# Of Sand and Sea:
## Teachings From the Southeastern Shoreline


*by*

Paula Keener-Chavis

*and*

Leslie Reynolds Sautter

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# *A Sense of Wonder....*

*What's the value of preserving and strengthening this sense of awe and wonder, this recognition of something beyond the boundaries of human existence? Is the exploration of the natural world just a pleasant way to pass the golden hours of childhood or is there something deeper?*

*I am sure there is something much deeper, something lasting and significant. Those who dwell, as scientists or laymen, among the beauties and mysteries of the earth are never alone or weary of life. Whatever the vexations or concerns of their personal lives, their thoughts can find paths that lead to inner contentment and to renewed excitement in living. Those who contemplate the beauty of the earth find reserves of strength that will endure as long as life lasts. There is symbolic as well as actual beauty in the migration of the birds, the ebb and flow of the tides, the folded bud ready for spring. There is something infinitely healing in the repeated refrains of nature—the assurance that dawn comes after night, and spring after the winter.*

*Rachel Carson*
The Sense of Wonder, *1956*

## Dedications

This book is dedicated to my parents, Paul and Lydia Keener, who,
with gifts of microscopes, lightning bugs, and love, inspired my sense of wonder
and to my son, Elliott Parker Chavis—may he find inner contentment and reserves of strength
in the miraculous beauty of the natural world.

Paula Keener-Chavis

....for my children, Will, Eric and Kaylie,
in whom I hope to instill a love for science, nature,
and man-kind.

Leslie Reynolds Sautter

*On the cover: Michael William Sautter II, Eric Reynolds Sautter, and Katherine Leslie Sautter, children of Leslie Sautter; and Elliott Parker Chavis, son of Paula Keener-Chavis.*

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## A Note from the Authors

The ocean's magnificent beauty and mystery have lured oceanic explorers in their quest for knowledge about the seas for thousands of years. As early as 2,000 B.C., the Egyptians were exploring the seas. In 325 B.C., one of the first documented marine biological laboratories was located along the coast of the Mediterranean Sea, operating under the direction of Aristotle. Christopher Columbus, Benjamin Franklin, and Charles Darwin were just a few of the others driven by an innate curiosity about the ocean and its inhabitants. Man's curiosity of the ocean began in earnest in 1872 with the voyages of the *H.M.S. Challenger*, a British sailing vessel that covered 70,000 nautical miles exploring the seas. Data collected during the *Challenger* expeditions were recorded in 50 books that required 23 years to publish.

How did the ocean form? Where does it get its power? Why is it blue, brown, or green? What is living in it? Why do marine plants and animals look the way they do? What do they eat and where do they come from? Why do marine organisms change color and shape as they grow? How do they protect themselves? How do they reproduce and what do their young look like?

These are some of the questions we asked as young children and continue to ask today. Perhaps these are some of the same questions that led the Egyptians on their voyages almost 4,000 years ago. We would venture to guess that you, too, have at some time, thought about similar questions.

Questions about the ocean and the life it supports that we had as young children led us to pursue careers in marine biology and marine geology. They also led us to pursue the opportunity to write this book. Our purpose in promoting marine science education is to better prepare youth to make intelligent, rational decisions on issues affecting our fragile marine environment. Sharing some of the knowledge you may learn from this book with a child may be one of the most rewarding experiences that you will ever have.

There is still much more to tell—so many truly fascinating things about the Ocean Planet that could not be addressed in the scope of this project. This book is the beginning of an attempt to answer, at least in part, some of your questions about the Ocean Planet.

*Paula Keener-Chavis and Leslie Reynolds Sautter*

## Acknowledgements

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Illustration and Photograph Credits

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CHAPTER I

# THE OCEAN PLANET

## A. Coverage

One would think that a marine biologist–or any other scientist whose research requires that they know scientific facts about the ocean–would have a thorough understanding of the ocean's vastness–that he or she would know the average depth of the ocean, the percentage of the earth that is covered by water, and the relative size of the major ocean basins. And, yes, these scientists do, in fact, learn the basic facts about the ocean's size and, in doing so, develop an appreciation for its enormity.

But to see our planet from the eyes of the astronauts onboard the Space Shuttle Discovery, even after having studied the ocean for many years, brings any scientist to the realization that knowledge gained from a textbook, or from onboard scientific research vessels, has its limitations. Seeing our planet as the astronauts have seen it from space is to see our planet in a different dimension–a kind of seventh sense that cannot be learned through any classroom textbook, instinct, or through the many scientific voyages or research projects that have been conducted over millennia. Because only when you see the earth through the eyes of the astronauts do you truly realize that you live on an Ocean Planet.

The astronauts have seen the Ocean Planet in its simple, naked form. They have seen a small, beautiful electric-blue sphere suspended by nothing at all in the black void of space. Streaks of white, which we call clouds, lightly brush the Ocean Planet's surface, while small, muted-green and dull-gold land masses appear to float on top of the electric-blue ocean. The edges of the Ocean Planet glow brilliantly as the sun rises, while the violent lightning bolts of thunderstorms act out their eerie, yet very fascinating, light show for those in space. And if you look very closely, you can see tiny lights shining on the muted-green and dull-gold land masses–the only evidence of human life on the Ocean Planet.

The Ocean Planet differs from all other planets in our solar system in several ways—the most significant of which is that the majority of its surface is covered by a layer of water known as the hydrosphere. Although scientists have found water ice on Mars and an ice crust has been discovered on Jupiter's moon Europa, it is no surprise that the Ocean Planet is the only planet presently known to mankind that is capable of supporting life—and it has continued to do so for over 3 billion years. Over 71 percent of the Ocean Planet is covered by water, 98 percent of which is oceanic.

The remaining two percent is fresh water, existing either in the form of freshwater lakes and streams, groundwater underlying the surface, or fresh water locked in the polar ice caps. Oceanic water is ultimately the source of fresh water on land, as oceanic water is cycled back onto the Ocean Planet's land surface through a process called the hydrologic cycle, which we will discuss in greater detail at the end of this chapter.

## B. The Major Ocean Basins

The global ocean is geologically divided into four major ocean basins: the Atlantic, the Pacific, the Indian, and the Arctic Basins (Fig. 1-1). Although each of these ocean basins is consolidated into one global ocean, each differs in ways that make it a very distinct body of

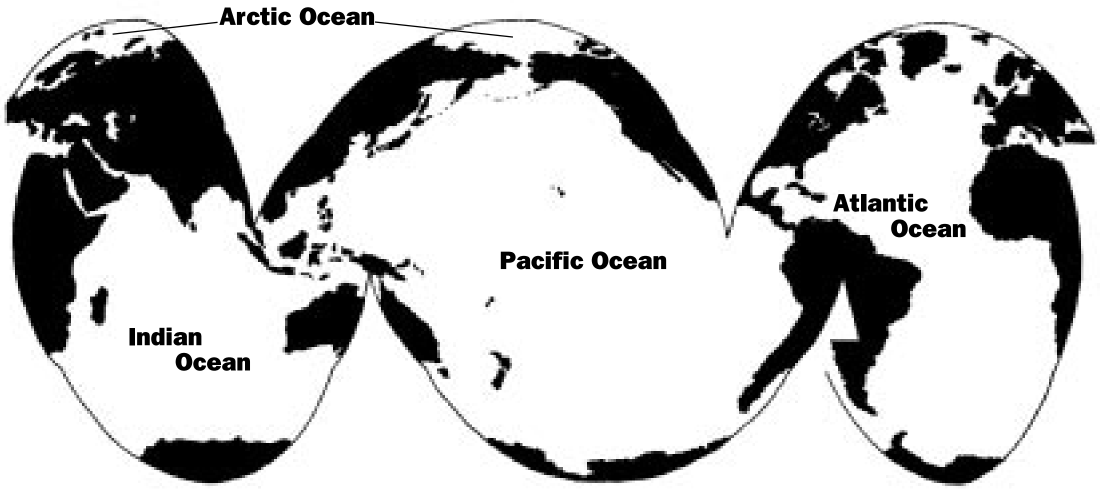



**Figure 1-1.**
*Four major ocean basins of the world.*

water. They not only differ in surface area and depth, but they also differ in physical, chemical, and biological properties, such as temperature, chemical composition, and the types of living organisms they support. Around the margins of some major ocean basins are semi-enclosed bodies of salt water, referred to as seas.

The Pacific Ocean contains most of the water on earth, with about half of the earth's water located in this one basin (Table 1). The Pacific Ocean not only contains the most water, but it is followed in surface area by the Atlantic and the Indian Ocean, with the Arctic Ocean being the smallest of the four ocean basins. The Pacific Ocean is also the deepest of all the major ocean basins, with an average depth of 4,282 meters (14,049 feet). The Indian Ocean has an average depth of 3,963 meters (13,003 feet), and the average depth of the Atlantic Ocean is 3,926 meters (12,881 feet). The Arctic Ocean is the shallowest of all the major ocean basins, with an average depth of 1,205 meters (3,954 feet).

Because the major ocean basins differ in their physical, chemical, and biological properties, there are a variety of habitats found throughout them. Some of these habitats, or specialized places where organisms live, are similar among the ocean basins, while others are quite different. These habitats, some of which will be discussed in detail in Chapter 4, support wonderfully diverse assemblages of marine organisms. Just as habitats may be similar, or quite different, among ocean basins, the organisms living in these habitats may also exhibit similarities to, or striking differences from, the organisms inhabiting other ocean basins. Even though each major ocean basin has its unique characteristics, remember that each basin, along with its inhabitants, is part of one global ocean.

**Table 1-1. Comparison of ocean basins.**

| Ocean | Mean Depth (m) | Area (km$^2$) |
|---|---|---|
| Atlantic | 3,332 | 106.4 x $10^6$ |
| Pacific | 4,028 | 179.7 x $10^6$ |
| Indian | 3,897 | 74.0 x $10^6$ |
| **All** | **3,795** | **361.0 x $10^6$** |

The coastline of the Southeastern United States abuts the western edge of the Atlantic Ocean. The Atlantic Ocean is very productive and teams with marine life of all forms, from the smallest phytoplankton (small plants that float with the currents at or near the ocean's surface) and zooplankton (small animals that float with the currents at the ocean's surface) to very large fishes and mammals. This productivity is evidenced by the greenish-blue hue that is characteristic of coastal waters and continues toward the deep ocean. The coloration is due to tiny, microscopic marine organisms that so abound in these waters because of the nutrients that are available to them. Productivity is discussed in detail in Chapter 5.

In the following section, you will learn more about how the major ocean basins are further divided into "zones." In Chapter 4 you will learn about the types of organisms inhabiting these zones.

## C. Zones of the Ocean

Ocean systems are complex and scientists have developed methods by which to classify major sections, or zones, of ocean basins. Methods of classification are generally based on the following factors:

- Exposure to tides;
- Vertical position (depth) in the water column;
- Distance from shore;
- Amount of sunlight penetrating the ocean depths; and
- Regions of the ocean floor.

### 1. Tidal Zones

Zones of the ocean that are influenced by the tides, or the periodic rise and fall of the ocean's surface, are the splash zone, the intertidal zone, and the subtidal zone. The splash zone is rarely submerged with water and typically receives only salt spray from the ocean. Periodic submergence of the splash zone occurs during storms and occasional extreme high tides accompanied with high winds.

The intertidal zone experiences the full effect of a tidal range, or the difference in the height the water between high tide and low tide, as it is completely submerged at high tide and completely exposed at low tide. The intertidal zone is also frequently called the littoral zone. Saltwater marshes, beaches, tidal rivers, creeks, sounds, and bays that are submerged during high tides and exposed during low tides occupy the intertidal zone.

The subtidal zone remains submerged all of the time, with possible exceptions occurring during times of extremely low tides. Portions of saltwater marshes, beaches, saltwater rivers, sounds, bays, and tidal creeks that are submerged at low tide are located in the subtidal zone.

### 2. Pelagic Zone: the Water Column

The pelagic zone extends from the ocean surface to just above the ocean floor (Fig. 1-2). In other words, it is the water column itself. This zone is sub-divided into the neritic and oceanic zones, based on the relative distance from shore. The neritic zone may be considered the "nearshore" portion of the pelagic zone. Its boundaries are from the shoreline's high tide mark to the point offshore where the water depth is 200 m (656 feet) (Fig. 1-2). The oceanic zone is that part of the pelagic zone that extends seaward of the neritic zone to the open ocean waters.

### 3. Benthic Zone: the Bottom of the Ocean

The ocean floor is also called the benthic zone. Even though some areas of the benthic zone appear to be devoid of life, many species have successfully made themselves at home in or on the seafloor sediments. Off the coasts of North Carolina, South Carolina, Georgia, and parts of Florida, the benthic zone may only consist of large expanses of sand, sparsely littered with brittle stars, sea stars, sea cucumbers, or an occasional lizard fish.

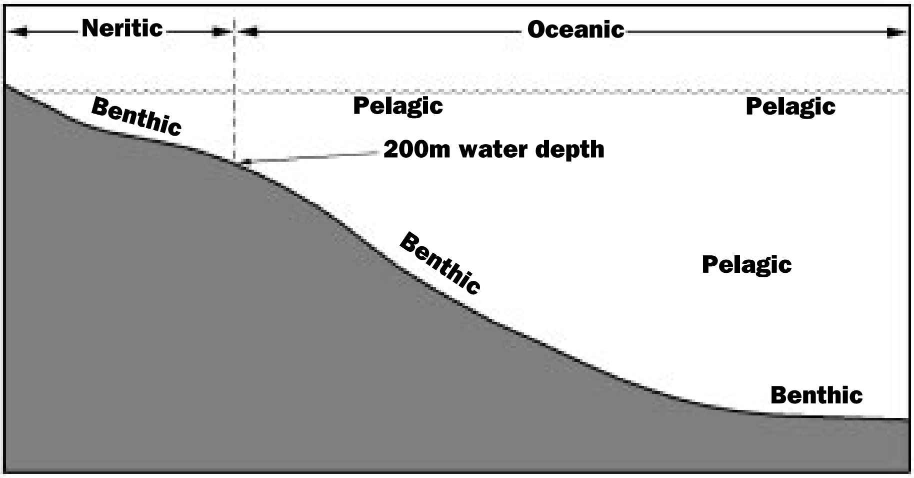



**Figure 1-2.**
*Pelagic and benthic zones of the ocean. The pelagic zone is further subdivided into a nearshore (neritic) and offshore (oceanic) zone.*

But there are rocky outcrops off the Southeastern U.S. coast that break the monotonous pattern of the sandy benthic zone. These rocky outcrops and overhanging ledges support beautiful gardens of soft coral, sponges, and tropical fishes, including brightly-colored butterfly fishes that are so characteristic of clear tropical waters. In section D that follows, you will learn more about the benthic zone. Specifically, you will learn about the shape, or bathymetry, of the ocean floor.

#### 4. Zones of Sunlight Penetration

The area of the ocean where light penetration is great enough to support plant growth is called the photic zone. This zone extends to a wide range of depths in different ocean basins. The photic zone typically extends from 50 to 100 meters (164 to 328 feet), depending on the productivity and/or clarity of the water. Water clarity is related to the concentrations of tiny plants, animals, and/or other particles suspended in a body of water. The photic zone reaches to much greater depths in tropical waters. A good example is the crystal clear Caribbean Sea. Along portions of the Southeastern U.S. coast, the depth of the photic zone is about 50 meters (164 feet), an indication that the Atlantic Ocean is very productive, and sometimes is very turbid, or "cloudy," due to the amount of suspended material in the water column. The disphotic zone is that area of the ocean where light levels are too low to support plant growth. The aphotic zone is the zone of no light penetration, generally below 1000 meters depth.

## D. The Ocean Floor

The ocean floor is not simply a featureless, vast receptacle for sediment that has been eroded from the earth's surface and transported seaward by rivers and streams. In fact, you will find many of the same topographic features seen on land located at the bottom of the ocean. Mountainous ridges, trenches, and undersea volcanoes called seamounts occur on the ocean floor. Some oceanic mountains extend above the ocean's surface to form oceanic islands. The Hawaiian Islands are seamounts which have grown above sea level. When measured from its base on the seafloor, Moana Loa on the Island of Hawaii is actually one of the largest mountains on earth, comparable in size to Mt. Everest.

Just as the ocean has been divided into various zones for ease of classification and study, scientists have also divided the ocean floor into various sections. Submerged edges of continents are called continental margins. During the Ice Age over 18,000 years ago, the uppermost part of the margins, the continental shelves, were exposed to air. At that time, large amounts of ocean water that today cover the shelves were locked in the polar ice caps and sea level was much lower. Sea level may have been approximately 120 meters (394 feet) below the present level! Ancient rivers carved deep valleys into the exposed shelves. These valleys are now submerged and are known as submarine canyons. They are found on many of the world's continental shelves.

Continental shelves vary in width. Off South Carolina and Georgia, the shelf is relatively wide (as much as 130 kilometers, or 80 miles) and dips very gently seaward to depths of 50 to 200 meters (164 to 656 feet). Off the coast of Cape Hatteras, N.C., however, the continental shelf is much narrower, extending only 50 kilometers (approximately 30 miles) offshore; and the shelf is less than 10 kilometers (6 miles) wide along the southern Florida coast. Worldwide, continental shelves extend to an average depth of 130 meters (426 feet).

The gentle slope of the continental shelf becomes more pronounced, or steeper with distance from shore. This area of the ocean floor is known as the continental shelf break (Fig. 1-3). The continental shelf break meets an area of the ocean floor where the gradient, or slope, increases, referred to as the continental slope. Most continental slopes are found at water depths from 3,000 to 4,000 meters (9,843 to 13,124 feet) in depth and continue seaward until the gradient becomes less pronounced. This area seaward of the slope is known as the continental rise, even though the ocean floor continues to drop, or increase in depth.

The continental rise continues seaward to large expanses of broad and virtually flat abyssal plains, at depths of 3,000 to 5,000

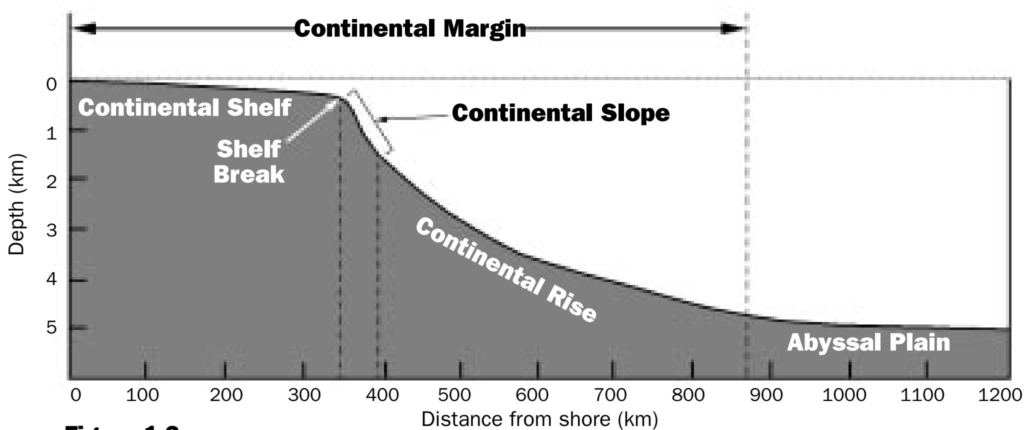



**Figure 1-3.**
*Typical continental margin profile off the east coast of the United States. The continental margin is subdivided into the shelf, slope and rise. Beyond the margin lies the abyssal plain.*

meters (9,843 to 16,405 feet). Abyssal plains are interrupted by ridges, trenches, and volcanoes. Ridges are comprised of long chains of underwater mountains, ranging from 1,000 to 4,000 kilometers (621 to 2,486 miles) in width. The Mid-Atlantic Ridge, which is located near the center of the Atlantic Ocean Basin, is the longest mountain chain in the world, extending from north of Iceland to the southern tip of Africa.

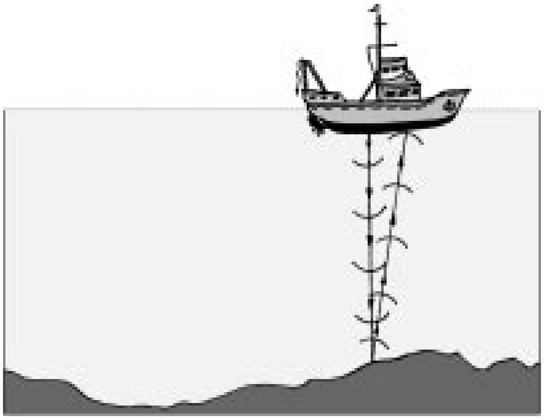


**Figure 1-4.**
*Because we know how fast sound travels in seawater (1,463 m/sec), we can measure the amount of time a sound wave takes to travel from a ship to the sea floor and back to the ship to determine the water depth. This "bouncing" of sound waves off the seafloor is called echo sounding.*

## E. Mapping the Ocean Floor

We have learned much of what we know today about the ocean floor within the last 50 years. Variation in the depth of the ocean floor is referred to as bathymetry, which is analogous to underwater topography. Deep sea bathymetry is determined by measuring ocean depths, using a variety of mapping techniques. Some of these techniques use highly advanced technological inventions that have only recently been developed.

Sounding lines were probably the first "instruments" used by scientists to record bathymetry at different locations around the world. These sounding lines were nothing more than hemp ropes with lead weights attached and lowered over the sides of ships to the bottom of the ocean. The length of rope was then recorded at each location. Piano wires and bowling balls replaced the earliest sounding lines! Today, echo sounding and other state-of-the-art sonar equipment has allowed us to easily "see" the surface of the ocean floor. Pulsing sound waves emitted from a ship bounce off the sea floor and return to the ship (Fig. 1-4). The travel time for the sound wave to reach the ocean floor and return to the ship is measured and used to determine the depth of the ocean floor. Additionally, deep-sea submersibles and robotic vehicles have just recently revolutionized how humans explore the depths of the ocean floor. Many discoveries lie ahead!

## F. Plate Tectonics

At the beginning of this chapter, we discussed why the earth is called the Ocean Planet. From the eyes of astronauts "muted-green and dull-gold land masses" were viewed "floating on top of the electric-blue ocean." Land masses only seem to "float" because they are above sea level.

In the early 1900's the German meteorologist Alfred Wegener first theorized that over 240 million years ago, the continents were once part of one large super-continent called Pangaea (also spelled Pangea) (Fig. 1-5). Wegener also theorized that Pangea broke apart and the segmented continents shifted and moved apart until they reached their present-day locations. He believed that continents drifted across the oceans, bulldozing sediments before them. Wegener's idea, known as the Continental Drift Hypothesis, is not accepted today in part because there was no evidence of bulldozed sediments and Wegener could not explain the *mechanism* that caused the continents to move. The existence of Pangaea, however, is supported by a great deal of geological evidence and is to this day considered to be a plausible concept.

Since the 1950s we have learned much about the structure of the outer layers of the earth. We have determined that the outer layer, or crust, is strongly coupled with the uppermost portion of the mantle and, together, they comprise the lithosphere (Fig. 1-6). The lithosphere is characteristically brittle, or rigid. Crustal material within the lithosphere may be either continental crust or oceanic crust, depending on its origin, composition, and location.

Because of the lithosphere's rigid nature, earth movements often cause it to break. The result is that lithospheric plates are formed. The surface of these plates, viewed on a map, includes oceanic floor *and* continental land masses (Fig. 1-7). Therefore, a continent is only part of a larger piece of lithosphere.

The occurrence of earthquakes and volcanic eruptions along the edges of lithospheric plates is evidence that plates are in continual motion. Volcanoes are very common along these plate boundaries where molten, or melted, rock makes its way to the surface through cracks and faults. Movement and friction along the plate boundaries frequently cause large amounts of energy to be released in the form of earthquakes. Scientists are able to measure the minute movements of plates with very sensitive instruments, and have shown that plates move very slowly around the earth. In fact, most plates are presently moving at a rate of 1 to 4 centimeters (0.4 to 1.6 inches) per year, yet some exceed 10 centimeters (3.9 inches) in a year. Compare these rates to the rate of your fingernail's growth which is approximately 2 centimeters (0.8 inches) per year!

The study of the earth's lithospheric plates involves investigation of their formation, interactions and destruction through time and

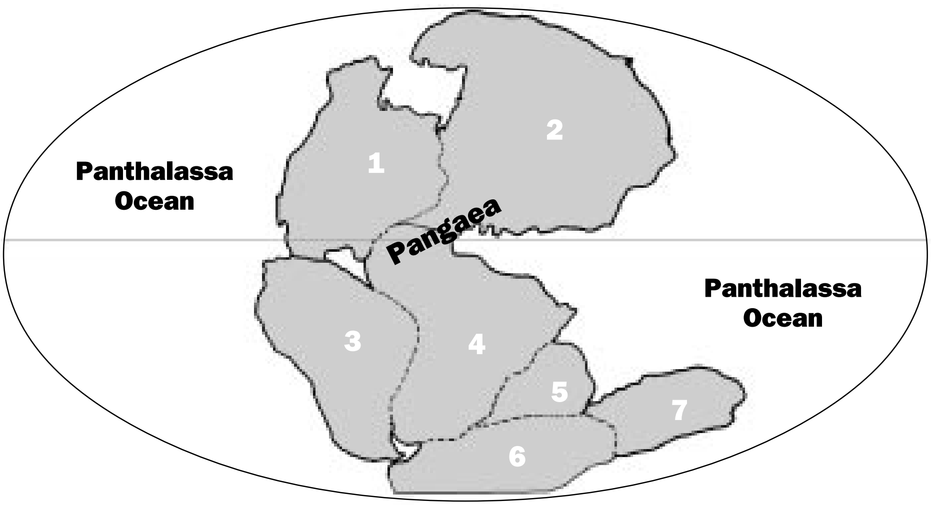



**Figure 1-5.**
*Reconstruction of the supercontinent Pangaea as it may have appeared approximately 240 million years ago. Modern continents are numbered: (1) North America; (2) Eurasia; (3) South America; (4) Africa; (5) India; (6) Antarctica; and (7) Australia.*

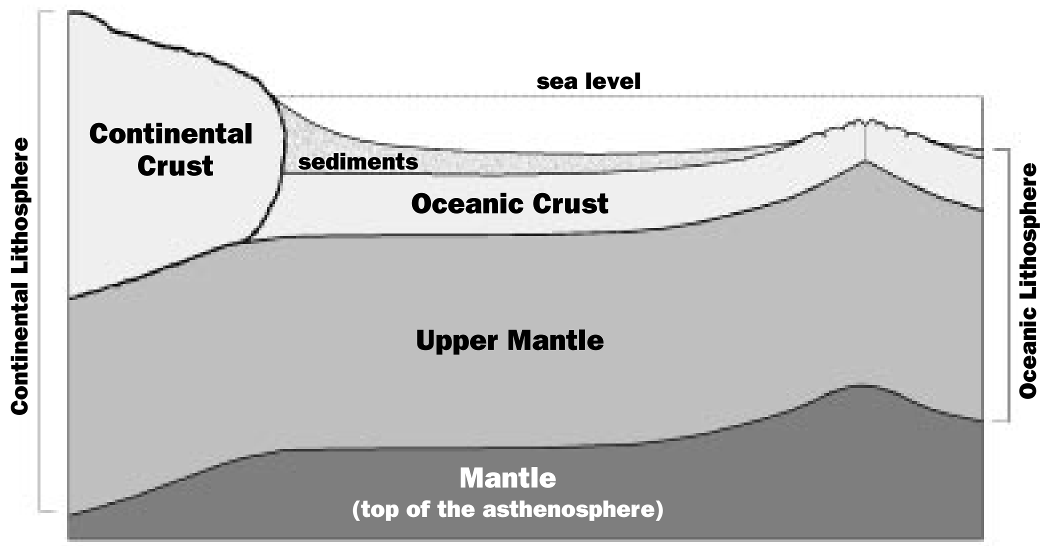



**Figure 1-6.**
*Cross-section of the earth's brittle lithosphere. The lithosphere includes the crust (both continental and oceanic) and uppermost mantle, and is located above the asthenosphere.*

helps us to understand the mechanisms for plate motions. The theory of how and why plates move is known as the Theory of Plate Tectonics. It has only been in the last four decades that we have compiled enough information on the earth's lithosphere to piece together like a puzzle the complex processes involved with plate motions and interactions. In the 1960's, Tuzo Wilson and numerous other scientists were able to utilize advanced technology and drilling ships to verify the movement of plates through time.

Wegener's concept of Continental Drift differs from the Theory of Plate Tectonics because Wegener believed that continents behaved independently from the ocean floor. We now understand that there are many lithospheric plates that contain both continental crust and oceanic crust which travel as a unit. Continents do not float or "drift" across the ocean floor. The Continental Drift Hypothesis is sometimes referred to synonymously with the Plate Tectonics Theory, but they are different concepts. Without question, the theory of Plate Tectonics developed as a result of Wegener's early ideas regarding Pangaea's existence.

Plate Tectonics is a very complex subject and much is still unknown about the mechanisms of plate motion. New evidence is uncovered continually. Thus, Plate Tectonics remains a theory. To understand the physical processes of Plate Tectonics and the resultant crustal features that are produced, we will focus on the plate boundary interactions and one of the current hypotheses as to *why and how* the plates move.

There are several types of interactions between plates at the plate boundaries. Two plates may be moving in opposite directions away from one another, resulting in a divergent boundary. Or, they may be on a collision course with one another, creating a convergent boundary. Also, two plates may slide past each other, as each moves in an opposite direction. This last example is referred to as a transform boundary. Different topographic and bathymetric features, both above and below sea level result from these three major boundary types.

### 1. Divergent Boundaries

In many areas, the earth's plates are being pulled apart by tensional forces. Enormous elongate cracks, or fissures, in the lithosphere allow molten rock from deep within the earth to rise and escape as lava. If a fissure occurs in oceanic lithosphere, the lava will erupt under water and cool very rapidly. The solid rock that is formed (called basalt) is oriented in elongate bands parallel to the fissure. Repeated events of tensional forces and escaped fissure lava continually add material to the plates being pulled apart. The result is that at divergent boundaries new lithosphere is produced and lithospheric plates "grow."

In regions of extensive and repeated fissure eruptions, ridges are formed (Fig. 1-8). Often these underwater ridges have substantial height (as much as 2,000 to 3,000 meters) and are considered to include the longest mountain chains in the world. As new oceanic crust forms at the ridges, older crust is progressively moved farther and farther from the ridge, creeping along at a rate of a few centimeters per year. This process is referred to as seafloor spreading. For this reason, we often refer to divergent boundaries as spreading boundaries. As the new oceanic crustal rock moves away from the heated ridge, it cools and contracts, decreasing the ridge height (i.e., increasing the water depth) of the ridge flanks.

Recently, the use of undersea submersibles has provided a window to view the mid-ocean

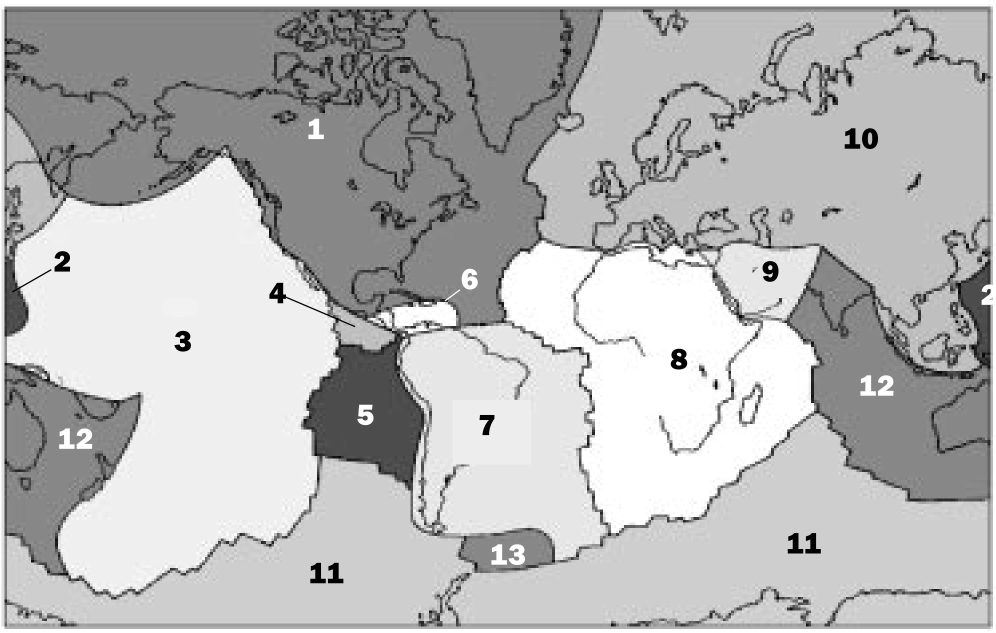



**Figure 1-7.**
*The major lithospheric plates of the earth. Plates are numbered: (1) North American Plate; (2) Philippine Plate; (3) Pacific Plate; (4) Cocos Plate; (5) Nazca Plate; (6) Caribbean Plate; (7) South American Plate; (8) African Plate; (9) Arabian Plate; (10) Eurasian Plate; (11) Antarctic Plate; (12) India-Australia Plate; (13) Scotia Plate.*

ridges. Scientists have actually observed new ocean floor being produced as red-hot lava flows from active fissures, instantly "freezing," or cooling, in the 2°C bottom water. Associated with the ridges are hydrothermal vents, where super-heated gases and minerals escape from deep within the earth.

The process of seafloor spreading not only forms ocean ridges, but over millions of years of seafloor spreading creates entire ocean basins. The modern oceans have all been formed by the divergence of two plates and the creation of newer oceanic crustal material. Examination of a map of the sea floor reveals a crooked but continuous mountain chain that divides the Atlantic Ocean, known as the Mid-Atlantic Ridge. Like the seams of a baseball, the ridge system continues around the globe, connecting with the Indian Ocean ridge system. Eventually the "seam" travels across the southern Pacific and appears to end as it runs into Central America. There it is actually broken into small segments in the Gulf of California. In fact, the Gulf of California is an excellent example of a young ocean being born. The Red Sea is another example. Investigation of a map of the seafloor will reveal a small, young divergent ridge system within the centers of both the Gulf of California and the Red Sea.

## 2. Convergent Boundaries

As you have seen, divergence and spreading cause the surface areas of the plates on either side of the ridge ultimately to increase. If all plate boundaries were divergent, the earth would be expanding! To compensate for the continual addition of plate surface area from divergence, plate material must be destroyed or consumed elsewhere. Because the edge of a plate may be composed of either oceanic crust *or* continental crust, and because two plates are involved in any one collision, there are *three* types of plate collisions: (1) when both plates have oceanic crust along their boundaries; (2) when one plate has an oceanic crust boundary and the other has a continental crust boundary; and (3) when both plates have continental crust boundaries.

### *a. Oceanic-Oceanic Collisions*

The collision of two plates with oceanic crust edges causes one of the plates to slide under the other (Fig. 1-9). This process is referred to as subduction, and the area where the plate is subducting is called the subduction zone. As

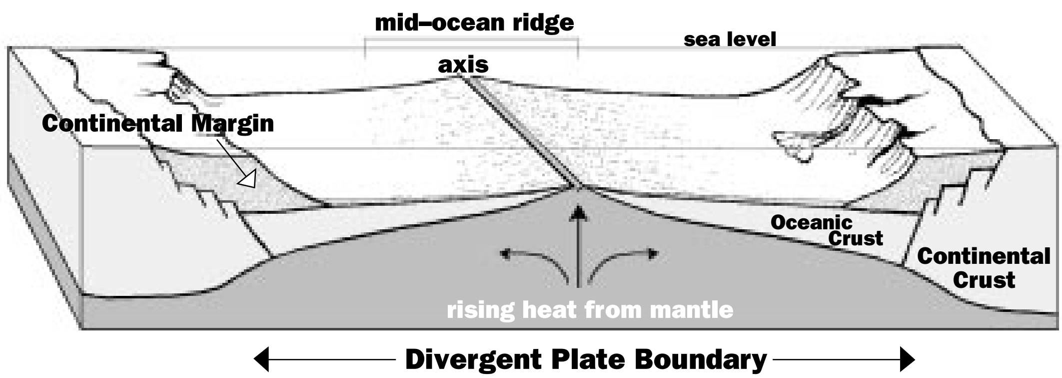



**Figure 1-8.**
*Divergent, or spreading plate boundary with a mid-ocean ridge. New oceanic crust is formed as plates diverge.*

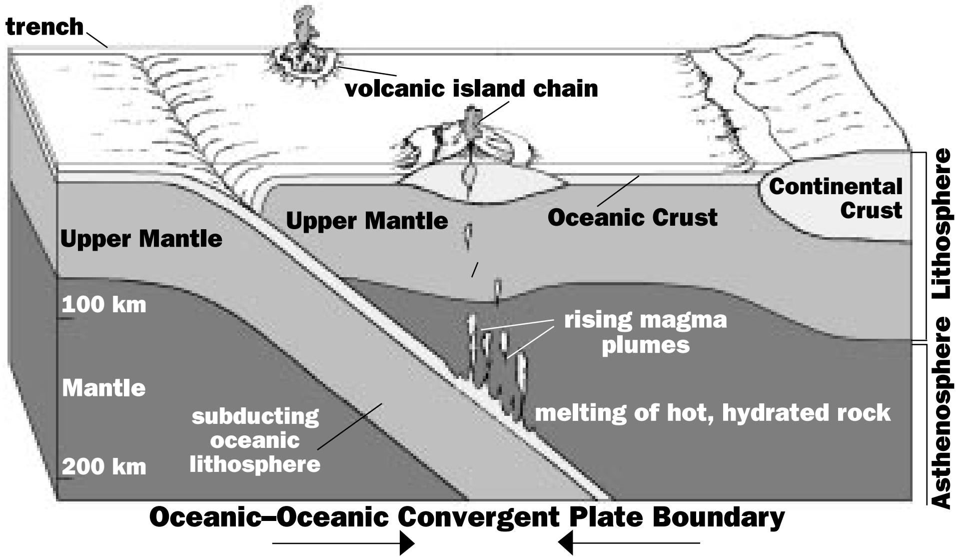



**Figure 1-9.**
*Oceanic–oceanic convergent plate boundary. Subduction occurs as two oceanic plates collide, resulting in the formation of a trench and volcanic chain of islands.*

the oceanic plate descends, it produces numerous earthquakes from the release of frictional and heat energy. A deep and elongate trench on the seafloor marks the top of the subduction zone and the boundary between the two plates. As subduction continues, the subducted plate's temperature increases and vaporized water within the plate may cause partial melting of the mantle rock above it. The molten rock material, referred to as magma, rises because of its lowered density. If the molten material reaches the surface of the lithosphere, a volcano is born. This type of volcano is initially built under the sea, but may grow and, eventually, reach above sea level, producing a volcanic island.

Because plate boundaries are often long and nearly linear features, the volcanic islands produced from subduction most often occur as a chain parallel to the plate boundary and trench. These volcanic island chains and associated trenches mark the locations where two oceanic plate edges have collided. Japan and the Aleutian Islands of Alaska are examples of volcanic island chains produced from oceanic-oceanic plate collisions.

#### *b. Oceanic-Continental Collisions*

Because oceanic crust is composed of denser material than continental crust, when the collision of two plates involves an oceanic plate edge and a continental plate edge, the oceanic plate slides, or subducts, underneath the continental plate. As with oceanic-oceanic collisions described above, this type of collision produces an elongate trench as well as a subduction zone with earthquakes (Fig. 1-10). The heated subducted plate may cause partial melt of the mantle, allowing plumes of molten rock to rise through the cracks and faults in the overlying continental crust. A chain of continental volcanoes often results. The Cascade Mountains in the northwest corner of the U.S. is actually a chain of volcanoes produced from the subduction of a small plate beneath Oregon and Washington. As evidenced by the eruption of Mount St. Helens in 1980, this is an active subduction zone! The

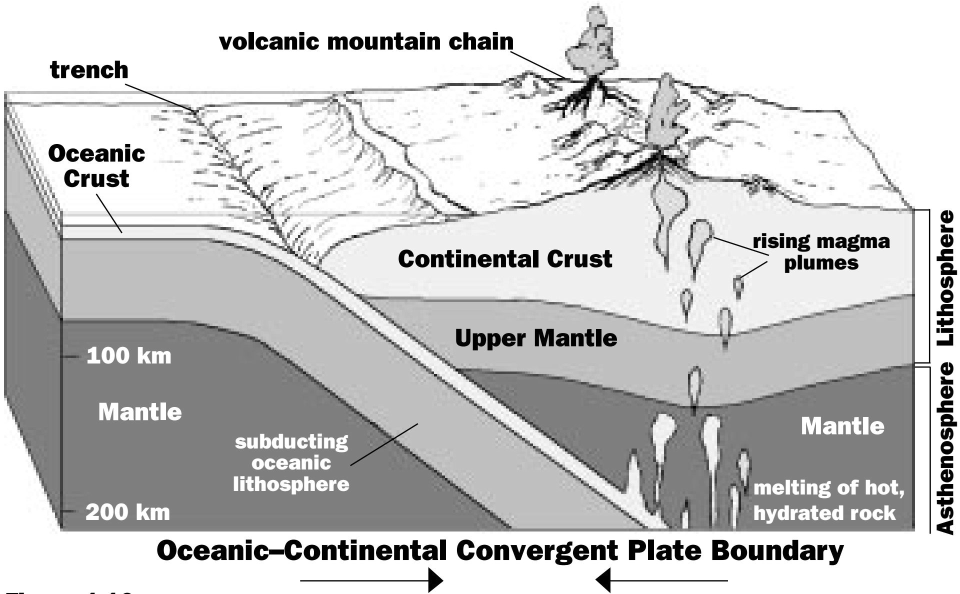



**Figure 1-10.**
*Oceanic–continental convergent plate boundary. Dense oceanic plates are subducted beneath the less dense continental plates, resulting in the formation of a trench and chain of continental volcanoes.*

Andes Mountains of South America are the result of the Nazca Plate's subduction beneath the South American Plate. Deep trenches and volcanic mountain chains are common features of oceanic-continental plate collisions.

If one examines a map of seafloor features, numerous trenches can be found along much of the Pacific Ocean's perimeter. Some of these trenches are the result of oceanic-oceanic plate collisions (northern and western Pacific), while the rest are from oceanic-continental plate collisions (along the coast of South America). A map of the globe showing locations of earthquakes and volcanoes reveals that the highest concentrations of each are found in a ring around the Pacific. Consequently, this ring is known as the Ring of Fire (Fig. 1-11).

#### *c. Continental-Continental Collisions*

When two continents collide, tremendous compressional and frictional forces are at play. These forces cause solid rock to bend, fold and fault, or break. Over the course of millions of years, enormous continental mountain belts are formed and uplifted as the land "wrinkles" from the continuous and extreme pressures (Fig. 1-12). A modern day example is the Himalayan Mountains that have been under construction for the past 40 million years, ever since the small plate on which India was originally located first collided with the Eurasian Plate. This collision is ongoing and has produced Mt. Everest, the tallest continental mountain on earth.

Closer to home in the Southeastern U.S., the Appalachian Mountains are remnants of a mountain belt formed when ancient plates collided over 250 million years ago during the construction of Pangaea! The Appalachians are no longer growing, but instead have been exposed to the natural forces of weathering and erosion for the past 200 million years, since the break-up of Pangaea.

### 3. Transform Boundaries

If one were to draw directional arrows on a map showing plate movement, arrows would be placed on either side of every mid-ocean ridge, with the arrows pointing away from one another. Because ridges are segmented on the curved earth, there are regions *between* the ridge segments where the motion is in opposite directions, and the edges of the plates are *sliding past* each other, rather than away from each other (Fig. 1-13). This is actually another type of plate boundary, referred to as a transform boundary. Because of the intense friction that results from the sliding motion of one plate past another, transform boundaries also have high occurrences of earthquakes.

Transform boundaries can be found connecting all the broken and offset segments of the mid-ocean ridge systems. They also connect segments of ridges that are quite distant from one another. For example, the ridge just east of Baja in the Gulf of California is actually connected to a small ridge off the coast of Washington and Oregon (the Juan de Fuca Ridge) by a long transform boundary between the North American Plate and the Pacific Plate (Fig. 1-13). This boundary passes through San Francisco and just east of Los Angeles. Divergence from the Juan de Fuca Ridge is in part causing the western edge of the North American Plate to move in a southeast direction. Divergence from the ridge in the Gulf of California is causing Baja and the rest of the Pacific Plate to move in a northwest direction, opposite to the North American Plate.

Intense frictional forces prevent the Pacific Plate from gliding easily past the North American Plate. Instead the plates are temporarily locked in position until the forces of movement overcome the frictional forces, resulting in an enormous release of locked-up energy: a California earthquake. Sunny California has the great misfortune of being situated astride the transform plate boundary, known as the San Andreas Fault.

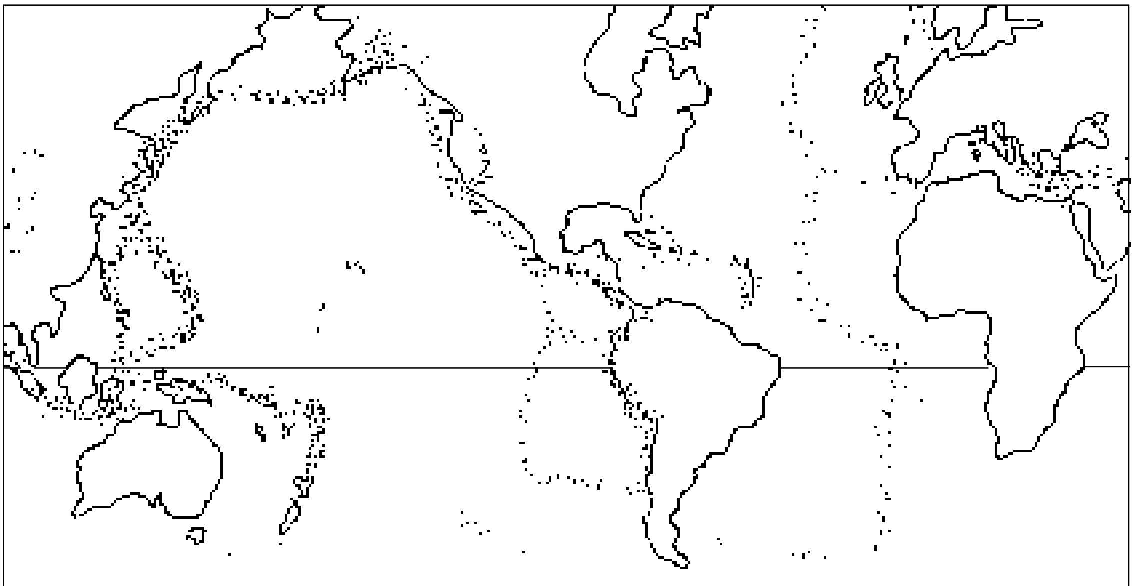


**Figure 1-11.**
*Global distribution of earthquakes. Active volcanoes are closely associated with this same pattern. The high concentration of volcanoes and earthquakes around the edge of the Pacific Ocean is referred to as the Ring of Fire.*

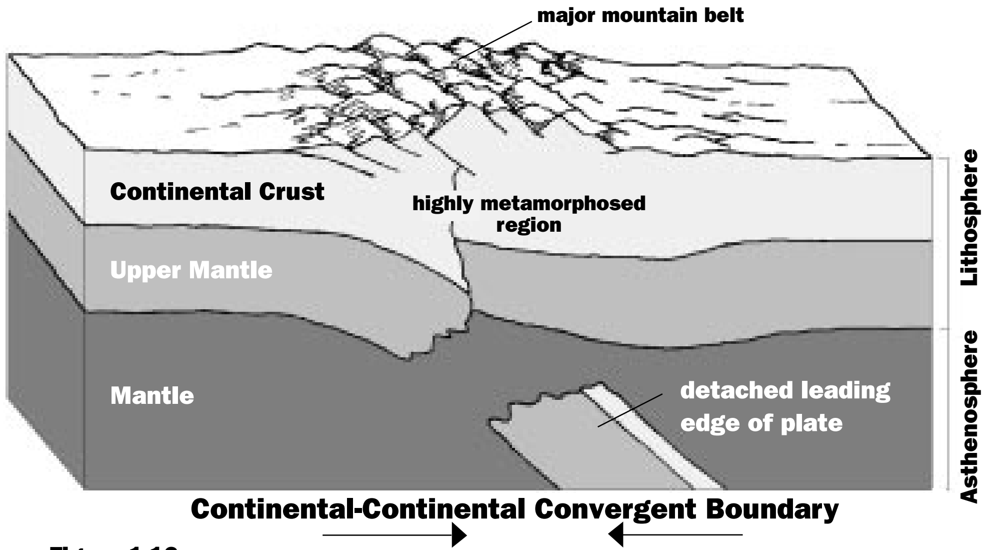



**Figure 1-12.**
*Continental–continental convergent plate boundary. When two continental plates collide they buckle, fold, and fault, resulting in large mountain chains.*

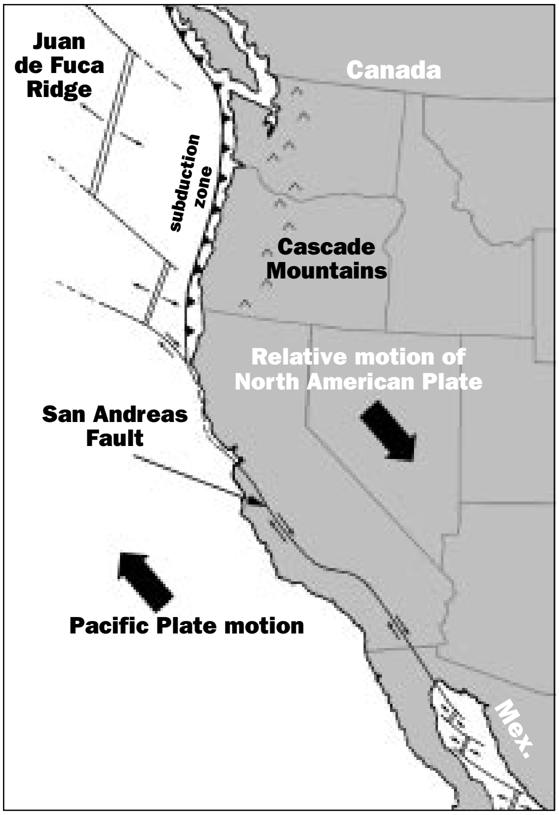



**Figure 1-13.**
*The San Andreas Fault is a transform boundary between the Pacific Plate and the North American Plate. Motion along the plate boundary is in opposite directions, as shown by the arrows.*

### 4. Hot Spots

Not all volcanoes and earthquakes are associated with plate boundaries. The Hawaiian Island chain of seamounts is located near the center of the Pacific Plate, without a spreading ridge or a convergent trench in sight! The Hawaiian volcanoes have been formed as the Pacific Plate has moved across an area known as a "hot spot" (Fig. 1-14). A hot spot is where a huge chamber of melted rock is located deep within the mantle, providing a tremendous source of molten material to the earth's surface. Scientists are still uncertain why hot spots occur, but the Hawaiian Island chain provides an excellent and active study site!

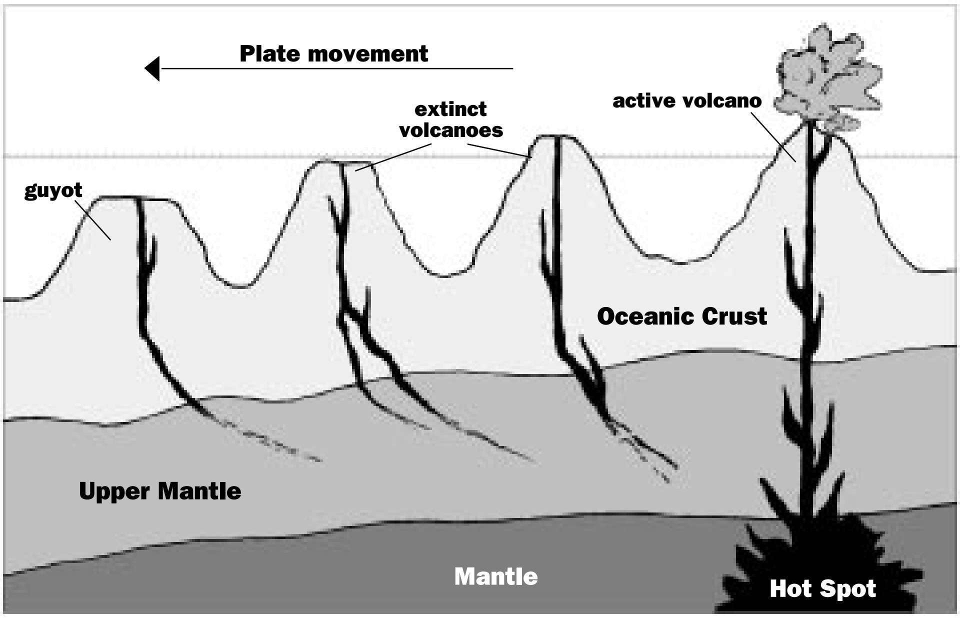



**Figure 1-14.**
*The Hawaiian Island chain of volcanoes was formed by the Pacific Plate passing over a "hot spot" of magma located within the mantle.*

The ages of the Hawaiian Islands are progressively older with increasing distance from the "Big Island" of Hawaii. On Hawaii, which is less than 2 million years old, the volcanoes Kilauea and Moana Loa today periodically erupt fountains and rivers of lava, ever increasing the mass and volume of this phenomenal lava-rock island that extends to the seafloor 9 km (nearly 6 miles) below its summit. Older islands house extinct volcanoes, quiet now after their own episodes of eruptive activity millions of years ago when they were created.

As the Pacific Plate passes over the hot spot a volcano is "born" directly above and is active for several million years. With time and movement of the plate, the volcano is carried far enough past the hot spot location to cause its dormancy and extinction. As it moves away from its position above the hot spot, the volcanic island cools and contracts, eventually sinking below the ocean waves. The result is a chain of volcanoes where increasingly older and smaller (from contraction) volcanoes can be found with increasing distance from the hot spot that created them.

### 5. What Drives the Plates?

Scientists have several ideas of the mechanisms that cause plate movements. Most agree that the earth's internal heat plays the most significant role. Beneath the rigid lithosphere tremendous heat causes solid rock to flow very slowly. This mobile rock is located within the asthenosphere, simply defined as the interior of the earth below the lithosphere. Because lithospheric plates are more rigid and do not flow internally, their

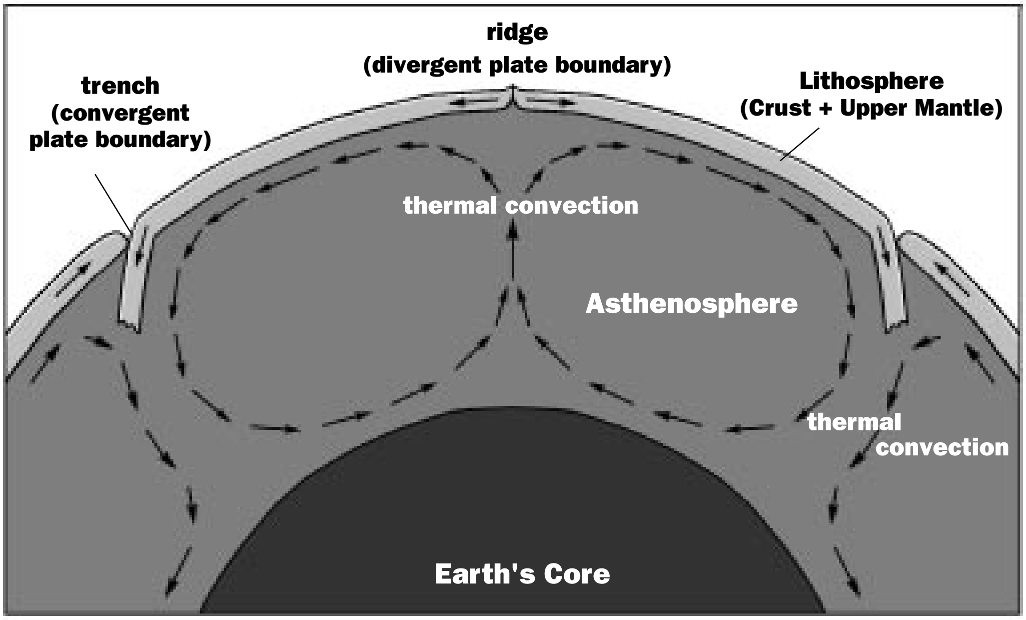



**Figure 1-15.**
*Thermal convection within the earth's mantle may drive the motion of the lithospheric plates. The actual depth of the convection is not known.*

movements as plates are most likely aided by the mobility of the upper asthenosphere on which they rest. But how does heat drive the lithospheric movement?

Consider a large pan of water on a stove burner. As heat is applied to the center of the pan's bottom, the warm water expands and rises because of its lowered density. As the warm water reaches the surface it is cooled and becomes more dense. Eventually the cooled water sinks because of its increased density. With a continuous source of heat applied to the center of the pan's base, a circular motion of rising heated water and descending cooled water is created. This circular motion is known as a thermal convection cell. Scientists believe that rising heat from the mantle causes overlying lithosphere to expand and may be the initial cause of breaking the lithosphere into plates. In areas where thermal convection cells diverge, divergent plate boundaries are found (Fig. 1-15). This idea is referred to as the Thermal Convection Hypothesis. The details of the depth of circulation are still unknown, but are being studied by geologists around the world.

There are still many unanswered questions of how and why lithospheric plates move. Certainly, heat alone does not move the plates, but without heat rising from within the earth, most scientists believe there would be no plate motion. Elevated ridges are formed where the lithosphere has expanded from the heat and new oceanic crust is being produced. Gravity may actually cause the plates on either side of the ridge to slide away from the fractured boundary, initiating plate motion. As scientists learn more about the structure of the earth and the internal flow of heat, many of the pieces of the plate tectonics puzzle will fall together.

## G. The Hydrologic Cycle

The hydrologic cycle, or water cycle, is a very complex transport mechanism through which water moves from the oceans onto land and then back to the oceans again. This cycle, though complex, is quite simple to understand (Fig. 1-16). The entire system is continuously driven by energy from the sun, with no net loss or gain of water to the system. Water from the ocean is evaporated into the atmosphere as the sun heats the ocean's surface. Ocean salts are left behind as this fresh evaporated water condenses and forms clouds. Clouds produce rain, or other forms of precipitation, such as snow, sleet, or hail. This precipitation then falls back to the earth's surface. Precipitation continually supplies fresh water to the land, rivers, streams, and the ocean. As we already know, freshwater rivers and streams flow to meet the ocean. Plants also play an important part in the hydrologic cycle, as their roots take up water from the soil. This water is then actively transported, or transpired, through their leaves back into the atmosphere.

There are over 1,360 million cubic meters (3.59 x $10^{11}$ gallons) of fresh water on earth. Rivers, streams, and groundwater are also the reservoirs that serve as sources of fresh water. Other sources of fresh water are the polar ice caps, glaciers, lakes, and moisture present in the soils. But the ocean is, by far, the largest reservoir of water on earth, comprising 97.2% of all the water available to the hydrologic cycle.

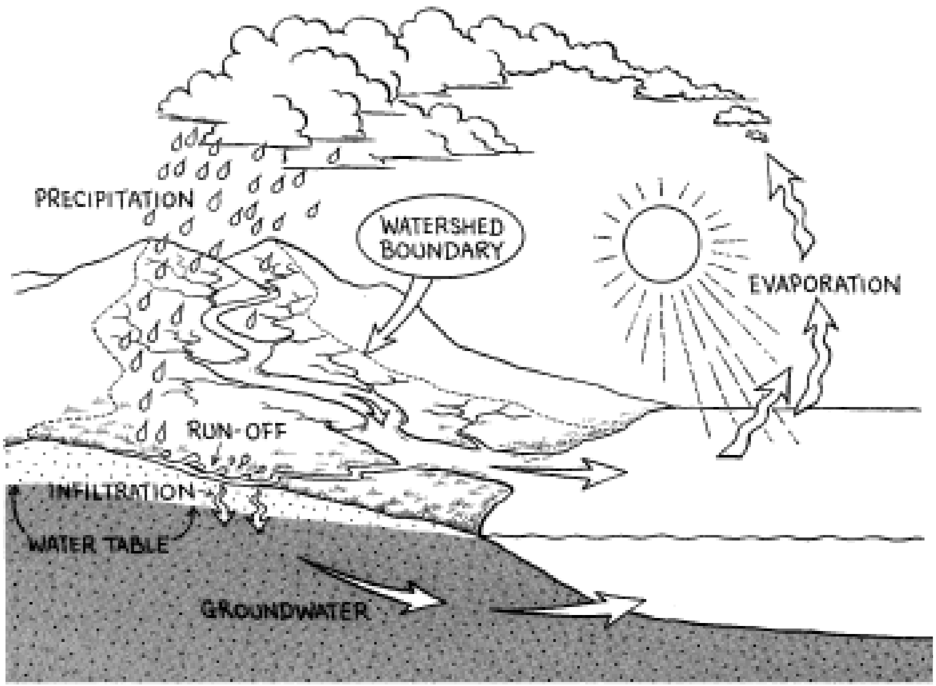



**Figure 1-16.**
*A simplified hydrologic cycle.*

Illustration by JOHN NORTON

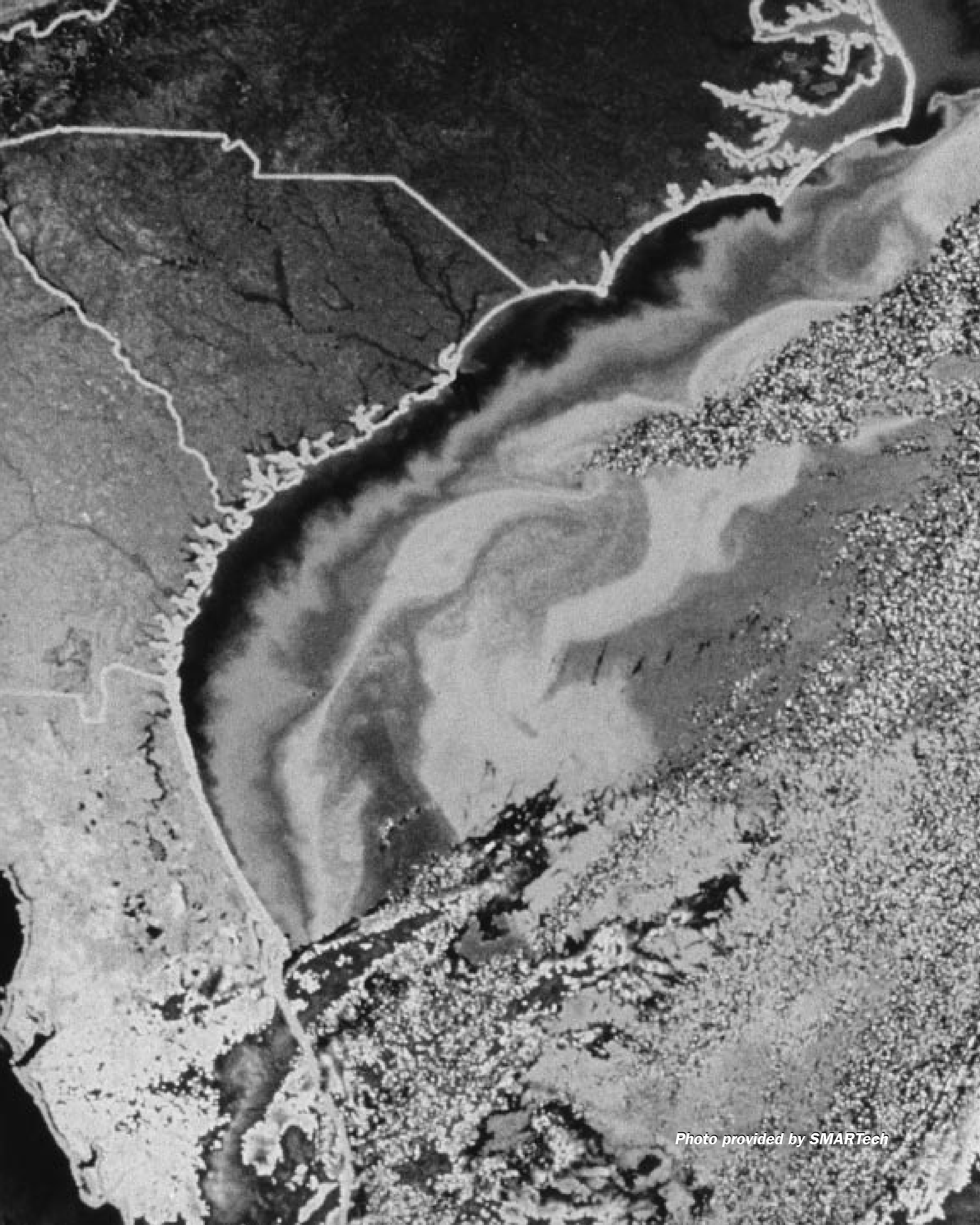


Photo provided by SMARTech

CHAPTER II

# PHYSICAL AND CHEMICAL PROPERTIES OF THE OCEAN

Terrestrial habitats exhibit extreme ranges in temperature and receive varying amounts of sunlight, precipitation, and wind. Additionally, they have other unique chemical and physical properties that make them suitable places for one species to live, but completely uninhabitable for another. So, too, oceanic habitats exhibit chemical and physical properties that make certain ocean zones suitable or unsuitable places for different species to live. In fact, chemical and physical properties of the ocean are crucial to the survival of marine organisms. This chapter addresses the chemical (salinity and dissolved gases) and physical (temperature, density, buoyancy, waves, tides, and currents) properties of ocean water that are delicately intermingled to produce one of the most self-sustaining life support systems on earth.

## A. Salinity

The ocean is salty. But what makes it salty when the water flowing into it is from freshwater rivers, streams, and precipitation? Freshwater rivers and streams weather, or slowly wear away, the rocks and soils they flow over as they make their descent from mountainous and other inland regions toward the ocean. Rocks and soils release inorganic salts and other chemical compounds as they are weathered by this continuous flow of water. These inorganic salts and other chemical compounds are finally deposited in the oceans at the end of their journey from far away inland places. Additionally, precipitation causes fresh water and chemical compounds to be released from the atmosphere into the oceans.

Some of the inorganic salts and other chemical compounds become dissolved in the ocean water once they reach the ocean. Sodium ($Na^+$), chlorine ($Cl^-$), magnesium ($Mg^{2+}$), and calcium ($Ca^{2+}$) are inorganic salts that make up most of the solid material that has become dissolved in the oceans (Table 2-1). Ocean water is approximately 96.5% pure water and 3.5% naturally-occurring dissolved substances.

**Table 2-1. Constituents of seawater.**

| Constituent | Symbol | % by Weight |
|---|---|---|
| chloride | $Cl^-$ | 55.1 |
| sodium | $Na^+$ | 30.6 |
| sulfate | $SO_4^{2-}$ | 7.7 |
| magnesium | $Mg^{2+}$ | 3.7 |
| calcium | $Ca^{2+}$ | 1.2 |
| potassium | $K^+$ | 1.1 |
| **Total** | | **99.4** |

Salinity is the term used to define the total amount of dissolved inorganic salts in the ocean. Salinity is measured, in most cases, in parts per thousand (ppt or ‰). For example, a salinity of 1‰, or 1 ppt, is equivalent to 1 gram of salt in 1,000 grams of pure water; a salinity of 30‰, or 30 ppt, is equivalent to 30 grams of salt in 1,000 grams of pure water.

There are a variety of different factors influencing the relative amounts of dissolved inorganic salts in the ocean. Sunlight, for example, causes only the fresh water part of the ocean to be evaporated, or absorbed by, the atmosphere, leaving only the inorganic salts behind. Frequent precipitation, on the other hand, adds fresh water back into the ocean system, thereby diluting the relative

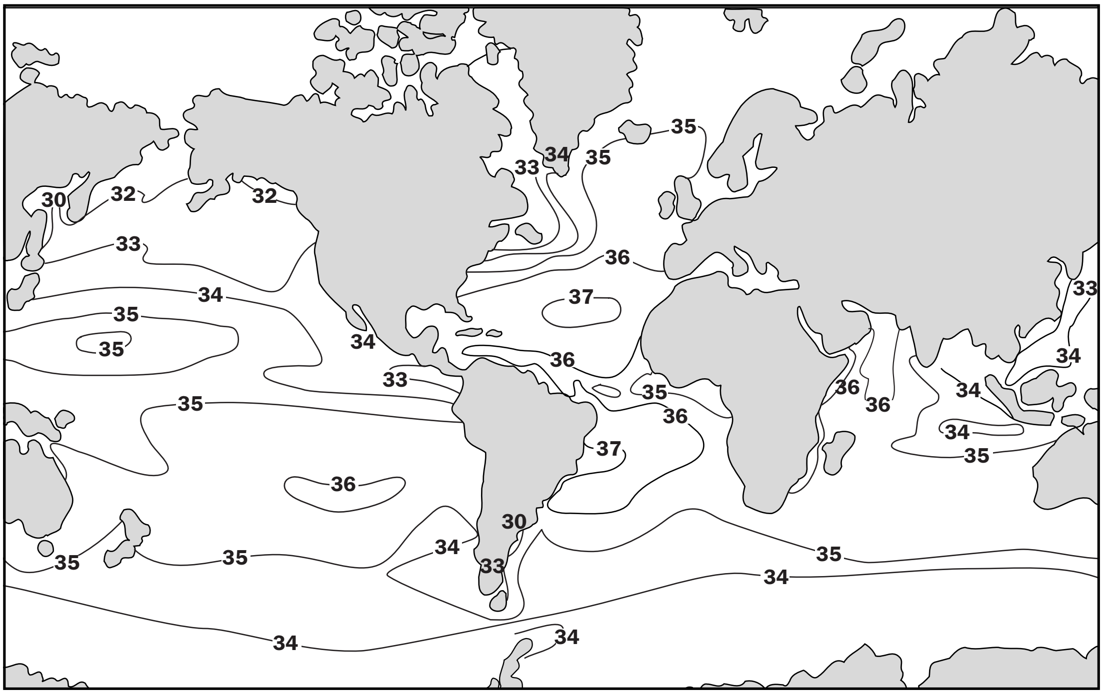



**Figure 2-1.**
*Worldwide surface salinity distribution expressed in parts per thousand.*

concentrations of inorganic salts in ocean water. Salinity can be varied by (1) changing the concentration of salts in the ocean, and/or (2) changing the concentration of water in the ocean. Rates of evaporation and precipitation can thus be related to salinity, with areas of generally high evaporation having high salinities and areas of high precipitation generally having lower salinities. Although the amount of dissolved inorganic salts varies among different areas of the world's ocean, the relative proportions of the inorganic salts themselves remain very similar throughout.

Salinities in the ocean range from less than 5‰ where rivers begin to reach coastal areas to as much as 45‰ in the saltiest oceans. The Black Sea has a relatively low salinity of 18‰, while salinities in the Red Sea, one of the saltiest seas in the world, range from 40 to 42‰. The salinity of open waters of the Atlantic Ocean averages 35‰, but may be as low as 15 to 25‰ in harbors, sounds, and bays, to about 30‰ along the coast. Salinity increases as the distance from shore increases, with salinities in continental shelf waters off the Southeastern U.S. ranging from 30 to 36‰, from 36 to 36.2‰ in the Gulf Stream, and from 36.2 to 37‰ in waters transported by currents from the Sargasso Sea.

The global distribution of sea surface salinities varies substantially (Fig. 2-1). This variability is mostly due to the relative amounts of precipitation and evaporation or the addition or removal of atmospheric fresh water. In tropical equatorial regions, evaporation is approximately equal to precipitation, and we observe a salinity of 34.5‰. Between latitudes 20 and 40° in both hemispheres, evaporation exceeds precipitation, resulting in high surface water salinities, reaching 35.7‰ (and higher). Near the polar regions (latitudes higher than 60° N and S), precipitation is significant and dilutes the seawater, resulting in much lower salinities (<33‰).

The salinity of different ocean areas is a major factor in determining the types of organisms capable of living there. As you will see in the following sections, interactions between salinity and temperature affect other physical properties of ocean water. Salinity also serves as one of the driving forces of major oceanic current systems, as discussed in Section H on page 29.

## B. Temperature

Temperature is one of the most important physical factors affecting the distribution of life in the oceans. Additionally, temperature controls the rate at which organisms metabolize, or break down, food items into nutrients that they can use. Exchange of gases, such as oxygen ($O_2$) and carbon dioxide ($CO_2$), in the marine environment is greatly affected by temperature. Ocean temperatures also affect the survival of organisms as they develop through various life cycle stages, such as egg, larval, and juvenile stages.

Sea surface temperature in the ocean ranges from very warm in the tropics to below freezing in the polar regions. Oceanic waters become warmer as one moves toward the equator and conversely, cooler as one moves toward the poles. Ocean surface temperatures generally range from 0 to 30˚C (32 to 86˚F). Because salt lowers the freezing point of pure water, which is 0˚C (32˚F), ocean water freezes at about -1.1˚C (30˚F). Just as inorganic salts are left behind in the ocean water when freshwater is evaporated into the atmosphere, only the freshwater portion of the ocean surface freezes, thereby leaving the ocean water beneath the frozen surface layer saltier. The temperature of the Atlantic Ocean ranges from -2˚C to greater than 30˚C (28.4 to 86˚F) (Fig. 2-2).

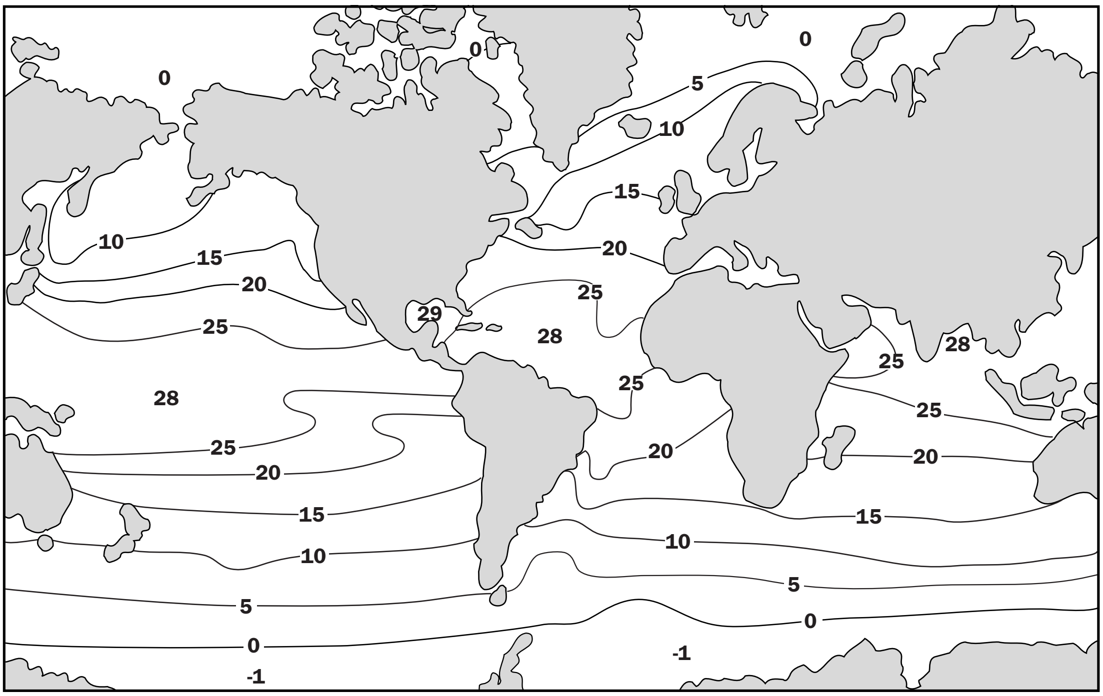



**Figure 2-2.** *Worldwide surface temperature distribution (in ºC).*

Surface temperatures in the ocean also vary seasonally, with the greatest differences in seasonal temperatures occurring near the poles. Temperatures remain relatively unchanged near the equator. Off the Southeastern U.S., ocean temperatures over the continental shelf can range from 9 to 25˚C (48 to 77˚F) at the surface and from 9 to 23˚C (48 to 73.4˚F) at the bottom during winter months to 27 to 30˚C (80 to 86˚F) at the surface and 20 to 28˚C (68 to 82˚F) at the bottom during summer months.

Generally, the deep ocean is very cold, and fewer organisms are capable of surviving these cold temperature extremes. But the recent discovery of hydrothermal vents along the ocean floor has revealed that heat is released from the earth's interior through fissures located on the ocean floor. These fissures and hydrothermal vents are most often located at the edges of divergent lithospheric plates (described in Chapter 1) and provide an oasis of warm water in the cold, deep ocean.

Most ocean waters have a subsurface temperature feature known as a thermocline. A thermocline is an area in the water column of the ocean where temperature changes very rapidly (Fig. 2-3). Thermoclines separate warmer surface waters from the cooler waters below. Because thermoclines are physical features that separate warmer waters from colder waters, they can be very effective barriers across which gases, nutrients, and in some cases, organisms, move. The vertical location of the thermocline can change seasonally.

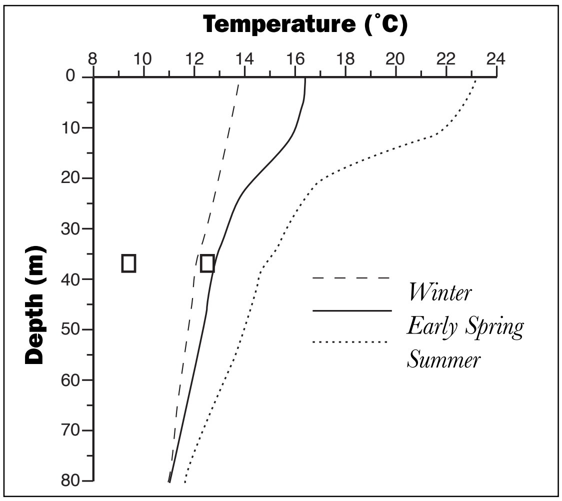



**Figure 2-3.**
*Seasonal variability in the shape and depth of the thermocline.*

## C. Density

Variations in density, or the ratio of mass to volume, of the ocean are a function of salinity and temperature. Oceanic waters with higher salinities are more dense than oceanic waters with lower salinities. In other words, a liter of water with a salinity of 36‰ weighs more than a liter of water with a salinity of 32‰. Additionally, waters that have cooler temperatures have higher densities than waters with warmer temperatures. Ocean waters with higher salinities and cooler temperatures have the greatest densities. Dense water masses actually "sink" toward the ocean floor, while less dense ocean water masses "float" at or near the ocean's surface.

In coastal areas, fresh water in a river tends to flow toward the ocean along the river's surface, while the more dense salt water flows upstream along the bottom of the river (Fig. 2-4). The degree of mixing between the two water masses varies, depending on river flow, tides, wind, and the width and depth of the river as it approaches the ocean.

At the beginning of this chapter, we discussed that unique chemical and physical properties, like salinity and temperature, vary somewhat among the different ocean basins. Water masses from each ocean basin must ultimately meet since all of the major ocean basins are interconnected and form one global ocean. The ocean is, therefore, made up of "layers" of different water masses that are continually sinking toward the ocean floor or rising toward the ocean surface, depending on their indi-

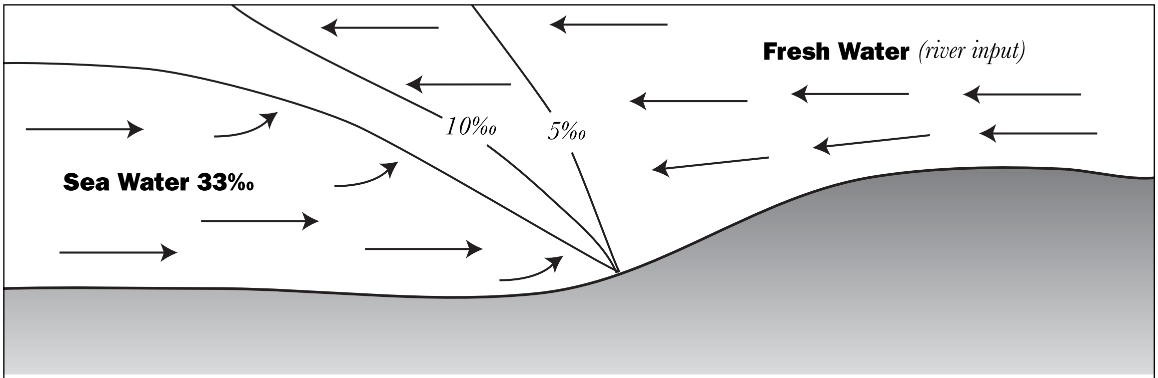



**Figure 2-4.** *Fresh water entering an estuary from a river is less dense than the salt water. In some estuaries, a wedge of denser salt water is created as the fresh water overrides denser water.*

vidual densities. It is the interactions among factors occurring at the ocean's surface, such as freezing, evaporation, precipitation, heating, and cooling, that determine the density of a certain water layer and thus, its vertical position in the "layered" global ocean.

## D. Buoyancy

Just as water masses with different densities either sink below or float on top of one another, objects that are denser than water sink while objects that are less dense than water float. Buoyancy is defined as the ability to remain afloat in a liquid. Because salt water is more dense than fresh water, salt water provides greater buoyancy to an object floating on the surface than does fresh water. A person or a boat is more buoyant in salt water than in fresh water (Fig. 2-5). Denser liquids have a greater buoyancy force, or the force that makes an object float. In order for an object to float in a liquid, it must be less dense than that liquid.

Some organisms living in the ocean float on top of the ocean's surface. These organisms are very buoyant, or less dense, than the sea water in which they live, and most of their body mass is, in fact, made up of water. Some of these organisms have specialized structures that make them more buoyant, such as the balloon-like floats of the Portuguese man-o-

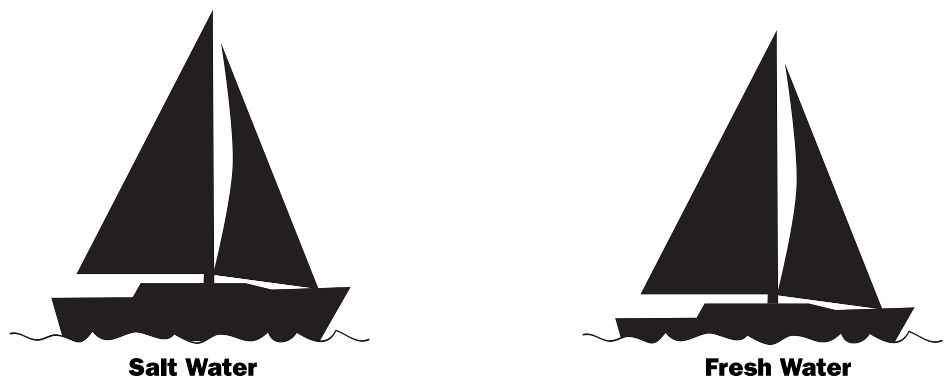



**Figure 2-5.** *An object is more buoyant in salt water than in fresh water.*

war or the air sacs of *Sargassum*, a brown alga common in the Sargasso Sea of the Atlantic Ocean (Fig. 2-6). *Sargassum* occasionally can be found washed ashore along the Southeastern U.S. coast. It can also frequently be found floating offshore in the Gulf Stream and makes up the "weed line" to which offshore fishermen often refer.

Oil floats on the surface of the water and many marine organisms produce an oil that makes them more buoyant. Even fish eggs may contain oil droplets, which enable them to remain at the surface or suspended in the water column. Increased body surface area and other unique adaptations, such as elongate spines and antennae, also retard the rate of sinking.

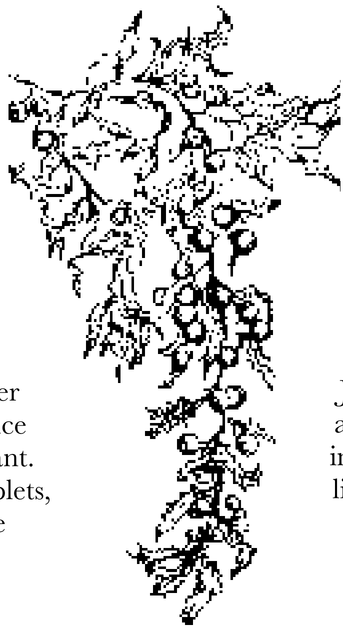


**Figure 2-6.**
Sargassum *is a buoyant brown alga found off the Southeastern U.S. coast.*

bicarbonate ($HCO_3^-$) for production of their protective shells. Other marine animals need oxygen ($O_2$) to breathe, and they give off carbon dioxide ($CO_2$) just as we do here on land. The ocean is the medium through which all of these nutrients and compounds are exchanged from organism to environment and back to organism again.

Just as organisms living on land are dependent on their surroundings for continued support of the life functions basic to survival, such as breathing and obtaining nutrients, so too are the organisms living in the ocean dependent on their surroundings for support of these same basic life functions.

## E. Nutrient Uptake and Gas Exchange

The ocean provides a medium for uptake of nutrients and gases and elimination of wastes for all of the organisms living in it. Plants living in the ocean need "fertilizers," such as nitrate ($NO_3^-$) and phosphate ($PO_4^{2-}$), for continued growth and survival just as terrestrial plants do. Marine plants get nitrate and phosphate from the ocean water that surrounds them. Nitrate and phosphate are two limiting nutrients in the ocean environment, as the amount of primary productivity in various regions of the world oceans is directly related to the availability of each. Marine plants also need carbon dioxide ($CO_2$) to make their own food through the process of photosynthesis (See Chapter 3, Section D). The ocean is also the source of $CO_2$ for these plants.

Still other marine organisms need magnesium ($Mg^{2+}$), calcium ($Ca^{2+}$), silica [$Si(OH)_4$], and

## F. Waves

Wind is a form of energy. Wind energy blowing along the surface of the ocean is transferred to the ocean as waves and currents (also see Section H). Waves originate in the open ocean and, in many cases, the waves we see along the coast were generated far away at sea (Fig. 2-7). The size of a wave depends on 3 factors: (1) the velocity of the wind, (2) the wind's duration, or the length of time the wind blows, and (3) fetch, or the distance of the ocean over which the wind is blowing. The harder the wind blows and the longer it blows, the greater its velocity and duration and the larger the waves. The longer the fetch, the larger the waves that are produced.

Waves can be so small that they are hardly noticeable. One of the largest waves ever recorded was 34 meters high (112 feet)!

Photo by CHERIE PITTILLO

**Figure 2-7.**
*Plunging waves on a beach.*

Earthquakes, submarine landslides, and volcanic eruptions also produce waves by displacing the water, thereby setting it in motion in the form of a wave.

There are different parts of a wave, each of which varies in size as the strength and duration of the wind varies. The highest part of the wave is called the crest and the lowest part of a wave is called the trough (Fig. 2-8). Wave height is the vertical distance between the levels of the trough and crest. Wavelength is the horizontal distance between the crests of two successive waves. Wave period is the length of time it takes a wave to pass a certain point. Wave velocity, or speed, can be calculated by dividing the wavelength by the wave period.

Because a wave is energy passing through water, the water through which the wave moves remains relatively still. The water moves in a circular motion as the wave passes through it. Alternatively, waves can move the water a great deal when they approach shorelines. As a wave approaches the shoreline, the depth of the water becomes shallower. The bottom of the wave is thus slowed down by friction as it begins to "feel" the bottom, but the top of the wave continues to move at its original speed. Also, the wave height increases as the water depth decreases. The wave then "trips," forming a breaker. An estimated 8,000 waves a day hit an average coastal beach. When ocean waves reach coastal shorelines, large amounts of energy are transferred from the wave to the beach and erosion of the land often takes place. Coastal erosion is discussed in more detail in Chapter 5. Nevertheless, waves can also transport and deposit sediment onto the shore, and thus serve to build certain shorelines.

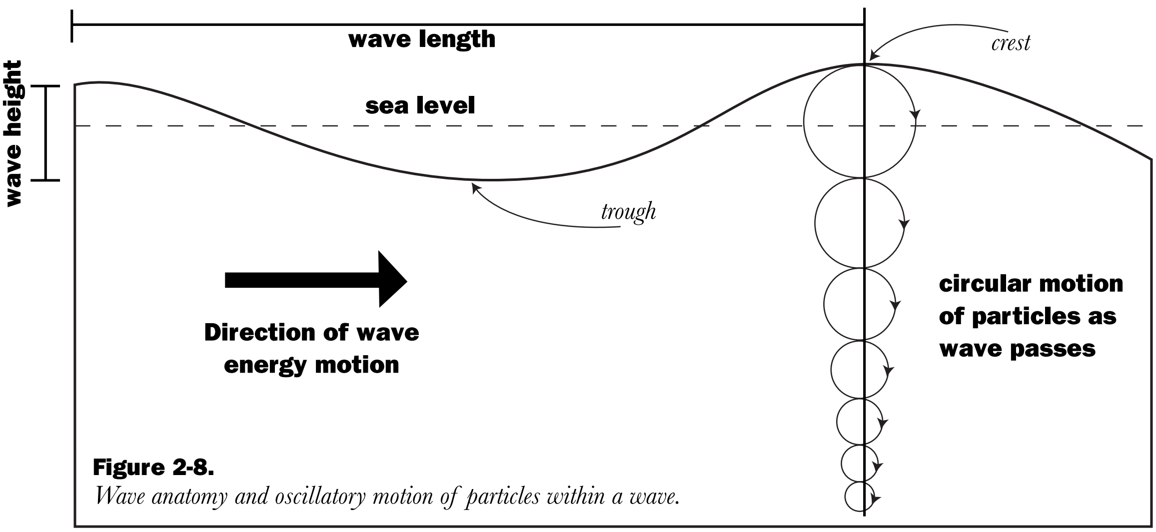
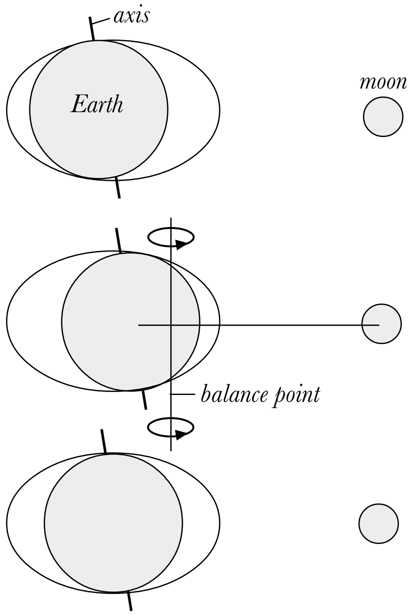



**Figure 2-8.**
*Wave anatomy and oscillatory motion of particles within a wave.*




***a) Effect of gravitational force.***

*The gravitational pull on the earth by the moon causes a tidal bulge on the side of the earth that faces the moon.*

***b) Effect of centrifugal force.***

*The earth-moon system rotates around a "balance point," or axis for the moon's revolution around the earth. Centrifugal force creates a tidal bulge on the side of the earth that faces away from the moon.*

***c) Combined effects of gravitational and centrifugal forces.***

*Two tidal bulges result from the combined influences of gravitational and centrifugal forces.*

**Figure 2-9.**
*Gravitational (a) and centrifugal (b) forces between the earth-moon system contribute to the formation of two tidal bulges (c), one on each side of the moon.*

## G. Tides

Tides, or the periodic rise and fall of the ocean's surface, are caused by the gravitational pull of the moon and the sun on the earth. Because the moon is much closer to the earth than the sun, its gravitational pull on the earth is much greater than that of the sun. The moon's gravitational attraction "pulls" the ocean covering the earth's surface toward the moon, creating a bulge of water at the point on the earth directly facing the moon (Fig. 2-9a). We will refer to this bulge of water as a "tidal bulge."

There is a second tidal bulge on the side of the earth that faces away from the moon. This bulge is the result of the moon's revolution around the earth. Imagine a bowling ball ("earth") and tennis ball ("moon") that are connected by a short rod ("gravitational force"). Because of the mass differences of the balls, the balance point on the rod between them would be located much closer to the bowling ball. This balance point is analogous to the center, or axis, of the moon's revolution around the earth. Thus, as the moon revolves around this axis, centrifugal force causes water in the oceans to bulge on the side of the earth opposite the moon (Fig. 2-9b). If the moon had an ocean, it would also experience tidal bulges. The result of the combined gravitational and centrifugal forces is that there are always two tidal bulges on the earth, and they are always in alignment with the moon (Fig. 2-9c). The earth rotates underneath the bulges and the low-water areas between the bulges, giving the effect of rising and falling water we call tides.

Think of the tide as a large wave with crests on opposite sides of the earth. The wavelength of this large wave is more than 20,000 kilometers (12,600 miles), or one-half the circumference of the earth. As the earth rotates, a single point on it (for example, Charleston, South Carolina) moves underneath each of the two tidal crests (tidal bulges) of the large wave every day (Fig. 2-10). Hence the name semidiurnal (semi = half; diurnal = daily) tides. In other words, as Charleston moves under a tidal crest, it experiences a high tide. Alternatively, when Charleston is located in the troughs between each of these two tidal crests, it experiences low tides semidiurnally, or twice daily.

Tides are referred to in many ways. High tide is sometimes called flood tide. Low tide is referred to as ebb tide, and slack tide is the time just before the tide turns during which there is little tidal water movement. Flood and ebb tides may also be referred to as rising or falling tides, respectively. Tidal levels are also referred to as high or low, in or out, and up and down! A tidal cycle, the complete cycling from one low tide to the next low tide is generally half a day in length. Tidal periods are the times from low tide to high tide, and are generally six hours in length in South Carolina.

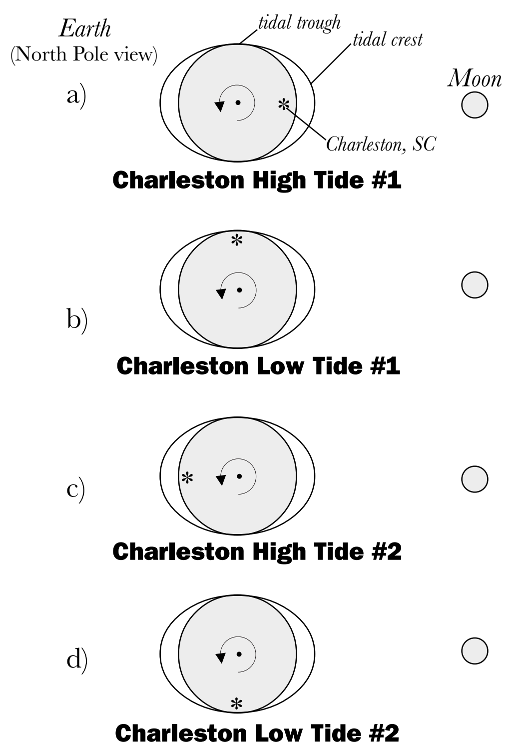



**Figure 2-10.**
*During the day, Charleston, South Carolina rotates on the earth's axis and passes through two tidal crests (high tides) and two tidal troughs (low tides). This occurrence is known as a semidiurnal tide.*

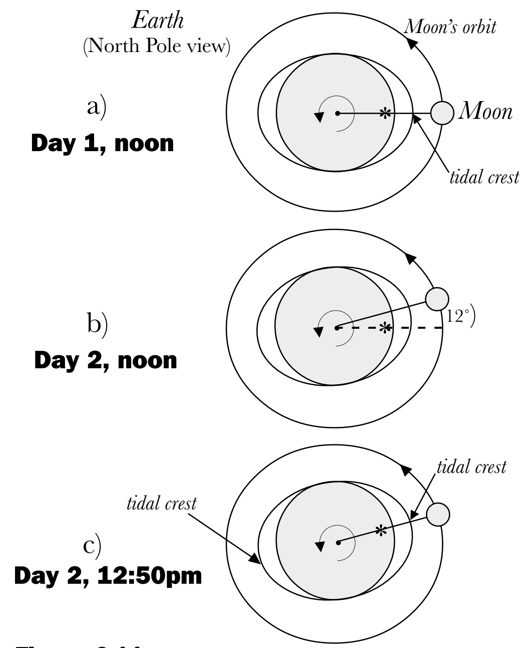



**Figure 2-11.**
*Why is high tide approximately 50 minutes later each day? The moon continually travels in its orbit around the earth. Each day a point on Earth, such as Charleston, South Carolina, has to "catch up" to the position of the tidal bulge that has advanced 12° along the moon's orbit. This catch-up takes approximately 50 minutes, thus delaying high tide.*

High and low tides do not occur at the same time every day. They instead occur approximately 50 minutes later each day. To explain this, let's use the following example. Charleston experiences a high tide at 12:00 noon on Day 1 (Fig. 2-11a). At 12:00 noon on Day 2, high tide has not yet occurred in Charleston and will not occur until 12:50 p.m., almost a full hour later. As you know, earth makes a

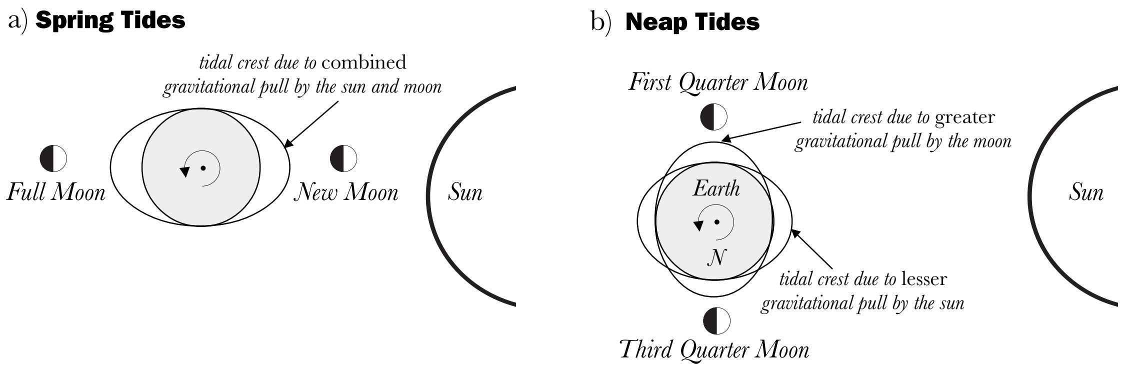



**Figure 2-12.**

*(a) Spring tides are the result of two combined tidal crests from the moon and sun. The effect is to accentuate the difference between high and low tides. (b) Conversely, neap tides are the result of two opposing tidal crests from the moon and sun. The effect is to dampen the difference between high and low tides.*

complete rotation on its axis every 24 hours. During this 24-hour period, the moon advances in its own orbit around the earth by 12° degrees of the orbit (Fig. 2-11b). Correspondingly the tidal crests, which as you will remember, are always in alignment with the moon, also advance with the moon 12° degrees. Thus, at noon on Day 2, Charleston is not underneath the tidal crest which caused the high tide at 12:00 noon on Day 1. The time of the mid-day high tide on Day 2 in Charleston occurs approximately 50 minutes later, as it takes approximately 50 extra minutes for Charleston to "catch up" with the tidal crests (Fig. 2-11c). Remember, since Charleston experiences semidiurnal tides, the amount of time between two successive high tides is only 12 hours and 25 minutes, or half of the 24 hours, 50 minutes.

Tidal range is the vertical difference in the height of the water between high and low tides. Ranges vary worldwide, from less than 30 cm (1 foot) in some places to over 15 meters (50 feet) in the Bay of Fundy, Nova Scotia. When the earth, moon, and sun are in alignment, tidal ranges are greater than average due to the added gravitational pull on the ocean's surface by the sun. These greater than average tidal ranges occur twice a month, during new and full moons, and are called spring tides (Fig. 2-12a). Conversely, when the moon is at a right angle to the sun and earth, the earth experiences neap tides, or smaller than average tidal ranges (Fig. 2-12b). During a neap tide the moon's gravitational pull is at right angles to the sun's lesser gravitational pull. Two tidal crests result and serve to diminish the difference between high and low tides. Neap tides, like spring tides, occur twice a month, during the first and third quarter moons.

Tidal ranges have been classified into three groups: microtidal, mesotidal, and macrotidal. These groupings were originally defined using the measurement unit of feet rather than meters. We refer to tidal ranges between 0 and 6 feet as microtidal; between 6 and 12 feet as mesotidal; and greater than 12 feet as macrotidal.

Along the Southeastern U.S. shoreline, tidal range varies considerably. From Cape Hatteras, N.C. to Bull Bay, South Carolina, spring tidal ranges are microtidal, whereas the range from Bull Bay to Savannah, Georgia is classified as mesotidal. Portions of the Georgia

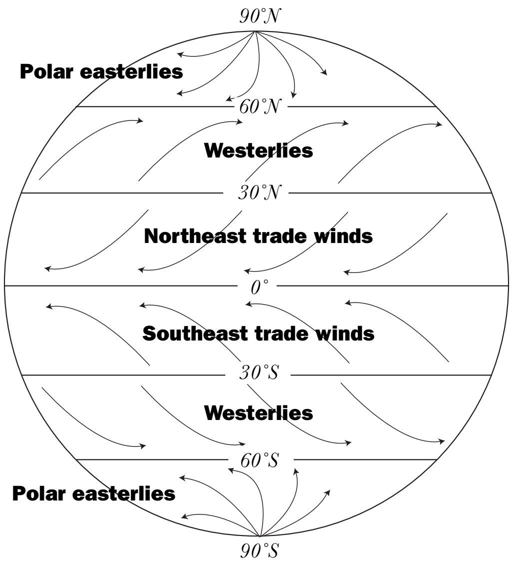



**Figure 2-13.**
*Global wind patterns.*

coastline have tidal ranges of 9 feet and more. The relative influences of waves and tidal currents have a strong control on the shape, or morphology, of the coastline, and will be discussed in Chapter 4.

As you will see in Chapters 3 and 4, organisms living in intertidal areas, or areas that are exposed to air during low tides, have developed special adaptations that enable them to live underwater during high tide, and completely exposed during low tide.

## H. Oceanic Currents

Movement of water along the surface of the open ocean, known as surface current circulation, is primarily caused by wind. Surface currents are slow, broad currents, the effects of which can extend to depths of 200 m (656 feet). Alternatively, density drives deep ocean currents to create thermohaline (temperature- and salinity-driven) circulation. Thermohaline circulation is much slower, and it has been estimated that it would take several hundred years for dense water that sinks in the North Atlantic to surface again in the Southern Hemisphere. Ocean currents, whether wind-driven surface currents or density-driven thermohaline circulation, are major factors determining the distribution of life on earth, as many of the early life history stages of marine organisms are transported far from their points of origin to new locations by ocean currents. Ocean currents also have major effects on weather patterns throughout the world.

### 1. Surface Currents

The major surface currents are driven by three latitudinal bands of winds: 1) the Trade Winds, which blow from east to west at about 20° Latitude (North and South); 2) the Westerlies, which blow from west to east along the 40-50° latitudes; and 3) the Polar Easterlies, which blow from east to west in the polar regions (Fig. 2-13). As ocean surface water is blown by the wind, the water does not move parallel to the wind. Instead, the earth's rotation causes surface waters to be deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. This phenomenon of deflection, or "bending" of currents, is known as the Coriolis effect.

Large circular surface currents, known as gyres, also occur in the open ocean and rotate in a clockwise direction in the Northern Hemisphere and in a counter-clockwise direction in the Southern Hemisphere. The North Atlantic Gyre rotates in a clockwise direction in the Atlantic Ocean (Fig. 2-14).

Each surface current has its own unique temperature, salinity, density, directional flow, speed, and well-defined boundaries between adjacent currents. The Gulf Stream off the Southeastern coast of the U.S. is one of the most well-known and well-studied surface currents. In fact, Benjamin Franklin mapped the Gulf Stream, an incident that is often cited

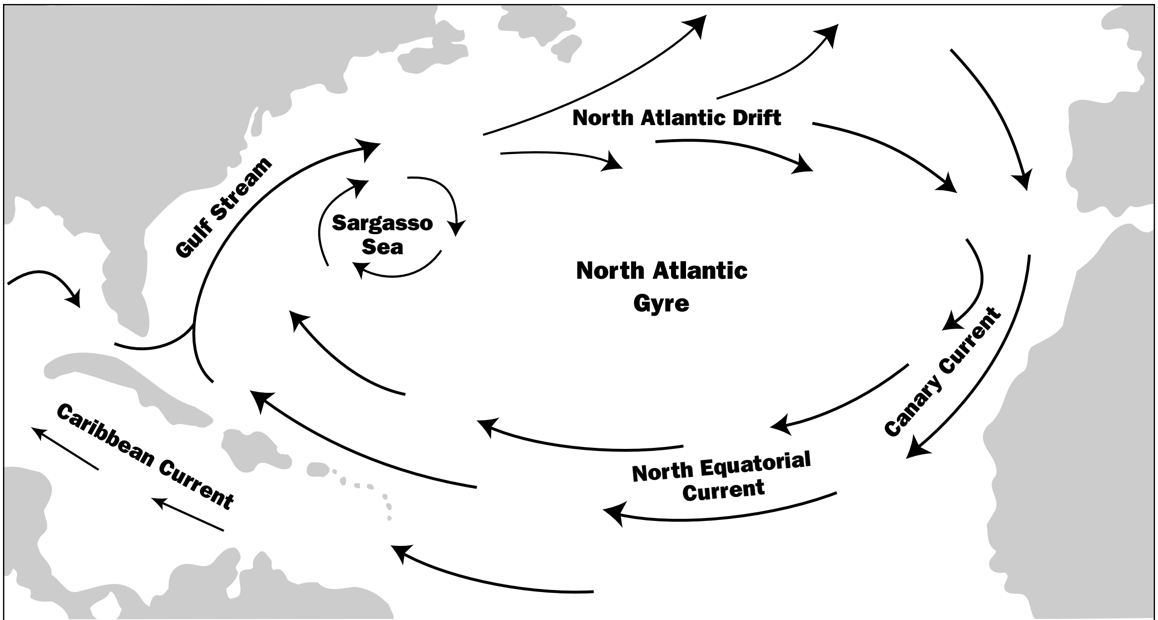



**Figure 2-14.** *North Atlantic surface currents.*

as the beginning of ocean science studies in the United States. The width of the Gulf Stream varies from 80 to 241 kilometers (50 to 150 miles) and its depth varies from 456 meters to 1,523 meters (1,500 to 5,000 feet). The Gulf Stream flows at a speed of 4.8 kilometers to 9.7 kilometers (3 to 6 miles) per hour, transporting 63.5 million metric tons (70 million tons) of water every second. The Gulf Stream is actually the western segment of the North Atlantic Gyre (Fig. 2-14). Along its northward journey, the Gulf Stream often weaves back and forth in s-shaped curves. These curves are referred to as meanders. Sometimes these meanders are so pronounced that they “pinch off” from the main current and depart as small rings of the Gulf Stream, known as eddies.

As the Gulf Stream flows northward along the Eastern Atlantic coast, it comes within 40 kilometers (24 miles) of portions of the Southeastern U.S. coast, carrying warm tropical waters with it. Beautiful, brightly colored tropical species of plants and animals that have been transported northward from the Caribbean are frequently found living far north of their original habitat. As the Gulf Stream moves northward along the East coast of the United States, the Coriolis effect causes it to be deflected toward the east where it crosses the Atlantic. At this point, the Gulf Stream becomes the North Atlantic Drift Current (Fig. 2-14). Because the North Atlantic Drift Current contains warm Gulf Stream water, it warms the British Isles.

### 2. Thermohaline Circulation

Thermohaline circulation is caused by the vertical movement of water as a result of temperature and salinity differences. Thermohaline circulation is the major factor driving deep ocean current patterns. As we discussed at the beginning of this chapter, cold dense water masses will sink below layers of ocean water. This phenomenon of "sinking" water layers, or downwelling, drives thermohaline circulation in the deep ocean. It is the combination of salinity and temperature of a particular water mass that determines its vertical position, or the depth to which it "sinks," in the water column. This sinking of cold, dense water masses must be balanced by rising water masses elsewhere.

Upwelling is the mechanism by which deep ocean waters rise toward the surface. Upwelling in the open ocean is in part driven by thermohaline circulation which displaces and "pushes" bottom waters upward as the denser water masses sink to the bottom. The upwelled bottom waters are rich with nutrients that have accumulated from the constant rain of recycled material to the sea floor. These nutrients enter the photic zone and microscopic plant life flourishes, providing food for a vast number of animals living in surface waters.

Thermohaline circulation in the Atlantic Ocean results in the formation of two distinct deep ocean water mass currents: the North Atlantic Deep Water (NADW) and the denser Antarctic Bottom Water (AABW). These two currents are formed by very cold, salty water and originate at the poles. The AABW sinks near the coast of Antarctica and travels northward (Fig. 2-15), hugging the seafloor. The NADW sinks in the Arctic and travels southward where it eventually meets the AABW. Because the AABW is the denser of the two water masses it moves underneath the NADW. The NADW continues to travel southward, but it "rides" over the AABW and a portion of the water mass eventually upwells in the Antarctic Ocean where it joins the surface current circulation. The other portion veers to the east and continues its trek into the Indian and Pacific Oceans.

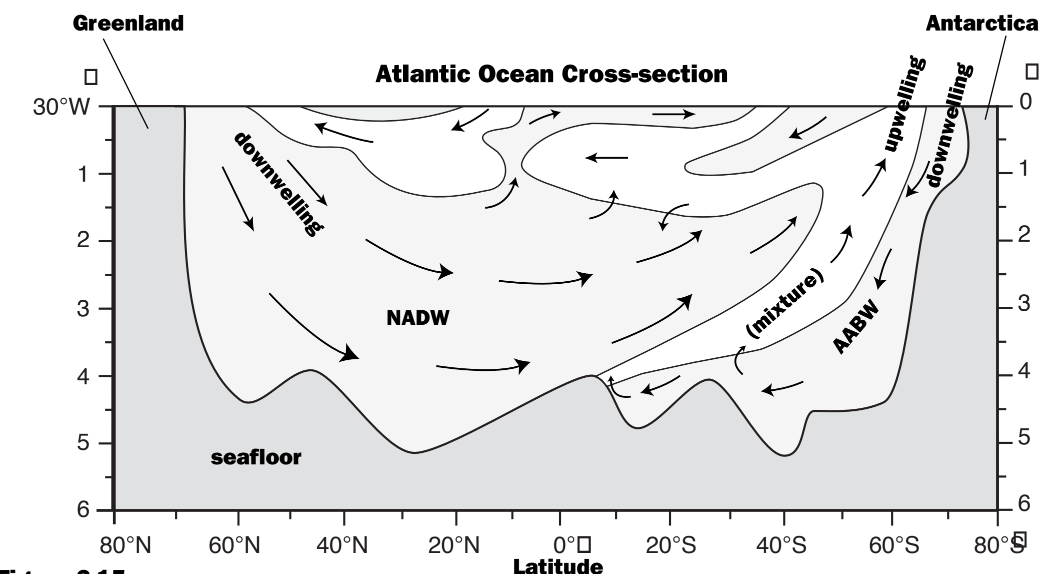



**Figure 2-15.**
*Simplified drawing of density–driven, thermohaline circulation of the North Atlantic Deep Water (NADW) and the denser Antarctic Bottom Water (AABW).*

CHAPTER III

# MARINE ECOLOGY

Previous chapters have introduced physical and chemical properties of the ocean environment–salinity, temperature, buoyancy, density, and tidal effect, to name a few. These physical and chemical properties are delicately and intricately interwoven to produce a wonderful variety of places in the ocean that are capable of supporting life. As you will see in this chapter, each organism has its own particular place in the ocean in which it obtains food, finds shelter, protects itself from potential predators, and successfully reproduces, thereby ensuring continuation of the species.

Because there are so many unique areas in the ocean that are capable of supporting life, amazingly diverse assemblages of marine organisms have become uniquely adapted to life in these areas. These organisms have done so by developing some of the most bizarre shapes, feeding structures, means of locomotion, defense mechanisms, and methods of reproduction known to humans. In this chapter you will be introduced to several unique places in the ocean, and to the strange and wonderful organisms living there.

## A. Environment

A population is a group of organisms of the same species living in a defined area. A community is all of the organisms, or all of the species, found inhabiting a defined area or environment. An environment is, in turn, defined as the external surroundings and conditions that affect the growth and development of an organism. The marine environment includes the properties of ocean water such as clarity, buoyancy, concentrations of nutrients, salinity, temperature, and density. Currents, waves, tides, availability of food, interactions among individuals, populations, and communities, and the type of ocean floor are also components of the marine environment. The environments in a defined area, as well as the communities found living in that area, are called an ecosystem.

The environment on land changes daily. One day may be sunny and pleasantly warm while the next day may be cold and rainy. Seasonal and interannual changes also occur. Marine environments are continuously changing too. For example, the salinity changes slightly from day to day, depending on the rate of evaporation and/or the amount of precipitation. The amount of cloud cover affects the depth to which sunlight penetrates. The amount of sunlight affects the rate at which tiny plants photosynthesize, produce oxygen ($O_2$), and grow. The amount of sunlight, and hence, the rate at which photosynthesis occurs in the ocean, ultimately affects the availability of food to other organisms. Additionally, currents may vary in their speed and position in the water column and tides on any one day may be extremely high or low, depending on the alignment of the earth, moon, and sun. A calm ocean surface may become a frightening sea within a very short time, depending on the speed, duration, and fetch of the wind.

Although the marine environment is always changing, the ocean is a very delicately balanced and fragile environment. We are continually altering this delicate balance by the activities of our daily lives. Pollution from stormwater runoff, heavy use of pesticides, automobile exhausts, coastal development, marine debris, oil spills, and over-utilization of ocean resources are all factors that tip the ocean environment's delicate balance to the "minus" side. Only recently have we recognized that our actions have affected the ocean environment–and in many cases, this effect has been negative. We have yet to determine and understand the full impact of our actions. We will discuss how we have altered the delicate balance of the ocean environment in more detail in Chapter 6.

## B. Habitat

A habitat is the physical place where an organism or group of organisms lives. Oceanic habitats can be divided into two categories:

- pelagic habitats, and
- benthic habitats.

These habitats can each be further subdivided into smaller categories based on distance from shore, tidal exposure, and clarity, much like the zones of the ocean defined in Chapter 1.

### 1. Pelagic Habitats

The pelagic habitat is the water column that extends from the surface to the bottom. Pelagic habitats located far from coastlines do not receive large amounts of nutrients from coastal areas and rivers and their productivity is, therefore, not as high as that of coastal habitats. Nevertheless, pelagic habitats everywhere support a wonderful diversity of organisms. Organisms living in pelagic habitats can be classified into one of two categories: plankton or nekton.

Planktonic organisms are those organisms found at or near the ocean's surface. The word plankton is derived form the Greek word, planktos, which means "to wander." Many planktonic organisms are transparent, which makes it easier for these organisms to survive in the brightly-lit surface waters. Perhaps this explains why plankton, as an entire group of organisms, was only recently discovered in the early 1800s, even though scientists had been using the microscope for over 100 years. Additionally, many planktonic organisms have bizarre structures that help them remain afloat at the surface. These structures include extremely elongate antennae and spines that retard the rate of sinking in the water.

Organisms living in planktonic habitats are generally divided into two groups: phytoplankton and zooplankton. Phytoplankton are tiny plants that float, or wander, at the mercy of currents. Zooplankton are tiny animals that cannot significantly alter their position in the water column and thus, like phytoplankton, they are primarily transported by ocean currents.

Phytoplankton are primarily unicellular plants such as diatoms and dinoflagellates. Phytoplankton are sources of food for many marine organisms. Many organisms are thus dependent on phytoplankton for survival. Phytoplankton photosynthesize and, in doing so, produce over 80% of the oxygen on earth. All life in the ocean is, therefore, dependent on phytoplankton through a complex linking of feeding levels. We will discuss how phytoplankton form the basis of the food web in Section D.

Phytoplankton will, in many cases, give a body of water its characteristic color. Areas of the ocean may appear various shades of blue-green to green from the chlorophyll and other pigments present in the phytoplankton living there. "Red tides" get their name from dinoflagellates that may impart a reddish color to the water whenever there is a bloom, or rapid increase in abundance, of these organisms. In the absence of large amounts of phytoplankton, as is often the case in tropical seas, the water is crystal clear.

Zooplankton consist primarily of single-celled protozoans (Fig. 3-1) and the multicellular

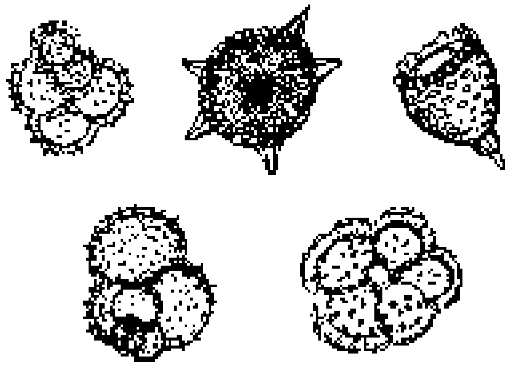


**Figure 3-1.**
*Plankton forms of Foraminifera and Radiolaria. These single-celled zooplankton are <0.5 mm in size and live in pelagic habitats.*

larval stages of many marine organisms. A larval stage is the form an organism takes when it hatches from the egg. Shrimp, crabs, and fish, as well as fish eggs, copepods, and arrow worms all have planktonic larval stages and are major components of zooplankton. Although most members of zooplankton have some means of movement, they cannot significantly alter their horizontal position at the surface, and thus, are transported with the currents. Many members of the zooplankton are transitory, as they only exist as zooplankton for a short period of their lives. These organisms are called meroplankton. As they continue to grow and metamorphose , or change in form, they develop into juvenile stages. As juveniles they settle out of the plankton and take up existence in the water column or on the ocean floor. They then continue their transformation into the adult stage. Still other forms of zooplankton spend their entire lives in the planktonic environment, such as copepods and euphausids, and make up a group of organisms known as holoplankton.

There are other planktonic marine animals and plants that, although they may be relatively large, cannot significantly alter their physical place in the water column and remain at the mercy of surface currents. Examples of these organisms are the Portuguese Man-o-War, comb jellies, jellyfish, and Sargassum, the floating brown alga found off the Southeastern U.S. coast (Fig. 2-6). Even the giant ocean sunfish, *Mola mola*, which can reach 3 meters (10 feet) in length, was once considered a planktonic organism, as it spends much of its time splashing around at the surface.

Nektonic organisms are generally fast, strong swimmers. Bullet-shaped bodies enable them to move rapidly with the least amount of resistance to the water which surrounds them. Tunas, some sharks, dolphins, swordfish, and mackerel are very rapid swimmers. Squid jet-propel themselves through the pelagic habitat. Additionally, many nektonic organisms have developed unique ways by which they remain suspended in the water column. Swim bladders and oily livers enable some fishes to remain afloat.

Some nektonic organisms migrate with seasonal changes. Some sharks off the Southeastern U.S. coast, for example, move farther south during winter and move back along the coast during the warmer months. Swordfish and tuna that occur off the Southeastern U.S. have extensive migratory routes, spending large amounts of time in the Gulf of Mexico. Whales also have extensive migration patterns, moving in the Pacific from Alaska to Hawaii and in the Atlantic from the Caribbean Sea to Canada.

**2. Benthic Habitats**

Organisms living in benthic habitats are divided into two categories: 1) epifaunal organisms, which are animals living on the surface of the ocean floor; and 2) infaunal organisms, which are organisms living within the sediment of the ocean floor (Fig. 3-2).

**Figure 3-2.** *Live bottom community with infaunal/epifaunal organisims.*

Epifaunal organisms can be mobile, either crawling on or swimming just above the ocean floor, or they may be sessile, or permanently attached to the ocean floor. Sea stars, crabs, whelks, and octopuses are examples of epifaunal marine organisms. Clams and worms are examples of infaunal organisms.

Organisms that live most of their lives attached to the ocean floor need a hard substrate to which they can affix themselves. Off the Southeastern U.S. coast, rocky outcrops that are exposed on a sandy bottom provide the perfect hard substrate to which marine organisms can attach. These sessile marine plants, called epibenthic flora, are limited in their distribution to those areas of the ocean floor that are shallow enough to receive sunlight from above. Although we primarily think of marine plants when discussing benthic marine organisms, there are many animals that attach to the ocean floor during certain life cycle stages. These animals include sponges, soft and hard corals, and the asexual stage of jellyfish. Although some organisms swim above the ocean floor, they spend most of their time at the bottom and are defined as benthic organisms. These organisms include many bottom fishes, such as snappers, flounders, groupers, and porgies.

As mentioned above, infaunal organisms are those organisms that live within the ocean sediments, such as worms and clams. Infaunal organisms generally live in tubes or burrows that they create. These tubes can be quite elaborate, constructed of different types and sizes of sand grains and shell material. Some of these tube-building organisms use mucous to "cement" grains of sand together. Burrows also may be very extensive, with multiple chambers branching off from the main burrow.

Discovery of hydrothermal vents located in the benthic zone of the deep ocean has revealed that quite bizarre organisms have adapted to survival in these abyssal areas where no light exists. Giant red tube worms, some of which reach a height of 2 meters (8 feet) thrive in these heated deep benthic habitats. Blind shrimp also occur near these hydrothermal vents. Bacteria carry out chemosynthesis, a process that uses hydrogen sulfide ($H_2S$) released from hydrothermal vents as a source of energy for the production of food. Bacteria use hydrothermal gases to produce their food much like plants use energy from the sun to produce food through photosynthesis. Bacteria are thus, the primary producers in areas where hydrothermal vents occur. They serve as a food source for other organisms in these areas of the deep sea.

Hydrothermal vents were first discovered in 1977 in the Pacific Ocean near the Galapagos Islands. Scientists now believe that these vents are located in all of the major ocean basins along the mid-oceanic ridges, where they form large geyser fields. These geyser fields have recently been discovered in the Atlantic Ocean, along the Mid-Atlantic Ridge approximately 2,896 kilometers (1,800 miles) off the coast of Miami at depths of 4 kilometers (2.5 miles).

Benthic organisms that cannot actively catch or make their own food are dependent on plant or animal material that is produced in the surface waters and falls to the sea floor. This decaying organic fall-out rains down through the water column to the ocean floor and supplies an abundance of food to many benthic marine organisms. Many of these benthic organisms are filter feeders, filtering their food out of the water column with specialized body parts. Some benthic organisms living in the deep ocean have developed interesting features that allow them to feed, grow, locate mates, and successfully reproduce in total darkness.

There are a variety of other marine habitats found along coastlines. These include rocky shorelines and their associated tidal pools, eel grass and turtle grass habitats, mangroves, and coral reefs. Habitats found along the Southeastern U.S. coast include estuaries, bays, sounds, salt marshes, beaches, dunes, maritime forests, inlets, tidal creeks, fouling communities on piers and docks, rocky intertidal habitats, grass beds, and mangroves.

### C. Niche

A niche is defined as all of the physical and chemical factors affecting an organism's habitat, as well as the role that the organism plays in its habitat. The diversity and abundance of marine niches is always changing, as organisms continue to adapt and evolve to very specialized niches to ensure survival of their species. Those that cannot adapt vacate the niche. Subsequently, their space in the niche which will be taken up by a better adapted and thus, more successful, organism. This process by which one organism excludes another from a niche is known as competitive exclusion, as two organisms cannot successfully occupy the same niche.

Examine for a moment the niche of a larval fish. This niche consists of the temperature, salinity, amount of sunlight and nutrients, and the speed of the current in which the larval fish is being transported, as well as many other physical and chemical factors that come into play to affect its planktonic habitat. The larval fish's niche also consists of its prey as well as the potential predators that may feed upon the larval fish itself. The role that the larval fish plays in the plankton includes the amount of food it eats, the by-products of its metabolism, the physical space that it requires, the amount of oxygen it uses, and the impact it may have on the abundance and diversity of a certain copepod upon which it feeds. All of these complex interactions among physical and biological factors, as well as the role that the larval fish plays in its habitat, makes up its niche.

### D. Trophic Level

Marine organisms are dependent upon their environment for food. Marine plants make their own food through photosynthesis. Photosynthesis is the process by which plants use energy from the sun to transform carbon dioxide ($CO_2$), water ($H_2O$), and nutrients, such as nitrate ($NO_3^-$) and phosphate ($PO_4^{2-}$), into a form of food and energy (i.e., sugars) that they can use. They also produce oxygen ($O_2$) as a by-product of photosynthesis. The basic equation for photosynthesis follows :

In the presence of sunlight and chlorophyll:

$CO_2 + H_2O = \text{Sugar} + O_2$

Plants are called producers, since they produce their own food. Areas of the ocean that have large amounts of phytoplankton are referred to as areas of high primary productivity, or areas where the rate of photosynthesis is relatively high. Although other marine plants, such as algae, contribute to an area's primary productivity, phytoplankton carry out most of the primary productivity that takes place in the ocean.

Other marine animals cannot make their own food and are dependent upon plants and/or other animals as a food source. These animals are called consumers. Consumers must either actively catch their prey or scavenge on the dead, decaying plant and animal matter as it slowly drifts down and comes to rest on the ocean floor. Primary consumers, such as zooplankton, feed directly upon phytoplankton. Secondary consumers are those organisms that feed on zooplankton, such as the filter-feeding soft corals and bivalves. Organisms that feed on filter-feeders, as well as other organisms in the ocean, are also secondary consumers. Organisms at the top "level" of feeding, or those organisms upon which few, if any, other organisms prey, are called top-level consumers. They are the ultimate predators.

Consumers can be further divided into three categories: herbivores, carnivores, and detritivores. Consumers feeding only on plant material are called herbivores. Consumers feeding only on animal material are called carnivores.

As plants and animals die, they are broken down by bacteria into a material known as detritus. Bacteria and other organisms that feed on dead and decaying plant and animal matter are called detritivores.

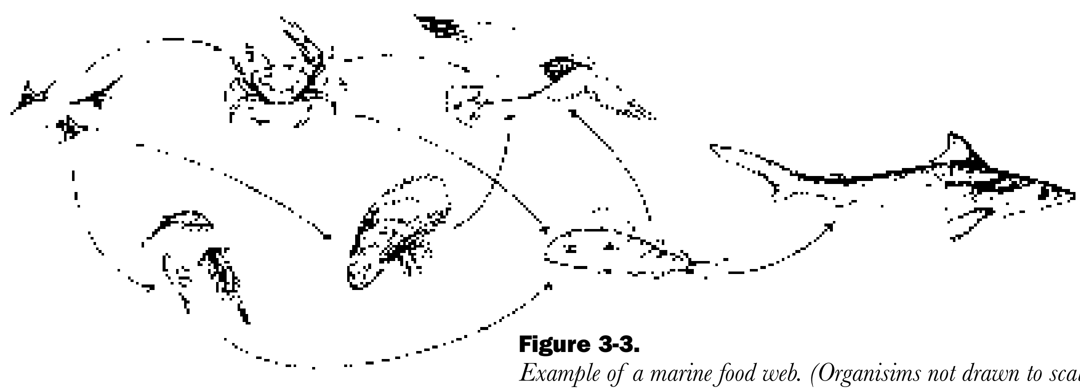


**Figure 3-3.**
*Example of a marine food web. (Organisims not drawn to scale).*

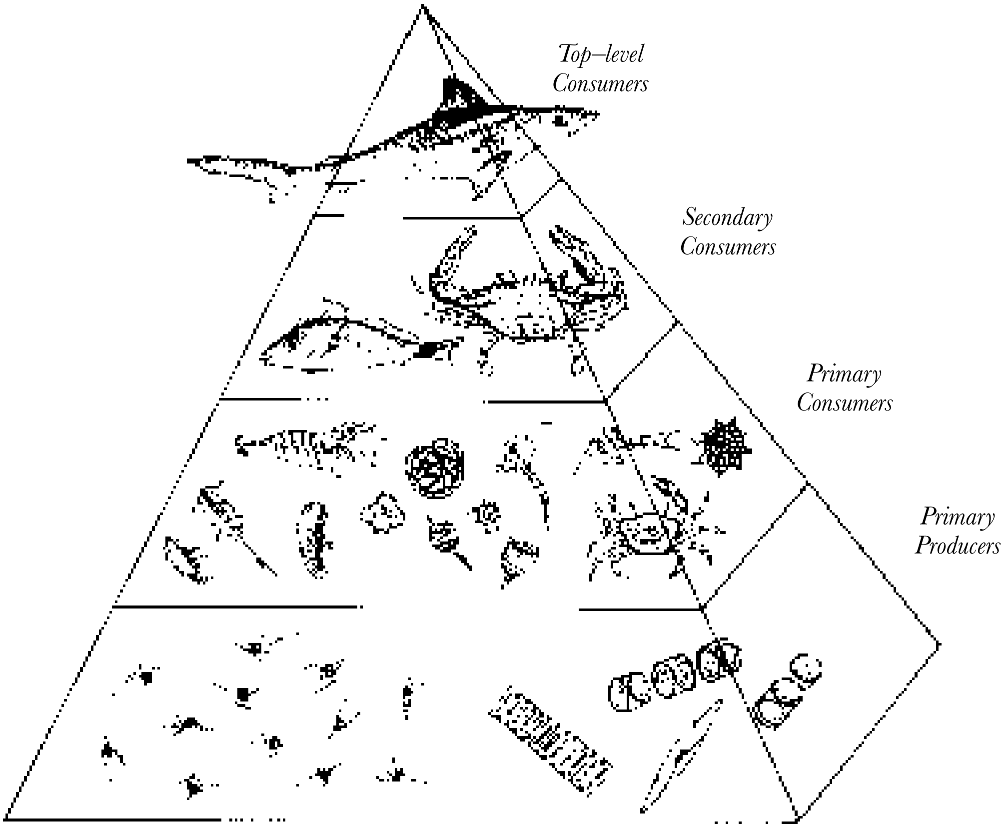



**Figure 3-4.**
*Example of a marine trophic pyramid. (Organisms not drawn to scale).*

As consumers eat producers, energy is obtained from the food as it passes up the different "levels" of feeding, or trophic levels. This transfer of food and energy from one level to another is defined as a food web (Fig. 3-3). The intricate feeding relationships that exist among marine producers, primary consumers, secondary consumers, and detritivores make up the marine food web, sometimes referred to as a "food chain." The word "chain" indicates a straight linking of trophic levels where, for example a diatom is eaten by a copepod that is then eaten by a small fish. Most marine food webs overlap in a complicated network, hence the more appropriate term, "food web."

Bacteria aid in the decomposition of top level predators and recycle nutrients that once again become available to phytoplankton. Perhaps a more appropriate term to describe transfer of food and energy among the different trophic levels would be "trophic cycle."

Trophic levels are often depicted as pyramids, with producers located at the bottom of the pyramid and high level consumers located at the top (Fig. 3-4). The amount of food energy passed up the pyramid decreases with each higher level. There are, therefore, considerably more producers at the bottom of the pyramid than there are consumers, since more food energy is available at the lower levels. Alternatively, since higher trophic levels are limited in the number of organisms supported, fewer consumers are located at the top of the pyramid. The pyramid structure is thus used to illustrate trophic levels because it represents the relative number of organisms that can be supported at each level.

## E. Adaptations

An adaptation is a genetically-controlled characteristic that aids an organism in surviving and reproducing in its environment. All marine organisms have special structures, or adaptations, that enable them to survive in their environments. For example, fishes have many body shapes and sizes and move in many different ways. Some are rapid swimmers, while others walk, burrow, leap, or even fly for short distances.

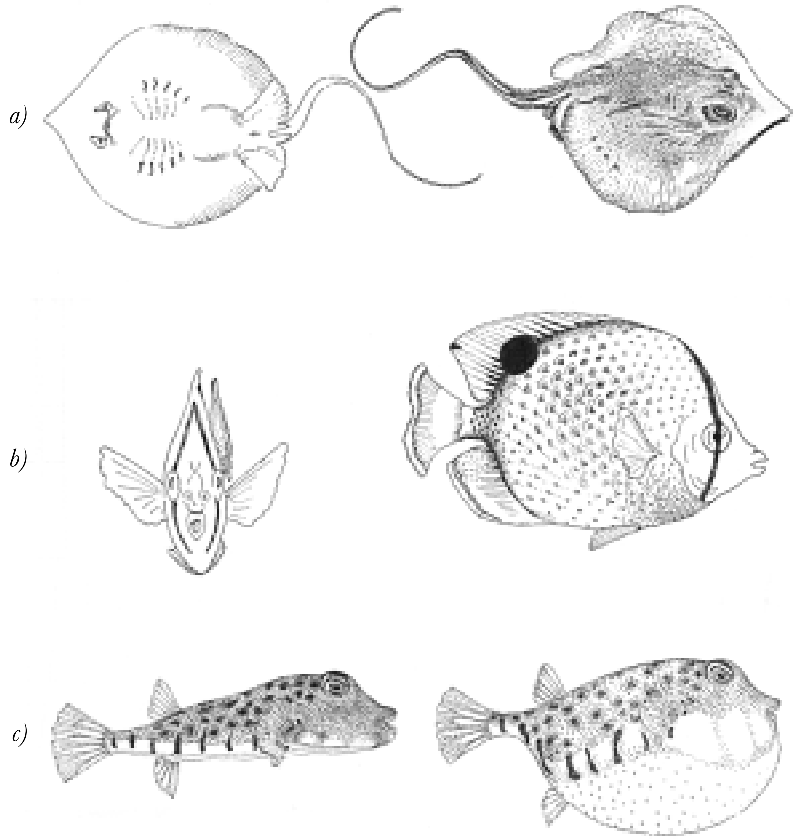



**Figure 3-5.**
*Examples of different fish body forms among a) a stingray; b) a butterfly fish; and c) a puffer fish.*

Because of the wide diversity of habitats in the ocean, we see amazing degrees of adaptations in body form and function among marine organisms. A wide range in body forms and swimming behaviors can be seen among fishes when one compares body shapes of puffers, butterfly fishes, stingrays (Fig. 3-5), eels, and flounders. Sizes, shapes, and locations of mouth parts of marine organisms are also adaptations that have enabled these organisms to expand into a wide diversity of oceanic habitats. In fact, the location, shape, and size of mouth parts can tell you quite a bit about where a particular organism lives and what it eats.

Some fishes have air bladders, or swim bladders, that function like internal balloons that can either "blow up" or reduce in size to enable the fish to move correspondingly up and down in its pelagic habitat. Some sharks have very large, oily livers that help them remain suspended in the water. Still other organisms, like the whales, dolphins, and porpoises, have large amounts of body fat, or blubber, that help prevent them from sinking.

Many pelagic organisms have developed fusiform bodies–torpedo-shaped and streamlined–that enable them to move rapidly with the least amount of resistance to the water which surrounds them. Tunas, some sharks, dolphins, swordfish, and mackerel are all very rapid swimmers. Squids can jet-propel their streamlined bodies through their pelagic habitats.

Marine organisms have developed very interesting ways to protect themselves from predators. Some pelagic organisms have developed special coloration, known as counter-shading, that affords them protection from potential predators. Counter-shading is discussed in more detail in Section 4-d. Other marine organisms have specialized body coverings, such as spines or poisonous mucous, that help them avoid predators. The puffer fish can rapidly change from a small round shape to a very large round ball to avoid being eaten by predators. Squids and octopuses produce ink to startle a predator as they escape to safer waters. Protective coloration, spines, the ability to change body shape, and ink production are just a few of the ways that these organisms successfully protect themselves.

We also see a fantastic diversity in modes of reproduction, degrees of parental care, and development of young. Some marine organisms simply release eggs and sperm into the water, also known as spawning, without exhibiting any means of parental care. Others lay eggs in nests and may even carry their eggs and young in their mouths. Still other marine organisms exhibit internal fertilization and bear their young alive.

There is also a wide range of developmental stages seen among the young of many marine organisms. Most marine animals that hatch from eggs go through various developmental stages, or changes in body form, called metamorphosis, as discussed in Section B-1. Most early metamorphic stages of marine animals not only look amazingly different from the adults, but they may also look quite bizarre. The young of the marine animals that bear live young have offspring that look very similar to the adults.

Let's look at how different marine animals have adapted to their environments in their own ways. To do this, we'll look specifically at how four different animals–a sea star, a clam, a crab, and a fish–have developed unique adaptations in body form, feeding, locomotion, protection, reproduction, development of young, and parental care.

### *1. The Sea Star*

#### *a. Body Form*

The sea star is a benthic organism that crawls on the ocean floor (Fig. 3-6). The body of the sea star exhibits pentamerous symmetry in the form of a flattened, central disk from which

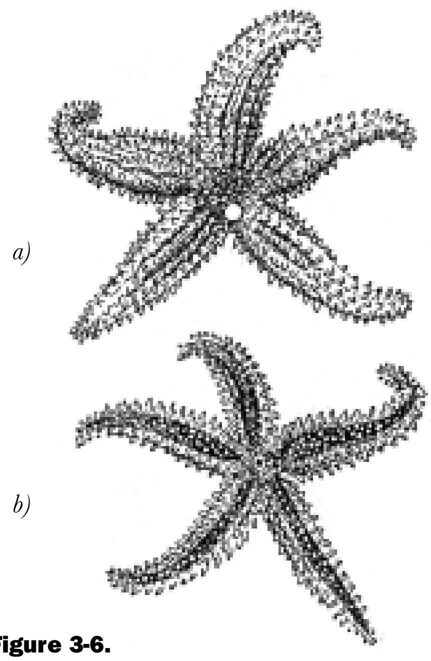



**Figure 3-6.**
*Sea stars: a) dorsal view; b) ventral view.*

five or more arms radiate. The sea star's arms are used in feeding and locomotion. One eye spot is located at the tip of each arm. These eye spots can only detect light and dark and do not function as true "eyes." The sea star's mouth is located in the center of its undersurface, or ventral surface.

#### *b. Locomotion*

A single large pore, called the madreporite is located on the top or dorsal surface of the central disk and allows ocean water to enter a specialized system that aids the sea star in locomotion and obtaining its food. This system is called the water vascular system. Water is drawn in through the madreporite and is channeled through the body via a series of canals. As water is pumped into the water vascular system, the tube feet are extended outward. As water moves back into channels from the tube feet, each tube foot is retracted, creating a suction against the ocean floor. The sea star pulls itself along the ocean floor by continually extending and contracting its hundreds of tiny tube feet. The water vascular system is also used in feeding, as it creates the suction that pulls the shells of bivalves apart.

#### *c. Feeding*

The sea star feeds primarily on clams, scallops, and mussels and has a most unusual way of obtaining its food. The sea star crawls on top of a clam, with its mouth positioned above the point where the shell opens, just opposite the clam's hinge. Special suction cup feet, or tube feet, line its ventral surface. The sea star uses its tube feet to exert a continuous force that eventually pulls the two shells of the clam apart. When the clam's muscles tire from the constant force exerted by the sea star's tube feet, its shell opens. The sea star extends its stomach out of its mouth and into the partially opened shell of the clam. It then digests the clam while the clam remains in its own shell!

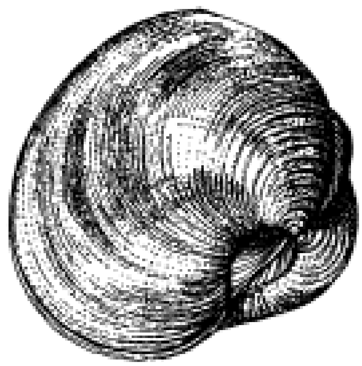


**Figure 3-7.**
*Clam, showing hinge.*

#### *d. Protection*

Although the sea star does not have very obvious ways to protect itself from predators, its exoskeleton, or "outside skeleton", is firm and covered with tiny spines, which afford some degree of protection to the sea star.

#### *e. Reproduction, Development of Young, and Parental Care*

The sea star releases either eggs or sperm into the surrounding waters. Fertilization occurs in the water and sea star larvae go through various metamorphic stages as they float in the plankton. A few species of sea stars brood, or incubate, their young. The young sea stars, whether planktonic or brooded, transform into small adult sea stars and take residence on the ocean floor.

### *2. The Clam*

#### *a. Body Form*

The clam is an infaunal organism, as it burrows in soft mud or sand. The clam has a soft body that is attached to two shells, or valves, hence the name bivalve (Fig. 3-7). The valves are hinged together, and two very strong muscles enable the clam to open and close its shell. Clams have incurrent and excurrent siphons that protrude to the surface of the sediment. The incurrent siphon brings water into the clam's shell. The water, once filtered, exits the clam's body through the excurrent siphon.

#### b. Locomotion

The clam has a large muscular foot inside of its shell. The clam enlarges its foot by engorging it with blood. The muscular foot extends out of the animal's shell and "anchors" itself in the mud or sand. As the foot remains anchored, the clam pulls itself toward its anchored foot. This action is repeated over and over as the clam moves through the sediment.

#### c. Feeding

The clam is a filter feeder. It has gills that are not only used for respiration, but also function in feeding. As water is filtered in through the incurrent siphon, it passes over the clam's gills. Food particles present in the water are selected out of the water by the clam's gills and are then passed to the clam's mouth.

#### d. Protection

The clam's hard shell protects its soft body from most predators. As we have seen, the clam's hard shell is no contest for the sea star or for that matter, other animals that feed on whole clams, such as large fishes.

#### e. Reproduction, Development of Young, and Parental Care

The female and male clams release, or spawn, either eggs or sperm into the water column. Fertilization occurs and the small clam larva goes through various metamorphic stages as it floats in the plankton. The clam larva then develops a very thin shell and looks very much like a small clam. It then settles to the bottom of the ocean. Clams do not exhibit parental care.

### 3. The Crab

#### a. Body Form

Crabs are epifaunal benthic organisms that walk along the bottom of the ocean (Fig. 3-8). Many crabs live in burrows. The crab has a hard exoskeleton underneath which its soft body parts lie. Its body is somewhat flattened with five paired legs located on either side of the crab's body. Each of the paired legs functions in a different way and may actually look quite different from other pairs of legs, enabling the crab to walk, swim, or obtain its food. Some crabs walk, while others primarily swim. A crab's mouth is located in front of its face and is surrounded by many paired feeding structures. Two stalked eyes rest on either side of paired antennae. Most crabs must molt, or shed their exoskeleton, to grow.

#### b. Locomotion

Crabs have specialized legs for walking and/or swimming. A crab's walking legs are usually pointed, and narrow. Its swimming legs are flattened, paddle-shaped structures that gracefully propel the crab through the water. The scientific name of the blue crab that commonly occurs off the Mid-Atlantic and Southeastern U.S. coast is *Callinectes sapidus*, which is Latin for "beautiful swimmer." Most species of crabs, however, are not capable of swimming.

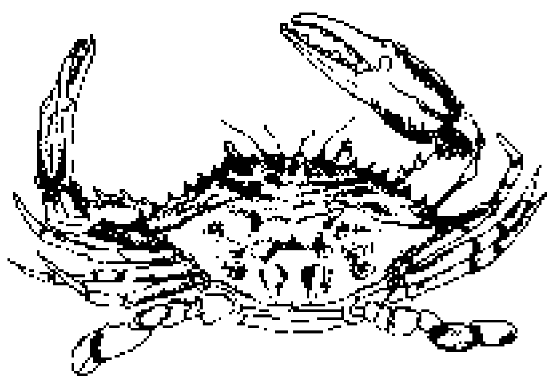


**Figure 3-8.** *A blue crab, dorsal view.*

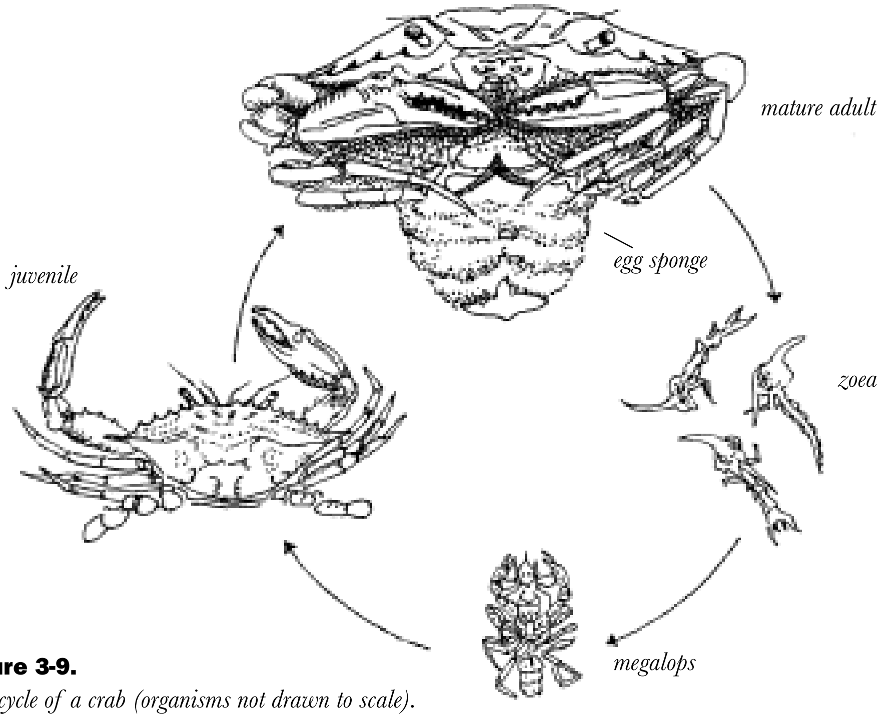



**Figure 3-9.**
*Life cycle of a crab (organisms not drawn to scale).*

#### *c. Feeding*

A crab uses its first pair of legs, which are modified as pincers, to capture food items or scavenge upon dead matter. Food is torn or picked apart and brought to the mouth where it is macerated by the many paired feeding structures that surround the crab's mouth. The next time you eat boiled crabs for dinner, check out the many paired feeding structures. You will certainly be amazed!

#### *d. Protection*

A crab's most anterior paired legs are large pincers that help keep predators at bay. Additionally, there may be sharp spines along the top and/or sides of the crab's body. A crab's hard exoskeleton also protects it from potential predators. Some crabs exhibit protective coloration and blend in with their surroundings. The decorator crab will actually decorate its body with sponges or seaweed to camouflage itself. Hermit crabs use abandoned shells as a means of protection.

#### *e. Reproduction, Development of Young, and Parental Care*

The female crab produces eggs. The male crab produces packets of sperm which are transferred to the female during mating, which in many species, only occurs when the female molts, or sheds, its shell (soft shell). A fertilized egg mass, or sponge as it is sometimes called, forms on the ventral surface of the female (Fig. 3-9). The eggs break off and small crab larvae (zoea) hatch from within and go through a variety of metamorphic stages, including the megalops stage, as they float in their planktonic habitat. As the crab larvae settle out of the plankton, looking like very small adult crabs, they begin to take up existence in the adult habitat. Crabs do not exhibit parental care.

#### *4. The Fish*

##### *a. Body Form*

Fishes are by far the most numerous of all vertebrates, with an estimated 20,000 species known to mankind. Fishes have adapted to a wide variety of habitats, occurring in both freshwater and saltwater environments. They range in distribution from shallow lagoons to the deep ocean, and from near-freezing Arctic waters to the warmth of tropical seas.

Because fishes have been so successful in a wide range of habitats, they also exhibit a wide range of body shapes (Fig. 3-10). Some are fusiform, which enables them to move through the water at rapid speeds. Others, like flounders and stingrays, live on the ocean floor and have "flattened" body shapes. Eels live in crevices among rocks and corals and have body shapes that allow them to twist and wriggle into small spaces.

##### *b. Locomotion*

A variety of fin types and shapes and therefore, modes of swimming, can be found among the fishes. Some fishes are very rapid swimmers, like the tunas, mackerels, and sharks. Sea horses, on the other hand, are very weak swimmers that live among coral and seaweed. Their tails are adapted to help them hold onto structures like soft corals and seaweed in swift currents. Other fishes have developed fins that serve as support structures, enabling them to "walk" along the ocean floor. Still others have developed fins that function as wings, much like the wings of a bird. These winged fish leap out of the water and briefly "fly" just above the ocean's surface. Anyone who has been out to the Gulf Stream has surely seen flying fish leaping out of the water as they gracefully glide a short distance along the ocean's surface.

There are many different types of fins on fishes. These include dorsal, pectoral, pelvic, anal, and caudal fins. Some fishes have very small modified fins called finlets.

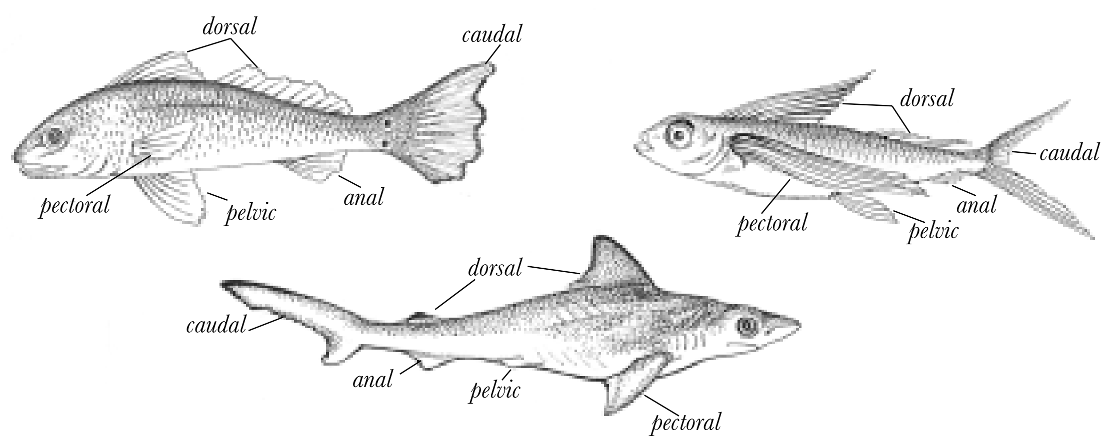



**Figure 3-10.**
*Variety of fish forms. Fin types are indicated on each.*

### c. Feeding

Fishes that feed near the surface may have mouths that are directed upward, while those fishes feeding along the bottom may have mouths that are directed downward with barbels that are used as feelers covered with taste buds on their "chins." Catfish are good examples of bottom feeders. These barbels help them locate food. Fishes that spend most of their lives in the water column have mouths that are located in the center of their "face." Teeth may be very sharp and well-developed, minute, or even absent in some species.

### d. Protection

Many marine fishes exhibit protective coloration. Types of protective coloration may be horizontal or vertical bars or lines, that assist fishes in hiding among algae or grasses. Some fishes have dark spots that look similar to eyes located on various areas of their bodies. These "eye spots," which are nothing more than circular areas of dark pigment, serve to confuse a predator. The predator may not be able to tell in which direction its prey's head is located, and may thus, miscalculate its predatory move.

Additionally, many pelagic fishes have developed counter-shading (Fig. 3-10 a,b). Fishes that exhibit counter-shading have a dark dorsal surface and a light ventral, or underside, surface. Counter-shading enables an organism to appear lighter to a predator swimming below it. The light underside effectively blends more easily with the lighter surface waters and sky above. Alternatively, countershading enables the fish to appear darker to a potential predator swimming above it, thereby blending in with the darker waters and ocean floor below. Counter-shading is a fantastic way for an organism to be camouflaged to potential predators from above and below!

### e. Reproduction, Development of Young, and Parental Care

Fishes exhibit many different modes of reproduction, development of young, and parental care. Because fishes have adapted to a wide variety of habitats, it is not surprising that one of the most fascinating aspects of the life histories of these remarkably diverse animals is their mode of reproduction. Each is interesting in its own way and it is difficult to decide which to discuss here. Some fishes release eggs and sperm and do not exhibit parental care. Others bear their young alive. And in some species, the males brood developing eggs in their mouths or in the case of male sea horses, in special pouches.

The sexes are separate in most species of fishes, with an individual maturing as a male or a female and remaining as that sex throughout its entire life. However, in some species, both male and female sex organs are present in the same individual and may actually produce eggs and sperm at the same time. This condition is referred to as simultaneous hermaphroditism. Although it is a common mode of reproduction in fishes, self-fertilization seldom occurs. Some simultaneous hermaphrodites may even spawn for a few moments as a female, displaying the behavior pattern and coloration unique to females, only to spawn several moments later as a male– displaying the coloration and behavior patterns unique to males!

Many deep sea fishes have specialized light organs that flash on and off in species-specific patterns. These "flashing lights" in many cases serve to locate mates in the dark abyss of the ocean. Nevertheless, to ensure that reproduction successfully occurs, some of the deep sea fishes are simultaneous hermaphrodites and self-fertilize, probably because of the difficulty involved in mate location in the deep sea environment.

Some fishes exhibit synchronous hermaphroditism, in which they spawn for several years as one sex, undergo sexual transition, actually "turning into" the opposite sex, and live the rest of their lives as the sex that they transformed into. Groupers and some of the sea basses are synchronous hermaphrodites and are referred to as protogynous, meaning "first female." These fishes mature first as a female, spawn for several years as a female, undergo transition, and turn into a male. Once a male, they always spawn as a male and never function as females again. In these fishes, the ovaries actually turn into testes.

Other fishes exhibit protandry, meaning "first male," and spawn first as males, undergo sexual transition, and change into females. Once they have transformed into females, they always spawn as females and never function as males again. In protandrous fishes, the testes become ovaries.

Let's look, for example, at how flounder reproduce and how their young develop. Male flounders release sperm into the water while female flounders release eggs into the water. There is no parental care, as the flounder eggs and larvae float in the plankton. Once a planktonic flounder larva hatches out of an egg, its eyes are located on either side of its head, just as in other fishes. This arrangement is beneficial since it swims upright near the surface, and it can see potential predators on either side of its body.

But something amazing begins to happen when the flounder larva begins to settle to the bottom and takes up the adult existence. As the planktonic larval flounder begins to settle to the bottom, one of its eyes migrates to join the other eye on one side of its head! Adult flounder live on their "side" on the ocean floor, with both eyes facing upward to help the flounder locate food and avoid potential predators. The larval flounder was not only able to successfully avoid being eaten while it lived in the plankton, but it can now continue to avoid being eaten as it takes up existence in the adult benthic habitat.

Photo by Cherie Pittillo

CHAPTER IV

# Coastal Ecosystems

In Chapters 1 and 2, we focused on various aspects of the ocean environment–its coverage and extent, features of the ocean floor, physical and chemical properties of the ocean, and the hydrologic cycle. In Chapter 3, we discussed oceanic environments and habitats, as well as some of the physical adaptations that organisms have acquired for continued survival in these areas. In this chapter, we will look at very specialized areas where the land environment meets the oceanic environment–the very fragile interface between humans and the ocean–the coastal zone.

## A. Estuaries

Estuaries are semi-enclosed bodies of water, such as harbors, bays, inlets, and sounds, where fresh water and salt water meet. Many estuaries along the East coast of the United States are actually flooded river valleys, as is the case when one considers the Chesapeake Bay. These valleys were made when sea level was lower thousands of years ago. Pamlico Sound, Winyah Bay, Port Royal Sound and the Altamaha Sound are just a few of the estuaries along the Southeastern coast that may be flooded remnants of ancient river valleys.

Estuaries are some of the most productive areas on Earth because they offer an abundance of nutrients, food, and shelter for many of the more common marine plants and animals. Plants in the estuaries photosynthesize, transforming energy from the sun into usable food energy. These plants, as well as other organisms, are eventually broken down by bacteria into detritus. Nutrients from detritus are released back into the system and recycled into the food web, just as we discussed in Chapter 3. Estuaries are extremely productive areas because nutrient-rich water is carried by rivers and land run-off from higher grounds and is added to the nutrient-rich waters of the estuary itself.

Estuaries are not only very productive areas, but they also offer some degree of protection to the young of numerous organisms from predators that might otherwise be encountered in the open ocean. Estuaries can, however, be very stressful places for marine organisms due to extreme variation in temperature, salinity, and water quality caused by cyclic patterns involving tides, currents, precipitation, and seasonal changes. Additionally, human activities, not only in and around coastal areas, but also those which occur far inland, can cause extreme stress to an estuarine system.

## B. Wetlands

Wetlands are areas of gradual transition where land meets water. They include swamps, freshwater and saltwater marshes, tidal mud flats, and lagoons. Wetlands are very specialized, dynamic habitats that function in a variety of ways that are important to both wildlife and humans. Some of these functions are described below.

- Wetlands function as buffers against fierce storms. In the fall of 1989, wetlands protected South Carolina's coastal residents from incalculable losses that could have occurred as a result of Hurricane Hugo. In fact, it has been estimated that an acre of wetland, if flooded to a depth of one foot, would hold over 1250 cubic meters (330,000 gallons) of water.

- Coastal wetlands function as nursery grounds for many marine organisms, as they afford an abundance of food, shelter, and protection from potential predators to the young of many species. For example, over 80% of South Carolina's recreational and commercially important species are dependent at some stage of their life cycle on coastal wetlands.
- Wetlands serve as filters for pollutants and traps for sediments and nutrients.
- Wetlands provide resting and/or breeding places for shorebirds and migratory waterfowl. Recent discoveries about neotropical migrant species have demonstrated the importance of coastal freshwater wetlands during migration for these species, as well.
- Coastal wetlands are the final endpoint for watersheds that originate far inland from the ocean. A watershed is the complex system of major rivers and all their tributaries that drain a region, ultimately reaching the ocean (Fig. 4-1). There are eight major watersheds along the Southeastern U.S. coast.
- Wetlands are home to many rare and endangered species. By definition, an endangered species is one that is in immediate danger of extinction.

**1. Coastal Marshes**

Although there are many different types of wetlands, some of the most familiar wetlands along the Southeastern U.S. coast are saltwater marshes. Many estuaries are bordered on their sides by an abundance of coastal salt marshes. But not all coastal salt marshes are adjacent to estuaries–many are influenced only by the tide, and as such, do not receive large amounts of freshwater input from riverine sources. For example, South Carolina has over 1,351 square kilometers (334,000 acres) of coastal salt marshes, more than occurs in any other state along the Atlantic seaboard.

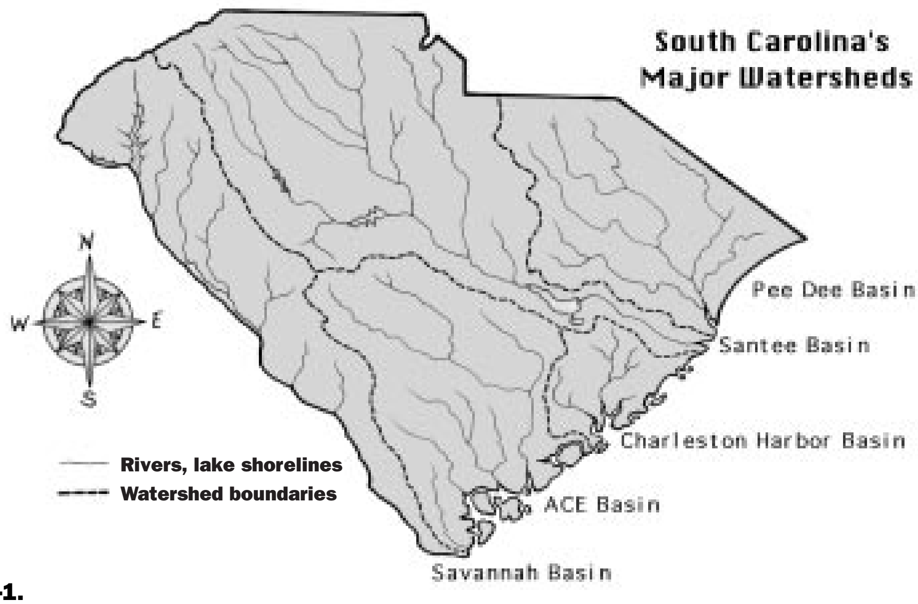



**Figure 4-1.**
*Watersheds of South Carolina.*

Illustration by JOHN NORTON

The most common plant in southeastern marshes is *Spartina alterniflora*, or smooth cord grass (Fig. 4-2). Because this plant thrives in estuarine environments, the taller *Spartina* grow closer to the water's edge, while the shorter *Spartina* are found near to the inland edges of the marsh. Although there are a variety of other plants growing within this high marsh zone, including shrubs and a few succulents, *Spartina* has developed specialized adaptations that allow it to withstand constant inundation by salt water. The next time you are in a salt marsh, look closely at the *Spartina* blade. You will see tiny white crystals of salt that have been transpired, or actively transported out through the plant's leaves. Rub your fingers along the blade and taste the salt!

*Spartina* is an extremely productive plant. In fact, an acre of *Spartina is* more productive than an acre of wheat. Like phytoplankton, *Spartina* photosynthesize and transform energy from the sun into usable food energy. Few animals actually eat living *Spartina*, but bacteria decompose the dead leaves, breaking them down into detritus. As we have seen, the detritus and the bacteria that decompose *Spartina* provide the necessary nutrients to many organisms living in the coastal marsh and estuarine habitat. Not only is *Spartina* an extremely productive plant, but the tall *Spartina* blades also provide protective coverage for larval, juvenile, and adult life cycle stages of numerous marine organisms.

The salt marsh is inundated with salt water twice a day as the tide makes its predictable rise and fall. As these intertidal areas are flushed with the tide, nutrients from the ocean are brought into the estuary, and nutrients from the salt marsh are transported out to sea. The flushing action of the tide also serves as a physical transport mechanism by which larval organisms are brought into–and transported out of–the estuary. Clearly, the abundance of food and protection from predators afforded in the coastal marsh habitat makes it one of the most productive areas on earth.

Photo by CHERIE PITTILLO

**Figure 4-2.**
Spartina alterniflora*, or smooth cordgrass, in the marsh.*

Daily submergence by the tides is not the only change that takes place in the salt marsh. Seasonal changes also occur, and contribute greatly to the productivity of the salt marsh. If you live along the coast, you have certainly noticed the blades of *Spartina* changing as the seasons change. In the fall, the marsh takes on a golden hue as *Spartina* begins to die and decay. In the winter, most of the *Spartina* turns brown and decays to become the nutrient "soup" that makes coastal saltmarsh areas so productive. As early spring arrives, small green *Spartina* blades arise from beneath the mud and the previous year's decayed *Spartina* that lines the bottom of the salt marsh. These tiny plants will continue to grow into the tall *Spartina* that gently wave in the warm summer breezes, only to turn golden brown in the fall again as they complete their seasonal cycle.

There are many organisms living in the salt marsh. Fiddler crabs , juvenile mullet, shrimp frequent the shallow waters along the edges of the salt marsh. Periwinkle snails slowly make their ascent to the tip of the *Spartina* blades as the tide rolls in, and patiently descend again as the tide falls. Oysters, mussels, and clams are some of the bivalves that can be found in the salt marsh. Many fishes slowly graze along the *Spartina* stems, while crabs and shrimp swim or walk nearby in search of detritus or other decaying matter.

**2. Tidal Creeks**

Nothing is quite so peaceful as wandering in a small boat in and out of tidal creeks (Fig. 4-3). Terns, skimmers, pelicans, egrets, and herons fly gracefully along the water's still surface. Beds of oysters occasionally squirt small streams of filtered water. Tall bright green stands of *Spartina* line the waterways as fiddler crabs run for their creek-side burrows and juvenile shrimp and mullet skip across the water's surface. These are the quiet places, the places that provide the greatest degree of protection from predation and an abundance of food. They are also the nursery areas. Although tidal creeks seem quiet and somewhat uneventful, closer inspection yields an environment teaming with life. Let's look closely at three habitats commonly found in tidal creeks–the mud flat, the sand flat, and the oyster reef (also known as an oyster bed or bar).

***a. The Mud Flat***

As we discussed in Chapter 2, freshwater rivers and streams slowly erode or wear away, the rocks and soils over and through which they flow, as they make their descent from mountainous and other inland regions toward the ocean. This erosion produces a wide variety of sediments, ranging in size from coarse sands to silts and fine clays, that are transported toward the coast in rivers and streams. Mud flats are features that form when silts and clays settle out of the water column and are deposited in areas of quieter flow. Some sands may also be found on the mud flat. Mud flats generally occur in quieter areas of creeks, where the water's energy is low enough to allow very fine muds to settle out of the water. Because mud flats are depositional features, they are constantly changing size and shape as current patterns and the availability of sediment from inland sources change (Fig. 4-3).

Anyone who has spent time along the coast during ebb tide has certainly smelled the characteristic odor of mud flats. Fine sediment particles, primarily silts and clays, are packed together so closely on the mud flat that oxygen is lacking between the sediment particles. Detritivores, primarily bacteria and fungi, living in the mud can carry out respiration without oxygen ($O_2$). This process, known as anaerobic respiration, removes sulfate from the surrounding water and releases hydrogen sulfide into the mud. Hence, the characteristic "rotten egg" smell of "pluff mud" on the mud flat.

A glimpse at a mud flat would lead one to believe that it is relatively devoid of life, with the exception of a few mud snails and wading birds. Closer inspection yields hundreds, or even thousands, of tiny holes in which a variety of animals burrow. The mud flat is home to many burrowing filter feeders. Clams, polychaete worms, amphipods, fiddler crabs (Fig. 4-4), and mantis shrimp are a few of the organisms found living in burrows within the mud flat.

*Ulva*, or sea lettuce, is an edible marine green alga commonly found on the surface of mud flats. Periwinkle snails, mussels, shrimp, crabs, flounders, stingrays, skates, horseshoe crabs, hermit crabs, and an occasional cluster of oysters are some of the more common inhabitants of the mud flat. A variety of wading shorebirds frequent the mud flat, since these areas are home to such an abundance of marine life upon which they feed.

Photo by CHERIE PITTILLO

**Figure 4-3.** *Tidal creek with mud flat.*

***b. The Sand Flat***

Like the mud flat, the sand flat is also a depositional feature. The source of its sediment may be far inland or transported from nearby island beaches by tides, currents, wind, or waves. Like the name indicates, sand flats are primarily composed of sands, with silts and clays being present in sparse quantities when compared to the mud flat. Sand flats are typically composed primarily of grains of the minerals quartz and feldspar, mixed with broken shell. These flats are most often located on the inside bends of swift-current areas, and they shift frequently as current patterns change. Their surface is commonly rippled, due to the flow of currents in the tidal creek during high tides.

The sand flat is home to many of the burrowing organisms that live on or in the mud flat. Fiddler crabs, clams, and amphipods make their homes in the sand flat. Sand dollars, brittle stars, and sea stars are also found on the sand flat.

**Figure 4-4.** *Fiddler crab.*

Photo by CHERIE PITTILLO

#### *c. The Oyster Reef*

Oysters are bivalves that are harvested both recreationally and commercially in many coastal states. The planktonic larvae of oysters settle on a hard substrate within one to three weeks after hatching from the egg. A settling larva must attach its left valve to a hard substrate. If no suitable hard substrate is found upon settlement, the oyster larva dies. A preferred settling structure for many oyster larvae appears to be the shells of adult oysters, both living and dead. Consequently, huge oyster reefs are formed in the intertidal habitat, as oyster larvae continue to settle on the shells of their own kind (Fig. 4-5).

Oyster reefs are not only home to oysters, but are also quite suitable habitats to a host of other marine organisms. Mussels are often found cemented in oyster reefs. Small crabs, tube worms, bryozoans, amphipods, brittle stars, barnacles, sponges, and polychaetes all join the oyster as members of the oyster reef habitat. It is not surprising that juvenile fishes find an abundance of food and safe haven in oyster reefs. Even the juvenile gag grouper, the most common grouper occurring off the South Carolina coast, can be easily captured in estuarine nursery areas for scientific study in plastic milk crates filled with clusters of oysters!

*Crassostrea virginica*, the Eastern oyster, is the only oyster occurring along the Southeastern U.S. coast. Oysters are filter feeders. They filter detritus, zooplankton, and phytoplankton from the surrounding water, with a single oyster capable of filtering as much as 15 liters (4 gallons) of water in an hour. They also filter pollutants from the surrounding waters, hence these pollutants would likely be ingested by anyone eating an oyster during times when water quality is poor.

Oysters can function as either sex, spawning, or releasing, gametes (eggs or sperm) into the water from April to October in South Carolina.

### C. Fouling Communities

Another type of coastal zone habitat with which you may be familiar is the fouling community habitat typically found on the undersides of floating docks and on the hulls

**Figure 4-5.**
*Oyster reefs at low tide.*

Photo by CHERIE PITTILLO

of boats moored at marinas. Fouling communities are a very unique assemblage of marine organisms. Although the individual organisms typically found in a fouling community are also found living independently throughout the marine environment, they are only truly closely associated with each other in the fouling community. Most inhabitants of the fouling community live their lives permanently attached to stable structures while other organisms crawl among the attached fouling community inhabitants. Barnacles, sea squirts, worms, isopods, sponges, bryozoans, caridean shrimp, algae, soft corals, and amphipods are among the most common inhabitants of the fouling community.

## D. Hard Substrate Intertidal Habitats

Intertidal habitats, like the coastal marshes and tidal creek areas described earlier, are some of the most dynamic and stressful habitats on earth. During flood tides, the intertidal environment and its inhabitants are covered with water. The water brings with it food, cooler surrounding temperatures, changes in salinity, renewed levels of oxygen ($O_2$), carbon dioxide ($CO_2$), moisture, and nutrients vital to survival.

During ebb tides when the habitat is exposed to the air, organisms must protect themselves from desiccation and heat. Additionally, they must be able to survive with little to no food and avoid predation from other organisms that gain access to them in exposed areas. Many organisms inhabiting the intertidal area have shells that they close to prevent drying out while others burrow down in the sand or mud.

Photo by CHERIE PITTILLO

**Figure 4-6.**
*Intertidal community found on hard substrate of a pier in South Carolina.*

Intertidal habitats are not only stressful places as a result of daily tidal action, but they also bear the brunt of major storms, buffering more fragile coastal areas from extreme flooding, high winds, and waves.

One intertidal community of organisms common to the Southeastern U.S. coast is that found attached to rocky jetties, groins, and concrete pilings (Fig. 4-6). Many of these organisms, like those found in fouling communities, need a substrate on which to attach. Barnacles, amphipods, isopods, sea urchins, algae, tube worms and other polychaetes, oysters, and mussels can all be found living on these structures. Many people fish around these structures, since larger fishes come in to feed on the smaller organisms that feed on the inhabitants of the hard substrate intertidal community.

## E. Barrier Islands

Barrier islands are islands that lie parallel to the coast and afford incalculable protection to coastal shorelines around the country (Fig. 4-7). Over 4,344 kilometers (2,700 miles) of our nation's shoreline are bordered by barrier islands. Those of us living on barrier islands during Hurricane Hugo in 1989 clearly understand and remember the wrath that barrier islands endure when faced with the extreme forces of nature.

Photo by RESEARCH PLANNING, INC.

**Figure 4-7.**
*Barrier islands of South Carolina (Bull Island, top; Capers Island, middle; and Dewees Island, bottom).*

Barrier islands are known for their beauty, and as such, they have inspired many writers and artists. George Gershwin composed the famous opera, "Porgy and Bess," while residing on Folly Island. Edgar Allen Poe once lived on Sullivan's Island, South Carolina and penned the short story, "The Gold Bug" (hence, the name Gold Bug Island). Books and songs have been written about the tranquillity that these areas offer, and countless canvases have been painted that depict lighthouses, marshes at sunset, and barrier islands during fierce storms.

Because of their beauty, remoteness, and tranquillity, many people seek residence on barrier islands. In fact, some barrier islands along the Southeastern U.S. coast support a population density several times the national average. But barrier islands are always changing due to the movement of sand by waves, winds, tides, currents, and storms. This is evidenced by the fact that most barrier islands are elongate. This elongation is in part the result of the transport of sand parallel to the beach known as longshore drift.

Longshore drift is generated by wave and current action. Along the Southeastern U.S. coast, the longshore drift is generally north to south. This motion occurs because waves most often approach and hit the beach on an angle (Fig. 4-8). As a wave breaks and washes at an angle up onto the beach, particles of sand are carried with it. The next time you have a chance to watch waves breaking on a beach, note how they usually approach at an angle to the beach. The run-up of waves onto the beach is called the swash. The swash of a wave is followed by its inevitable return to the sea, or backwash, down the slope of the beach. A zig-zag pattern of up and down movement results due to the swash and backwash of waves. A particle of sand or silt travels along this zig-zag path, continuously working its way toward the

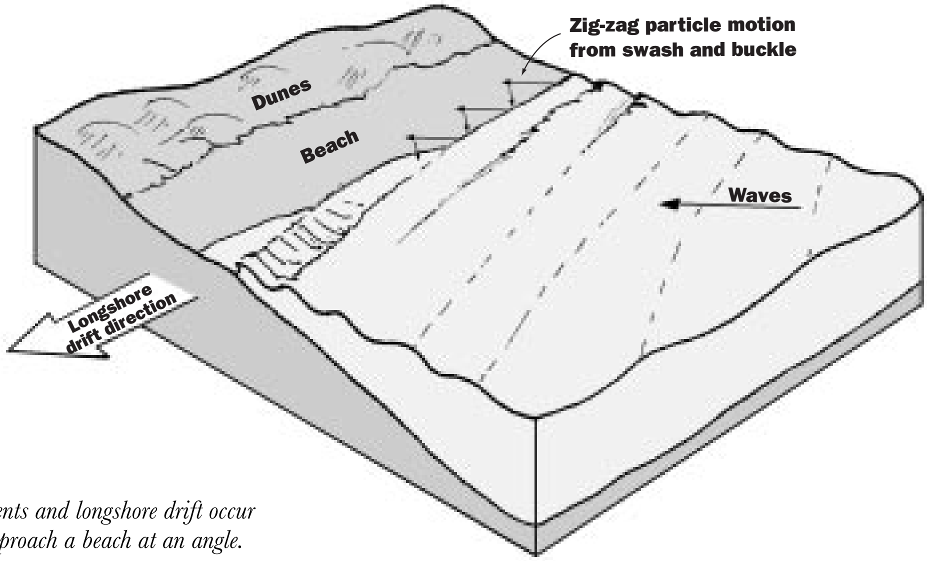



**Figure 4-8.**
*Longshore currents and longshore drift occur when waves approach a beach at an angle.*

downdrift end of the beach. This pattern of water movement establishes a longshore current moving parallel to the beach, carrying sediment with it.

Because of the longshore drift of sediments southward, many barrier islands along the Southeastern U.S. coast erode on the north end. The south ends generally "grow," grain by grain, often forming an extended hook-shaped lobe of sand known as a spit. Tremendous volumes of sand are transported along these islands each year.

Along much of the Southeastern U.S. coast, the barrier islands are generally wider on the updrift northern ends. Remnants of older, vegetated dune ridges can be observed from the air on these updrift ends (Fig. 4-9). Hook-shaped spits are characteristic of the downdrift southern ends. This particular type of barrier island typically occurs in areas with a tidal range between 2 and 4 meters (approximately 6 to 9 feet), or a mesotidal tidal range, and is nicknamed a "drumstick" barrier island (Figs. 4-9 and 4-10).

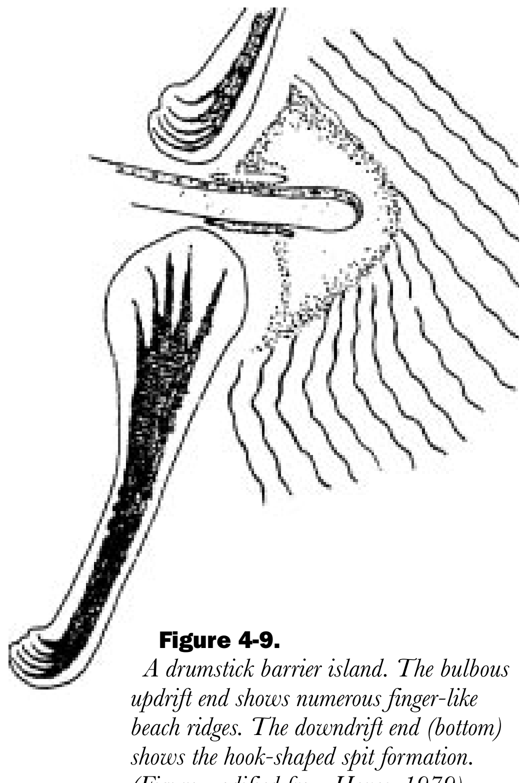


**Figure 4-9.**
*A drumstick barrier island. The bulbous updrift end shows numerous finger-like beach ridges. The downdrift end (bottom) shows the hook-shaped spit formation. (Figure modified from Hayes, 1979).*

In many cases, barrier islands also migrate toward the mainland, as storm waves wash over their low-lying areas, removing beach sand and casting it over the dunes to the marsh behind in the form of a washover (Fig. 4-11). This "rolling over" of the beach more often occurs on barrier islands with lower profiles and fewer dune ridges. Low profile barriers are more common in microtidal areas (<2m tidal range). Cape Romain in South Carolina, and the capes of North Carolina (Hatteras, Lookout, and Fear) are located in areas of lower tidal ranges, where storm waves are the major contributors to building washovers.

Photo by RESEARCH PLANNING, INC.

**Figure 4-10.**
*Bull Island in South Carolina is a classic example of a drumstick barrier island. Note the beach ridges at the top of the photo and the recurved spit at the bottom.*

Barrier islands have a zonation that is quite unique. Moving horizontally from the ocean toward the mainland, most barrier islands have the following components: offshore sand bars, beach, primary dune system, secondary dune system, and maritime forest (Fig. 4-12). The back marsh lies on the landward of the maritime forest and may also be called the lee or bayside marsh. Mud and/or sand flats may be found in the back marsh. The transition between each of these zones is rapid, within a very short horizontal distance from the ocean to the mainland. Each is unique in the amazing diversity of its habitat and the life which it correspondingly supports. Let's look in detail at the beaches, primary and secondary dune systems, and maritime forests of barrier islands.

### 1. The Beach

Just as we saw with mud flats and sand flats, beaches are also depositional features formed when sediments, such as sands (primarily quartz and feldspar minerals), silts, and clays, are transported toward the coast by inland rivers and streams. Sediments are redistributed by longshore currents. Beaches occur in coastal areas where waves, tides, and currents are strong enough to wash away the finer silts and clays, yet weak enough so that the sand remains behind. Because beaches form the seaward edge of barrier islands, beach profiles are always changing in response to availability of sand due to longshore drift, tides, and seasonal variations in waves and current patterns.


Photo by RESEARCH PLANNING, INC.

**Figure 4-11.**
*Cape Romain, South Carolina is an excellent example of a low-profile barrier island that is steadily moving landward. The arrow points to a washover feature that is the result of storm waves.*

Not all beaches are eroding. As we discussed above, portions of one barrier island may be eroding, while other portions may be growing, or accreting. Whether a beach erodes or accretes is determined by a combination of several variables, including tidal energy, wave energy, longshore currents, and most importantly, the availability of sediment. If the sediment supply is low, chances are a beach will eventually erode, particularly if wave and longshore current energies are high. In areas with abundant sediment and moderate wave energy, for example, the beach will most likely accrete.

The beach has several zones, extending from the dunes seaward to the outermost region of breaking waves (Fig. 4-13). These zones are defined in part by the high and low tidal water levels, but also by the shape of the shifting sands above and below sea level. In a mesotidal setting, the backshore extends from

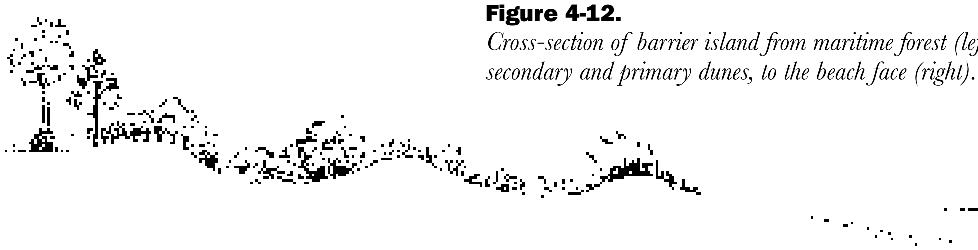


**Figure 4-12.**
*Cross-section of barrier island from maritime forest (left), through secondary and primary dunes, to the beach face (right).*

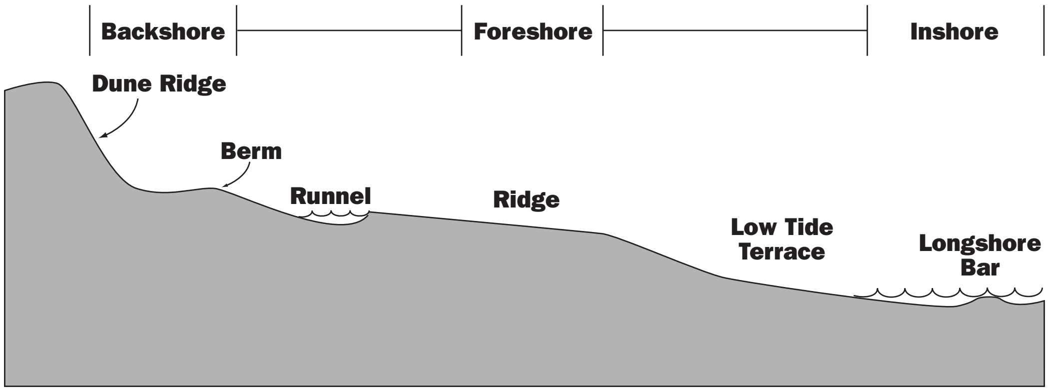



**Figure 4-13.**
*Typical mesotidal beach profile (summer conditions).*

the base of the dunes to the mean high tide mark, and is the region affected most by wind and storm activity. The foreshore marks the region between the mean high and mean low water levels. This region is greatly influenced by the swash and backwash of breaking waves and longshore currents. Beyond the foreshore lies the inshore where waves break and surfers roam! Longshore bars, submerged elongate mounds of sediment, may be found in the inshore region.

The beach profile is the shape of the beach across the backshore, foreshore, and inshore zones. It varies from shoreline to shoreline, and from season to season. The profile is a function of several variables including sediment size and amount, tide, wave, and wind energies. However it is wave action that ultimately controls the shape of the beach as a whole, because waves have enough energy to pick up and move the millions of grains of sediment.

Certainly, beaches vary from place to place. Mesotidal beaches, such as those found along parts of the Southeastern U.S. coast, have many characteristic features, as illustrated on Figure 4-13 and described below.

- dune ridge (backshore): consists of fine wind-blown sands; may or may not be vegetated; storm waves may erode the base, creating a large dune scarp.
- berm (backshore): deposits left behind from receding storm waves or spring tide high water levels; often terrace-like with crests defining individual berms; location for wrack lines and the early formation of dunes.
- runnel (foreshore): depression in the beach profile, often filled with seawater throughout tidal cycle; linear and parallel to the shoreline; width is determined by the landward advance of the ridge.
- ridge (foreshore): formed by normal wave action and accretion of sediment to the beach; often advances landward over the existing runnel; broad and gently sloping, but steeper than the low tide terrace; longshore drift occurs here during high tide.
- low tide terrace (foreshore): region of fluctuating cover by water; tidal and wave energy is very significant; location for major portion of longshore transport; smooth and low slope.
- longshore bar (inshore): elongate and parallel to the shoreline; submerged except during

unusually low spring tides; region where waves break; possible sediment supply area for accretion onto beach; possibly formed by deposition of sediments eroded from the beach.

The features just described are most commonly found during the summer when gentle waves tend to accrete, rather than erode, sand to beaches. During winter when winds and waves are stronger, erosional processes dominate. Severe storms may strip the beach, often leaving a flat, featureless, hard-packed sand profile. Dunes may be wave-cut, or scarped. Over time as gentle waves return and roll in, they carry sands landward from offshore and the ridge begins to develop and move landward. A runnel is "born" but only shrinks as the ridge advances. Berms are deposited only during the higher high tides. Usually, by summer the "typical" profile is restored.

As you may guess, beaches are unstable habitats, as the sand that is deposited on them is constantly shifting, making it a difficult place for many organisms to successfully inhabit. It has been estimated that a single grain of sand can move as much as 21 meters (70 feet) a day. In fact, no species of plant has ever adapted to survival at the beach/ocean interface. Nevertheless, the beach is home to a host of marine animals, most of which you cannot see unless you dig for them. Many beach inhabitants burrow in the sand in an attempt to avoid the continual shifting of sand at the surface. Burrowing also serves to prevent desiccation that would otherwise occur if these organisms were left exposed for extended periods of time.

There is a different assemblage of burrowing animals found at the beach than that found in the mud flat, as these areas represent two very different habitats. Mole crabs, coquina clams, razor clams, amphipods, isopods, polychaete worms, and sand dollars are some of the organisms that burrow in beach sand. There is also a marked difference in the diversity and abundance of these organisms at the beach as you move from the dunes to the ocean. Because the upper reaches of the beach are inundated with waves less often than the lower areas, the backshore is relatively dry and food is less abundant than it is closer to the water's edge. The number and diversity of burrowing organisms in the backshore is correspondingly sparse. But as you move closer to the water's edge, organisms become much more abundant due to an increase in the amount of moisture and the availability of food. Many of the burrowing beach inhabitants are filter-feeders, feeding on abundant phytoplankton that are present due to turbulent oceanic water.

Ghost crabs are frequent inhabitants of the backshore region of the beach. As the waves roll in, they scavenge toward the water in search of food and quickly retreat into their burrows to hide as the ocean recedes again. A tremendous variety of shorebirds also feed on the burrowing marine organisms at the water's edge. Terns, sanderlings, ruddy turnstones, gulls, and sandpipers are just a few of the shorebirds frequenting the Southeastern U.S. coast.

### 2. Primary and Secondary Dunes

The continual shifting of sand on the beaches makes the beach a difficult place for many organisms to survive. Although no plants have adapted to survival at the beach/ocean interface, plants do exist and are well adapted for certain zones on barrier islands. These zones are slightly more stable than the beach/ocean interface. The first of these zones that you encounter as you move inland from the water's edge are the primary and secondary dune zones (Fig. 4-12). Let's look at how dunes are formed.

Although much decaying plant matter, such as *Spartina*, remains in the estuary, some decaying *Spartina* and other plant matter are washed out to sea through inlets. Wind, waves, and tides wash some of this plant matter back onto the beaches, where it remains and forms a

**Figure 4-14.**
*Formation of a dune from a wrack line over time.*

"wrack" line that runs up and down the beach at the places where the tide reaches its highest point (Fig. 4-14). Windblown sand hits the wrack, falls out of the air, and begins to accumulate around the wrack line. Plant seeds carried by the wind also settle in the wrack and have a perfect mulch of decaying matter on which to begin deriving moisture and nutrients.

As the plants begin to grow, their roots provide an anchor that keeps them stationary in the shifting sand. As sand continues to accumulate around the base of the plants, a more stable zone is produced, enabling these plants to continue their growth. This stable zone has now become a sand dune. In fact, if undisturbed by severe wave action, a wrack line may someday become a primary dune. Primary dunes include the line of dunes closest to the water's edge. Primary dunes can be washed away during extremely high tides that are accompanied with high winds and storms. Secondary dunes are farther inland than primary dunes and are thus more protected. Secondary dunes are formed by the same process as just described, but over the years they have escaped destruction, being protected by newer sets of dunes–the primary dunes built on their seaward side.

Dune habitats are similar to deserts–the wind blows frequently, shifting the sand, and water is scarce. Plants living in the dunes have developed special features enabling them to survive this desert-like habitat. Sea oats, one of the most commonly occurring plants in dune systems along the Southeastern U.S. coast, have developed long stems and leaves that are very flexible in high winds. Narrow leaves also aid in surviving frequent salt spray and retaining water. Sea oats have extensive root systems that reach deep into the sand for fresh water. Sea oats are protected by federal law and it is illegal to disturb their growth in any way. Fines for picking sea oats can be as high as $200 per oat! *Spartina* also inhabits the primary dune system.

Secondary dunes are also colonized by sea oats, but because they are more protected from battering winds off the ocean, they are more stable than primary dunes and are able to support a greater diversity of plants. Many species of succulents, such as cacti, can be found in secondary dunes. These plants have thick, waxy leaves resistant to desiccation. Additionally, their leaves are capable of storing relatively large volumes of water. Saltwort, pennywort (dollar weed), butterfly peas, sea oxeye, yucca plants, greenbrier, sandspur, broom sedge, and camphorweed are just a few species of plants occupying secondary dunes.

Plants are not the only organisms surviving in primary and secondary dune systems. Ghost crabs build their burrows there and many shorebirds nest in the dunes. Raccoons, mice, rats, opossums, rabbits, snakes, lizards, and foxes forage in the primary and secondary dunes. The loggerhead turtle, a threatened species on the state and Federal Threatened and Endangered Species List, crawls onto barrier island beaches at night from May through August to lay its eggs in the dunes. It is also interesting to note that barrier islands and their dune systems probably support more species of birds than any other ecosystem in the continental United States. Clearly, they are habitats well worth protecting.

#### 3. The Maritime Forest

Many barrier islands have maritime forests located landward from their primary and secondary dune zones. Maritime forests are frequently found in the interiors or back sides of larger barrier islands. These areas are buffered from the full force of winds by the dune zone. Nevertheless, they are affected to a lesser degree by salt spray, high winds, and sandy soils. Many maritime forests are located on what once was a secondary dune. As new dunes become established seaward of the primary and secondary dunes, these areas become more stable, eventually transforming into mature maritime forests. As one moves from the water's edge toward the maritime forest, it is easy to see: 1) the wrack line and its embryonic dune, 2) the primary dune with its sea oats, 3) the secondary dune with its sea oxeye and broom sedge, and 4) the maritime forest with its mature saw palmettos and live oaks–the entire sequence, or stepwise progression of the growth and establishment, of a stable coastal terrestrial supratidal environment. In fact, maritime forests often appear as a linear beach ridge if seen from the air.

The seaward edge of the maritime forest abuts the landward edge of the secondary dune zone. Trees and shrubs are dwarfed by winds that blow sand and salt spray, essentially "pruning" these plants on a continual basis. Many tree tops and shrubs at the edge of the maritime forest have flattened top branches as a result of this salt pruning process.

Maritime forests absorb much of the heat on barrier islands and offer protection from extreme temperatures, an abundance of food, and nesting areas to a variety of organisms. Low-lying areas of the maritime forest trap and hold rainwater and are thus a source of fresh water for many inhabitants. Because they are located so close to the mainland, maritime forests support similar species that the mainland areas support. Live oak, American holly, yaupon holly, sweetgum, wax myrtle, red cedar, cabbage palm, saw palmetto, pines, dogwoods, and magnolias are a few of the trees that occupy the maritime forest habitat. Deer, raccoons, snakes, lizards, rabbits, eagles, ospreys, hawks, bobcats, and foxes are some of the larger animals living in the maritime forest.

### F. Inlets

Salt water from the ocean enters estuaries and backmarshes through inlets. Inlets are waterways between islands. They are the passages through which sediments are transported by tidal flow. Sediments deposited adjacent to inlets serve as sediment reservoirs that feed many barrier islands along the Southeastern U.S. coast.

Depending on the relative strengths of the local tidal currents and waves, lobes of sand and silt may accumulate on either the landward or seaward side of the inlet. Along most of the South Carolina and Georgia coastline, the tidal range is great enough (i.e., mesotidal tidal range) to create a significant flow of water, or tidal current, during ebb tide. Wave action is less significant and, therefore the tidal currents pass through the inlets and extend seaward. These ebb tidal currents decrease in velocity as they enter the coastal ocean, allowing sands and silts to settle out. Ebb tidal deltas and bars of sand called shoals are formed by these deposits seaward of the inlet (Fig. 4-15). In microtidal regions, such as the northernmost stretch of the South Carolina coast on up into North Carolina, tidal currents are diminished. Wave action in these regions is quite significant and serves to prevent the weaker tidal currents from carrying their sediment load seaward of the inlets. Instead, flat areas of silt and sand are deposited on the landward side of the inlets as flood tidal deltas.

The numerous ebb tidal deltas along mesotidal sections of the coastline may contain nearly as much sand and silt as is found exposed on the beaches! It has been estimated that 30% to 40% of the total sediment deposited on barrier islands along the Southeastern U.S. coast originates from sand shoals and ebb tidal deltas.

Shifting sediment and tidal action cause many inlets to constantly change position. Sediments are moved by the combined effects of wave action and longshore currents. Sands carried along the length of a barrier island eventually encounter an inlet. Some particles remain as dune or spit deposits, described earlier, while others become part of the inlet-tidal delta system. An enormous "package" of sand accumulates at the island's downdrift end and slowly works its way around the lobe of the ebb tidal delta itself. This process is called inlet bypassing and allows for the continued flow of the enormous volume of sediments southward along the Southeastern U.S. coast. When the sand package completes its trek around the delta lobe, waves continue to push it toward the adjacent barrier island, "welding" the bar to that island's updrift end. This welding of huge packages of sand is in part the reason for the greater widths of barrier islands on their updrift end. Some of these welded beaches eventually become vegetated, forming anchored beach ridges.

Areas of land located on either side of inlets are thus very unstable as their profiles change in response to different phases of the inlet bypassing process. A single inlet bypass may take between 5 and 100 years, depending on the size of the delta and the strength of the longshore currents and waves.

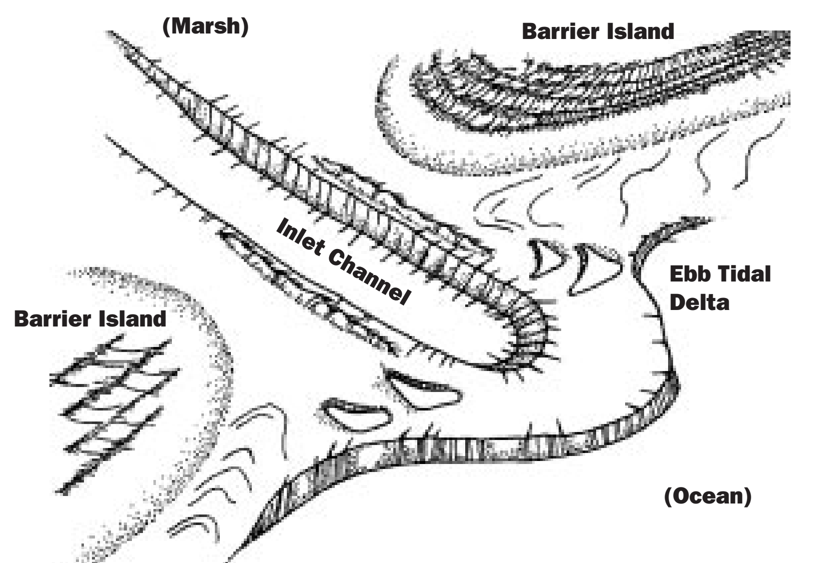



**Figure 4-15.**
*Inlet and ebb tidal delta. (Figure modified from Hayes, 1980).*

Fierce storms can cause inlets to form in low-lying, unvegetated, or narrow areas of islands located along the coast, particularly in the microtidal sections. Flows during maximum tidal stages can be quite rapid, as inlets function as "garden hoses" funneling large volumes of water through narrow openings. Flows through inlets can be particularly dangerous during ebb tides and many people have drowned while swimming and wading in these inlets.

Inlets not only are conduits for sediments, but they are also pathways through which nutrients, gases, salts, food, and pollution enter the ocean. Tidal inlets enable salty ocean water to mix with the less saline water of estuaries during high tides. They also allow for the twice-daily flushing of estuarine areas along the coast.

Organisms that are spawned offshore, but are dependent on estuaries as nursery grounds, enter estuaries through inlets. Larvae of shrimp, crabs, certain types of groupers, and many other commercial and recreational species enter estuarine areas riding the flood tide currents. Once inside, they settle out from their planktonic habitat and take up a benthic existence in their new estuarine nursery grounds. Organisms that are dependent on estuarine nursery grounds find an abundance of food and shelter in inlets and the smaller tidal creeks which meander throughout saltwater marshes.

Photo by Wade Spees

CHAPTER V

# LIVING IN HARMONY WITH THE MARINE ENVIRONMENT

*We have not inherited the Earth from our ancestors. We have borrowed it from our children.*

*Author Unknown*

Photo by CHERIE PITTILLO

**Figure 5-1.** *Recreational fishing using a cast net.*

Past chapters have introduced you to many aspects of the marine environment—the ocean's vastness, the physical and chemical properties of the ocean and, the hydrologic cycle. We have also looked at the plants and animals that live in a wide variety of coastal and oceanic habitats, and the adaptations that have enabled them to survive in these areas. The importance of coastal wetlands and the dynamic environment of barrier islands have also been addressed.

These chapters however, for the most part, have not addressed human impact on the ocean environment. We know, from previous chapters, that physical and chemical properties of the ocean are delicately intermingled to produce one of the most self-sustaining life support systems on earth. In this chapter, we discuss how human activity can very easily–and oftentimes, undetectably–offset this self-sustaining ocean system. The ocean has its own way of telling us that the system is becoming unbalanced. In many cases, however, the ocean shows signs of human-induced imbalance far too late for us to change our actions–actions that have permanently affected a once self-sustaining, natural system.

## A. Resource Utilization

Ocean resources have supported the activities of humans for thousands of years, whether these activities were a means of basic survival or enjoyment and recreation. Historically, the ocean has been used for fishing, transportation, and recreation (Fig. 5-1). The development of new technologies has opened the door for other uses of the ocean as a resource. Advancements in technologies have enabled us to mine the ocean for fuels, such as petroleum and natural gas. In fact, over $1 million a day is spent in search of oil within the ocean floor in the Gulf of Mexico.

Metals, such as gold, silver, tin, and iron are mined from the ocean floor. Manganese ($Mn^{2+}$) nodules are extremely abundant in certain areas on the ocean floor. Calcareous shells taken from the ocean serve as a source of calcium carbonate ($CaCO_3$) which is used in the production of cement and fertilizer. Minerals taken from the ocean include salt, magnesium, and bromine. Even fresh water is extracted from sea water for human use. The ocean can also be used as a source of energy through tidal power and serves as a large open area from which to collect the wind's energy.

More recently, aquaculture, or the intensive culture of marine (and freshwater) organisms, has become an increasingly popular use of ocean resources (Fig. 5-2). In fact, explosions in population growth on a global level will most certainly necessitate increased utilization of the ocean as a source of food. Additionally, scientists are just beginning to unlock the medicinal possibilities of the ocean through the discovery of antibiotics and other drugs that can be produced by marine organisms.

Many of us tend to think of a resource as something that is available to us–a supply, a stock, or a means of support. More often than not, we have viewed the ocean as a renewable resource, or one that is unlimited in its bounty and ability to renew itself. But recently, we have learned quite the opposite–that the ocean is limited in what it can provide. We have seen declining fish populations off our own coast, we have removed dead animals that have become entangled in fishing line and nets from our beaches. Additionally, we remove tons of marine debris, including medical wastes, from the beach every year. In fact, in recent years, there have been more closures of public beaches throughout the country than has ever occurred before.

Human activities such as mass taking of marine organisms for food have certainly expressed their effects on the populations of marine organisms, particularly in light of poor management strategies and more effective technologies used to locate and catch marine organisms. Total fish production, including aquaculture, had increased from approximately 18 million tons in the mid-1940s to

Photo by CHERIE PITTILLO

**Figure 5-2.** *Aquaculture farm.*

101.3 million tons in the early 1990s. Estimates of fish stocks overfished around the world range from 36% in the East Central Pacific to 90% in the Pacific and the West Central Pacific. An estimated 53% are overfished in the South Atlantic, with sharks, tuna, swordfish, marlin, sailfish, drum, croaker, and weakfish reported as species in trouble and the shortnose sturgeon being reported as in danger of extinction (Bureau of the Census, US Department of Commerce, FAO).

Additionally, we have seen that fishing for target species can, in certain cases, affect other animals, such as porpoises and dolphins, that live in close association with the sought-after organisms. We now understand that the ocean is not a limitless bounty–it is very easily altered by human activity. We have yet to learn the consequences of many of our actions, both past and present.

## B. Coastal Development and Erosion

Over one-half the population of the United States lives within 160 kilometers (100 miles) of the coast, with coastal populations reaching five times the national average. Consequently, wetlands are impacted by human development, as they receive pollutants from a variety of sources, including runoff from inland areas. Local stormwater runoff, wastewater discharges, and other residential and industrial activities also affect wetland habitats. Atmospheric deposition and oil seeps are naturally-occurring sources of wetland pollution. One of the most important functions of wetlands is that they serve as filters for pollutants since they trap contaminants from both natural and human-induced activities in their sediments and purify some of the waters passing through them. Wetlands can, however, become overloaded with pollutants from a variety of sources if the input of the pollutants occurs at a rate which is faster than the purifying capacity of the wetland.

It has been estimated that both naturally-occurring and human-induced activities have resulted in an estimated loss of over half of the Earth's existing wetlands. Despite present day knowledge of the function and value of wetland resources and international efforts to halt their loss, these fragile habitats are disappearing at a rate of 1,214 square meters (300,000 acres) each year. Additionally, with estimates that 75% of our nation's population will live within 80 kilometers (50 miles) of the coast by the year 2000, human-induced activities near coastal wetlands are certain to result in increased stress on these fragile areas.

Because barrier islands are in a constant state of flux, they are not suitable areas for dense human populations to reside. The continual change makes it nearly impossible for permanent dwellings to exist on the shoreline. Erosion, or the loss of shoreline, is frequently caused by storms, winds, high tidal surges, and/or man-made structures. Coastal areas nationwide have subsided a total of 20 centimeters (8 inches) during the past 100 years due to sea level rise and natural subsidence, or settling, of these coastal areas. According to the United States Environmental Protection Agency, scientists estimate that we can expect a subsidence of 0.7 to 1.4 meters (2.3 to 4.5 feet) over the next 100 years. The Agency also estimates that the Charleston, South Carolina area alone could see a loss of 50% of its coastal marshes if it experiences just a 1 meter (3-foot) rise in sea level.

Erosion rates vary along the Southeastern U.S. coast. Estimates for South Carolina's coast, for example, indicate that one-fourth to one-third of the coastline is eroding and 97 kilometers (60 miles) of the coast are critically eroding at a rate of over 0.3 meters (1 foot) per year. Erosion of North Carolina and northern South Carolina beaches is primarily the result of wave action, as tidal ranges are relatively small (microtidal). Farther south, along South Carolina's mesotidal beaches, erosion is due to the combination of wave and tidal action, and Georgia's beaches are being eroded primarily by tidal action.

Humans interfere with the ocean's force and the natural migration of these barrier islands by placing seawalls, bulkheads, groins, and jetties on beaches in an effort to protect the existing beach, which consists of both public and private property, against these natural forces. Each of these man-made structures is defined below:

- seawall—a solid, vertical structure constructed parallel to the beach
- bulkhead—a sloping barrier often composed of large rocks placed parallel to the beach
- groin—a vertical structure placed perpendicular to the shoreline that extends from the upper edges of the beach to beyond the low tide mark (Fig. 5-3)
- jetty—rocks or other structures, placed perpendicular to the shoreline, that extend seaward from the upper edges of the beach; typically used to stabilize migration of inlets; often placed in harbors to slow natural longshore drift of sand and subsequent sand build-up in the harbor. Examples are the Charleston Harbor Jetties and the Georgetown Jetties off South Carolina.

These man-made defenses against natural barrier island migration only exacerbate erosion, particularly in areas immediately adjacent to these "ocean barrier" structures.

Additionally, the loggerhead turtle, a threatened species on the state and Federal Threatened and Endangered Species List, crawls

**Figure 5-3.** *Groin made from concrete, steel and rock.*

Photo by CHERIE PITTILLO

onto to barrier island beaches at night from May through October to lay eggs in the dunes. Alteration of nesting habitat and blocking access to dune nesting areas by man-made structures clearly has had significant impact on this species.

In 1988, the South Carolina General Assembly passed the Comprehensive Beachfront Management Act to protect coastal areas from conflicts with development by setting policies that addressed altering sand in dune systems and erosion control. It also called for the establishment of a setback line for placement of erosion control devices and coastal development.

## C. Pollution

*'If seven maids with seven mops*
*Sweep it for half a year,*
*Do you suppose,' the Walrus said,*
*'that they could get it clear?'*
*'I doubt it, said the Carpenter,*
*'and shed a bitter tear.'*

from: *"The Walrus and the Carpenter"*
*Through the Looking Glass*
*by Lewis Carroll (1871)*

The 20th anniversary of the national legislation protecting public bodies of water and aquatic resources, known as the Clean Water Act, was celebrated in 1992. Over 40 governors and the past President of the United States proclaimed 1992 as the Year of Clean Water. Nevertheless, there has been a steady decline in public understanding of water as a limited, natural resource as well as a lack of pollution prevention technology to assist people with protecting water resources. In fact, over one-third of the nation's shellfish beds are closed due to pollution. As the number of people living in coastal areas around the country continues to increase, an increase in ocean pollution is certain to occur.

We frequently hear the terms "point source" and "nonpoint source" pollution. Point sources of pollution are simply sources of pollution that can be tied to a single source, such as discharge into a river from a pipe (Fig. 5-4). Nonpoint sources of pollution cannot be tied to a single source. An example of nonpoint source pollution is stormwater runoff from an entire watershed into a coastal body of water.

Photo by CHERIE PITTILLO

**Figure 5-4.** *Point-source pollution.*

Point and nonpoint sources of pollution affecting coastal waters along the Southeastern U.S. coast include stormwater runoff from land areas after heavy rains, runoff from agricultural areas, discharges of industrial wastes, and releases from sewage treatment plants. Dredging, construction operations, offshore drilling for oil, shipping, and recreational activities also constitute ways in which the coastal and oceanic environments can be altered by human-induced activity.

In the past several years, problems with marine debris, or garbage disposed in the ocean, has been foremost on the minds of many environmentalists, particularly those concerned about ocean resources. Disposal of plastics in the ocean is of particular concern, since plastics are durable and do not readily break down. A plastic six-pack ring can take up to 350 years to degrade and poses a potential threat to small animals that may become entangled within the rings.

Plastic in the ocean causes problems for two reasons: 1) entanglement and 2) ingestion. Many marine organisms become entangled in plastic netting and line used in fishing activities. Additionally, many marine organisms; including porpoises, dolphins, and turtles; ingest small plastic pieces, Styrofoam, or plastic bags since these items resemble the food upon which these organisms frequently feed. In fact, plastic has been found in the stomachs of over 50 species of the world's 250 species of seabirds. Additionally, these seabirds take plastic pieces back to their nests as food for young chicks.

Another form of pollution that we hear or read about, but often do not correlate with alteration of the ocean environment, is the release of compounds that deplete the ozone layer and increase levels of carbon dioxide ($CO_2$) in the atmosphere. Levels of $CO_2$ have increased by 25% during the past 200 years. These increased levels of $CO_2$, coupled with the depletion of the ozone layer, result in warmer temperatures on Earth, often referred to as global warming. Warmer temperatures, in turn, cause melting of the polar ice caps and a resulting rise in sea level. Changes in the global ocean's salinity and temperature will surely take place as a result of this gradual melting of the polar ice caps due to global warming. A rise in sea level will submerge many productive coastal marsh areas. Weather patterns will also change and, in turn, will affect ocean circulation.

It is unfortunate that it takes disasters like the Alaskan oil spill in Prince William Sound from the Exxon *Valdez* tanker, medical wastes washing up on beaches, and closure of public waterways to fishing and swimming to capture the attention of many people and educate them about ocean pollution. Progress is being made, however, in making people more aware of the problems caused by ocean pollution. The International Coastal Cleanup, one of the planet's largest volunteer cleanups, is an annual event in which more than 50 U.S. states and territories and more than 75 countries participate. For over ten years, South Carolina has held its cleanup–Beach Sweep/River Sweep (Fig. 5-5). On that day, thousands of volunteers flock to the state's beaches and waterways and clear away anywhere from 50 to 70 tons of aquatic debris. The Sweep has resulted in a tremendous increase in the awareness of the problems with disposal of trash in oceans and in waterways. Pollution prevention efforts, such as recycling and use of environmentally friendly products, coupled with education about the marine environment and the formation of regulations by an aware and educated public, are clearly steps in the right direction.

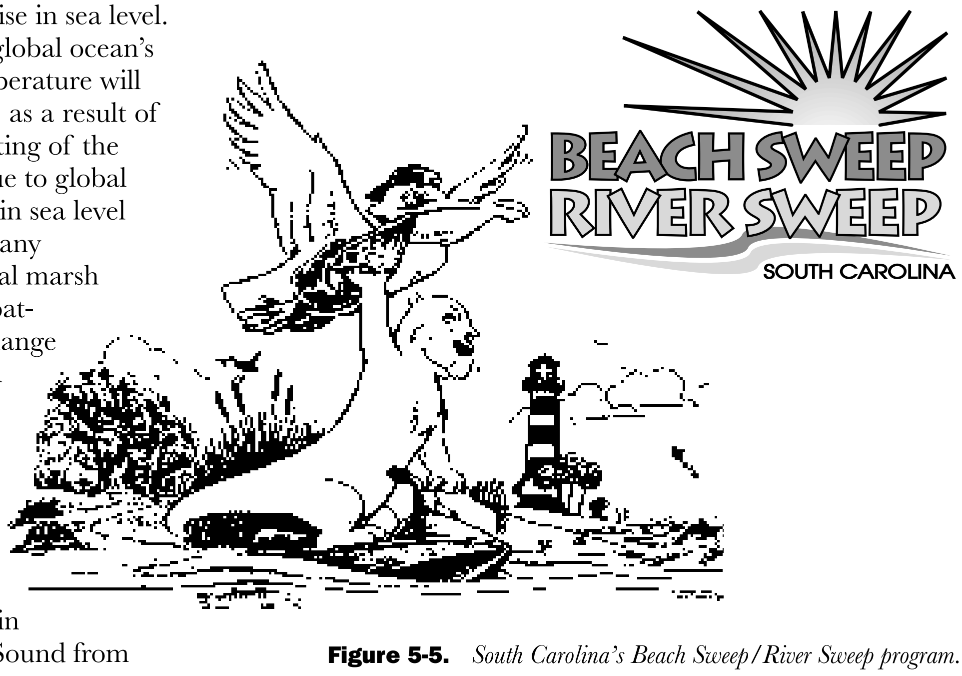



**Figure 5-5.** *South Carolina's Beach Sweep/River Sweep program.*

## D. Endangered and Threatened Species

As we discussed in Chapter 3, organisms develop very unique adaptations that allow them to survive in certain habitats. Adaptations enable organisms to fill very specialized niches within these habitats. An organism's niche affords an abundance of food, shelter, and protection from potential predators so that the organism survives and successfully reproduces, thereby ensuring continuation of its species.

Human activities, as we have seen, can alter the delicate balance of the environment. This "tilting of the balance" also expresses itself in the niches of many organisms. Slight alterations in habitat can cause organisms to compete with one another for a place within a niche. When this competition fails, the "losing" species can become extinct if it is unable to readily adapt to a new habitat and become successful in its new niche.

When a species becomes extinct, it is no longer in existence–it is lost to the world forever. Species that are termed "endangered" are in danger of becoming extinct because their populations have been reduced to very small numbers, usually as a result of negative human-induced impact upon the species itself or its habitat. Examples of extinct marine organisms include many species of invertebrates, such as the trilobites, which are "cousins" to shrimp and crabs. Trilobites were very similar to the modern horseshoe crab, which are, in fact, their only "living relative!" Many species of vertebrates, including fishes, have become extinct. Marine organisms currently in danger of becoming extinct include certain species of whales, seals, and sea turtles. Species that are "threatened" have decreasing population levels or could experience population decreases because their numbers or available habitat is decreasing. If population levels of these organisms continue to decline or available habitat continues to be lost, these threatened organisms could be listed as endangered, and ultimately, become extinct.

The passenger pigeon and the Carolina Parakeet once occurred in the Southeastern United States. They are now both extinct. Examples of endangered or threatened species in the region include the morning glory, the Venus' flytrap, the yellow honeysuckle, the ivory-billed woodpecker, the loggerhead turtle, the Eastern brown pelican, the Southern bald eagle, the wood stork, and the swallow-tailed kite.

## E. Our Coastal Heritage

Webster's dictionary defines heritage as "property that is or can be inherited," "something handed down from one's ancestors or the past," "ancestry," "gift," and "birthright." Coastal areas have been used by humans for thousands of years, as these areas were once inhabited by the Native American Indians. Humans have used these areas for cultivation and harvesting of food, commerce and trade, and defense of a young nation. Today, we use these areas for some of these same types of activities, but to a much larger degree. The coast is under more stress from human-induced activity than it has ever been before. With the startling projections of population increases in coastal areas around the country, this stress will only continue to increase.

It is our coastal heritage, or birthright, to protect our nation's waterways and coastline. Throughout each of these chapters, we have seen how valuable these areas are. They are home to the smallest of bacteria living in the sediment on the mud flat. They are temporary homes to a myriad of other organisms, including shrimp, crabs, and fishes, and other organisms that use these areas as nursery grounds. These coastal areas also supply an abundance of nutrients to near coastal waters. Organisms using coastal areas as nursery grounds eventually move offshore to their adult habitats, providing another link in the food web leading to higher level predators inhabiting offshore waters.

Crabbing, fishing, boating, walks on the beach at sunset, and adventures in "marsh classrooms" are just a few of the opportunities that we have been given as part of our coastal heritage. We have also received the contamination that has been handed down from past generations–generations that did not recognize the consequences of their actions. We now know what some of these consequences are, and it is our responsibility to pass this information on to others who have yet to learn. Finally, ensuring that these fragile coastal areas continue to exist for the responsible enjoyment of future generations is our obligation.

## F. Young Children and Environmental Stewardship: It's Our Responsibility

A steward is defined as "a person entrusted with the management of estates or affairs not their own." Environmental stewardship is, therefore, entrusting people to reasonably manage their activities so that they have minimal effects on our environment. Young students are, by far, the most receptive to becoming environmental stewards, or leaders. There are many ways to introduce children to environmental stewardship and teach them the proper behavior and actions that are so very critical to survival of all species on the Ocean Planet. Participation in the following activities are certain to instill some degree of environmental stewardship in your children:

- Use of hands-on activities in the classroom and understanding the connection and application of those activities to the environment
- Adopt-A-Beach/Adopt-A-Highway programs
- Beach Sweep/River Sweep, an annual cleanup
- Recycling programs at home or at school
- Membership in science clubs
- Family science enrichment programs
- Field trips to nature centers and other programs offering outdoor environmental education activities
- School gardens
- School nature trails and nature walks
- Classroom aquaria and other live educational exhibits
- Last, and most importantly, a teacher who is not afraid to say "I do not know" and who is willing to explore all possible answers with his or her students.

It is our hope that you have learned something about the marine environment from this text. We started this text with a chapter that described the Ocean Planet as a small, beautiful electric-blue sphere suspended by nothing in the black void of space. We have ended with a chapter focusing on how we, existing simply as another species on the Ocean Planet, have developed behaviors and technologies that alter this fragile ecosystem on a daily basis.

It has not been too many years ago that we were hearing discussions about how water supplies would one day not be fit for drinking. Many of us probably thought this "one day" would occur during some future generation–long after we ourselves or our families continued to exist on the Ocean Planet. Today, many of us purchase bottled water for our own homes. But we have a great advantage over all the other species on earth–we have the ability to reason and make intelligent decisions. This reasoning and ability to make intelligent decisions must guide our actions and change the affect that our actions have on the Ocean Planet.

So the next time you are out calmly cruising the creeks or walking along the edge of a salt marsh, consider the complexity and value of this environment. At the same time, consider point and nonpoint source pollution, marine debris, overharvesting of marine species, marinas, boat ramps, condominiums along the water's edge and the massive influx of people occurring at an alarming rate in coastal areas throughout the country. As educators, you should take the responsibility to impart some of this information to your young students to increase their awareness of this fragile marine environment. Maybe then, some of these future leaders will understand that fish, crabs, shrimp, and oysters do not always come surrounded with French fries and cocktail sauce. Perhaps, too, this next generation of leaders, residents, and visitors to these wonderful coastal environments will truly be environmental stewards–people we can trust "with the management of estates or affairs not their own."

*"Together we have an opportunity to enlighten the naive, encourage the complacent and empower a generation to protect our precious world."*

Ann-Margret

Photo by CHERIE PITTILLO

# About the authors....

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## Glossary

**abyssal plain**–large expanse of deep ocean bottom, located at depths of 3,000–5,000 meters. Abyssal plains are interrupted by ridges, trenches, and seamounts

**air bladder or swim bladder**–balloon-like internal organ functioning in buoyancy control; found in some fish

**anal fin**–stabilizing fin found on the ventral, posterior section of some fish

**Antarctic Bottom Water**–a deep ocean current formed by thermohaline (density-driven) circulation in the Atlantic Ocean

**aphotic zone**–the area of the ocean where light levels are too low to support plant growth

**atmospheric deposition**–the release, or deposition, of water and other chemical substances back into the ocean from the atmosphere

**aquaculture**–the intensive culture (growth in artificial conditions) of marine and freshwater organisms

**asthenosphere**–the portion of the mantle that underlies the lithosphere. The asthenosphere is solid rock that "flows," potentially allowing the overlying lithospheric plates to move horizontally.

**back marsh**–marsh that is located on the landward side of a barrier island, closest to the mainland

**barbels**–sensory structures, usually paired, found on the head or chin of some fish

**barrier island**–an island that is oriented parallel to the coast and affords protection to coastal shorelines

**bar**–coastal depositional feature comprised of mud, shell, and/or sand

**bathymetry**–ocean floor depth. A bathymetric map shows variations in the ocean floor depths

**bicarbonate**–a chemical ion ($HCO_3^-$) used by certain aquatic organisms in shell production

**bivalve**–a class of organisms belonging to the Phylum Mollusca; the soft bodies of these animals are covered by two shells, held together by a common valve, or hinge.

**benthic habitat**–habitat located on the ocean floor

**benthic zone**–the ocean floor

**bloom**–a rapid increase in abundance of an organism, typically associated with phytoplankton or zooplankton

**breaker**–a term used to describe a wave as it begins to "trip" over itself as it approaches shallow water

**brood**–to incubate, as in to brood eggs or young

**bulkhead**–a sloping man-made structure, often composed of large rocks, placed parallel to the beach to retard the rate of erosion

**buoyancy**–the ability to remain afloat in a liquid

**calcium**–a naturally-occurring chemical ion ($Ca^{2+}$) used by certain aquatic organisms in shell production

**carbon dioxide** ($CO_2$)–a naturally occurring gas, produced during the process of respiration and used during the process of photosynthesis

**carnivore**–a meat-eating organism

**caudal fin**–the posterior-most fin of a fish; the tail fin

**chemosynthesis**–a process by which organisms synthesize organic molecules by using energy derived from chemical reactions

**Clean Water Act**–Federal legislation enacted in 1972 to clean up the nation's waterways and bordering oceans

**community**–all of the species living in a defined area or environment

**consumer**–an organism that actively catches its prey or scavenges on dead, decaying plant and animal matter

**continental crust**–the portion of the Earth's outer layer (crust) that comprises continents

**Continental Drift Hypothesis**–the concept that continents "drift" across the ocean floor, developed by Alfred Wegener

**continental plate**–a lithospheric plate that consists primarily of continental crust

**continental rise**–the area of the deep ocean at the base of the continental slope, where the seafloor becomes less steep and flattens; occurs at depths of approximately 3,000 meters

**continental shelf break**–the transition between the continental shelf and continental slope, where the seafloor gradient increases rapidly

**continental shelf**–the uppermost part of a continental margin, adjacent to the coast

**continental slope**–the steepest area of the continental margin, just beyond the continental shelf

**Coriolis effect**–due to Earth's rotation, objects are deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere

**counter-shading**–a form of protective coloration where the dorsal (upper) surface of an organism is more darkly shaded than the organism's ventral (bottom) surface

**crest**–the highest part of a wave

**current**–movement of water caused by winds or density differences

**delta**–the feature made of sediments where a river meets the ocean (or a lake).

**density**–the ratio of mass (m) to volume (v) where $D = m/v$

**detritivore**–an organism that feeds on dead and decaying matter

**diatom**–microscopic unicellular plant

**dinoflagellate**–a microscopic protozoan that has some animal-like and plant-like characteristics

**dorsal**–the upper surface of an organism; opposite of ventral

**dorsal fin**–a stabilizing fin found on the dorsal surface of most fish

**ebb tide**–the outgoing tide, during the transition from high tide to low tide, when tidal currents move seaward

**echo sounding**–the pulsing and bouncing of sound waves from an instrument to an object and back to the instrument again; used to map the ocean floor (see sonar)

**ecosystem**–the living and non-living parts of an environment

**endangered**–a term used to describe an organism or group of organisms on the verge of extinction

**environment**–the external surroundings and conditions that affect the growth and development of organisms

**epifaunal**–organisms living on the surface of the ocean floor

**epipelagic zone**–the uppermost part of the pelagic zone that extends to about 200 meters depth

**estuary**–a semi-enclosed body of water, such as a harbor, bay, inlet, or sound, where fresh water and salt water meet

**excurrent siphon**–a small tube-like structure found in clams and other bivalves used to expel filtered water from the organism

**exoskeleton**–outer skeleton found on some marine organisms such as crabs, sand dollars, and sea stars

**extinct**–a term used to describe species that are no longer found living on earth

**eye spot**–a structure used to detect light and dark; found in some marine organisms

**fertilization**–the joining of male and female gametes (eggs and sperm)

**fetch**–the distance of the ocean (or other body of water) over which the wind blows

**filter-feeder**–an organism that filters its food from surrounding waters, such as a clam or an oyster

**finlet**–a very small modified fin found on some fish

**flood tide**–the incoming tide, during the transition from low tide to high tide, when tidal currents move landward

**food chain**–the intricate, often overlapping, feeding relationships that exist among producers, primary consumers, secondary consumers, and detritivores; also referred to as a food web

**food web**–the intricate feeding relationships that exist among producers, primary consumers, secondary consumers, and detritivores; also referred to as a food chain

**foot**–a muscular structure found in clams; used for burrowing

**gill**–a respiratory structure that functions in the exchange of gases ($O_2$ and $CO_2$) and other compounds between certain organisms and their environment

**groin**–a man-made structure placed perpendicular to the shoreline that extends from the upper edge of the beach to beyond the low tide mark; intended to retard the rate of erosion

**Gulf Stream**–one of the most well-known and most extensively studied surface currents; found on the western side of the Atlantic Ocean, traveling north

**gyre**–a large circular surface current; often covers a large portion of an ocean, as with the North Atlantic Gyre (includes the Gulf Stream)

**habitat**–the physical place where an organism or group of organisms lives

**hadal zone**–the deepest part of the ocean; begins at a depth of 6,000 meters

**herbivore**–an organism that feeds on plants

**hydrologic cycle**–a complex series of transport mechanisms by which water moves from the oceans onto land and back to the oceans again

**hydrosphere**–the water that covers the surface of the earth

**incurrent siphon**–a small tube-like structure found in clams and other bivalves; used to bring water into the organism from the surrounding environment

**infaunal organism**–an organism that lives within the sediment of the ocean floor

**jetty**–a man-made structure placed perpendicular to the shoreline, that extends seaward from the upper edge of a beach; typically used to stabilize an inlet to prevent migration; often placed at the entrance to harbors to slow the natural longshore drift of sand and subsequent sand build-up in the harbor

**lithosphere**–the rigid, brittle portion of the outer layers of the earth. The lithosphere is comprised of the earth's crust and the uppermost mantle

**lithospheric plate**–plates formed when the brittle lithosphere breaks into huge pieces

**littoral zone**–the intertidal zone

**longshore drift**–the movement of sediment parallel to the coast, along the beach; results from the zig-zag motion of breaking waves that meet the coast at an angle

**madreporite**–large pore located on top of the central disk of the sea star which allows ocean water to enter the organism

**magnesium**–a naturally-occurring chemical ion ($Mg^{2+}$), used by certain aquatic organisms in shell production

**metamorphosis**–distinct changes in body form that occur as an organism transforms from an embryo to the adult form

**Mid-Atlantic Ridge**–a long chain of submarine mountains found near the center of the Atlantic Ocean; formed by seafloor spreading

**molt**–the process by which an organism sheds its exoskeleton

**mud flat**–a coastal depositional feature composed primarily of fine silts and clay (mud)

**niche**–all of the physical and chemical factors affecting an organism's habitat, as well as the role that the organism plays in its habitat

**nitrate**–a naturally-occurring chemical ion ($NO_3^{2-}$) that serves as a nutrient to aquatic organisms; the most common form of nitrogen (N) found in the ocean

**neap tide**–when tidal range is less than the average; occurs twice a month during the two quarter phases of the moon, when the sun and moon are at a right angle relative to the Earth

**neritic zone**–the part of the pelagic zone that extends from the high tide mark seaward to a depth of approximately 200 meters

**nonpoint source pollution**–pollution that cannot be attributed to a single source

**North Atlantic Deep Water**–a deep ocean bottom current in the Atlantic Ocean formed by thermohaline (density-driven) circulation

**North Atlantic Gyre**–a large circular surface current that rotates clockwise in the Atlantic Ocean in the Northern Hemisphere; includes the Gulf Stream

**nourishment/renourishment**–a man-made attempt to redirect or replenish sand on beaches, so as to retard the rate of erosion

**nursery**–an area of high productivity where organisms in their early life cycle stages find an abundance of food and protection from predators

**ocean basin**–each of the Earth's four major oceans is defined by the basin-like appearance of its seafloor

**oceanic crust**–the portion of the Earth's outer layer that is formed at spreading ridges and is the solid rock that underlies ocean sediments

**oceanic zone**–the part of the pelagic zone that extends from 200 meters depth seaward to deep ocean waters

**oyster reef (or bed)**–a unique coastal habitat composed primarily of oysters and vacated oyster shells

**ozone layer ($O_3$)**–found in the Earth's upper atmosphere; acts as a protective layer by reducing the amount of ultraviolet radiation that reaches the Earth's surface

**Pangea (or Pangaea)**–the supercontinent that existed more than 240 million years ago, the break-up of which led to the development of our modern continents

**pectoral fins**–a pair of lateral fins used for swimming in fish

**pelagic habitat**–the open ocean

**pelagic zone**–the area of the open ocean located just below the ocean's surface

**pelvic fins**–paired fins on the ventral surface of fish; function in steering in some fish

**photic zone**–the area of the ocean where light penetrates enough to support plant growth

**phytoplankton**–small plants that float with the ocean currents, most of which are photosynthetic

**phosphate**–a chemical ion ($PO_4^{3-}$) that serves as a nutrient to aquatic organisms; the most common form of phosphorus (P) found in the ocean

**photosynthesis**–the process by which plants use energy from the sun to transform carbon dioxide ($CO_2$), water ($H_2O$), and nutrients, such as nitrate ($NO_3^{2-}$) and phosphate ($PO_4^{3-}$), into a usable form of food and consequently, energy. Oxygen ($O_2$) is given off as a byproduct

**pincer**–a modified appendage that functions in feeding and protection in some crustaceans (e.g., crabs)

**plankton**–generally small plants and animals that float with currents near the ocean's surface; plankton typically are not strong swimmers, if they swim at all

**plate boundary**–the edge of a lithospheric plate

**plate**–see lithospheric plate

**point source pollution**–pollution that can be connected to a single source

**Polar Easterlies**–winds that blow from east to west in the polar regions

**population**–a group of organisms of the same species living in a defined area

**predator**–an organism that feeds on other organisms; usually refers to animals that hunt and eat other animals

**primary dune system**–the line of sand dunes closest to the water's edge

**primary producer**–a green plant that produces its own food through the process of photosynthesis

**primary productivity**–related to the amount of photosynthesis occurring in a certain region

**producer**–an organism that produces its own food; for example, green plants make their food through the process of photosynthesis

**protandry**–a form of sexual hermaphroditism; an organism matures first as a male, spawns for several years as a male, then undergoes sexual transition as it transforms into a female, living the remainder of its life as a female

**protective coloration**–an adaptive color trait that aids an organism in avoiding predators

**protogynous**–a form of sexual hermaphroditism; an organism matures first as a female, spawns for several years as a female, then undergoes a process of sexual transition as it transforms into a male, living the remainder of its life as a male

**protozoan**–a microscopic unicellular organism

**renewable resource**–a resource that is unlimited in its bounty and ability to renew itself, such as energy from the sun

**rocky outcrop**–rocks and overhanging ledges that are exposed on the seafloor and form unique marine habitats; also known as live bottom or hard bottom habitats

**salinity**–total amount of dissolved inorganic salts in the ocean; expressed in parts per thousand, or ‰

**sand bar**–a coastal depositional feature composed primarily of sand; forms elongate bottom features; sometimes exposed at low tide

**sand flat**–a coastal depositional feature comprised primarily of sand in a broad, flat area; often exposed at low tide

***Sargassum***–a floating brown alga abundant in the Atlantic Ocean's Sargasso Sea

**seamount**–a volcano that has its origin on the seafloor. Seamounts that grow above sea level are most often referred to as volcanic islands.

**seawall**–a man-made solid vertical structure constructed parallel to the beach; intended to retard the rate of erosion and protect beaches or buildings

**secondary consumer**–an organism that feeds on other consumers

**secondary dune system**–a system of sand dunes located landward of the primary dune system

**semidiurnal**–occurring twice in a 24-hour time period, as with semidiurnal tides

**simultaneous hermaphroditism**–a form of sexual hermaphroditism in which both male and female sex organs are present in the same individual

**slack tide**–the time just before the tide turns during which there is very little tide-induced water movement

**sonar**–the pulsing or bouncing of sound waves from an instrument to an object and back to the instrument again; used to map the ocean floor (see echo sounding)

***Spartina alterniflora***–smooth cord grass found in saltmarsh and wetland areas

**spawn**–to release gametes (eggs or sperm)

**spit**–the elongate extension of sand on the downdrift end of a barrier island; formed as a result of longshore drift

**spring tides**–when tidal range is greater than the average; occurs twice a month, during the full and new moon phases, when the sun, Earth and moon are arranged in a line

**stormwater runoff**–refers to rainwater as it flows over and through the ground

**supratidal environment**–any coastal area that is above the high tide mark

**surface current circulation**–the movement of water as the result of wind motion along the surface of the open ocean

**swash**–the movement of the waves up onto the beach as they break and release energy

**swim bladder or air bladder**–a balloon-like internal organ functioning in buoyancy control; found in some fish

**synchronous hermaphroditism**–a form of sexual hermaphroditism in which an organism spawns for several years as one sex, undergoes sexual transition, actually "turning into" the opposite sex, and lives the rest of its life as the sex that it transformed into

**thermohaline circulation**–temperature and salinity-driven (i.e., density-driven) circulation of water masses throughout the ocean (surface and deep)

**Thermal Convection Hypothesis**–the concept that convection cells of heat within the Earth's mantle generate the energy that ultimately drives the lithospheric plates on the Earth's surface

**thermocline**–where temperature changes rapidly; typically in the upper 75 meters of the ocean's surface

**threatened**–refers to organisms in danger of becoming extinct

**tidal bulge**–the elevated portion of the sea surface (i.e., high tide) that results from the "pull" of gravitational attraction between the Earth and moon (and from the Earth and sun)

**tidal cycle**–the complete cycling from one high tide to the next high tide

**tidal range**–the vertical difference in the height of the water between high and low tides

**tides**–the periodic rise and fall of the ocean's surface due to the gravitational attraction on the Earth by the moon and sun

**top-level consumer**–an organism near or at the top of a food chain or food web

**topography**–the shape of the surface of land above sea level

**Trade Winds**–the major surface currents driven by winds which blow from east to west at about 20 degrees of latitude

**trophic levels**–different "levels" of feeding, as in a food web

**trough**–the lowest part of a wave; between two crests

**tube feet**–special suction cup feet found in sea stars

**ventral**–the underside surface of an organism; opposite of dorsal

**watershed**–all precipitation that falls over a specific geographic region that is physically separated from other drainage basins by areas of higher elevation. This precipitation accumulates in streams, rivers, lakes, and ultimately the ocean.

**water vascular system**–specialized system that aids the sea star (and its nearest relatives) in locomotion and with obtaining its food

**wave height**–the vertical distance between the trough and crest of a wave

**wave length**–the horizontal distance between the crests of two successive waves

**Westerlies**–winds that blow from west to east along the 40-50 degree latitudes

**wetland**–an area of gradual transition where land meets water; classified by water saturation for specific time periods annually.

**zooplankton**–small animals that float with the currents at the ocean's surface; these organisms cannot significantly alter their position in the water column

## References

**Adkins, A.T.**, (Editor). 1982. *Understanding Our Coastal Environment.* South Carolina Coastal Council, 40 p.

**Ballantine, T.** 1991. *Tideland Treasure.* University of South Carolina Press, South Carolina, 218 p.

**Castro, P. and M.E. Huber**. 1997. *Marine Biology*. Wm. C. Brown Publishers, Iowa, 450 p.

**Coulombe, D.A.** 1992. *The Seaside Naturalist*, Simon & Schuster, New York, 246 p.

**Garrison, T.** 1996. *Oceanography—An Invitation to Marine Science*, Wadsworth Publishing Company, California, 567 p.

**Gosner, K.L.** 1987. *A Field Guide to the Atlantic Seashore from the Bay of Fundy to Cape Hatteras*. Houghton Mifflin Company, Boston, 329 p.

**Greene, T. F.** 1998. *Marine Science*. Amsco School Publications, Inc., New York, 580 p.

**Hayes, M.O. and T.W. Kana**, Editors. 1980. *Terrigenous Clastic Depositional Environments*, University of South Carolina Press, Technical Report No. 11-CRD, 316 p.

**Kana, T.W.** 1988. *Beach Erosion in South Carolina*, South Carolina Sea Grant Consortium Special Publication SCSG-SP-88-1, 55 p.

**Kaufman, W. and O. Pilkey** 1983. *The Beaches are Moving*. Duke University Press, Durham, NC, 336 p.

**Meyer, P.** 1992. *Nature Guide to the Carolina Coast.* Avian-Cetacean Press, North Carolina, 148 p.

**Natural Resources Defense Council**. *Ebb Tide for Pollution: Actions for Cleaning Up Coastal Waters*. Natural Resources Defense Council, Washington, 43 p.

*Report of the Governor's Freshwater Wetlands Forum*. 1990. Springs Foundation, Inc., South Carolina, 52 p.

*South Carolina Public Beach & Coastal Access Guide*. South Carolina Department of Parks, Recreation & Tourism and the South Carolina Coastal Council, 127 p.

**Sumich, J.L.** 1976. *An Introduction to the Biology of Marine Life*. Wm. C. Brown Company Publishers, Iowa, 348 p.

**Turekian, K.K.** 1976. *Oceans*. Prentice-Hall, Inc. New Jersey, 149 p.

**Weber, M. and R. Tinney**. 1986. *A Nation of Oceans*. Center for Environmental Education, Inc. Washington, 95 p.

**Wells, J.T. and C.H. Peterson**. *Restless Ribbons of Sand—Atlantic & Gulf Coastal Barriers*, Louisiana Sea Grant College Program, Louisiana, 19 p.

**Williams, S.J., K. Dodd, and K.K. Gohn**. 1991. *Coasts in Crisis*. U.S. Geological Survey Circular 1075, 32 p.

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