumes of water. This caused sea level to fall and expose large areas of land that had 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 low 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. During these periods, deep valleys were carved out by rivers flowing across the coastal plain. Today that plain is the continental shelf. And the valleys are the sites of drowned rivers called estuaries. The Neuse, Pamlico, Roanoke, Cape Fear and New River estuaries are examples of this feature in North Carolina.

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. Smaller fluctuations 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 formed from
Figure 22: Watersheds

River Drainage Systems
of North Carolina

[Map showing the Roanoke, Pamlico, Neuse, and Cape Fear watersheds]
sediments carried to the seacoast by rivers during periods when sea level was lower than it is now. (The theories of barrier island formation have been described elsewhere in this book.) 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 estuaries in the river mouths. 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 latest ice age occurred about 17,000 years ago. Since then, the great North American ice sheets have been melting. This has resulted in rising sea level that has been continually flooding North Carolina's low-lying coastal areas. 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 layers of peat in the Great Dismal Swamp show that cold weather forests of fir and spruce occupied uplands of Beaufort and Bertie counties less than 50,000 years ago. A 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 trees replaced conifers. Later, they were replaced by oak and hickory. Pines occupied well-drained sand beach ridges and vast areas cleared by fires in the hardwood forests.

As this change occurred inland, other plants began to colonize on the edges of the sounds and estuaries. 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 rise of sea level slowed, salt marsh plants took hold. Grasses began to grow where tides flooded the ground less than half 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 rose, plant growth and trapped sediment simultaneously raised the level of the marsh. Spartina patens grew well on layers of peat accumulated from the roots and leaves of previous growth. And as seawater crept inland, the marsh extended inland with it. Freshwater grasses and shrubs were engulfed by rising salt water and were replaced by salt marsh grasses. Freshwater cypress swamps became flooded with sea water. And as the soil became soaked with salt, the cypress died and the salt marshes marched on in claim larger areas of what had been freshwater swamps. (Figure 23A).

The same drama occurred along creek banks and bogs. Usually the
Figure 23. *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.

water in the creeks moved rapidly, eroding the curved edges of the creeks. This caused sediment to be deposited farther along the creeks. Heavy rains helped create channels in the marsh and in rivers. This allowed salt water to move inland where the process of marsh-building continued. (Figure 23B).

The marsh-building process continued over thousands of years. North Carolina’s northeastern coastal marshes have been inundated by 6 to 12 inches of water each century, or 5 feet every thousand years.

How do we know this is happening? When building highways, workers found huge cypress logs buried under 10 feet of salt marsh peat. In addition, geologists often find thick layers of freshwater peat under salt marshes indicating former freshwater bogs. And in the North Carolina’s sounds, boaters often find submerged stumps and logs that are remains of ancient forests.

Single cypresses still stand miles from the nearest land. Examination of early maps and navigational charts reveal that these logs and trees were once on small islands with houses and orchards present during the colonial period. Batts Island, once located in Albemarle Sound, is an example of one of these occupied islands.

The struggle between land and sea continues. One example is Indian Island. This small island in the Pamlico River lost about 102 feet of shoreline between 1938 and 1970. At the present rate of erosion (3.2 feet per year), Indian Island will probably be gone in 150 years.

If sea level continues to rise at an accelerated pace, much of the low-lying coastal plain will be inundated. Areas in Dare, Hyde and Tyrrell counties are especially vulnerable.

No “remedies” for erosion exist. Some methods such as bulkheads and sea walls are prohibited along North Carolina’s oceanfront. The effectiveness of other methods is still in question. Therefore, the concept of a changing shoreline due to sea level rise is important to discuss.
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 the 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 million years ago that 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 to a rising sea level or coastal subsidence.

Terraces - wide, step-like features. They are relatively level surfaces bounded by a steep, upward slope on one side and a steep downward slope on the other side.
Layering of Sediments

Objective
To observe how sediments settle in layers.

Teacher Preparation
About a pint of sand; rock particles; soil; tap water; pail; masking tape; gallon jar; spoon.

Procedure
1. Mix one part each of sand, soil and pebbles in the pail and add enough water to hold them together.

2. Fill the gallon jar with water.

3. Add 3 to 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 that take place throughout the day. Tape may be applied to the outside of the jar to note height of the layers and the time of day. More spoonfuls may be added to show how the layering is a continual process.

Discussion
1. How does this activity represent what may be happening in the estuaries when rivers and inlets deposit sediment? (Figure 22) (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)
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 this way.

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

Sediment in the sound is made up of river sediment and sea sediment washed in through inlets. As estuaries flood rivers via rising sea level, river flow is very slow and most of the river sediment has already been deposited before reaching the sound.
Siltation Rates

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

Teacher Preparation
Prepare about a pint of clean, fine-grain sand and various sizes of pebbles; two clear containers; water; metronome or stopwatch; paper; pencil; and measuring tape.

Procedure

1.
Have children guess which particles they think will sink fastest.

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

3.
The students record the time it took for the particle to fall and their observations of it. Have them draw the particle to size and record the time underneath it. (It is helpful if the student wet his finger, puts the particle on it, then touches his finger to the water's surface at "go.")

Discussion
How would the rate of sinking affect 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 farther into the ocean or sound.)
Microsediments in Estuaries

Objectives

To observe sediment particles and perhaps some microfossils under the dissecting scope or a low-power microscope.

To realize that some areas once underwater will have microfossil remains.

To locate some microorganisms in marine or freshwater environments today and observe the shapes.

In a sediment sample, the nonliving parts will include particles of clay, salt, sand and other eroded minerals. They have shapes and colors that can be observed and drawn. Also the sediments contain small organisms that 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 or “forams.” A foraminiferous shells usually is coiled like a tiny snail shell and made of calcium carbonate. (Examples - Figure 25)

Teacher Preparation

Obtain sediment from the top centimeter of a marine habitat such as a marsh or mud flat. (You can 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, too. Obtain some screen sieves to separate out the coarse material, aluminum foil to make drying dishes for samples; dissection scopes; microscopes; small paintbrush for separating samples; and black paper for mounting samples for the dissecting scope.

Procedure

1. Collect the sediment sample. Separate out coarse material by washing the sample through a sieve. 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. When the sample is dry, take a small paintbrush that is slightly wet on top and transfer individual grains from the foil to a section of black paper stuck to a slide. Some samples 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 diluted hydrochloric acid on the sample. This will cause any calcium carbonate or shell material to bubble and fizz.

Discussion

1. Discuss the types of sediment particles found in relation to their habitats.

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

3. What would the presence of foraminifera tell you about the origin of a sediment sample?
Foraminifers Often Found in Sediment

Size: 5 to 8 mm
Resources

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
Estuarine Ecology

North Carolina has an irregularly shaped coastline. Numerous rivers and bodies of water indent the coast. And hundreds of fingers of land project out into the water. The ocean coastline is a series of fringing islands. These sandy, offshore beaches border the coast more or less continuously from Sandy Hook, N.J., to Miami, Fla.

Along North Carolina's coast, these offshore "banks" form barrier islands. This chain of islands is broken at several places by inlets of various sizes. And broad, shallow sounds separate the islands and the mainland. At the northeastern end of the coast, these islands are up to 25 miles away from the land. At the southern end, the barrier islands lie closer to the mainland, making the 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 are defined as semi-enclosed bodies of water with free connections to the open sea. Here, sea water is diluted measurably by fresh water draining off the land. The term "estuary" is restricted to river mouths, but general texts usually refer to the sounds of North Carolina as "tidal estuaries."

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.

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. Circulation within these estuaries is related to river flow and tidal currents. Since river water is lighter than salt water, it flows out over the sea water. This establishes two different layers of water separated by a density interface where 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 and enclose coastal water to form shallow estuaries. Currituck Sound is North Carolina's best example of such an estuary.

Background Reading

North Carolina's estuarine system is large and linked together by circulation of brackish water.
Figure 26

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 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 rivers. The Roanoke, Pamlico and Neuse rivers drain the Piedmont and coastal plains. The others drain only the coastal plain. The Cape Fear River differs from all others as 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 tides and winds to mix with freshwater 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 28)

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 that receive little current or wave action. (Figure 26). Oyster reefs form on a firm substrate when oysters (Crassostrea virginica) attach, then provide additional substrate for other oysters. Grass beds form in shallow areas where currents move slowly, providing 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 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 firm, sandy bottom surfaces and are drained by short, relatively unbranched, tidal creeks. 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. Black needlerush (Juncus roemeria-
is the most dominant plant. It grows to about 3 feet and is very dense.

Regularly flooded salt marshes are flooded by almost every normal high tide. There are about 58,000 acres of regularly flooded salt marshes in North Carolina. Long, dendritically branched tidal creeks drain these soft-bottom marshes.

North Carolina also has about 47,000 acres of coastal freshwater marshes that are rarely flooded with salt water. In general, the waters flooding these marshes are fresh to moderately brackish. Over 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 the creeks that later serve as conduits and carry water into the marsh.

The distribution of marsh plants is usually in distinct zones. The zones are controlled by tidal creeks fed by flooding regimes. Salt marsh cordgrass (*Spartina alterniflora*) grows close to the creek banks. As you move farther away from the tidal creeks, you see other plant species such as another species of *Spartina*, *S. patens* (salt marsh hay, spike grass — (*Distichlis spicata*), black needlegrass (*Juncus roemerianus*), and glasswort (*Salicornia* spp), are the most common.

At the upland border of salt marshes, you sometimes find a barren zone that is flooded only during the highest high tides. This area, known as the salt pan, often has soil waters two or three times as salty as sea water. Another feature sometimes associated with marshes is a hammock, an elevated area covered with cedar and hardwood trees.

Twelve major sounds lie along North Carolina's coast. They vary in size, shape, depth and salinity. Most are shallow and differ in the amount of freshwater runoff that reaches them from the mainland. The plants and animals of these sounds vary due to the resultant differences in salinity regimes. (Figure 27)

Currituck Sound is about 40 miles long, three to four miles wide, and less than 7 feet deep in most areas. 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. And the Inland Waterway links it with Norfolk to the north and with the North River tributary of Albemarle Sound to the southeast. The mouth of Currituck Sound is about 24 miles from Oregon Inlet, which is the nearest opening to the ocean. Consequently, the sound's waters are fresh to brackish and support waterfowl, freshwater game fish, and such migrants to fresh water as striped bass and alewive.

Albemarle Sound stretches east to west about 55 miles. It averages seven miles wide and has a fairly level bottom surface about 18 feet deep. Eight rivers, including the Roanoke and Chowan, drain into the sound. And the sound drains through Pamlico and Roanoke sounds into the upper part of Pamlico Sound. The Inland Waterway connects it with Currituck Sound to
The Sounds of Coastal North Carolina
the northeast, and, by way of the Alligator River, with Pamlico Sound to the south. Albemarle is essentially a freshwater sound. It is an exceptionally favorable habitat for anadromous fishes (those that seek fresh water to spawn). The resulting fish migrations coupled with the level bottom surface suitable for staking nets create the environment for the intensive fishery of the area.

Roanoke and Croatan sounds parallel each other and extend south from eastern Albemarle into northeastern Pamlico Sound. Roanoke Sound is about eight miles long, one half to two miles wide, and is 1 to 3 feet deep in most areas. Croatan Sound, west of Roanoke Island, is also about eight 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. But because of high freshwater circulation, it has not produced many 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 bottomland is fairly level at approximately 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, especially the two larger ones — the Neuse and Pamlico,

4. Extending northward from Ocracoke Inlet as Bluff Shoal. This shoal is created from 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. Near Beaufort it joins Bogue Sound, which stretches about 25 miles west to Swansboro. These sounds vary from 1 to 6 miles in width and are extremely shallow. Core Sound averages only 3 1/2 feet deep and Bogue Sound about 2 1/2 feet deep. Considerable drainage runs 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. Here it takes a westerly course through Bogue Sound.
In addition to Beaufort and Bogue inlets, two other inlets --- Ocracoke 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 that contributed to the rise of Beaufort and Morehead City as fishing towns and seaports.

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 sizable 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 continues southward through the sounds and marshes mentioned above, cuts through marshes in this area and leads to Charleston, S.C., and eventually Brownsville, Texas.


**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. It may also be the area where a 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 such as a usually a drowned river.

**Estuary** - a semi-enclosed coastal body of water having free connections with the open sea where sea water is measurably 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.

**Lagoon** - 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.

**Regularly Flooded Marshes** - lowland marshes that receive salt water as the tides move in and out of the marsh 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 wash away, so the area is too salty for most plants to grow.

**Sound** - the body of water between a barrier island and the mainland.
Let's Make An Estuary

Write the following geological terms in the order they occurred during the geological making of an estuary/marsh system.

<table>
<thead>
<tr>
<th>Term</th>
<th>Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>estuary</td>
<td>1.</td>
</tr>
<tr>
<td>volcanic activity</td>
<td>2.</td>
</tr>
<tr>
<td>streams</td>
<td>3.</td>
</tr>
<tr>
<td>glacier</td>
<td>4.</td>
</tr>
<tr>
<td>warming trend</td>
<td>5.</td>
</tr>
<tr>
<td>sand bar</td>
<td>6.</td>
</tr>
<tr>
<td>storm</td>
<td>7.</td>
</tr>
<tr>
<td>ice age</td>
<td>8.</td>
</tr>
<tr>
<td>sediments</td>
<td>9.</td>
</tr>
<tr>
<td>barrier island</td>
<td>10.</td>
</tr>
<tr>
<td>inlet</td>
<td>11.</td>
</tr>
<tr>
<td>ocean</td>
<td>12.</td>
</tr>
<tr>
<td>rocks</td>
<td>13.</td>
</tr>
<tr>
<td>weathering</td>
<td>14.</td>
</tr>
<tr>
<td>mountain</td>
<td>15.</td>
</tr>
</tbody>
</table>

Your answers may vary slightly from your neighbors'. Be ready to explain your sequence of events.
Stratification of an Estuary

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

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

1.
Mix three separate concentrations of salt water in three different containers. The first concentration should be significantly denser than the second. One of the beakers may contain only water. E.g.

<table>
<thead>
<tr>
<th>200ml H₂O</th>
<th>200ml H₂O</th>
<th>200ml H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>20g NaCl</td>
<td>10g NaCl</td>
<td></td>
</tr>
</tbody>
</table>

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

3.
Pour the more dense saltwater mixture into the tall jar or graduated cylinder. Next, slowly pour the second most dense saltwater 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 seawater.

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)
What are the Marshes Made Of?

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

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

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).
Figure 29: Student chart of an estuary and marsh.
Resources

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


