Scope, Sequence & Coordination

A National Curriculum Development and Evaluation Project for High School Science Education

A Project of the National Science Teachers Association

This project was suppported in part by the National Science Foundation.
Opinions expressed are those of the authors and not necessarily those of the Foundation.

Scope, Sequence & Coordination

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** Not part of the NSF-funded SS&C project.

Student Materials

Learning Sequence Item:

948

Examples of Convection

March 1996
Adapted by: Patricia Allick

Contents

Lab Activities

Readings

This micro-unit was adapted by **Patricia Allick** (Kalispell Junior H.S., Kalispell, Mont.)

Science as Inquiry

We Just Don't Mix

Procedure:

Stick the straw in the potato (or clay), at an angle. Don't push the straw all the way through. Test for leaks. Add small amounts (about 1 cm) of each solution to the straw until you produce three distinct layers that do not mix. If solutions mix, empty the straw into the waste container (extra beaker or cup), and try again.

Questions:

1. What was the final order of the colored solutions?

2. Match the colored solutions to the following: river water (fresh), brackish water, ocean water(salt). Explain your choices.

3. You are at a coastline where a river is flowing into the ocean. Where would you predict the water would be the saltiest—near the surface, in the middle, or toward the bottom? Explain your answer.

Science as Inquiry

Soda Straw Float

Procedure:

Obtain a piece of masking tape over 8 cm long. At one end, draw an 8-cm-long line. Using the ruler and marker, mark off each millimeter—making an extra long mark every 5 mm. Label the long marks 0, 5, 10, etc., up to 80 mm (8.0 cm). Starting at one end of the straw, wrap the tape as shown. To the other end of the straw, add a small ball of clay—making a water tight seal. Fill the container with 1L of water and float the straw, in the container, in an upright position. Record the reading on your straw hydrometer. Add 10 g of salt to the container and stir. Use your straw hydrometer to measure the level again and record your result. Continue this procedure until you have added 50 g of salt.

Questions:

1. Use your data to create a graph showing the relationship between the readings on the straw hydrometer and the water's salinity.

2. Explain the relationship between the density of water and the amount of salt (salinity).

Science as Inquiry

Look Ma, I Can Float!

Procedure:

Using the graduated cylinder, fill the jar or beaker 3/4 full of cool tapwater, and record the amount in mL. Place the hard-boiled egg on the spoon and slowly lower (not drop) the egg into the water, record your observations and then remove the egg. Measure 10 mL of salt in the metric measuring spoon—using the ruler to level the salt. Add the salt to the jar or beaker and stir until the salt dissolves. Place the hard-boiled egg back in the beaker, and record your observations. Repeat removing the egg and adding salt until a change is seen. You can also use the straw hydrometer you made in a previous activity and use it to check relative density after each step.

Questions:

1. What happened when the egg was placed in fresh water?

2. Compare the density of the egg to the density of fresh water and explain your answer.

3. What differences were seen when the egg was added to the salt water compared to the fresh water?

4. Compare the density of the egg to the density of the salt water and explain your answer.

5. Explain the relationship between the salinity (salt concentration) and density of water.

6. Why is it easier to swim in the ocean than in a pond or a swimming pool?

7. Based on the class results, calculate the average salinity(g of salt per 1000 mL) of water required to float the egg. Using the class average find how much salt would be needed to float an egg in 10 L of water. Show your math.

Student Sheet

Science as Inquiry

Currently, Deep in Thought

Procedure:

Fill three of the bottles with the same temperature tap water. Make a saturated salt solution and pour in the fourth bottle. Label the fourth bottle “salt solution.” Add five drops of food coloring to the bottle of saltwater and five drops to one of the bottles of tap water. The two bottles of blue water will be inverted over the two bottles of clear water. Write a hypothesis of what you think will happen. Put the index card over the bottle of blue tap water and invert. Carefully, place this inverted bottle directly over one of the bottles of clear water and slowly remove the card. *Don’t bump the table!* Do the same with the bottle of blue salt water and the remaining bottle of clear water. Write down your observations.

Questions:

1. Draw what you saw.

2. Did the results match your hypothesis? If they did explain why, and if they didn’t, explain why.

3. If cold, dense, salt water is found near the poles, describe how this water would act and where it would go. Use drawings to help with your explanation.

Science as Inquiry

Not Too Much, Not Too Little

Procedure:

On the bottle supplied by your teacher, draw a line on the bottle 2/3 of the way up the container. Attach the bottle to the faucet or water supply with a rubber hose. Write down your prediction of what will happen when the water supply is turned on. Reduce the flow to the bottle and write down your observations. Increase the flow to the bottle and write down your observations. Plug a few of the holes and write down your observations.

Questions:

1. Describe when your system seemed to be stable or in "equilibrium."

2. What continually changed in your system even when it was in equilibrium?

3. There are many natural systems on the earth that are in a state of "dynamic equilibrium." Name one natural system and explain why the system is in dynamic equilibrium.

Science as Inquiry

Living Reefs, Living Oceans

A reef is a rocky structure extending upward from the bed of the sea to within a short distance of the ocean the surface. If a reef is located near shore, the top of it may be exposed at low tide.

For mariners, '"reef" has a very specific definition as any rocky structure found within 11 meters (36 feet) of the ocean surface at low tide. Sailors must be wary of reefs, since many ships (and lives) have been lost by running aground on reefs.

Swimmers must also beware of reefs, especially those that are submerged below the ocean surface. I can testify from personal experience that getting swept across a submerged reef by an unexpected wave is very painful (and bloody)! But reefs are not just dangerous; they are also focal points for a wide range of marine life.

As a scuba diver, I've long been fascinated by the beauty and diversity of reef structures and life, particularly coral reefs in warm tropical waters. In this column we'll look at reefs and how they serve as habitats for a variety of life.

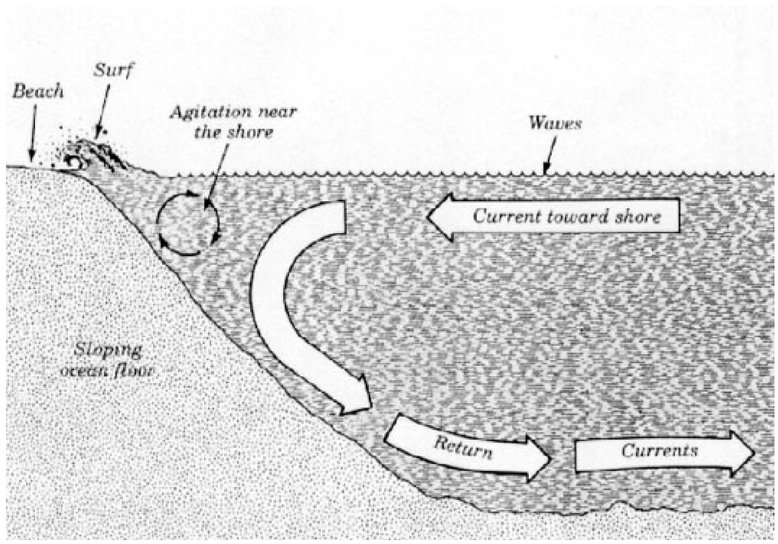

Fig. 1. Ocean currents "recirculate" unimpeded on shore lines without reef structures.

The Coastline and Reefs

One definition of a reef is a natural, rigid, and wave resistant structure. "Wave resistance" is an important reason why reefs are habitats for many forms of marine life.

Not all ocean shores have reef structures. Many coastlines are like the one shown in Figure 1. Waves are able to move unimpeded to the shore. These waves recirculate water, sand, and other materials as shown, creating a continuous turbulence along the coast. Some ocean life benefits from this circulation, as a continuous stream of nutrients is present. The sand crabs that burrow into the sandy bottom of the shoreline of the Atlantic Coast of the southern United States are examples of the life that has adapted to the coast in Figure 1.

The problem for many marine life forms is that they need some sort of "anchor" or adaptive behavior (such as dwelling on the bottom near the

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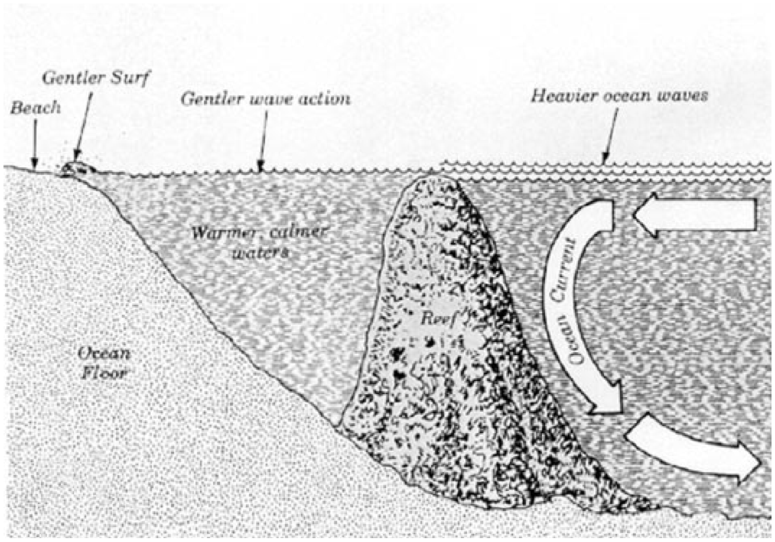

Fig. 2. Reef structures moderate the effects of the ocean currents and provide "anchors" and shelter for different types of marine life.

shore) to keep them from being recirculated by the ocean currents. For this reason, many fish also avoid the area near the shore.

Now look at Figure 2. This reef structure intercepts the brunt of the wave action and provides a secure foundation for several types of marine life, such as barnacles, mussels, starfish, and sea urchins, to attach themselves.

Many reefs like the one in Figure 2 roughly parallel the shoreline where they form a barrier to ocean waves. These barrier reefs are not continuous, but instead have several openings (or channels) which lead to the open sea. The water between the reef and shore, while still subject to tidal forces and currents, is far less turbulent than that shown in Figure 1. If the barrier reef is extensive, as often is the case in tropical waters, a relatively calm lagoon will be formed. Other reefs extend from the shore to the open sea. These are called fringing reefs.

Those animals which attach themselves to reefs can often be seen at the top of reefs at low tide. (I've noted spectacular starfish "clumps" atop reefs on the Oregon coast at low tide.) More mobile marine life, such as fish and crustaceans, make their homes along reefs. This is because reefs are rich sources of food such as algae. Reefs also offer shelter from predators and numerous places to lay eggs.

While diving in the waters of southern California, I've surprised—and been surprised by—lobsters that make their homes on the reefs there. Reefs also blunt the effects of waves and tides, and the resulting calmer waters are more hospitable to such animals.

The water of the lagoons produced by barrier reefs tends to be warmer than the oceans they're isolated from. The isolation from the rest of the sea lets the sun heat the lagoon waters, providing a suitable environment for fish and other life that thrive in warmer water.

Types of Reefs

One way to classify reefs is by their composition. Inorganic reefs are basically little more than ordinary rocks located offshore. Inorganic reefs are produced by the same geologic forces that produce the onshore terrain. However, the waves and tidal currents often shape inorganic reefs into very different forms than their land-based counterparts.

While such reefs are inorganic in origin, they often become home to some types of marine life, such as barnacles and oysters, which can leave behind deposits and shells that become part of the reef and add to it. By the way, artificial reefs have been created by sinking ships in shallow water near the shore.

Like natural rocks, these soon become home to numerous marine animals.

Organic (or biogenic) reefs are those formed as a by-product of the life processes of marine animals, such as reefs composed of the shells of marine mollusks, sponges, and even certain types of algae. But when most people think of reefs—whether organic or inorganic—they usually think of coral reefs. This isn't surprising, since coral reefs are stunningly beautiful. But coral reefs are more than just pleasing to the eye. They are incredibly complex ecosystems built from the skeletons of millions of tiny coral animals.

Over several years, the skeletons create intricate limestone formations of delicacy and beauty. Coral can resemble fans, pipes, domes, tree branches, mushrooms, lettuce leaves, and even the human brain. Those fanciful shapes are home to fish, algae, and other marine life that find food and protection within the reef. In a literal and figurative sense, a coral reef is alive.

Let's pay a visit to a coral reef and observe firsthand the life processes taking place there.

How Coral Reefs Form

Reef-forming corals mainly grow only in waters whose normal temperature is at least 18 degrees Celsius (65 degrees Fahrenheit). However, small patches of coral can be found in waters as far north as New England. Coral reefs are common in southern Florida and the Caribbean, much of the Pacific Ocean between the tropics, much of the northern Indian Ocean, and the coast of Brazil. The northernmost coral reefs are found in Bermuda, where the waters of the Gulf Stream counteract Bermuda's location east of North Carolina.

Coral reefs can grow to extraordinary size. Many islands in the South Pacific are composed entirely of coral, while the largest coral reef, Australia's Great Barrier Reef, extends for over 2,000 kilometers (1,250 miles).

Individual coral animals are known as polyps. Most are less than 2.5 centimeters (1 inch) in diameter and are cylinder shaped. One end of the polyp can attach itself to hard surfaces such as other coral or rocks. The other end of the polyp is a mouth surrounded by tentacles that steer food into the opening.

Coral polyps feed on the tiny swimming larvae of shellfish and food "manufactured" by algae living within the tissues of the polyps. Algae play an indispensable role in the ecology of a coral reef. The same algae within coral polyps that produce food for them also help coral secrete limestone (calcium carbonate) which forms the skeletons for coral. Coral animals take calcium from seawater, and use chemicals produced by the algae to form their limestone skeletons. This means that coral reefs can only form in waters and at depths that allow enough sunlight to penetrate and allow photosynthesis in the algae.

Coral polyps live together in colonies and attach themselves to each other by a layer of tissue located at the middle of each polyp. Limestone is secreted below this layer of tissue, and as the polyps grow the colonies form the kind of formations you can see in the accompanying photographs. As the coral animals die, new generations build atop the limestone skeletons, forming massive reefs over time.

Most coral animals have external limestone skeletons like those we've discussed so far. these are known as stony corals. But some corals have internal skeletal structures.

Coral jewelry is made from the so-called precious corals. The internal skeletons of these species can have red, rose, or pink coloration, and can be cut into various shapes and polished to gem-like brightness. Precious corals are found in the Sea of Japan and the Mediterranean Sea, where they grow in bush-like formations.

Other forms of coral with internal skeletons are gorgonian corals. These corals are extremely flexible, and look like undersea bushes as they move in the ocean currents. Gorgonian corals are yellow, rose, purple, brown and black. They are often found in the West Indies.

Coral Atolls

An atoll is an island composed of coral. They are especially common in the Pacific Ocean. Atolls are ring-shaped, and are usually a result of volcanic activity.

The Pacific is littered with the submerged remnants of volcanoes, with many sources placing the total number at over 10,000. Many of these volcanoes at one time extended above the level of the sea, but have gradually been eroded so that their tops have been submerged. However, these extinct volcanoes still have a flattened top. They are named guyots after the French geographer.

When the top of the volcano is above or near the surface of the ocean, a coral reef can develop. Over hundreds of thousands or even millions of years, the level of the sea will rise and fall. When the sea level falls, the coral will be exposed, die, and become part of a limestone foundation atop the guyot. When the sea level rises, another coral reef will form around the guyot.

As this cycle repeats, in time an island of coral will form. A lagoon will form in the middle of the atoll, and there will be some channels leading to the open sea.

Many well-known islands in the Pacific Ocean are atolls, including Wake Island, the Marshall Islands (including Eniwetok), the Society islands (including Tahiti), Samoa, and the Gilbert Islands. The northernmost islands in the Hawaiian archipelago, such as Kure and Midway Islands, are also atolls.

With continued erosion and future cycles of rising and falling sea levels, many of the current populated Hawaiian islands may wind up as atolls. Meanwhile, an undersea volcano south of Hawaii will eventually emerge from the sea.

THE REEFS OF WEST TEXAS

In October of 1987, I saw some of the most-impressive reef formations I've ever seen. I was in West Texas near the New Mexico state line and no ocean was anywhere in sight. (Nor, for that matter, was much of a man-made nature.) I was in the Guadalupe Mountains National Park, and I was looking at the fl Capitan Reef, a fossil reef structure formed millennia ago when the Guadalupe Mountains were lifted above what was once an ocean. These mountains rise sharply and abruptly from the desert floor, and are visually striking.

The Guadalupe Mountains are the highest mountains in Texas, topped by Guadalupe Peak at 2,667 meters (8,749 feet). They once were part of the shore line of an extensive sea that covered large parts of what are now West Texas, eastern New Mexico, Oklahoma, and Kansas. This sea is believed by geologists to have formed some 280 million years ago during the early Permian period of the Paleozoic era. The area once covered by that sea is known as the Permian Basin. Geologists further divide the Permian basin into several separate "subbasins," such as the Delaware, Marfa, and Midland basins of West Texas.

Today the Permian Basin is a rich producer of oil and natural gas because of hydrocarbon deposits left by the ancient seas. Pumping jacks and oil storage tanks are a common sight on the way to the Guadalupe Mountains.

At the end of the Permian era, faulting lifted the banks and reef formations of the shore line and over the centuries thrust them skyward to become part of the mountain range. The seas were isolated and eventually vanished, and the marine life contained in them is believed to have formed the oil and gas deposits found in the Permian basin today. A legacy of these seas bedevils oil and gas developers today—many exploratory wells drilled in Texas and Oklahoma produce salt water instead of hydrocarbons! Further north in Kansas are several subterranean salt deposits.

The El Capitan Reef is not a coral reef; instead, it is composed mainly of limestones and other carbonates precipitated by ancient reef animals. Numerous fossils of those animals can be found in different sections of the reef. The Guadalupe Mountains National Park has several hiking trails so that you explore these formations, including a trail to the summit of Guadalupe Peak. [Further north in New Mexico, you can see the reef from the inside by taking a tour through Carlsbad Caverns. Editor]

Oyster Reefs

Coral isn't the only kind of marine life that can "grow" a reef. While coral reefs are better known and far more beautiful, a common type of seafood builds more reefs along the coasts of the United States and the rest of the world than coral. This active reef builder is the humble, homely, but (to this writer!) delicious oyster.

Oysters are bivalve mollusks found in coastal areas and estuaries through the world. Mature female oysters produce millions of eggs each year, but only a few larvae survive the one to five years needed to become adults. Oyster larvae select safe areas to grow to maturity, with shells of live adult oysters being a favorite spot. If live adults aren't available, dead shells are used. Oyster larvae tend to settle together, and as their shells develop they become cemented' to each other and to rocks. As years pass, reefs form from these accumulated oysters. Barnacles and other mollusks also attach themselves to the reefs and help bond the oysters together.

An oyster feeds itself by pumping many liters of water each hour and catching plankton and food particles on a mucous "net" near the mouth. However, not all food particles are consumed by the oyster. These are recirculated by flowing water to other oysters and filter-feeding animals on the reef, creating a beneficial relationship between the oysters and other reef animals.

In the United States, oyster reefs are common in tidal flats, partially enclosed bays, and river mouths where the water salinity is moderate. Such environments let oysters survive, but diseases and their major predators cannot. Some of the largest and most extensive oyster reefs in the United States are found in Chesapeake Bay.

Coral Reefs as Life Havens

I've gone scuba diving among coral reefs in Florida and Hawaii, and the most striking thing about them is not the coral formations themselves. Instead, it is the incredible array of life that finds a home on and among coral reefs. It was this profusion of life that first attracted Charles Darwin's attention to coral reefs. In fact, Darwin was the first person to use the terms "barrier,'" "fringing," and "atoll'' to describe different types of Coral reefs. Algae is found throughout coral reefs. Algae covers coral formations and other rock structures of the reef, and gives them such colors as bluish-green, red, green, and brown. Algae provides abundant food for fish and other animals. Many fish "graze" like cattle on the reef, scraping the surface of the formations with their mouths for the algae. Other fish—like the bullethead parrot fish commonly seen in Hawaiian waters—actually bite out little chunks of the reefs (fortunately, usually dead coral), crush it in their mouths, filter out the algae, and then "spit out" the crushed limestone into the water.

I've had the opportunity to watch parrot fish feed during my dives and distinctly heard tearing and crushing noises as they bit off and chewed pieces of the reef. A few seconds later, the parrot fish expelled small milky "clouds" of powdered limestone from their mouths, much like a cigarette smoker exhaling!

The relationship between coral reefs, algae, and fish is one of mutual benefit, or symbiosis. While reefs provide food through algae, the fish also keep the amount of algae growing on the reef under control. Without the fish that feed on it, the algae would overgrow and eventually kill the coral colonies. Yet the coral colonies need some level of algae to produce their limestone skeletons. Surprisingly, the more types of algae-eating fish that are present on a reef, the more different types of algae that are found on the reef.

Besides food, coral reefs offer protection from predators. Their many nooks and crannies provide many hiding places for fish and other animals. For example, the parrot fish is mainly active during the day. At night, it backs into crevices and openings in the reef. Other fish reverse this pattern, hiding during the day and feeding at night. Despite this protection, many reef fish wind up as food for other fish (such as sharks) or other marine animals.

The reef environment is favorable for animals such as clams that feed by filtering food from the water. Abundant food particles and nutrients rapidly circulate within coral reefs. In fact, the limiting factor to the number of filter-feeding animals found on coral reefs is the availability of space for "anchoring" on the reef, not the amount of food.

Coral polyps themselves are a food source for other marine animals, with the crown-of-thorns starfish being notable for the damage it has done to some reefs. In most cases, however, any losses are easily offset by development of new coral colonies and growth in existing ones. A more serious danger to many coral reefs comes from large, air-breathing mammals normally found on land—man. In years past, many thoughtless souvenir hunters have broken off large sections of coral reefs. Thankfully, most divers today are well aware of the fragile nature of coral reefs and go to great lengths to take only photographs and memories from them.

The sex life of a coral polyp is interesting, since it can reproduce either sexually or asexually by budding. In conventional sexual reproduction, a mature coral polyp will produce both spermatozoa and eggs. The eggs remain attached within the polyp. When the spermatozoa reach a certain maturity, they will flow through the mouth of the polyp and float in the sea water until they reach other polyps. The other polyps draw the spermatozoa inside them by using their tentacles. Once inside, the spermatozoa fertilize the other polyp's eggs. Once the eggs are fertilized, the eggs are released and flow through the mouth of the polyp like the spermatozoa did.

Once the eggs hatch, the resulting coral larvae settle to the sea bottom and begin to form new colonies. These new colonies grow by budding. At various times, small, knobby "bud" of tissue form on the body of adult polyps or on the connecting tissue between polyps. As these buds grow larger, they separate from the "parent" polyps and begin to secrete limestone on their own.

Visiting a Reef

Fortunately, you don't have to be a certified scuba diver to explore a reef. Due to the relatively shallow waters most are located in, snorkeling is a fun way to see reefs and their life processes for yourself. If you can swim, glass-bottom boats offer trips over coral reefs in such tourist areas as the Florida Keys, the Caribbean, and Hawaii.

Two of my favorite coral reefs that I never tire of exploring are John Pennekamp State park on Florida's Key Large and Kealakekua Bay on the Big Island of Hawaii. Both of these can be explored by either snorkeling or scuba diving.

While southern California's coastal waters are too cold to support coral reefs, there are many inorganic reefs located within a short swimming distance of the shore in many areas. These reefs are heavy with algae and let you observe many of the life processes discussed in this column. However, for southern California reef exploration you'll need to be a good swimmer (many are located in waters with strong currents) and a wetsuit will probably be necessary for comfort even in mid-summer.

Organic reef formations produced by animals such as oysters are located in many coastal areas. Local scuba diving shops are good sources of information on interesting reefs in an area. They can also give you details about any potential dangers (such as currents) you need to be aware of. Dive shops in such as areas as Florida, Hawaii, and the Caribbean often conduct guided snorkeling and diving trips to local reefs. ★

Science as Inquiry

Nature's Most Violent Storms

Destructive tornado over Manitou Springs, Colo., at the foot of Pikes Peak on June 24, 1979. Funnel never extended more than 30–40% downward to surface from parent cloud base.

A tornado is a violently rotating column of air extending from a thunderstorm to the ground. Although the average speed of a tornado is 30 mph, some have reached speeds of 250 mph.

Although tornados occur in many parts of the world, these destructive forces of nature are found most frequently in the United States east of the Rocky Mountains during the spring and summer months. In an average year, 800 tornados are reported nationwide, resulting in 80 deaths and over 1,500 injuries.

A tornado is defined as a violently rotating column of air extending from a thunderstorm to the ground. The most violent tornados are capable of tremendous destruction with wind speeds of 250 miles per hour or more. Damage paths can be in excess of 1 mile wide and 50 miles long. Once a tornado in Broken Bow, Okla., carried a motel sign 30 miles and dropped it in Arkansas.

What Causes Tornados?

Thunderstorms develop in warm, moist air in advance of eastward-moving cold fronts. Before they develop, a change in wind direction and an increase in wind speed with increasing height creates an invisible, horizontal spinning effect in the lower atmosphere. These thunderstorms often produce large hail, strong winds, and tornados. Rising air within the thunderstorm updraft tilts the rotating air from horizontal to vertical. An area of rotation, 2-6 miles wide, extends through much of the storm. Most strong and violent tornados form within this area of strong rotation. Tornados in the winter and early spring are often associated with strong frontal systems that form in the central states and move east. Occasionally, large outbreaks of tornados occur with this type of weather pattern. Several states may be affected by numerous severe thunderstorms and tornados.

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During the spring in the Central Plains, thunderstorms frequently develop along a “dryline,” which separates very warm, moist air to the east from hot, dry air to the west. Tornado-producing thunderstorms may form as the dryline moves east during the afternoon hours.

Along the front range of the Rocky Mountains, in the Texas panhandle, and in the southern High Plains, thunderstorms frequently form as air near the ground flows “upslope” toward higher terrain.

If other favorable conditions exist, these thunderstorms can produce tornados.

There are many variations in tornados. Some may form during the early stages of rapidly developing thunderstorms. This type of tornado is most common along the front range of the Rocky Mountains, the Plains, and the western states. Some may appear nearly transparent until dust and debris are picked up. Occasionally, two or more tornados may occur at the same time.

Shapes and Sizes

Tornados are classified as weak, strong, or violent. Weak tornados account for 69% of all tornados, cause less than 5% of tornado deaths, have a lifetime of 1-10+ minutes, and have winds less than 110 mph. Strong tornados account for 29% of all tornados and 30% of resulting deaths. They may last 20 minutes or longer and have winds of 110–205 mph. Violent tornados account for only 2% of all tornados, but they cause 70% of all tornado deaths. Their lifetimes can exceed one hour and winds may be greater than 205 mph.

Tornado Frequency

Tornados can occur at any time of the year. In the southern states, peak tornado occurrence is from March to May, while peak months in the northern states are during the summer. They are most likely to occur between 3:00 and 9:00 P.M. but have been known to occur at all hours of the day or night. The average tornado moves from southwest to northeast, but tornados have been known to move in any direction. The average forward speed is 30 mph, but it may vary from nearly stationary to 70 mph. ✷

Science as Inquiry

The Ocean/The Ocean: A Global View

The Ocean

Just as water is unique among molecules, its existence in our ocean makes Earth unique among the planets. Our planet is the only body in the solar system that has a vast open ocean of liquid water. Mercury, Venus, and the Moon are completely dry. The only water found in the gas giants Jupiter, Saturn, Uranus, and Neptune is lost in mixture with greater quantities of hydrogen and helium. On the smaller worlds that lie beyond Earth, including Mars, Pluto, and the moons and other satellites of all of the planets, any water that has been detected is in the form of ice. It is Earth's vast ocean, in combination with its fortunate position in the solar system, that makes our planet life-bearing.

There are two main hypotheses presented to explain the origin of the world ocean, which now covers over 70 percent of Earth's surface. The first hypothesis proposes that water vapor was slowly released from molten material beneath Earth's surface by volcanic activity. As the concentration of water vapor in the atmosphere increased, some of the vapor condensed, clouds were formed, and rain began falling on the planet's surface. The second hypothesis suggests that most of Earth's water originated in comets, which were much more abundant in the first billion years of the planet's history than they are today. According to this hypothesis, as comets entered Earth's atmosphere, they instantly vaporized, adding moisture to the air that eventually fell to Earth as rain or snow.

For whichever reason, or combination of reasons, the rain began. As it continued, the low places on Earth's surface were filled with water and the ocean was formed. Rain has tended to mold Earth into a smooth sphere through the process of erosion ever since. Fortunately for us, tectonic forces within Earth keep raising up new land masses; otherwise, our planet would eventually be covered by a vast ocean, about 2400 meters deep, unbroken by continents.

Like any large environmental system, the ocean is usually subdivided into characteristic regions when studied scientifically. The most fundamental scheme of subdivisions is tile one followed here, i.e., coastal ocean and open ocean, with the open ocean further divided into surface, transitional, and deep layers. These oceanic subdivisions differ from one another in many ways, but treating them separately should not obscure the fact that energy, matter, and organisms move from one subdivision to the other; i.e., the ocean as a whole is an integrated environmental system even though scientists subdivide it for convenience of study. See Figure 1.

The coastal ocean refers to the 10 percent of ocean over the continental shelves (the undersea extensions of the continents which descend gradually and are not part of the deep ocean floor). It provides almost all of the world's seafood harvest, it is the source of all of the minerals and petroleum currently recovered from the ocean, and the coastline itself is home to a large and growing percentage of the human population. It is estimated that more than 60 percent of the population of the

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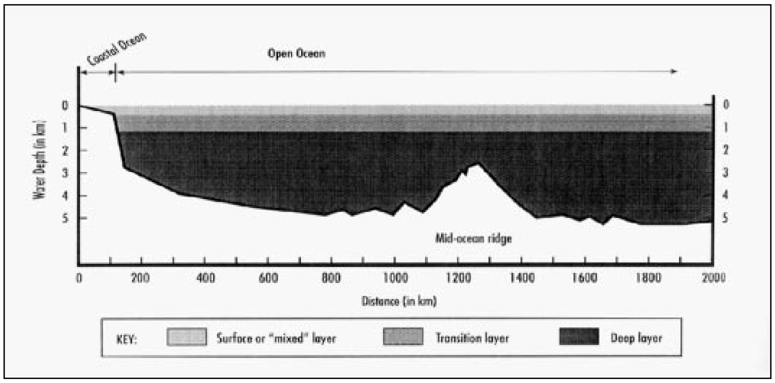

Fig. 1.

United States will live within 50 miles of the ocean or Great Lakes coastlines by the year 2010. The concentration of natural resources, human population, and economic activity make it no surprise that almost all conflicts and controversies regarding the use of the ocean originate from coastal ocean activities.

The single most characteristic feature of the coastal ocean environment is rapid change. Coastal winds are strong and variable, and they drive much of the coastal water circulation. Coastal winds also create waves that break on shore and move sediments, an action which can contribute to beach erosion. Coastal rainfall varies seasonally and within shorter time frames, and has a direct impact on the salt content of coastal waters. Variations in air temperature are generally reduced by the capacity of ocean water to store and release heat; but local and regional winds can overwhelm the moderating effect at relatively low speeds. Humidity, especially in summer, is generally high, and helps fuel potentially violent thunderstorms and hurricanes that can quickly alter human activities and environmental conditions. Freshwater and sediment runoff from major rivers—especially after prolonged periods of rainfall—can also dramatically affect the coastal environment. The complexity of the coastal environment lends fascination to the phenomena that occur there, but may lead to oversimplification of ideas or the development of misconceptions among students.

An important feature of the coastal ocean is the estuary. An estuary is a semi-enclosed body of coastal water that exhibits measurably reduced salinity due to the introduction of fresh water from rivers, streams, and other sources of continental runoff. Most estuaries exhibit two-way movement of water. Less dense fresh (river) water flows seaward along the surface, while more dense, salty ocean water flows landward underneath it. Varied amounts of mixing of fresh and salt water occur, depending on factors such as wind speed, tide level, the depth and contour of the estuary bottom, and the relative inflow of river versus seawater. When mixing is minimal, a salt-wedge type of estuary develops, with a wedge of seawater undercutting an overlying wedge of fresh water. See Figure 2.

Estuaries and other coastal regions account for much of the biological productivity of the ocean. These areas are nutrient-rich from the accumulation of materials brought from the land via runoff; and they provide relatively sheltered habitats that are the spawning places and nurseries for many forms of marine life.

The remaining 90 percent of the ocean is open ocean—that is, it occurs seaward of the world's

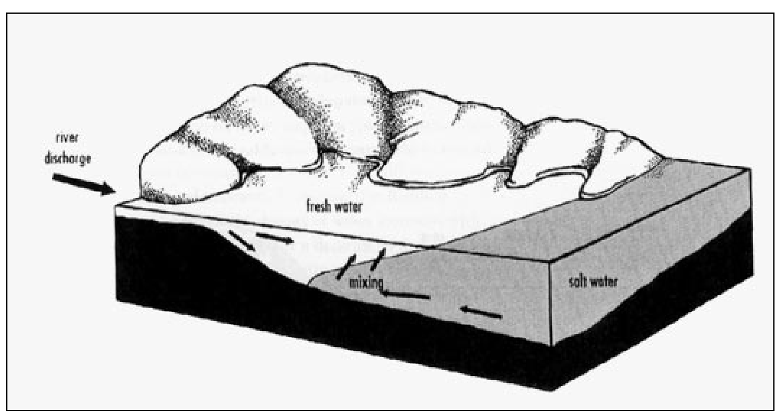

Fig. 2. A typical salt-wedge estuary.

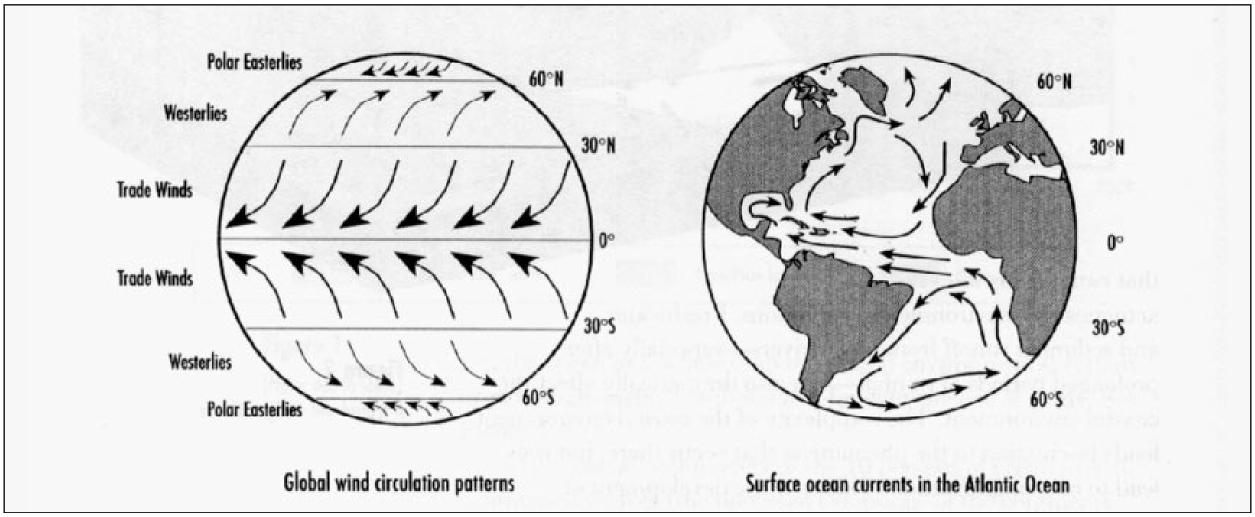

Fig. 3. The relationship between global wind patterns and ocean surface currents.

continental shelves. The open ocean is characterized by the surface layer, the transitional layer and the deep water zone. In the surface—or "mixed"—layer, turbulence due to wind, waves, and surface currents produces fairly constant physical properties of temperature and salinity. This layer is a few hundred meters thick (about 300 m in equatorial regions); its depth varies according to latitude and frequency of storms. The mixed layer acts as a thermal cap. Below it the temperature drops from whatever it is at the surface to the average temperature of deep water, which is a few degrees Celsius. This region of change is called the transition zone and is where we see the presence of a thermocline (rapid change in temperature), halocline (change in salinity), and pycnocline (change in density). The transition zone has a strong thermocline in equatorial regions where the difference between the surface and deep water temperatures is greatest. The thermocline weakens with increasing latitude and weakens seasonally in winter months in the mid-latitudes. The transition zone extends to a depth of about 1000 m. Beneath the transition zone, the physical properties of water are quite stable and uniform. This is the third layer, the deep water zone.

Among the winds that stir the currents are the trade winds and prevailing westerlies. These global winds blow in opposing directions and, in combination with Earth's rotation, cause a powerful system of rotating currents—called gyres—to develop. The water in the Gulf Stream region of the North Atlantic Gyre, for example, moves at speeds of up to 112 km/day. The correlation between global wind patterns and surface ocean currents can be seen in Figure 3.

The slowly circulating open ocean deep layer covers more than 75 percent of the area of the ocean basins, and more than half the total surface area of Earth. The deep ocean layer is the area of Earth about which the least is known. It has been determined, however, that the waters of the deep sea circulate in a pattern of convection currents which results from differences in the densities of masses of seawater. [As discussed in Reading 1, "Water: The Sum of Its Parts,"] the density of water increases with an increase in salt content (salinity) or a decrease in temperature; and more dense water tends to sink relative to less dense water. Therefore, seawater with high salinity sinks relative to seawater with lower salinity and cold water sinks relative to warmer water.

Much of the density variation in the deep ocean layer has it origin in the polar regions of Earth where seawater in the surface layer freezes and icebergs are formed. When water freezes to form ice sheets, which in turn sometimes break apart to form icebergs, the salt it contained remains dissolved and is concentrated in remaining unfrozen ocean water, increasing its salinity. (This is because the salt ions cannot easily fit into the crystalline structure of the ice.) In addition, the concentration of salts in the unfrozen water lowers its freezing point, allowing it to remain liquid below its normal freezing point of 0°C. This cold, salty water is more dense than the surrounding surface water and therefore tends to sink toward the seafloor and move away from the poles. Elsewhere, deep water is displaced upward toward the surface layer.

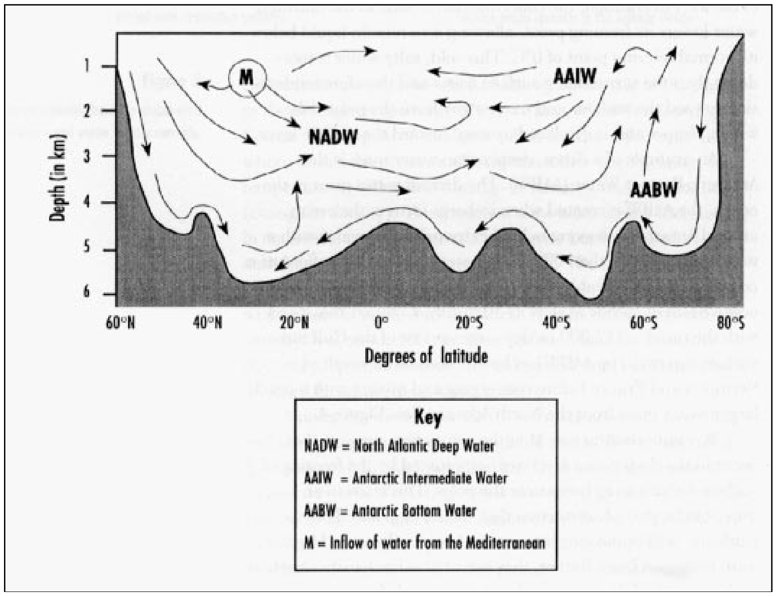

Fig. 4. Deep ocean currents in the Atlantic Ocean.

An example of a dense, deep-ocean water mass is the Antarctic Bottom Water (AABW). The densest water mass in the ocean, the AABW is created when icebergs form in the ocean around Antarctica, leaving behind extremely salty water with a temperature of less than 0°C. This water sinks to the seafloor as a coherent and identifiable mass. It creeps along the bottom of the ocean basin at speeds as slow as 30 m/day. Contrast this speed with the rapid—l 12,000 m/day—movement of the Gulf Stream surface current! The AABW has been traced as far north as Bermuda and France before converging and mixing with a much larger water mass from the North Atlantic. See Figure 4.

It is important to note that the convection currents that occur in the deep ocean layer are perpetuated by the freezing of surface water into icebergs near the poles. This leads to an important aspect of convection that should be pointed out to students: convection currents are not necessarily caused by the introduction of heat. Rather, they are caused by density variation within in a fluid. Variation in density can result from nonuniformity in temperature (due to uneven heating or cooling), salinity, or both. The deep ocean layer's system of density-driven flow (convection) is referred to as "thermohaline" circulation, since its is caused by differences in temperature (thermo) and salt content (haline) of oceanic water masses.

The concept of a three-layered ocean is important to a study of the ocean as a whole. It is also an essential feature of all mathematical models of Earth's climate, since the surface layer exchanges water and energy with the atmosphere, while the deeper layers do not. It is important to recognize that the layers are not totally distinct and that individual water molecules circulate throughout both. It may take hundreds of years, however, before cold, dense ocean water that sinks to the ocean floor near the poles returns to the surface layer again. Oceanographers and climatographers are therefore examining the feasibility of introducing atmospheric greenhouse gases, such as carbon dioxide, into the sinking waters, thereby removing them from exchange with the atmosphere for long periods of time.

The Ocean: A Global View

The world ocean plays an integral role in the lives of all of Earth's inhabitants through its effect on global climate. [As explained in Reading 1, "Water: The Sum of Its Parts,"] the ocean's significance in climactic regulation is largely attributable

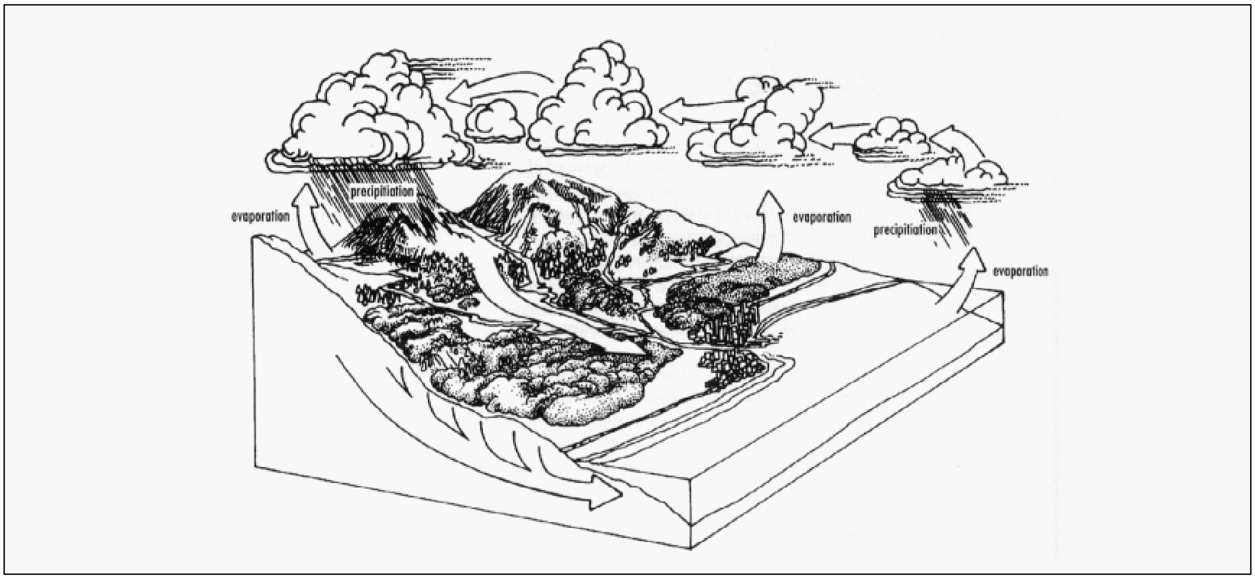

Fig. 5. Earth's hydrologic cycle.

to various characteristics water. The high specific heat of water means that a relatively large amount of heat energy must be absorbed or released by liquid water before a change in its temperature can occur. Because of the large volume of water in the ocean, ocean temperatures change slowly and vary less than the temperatures of land masses.

The ocean helps moderate temperatures over the globe through its effect on the conditions in masses of air that move across its surface. The air masses, when they move over land, moderate the temperature of land masses through precipitation and heat exchange. The moderating effect is most obvious in coastal regions, but regions far from any coastline also experience its influence. In fact, Earth's ocean causes the planet's overall temperature to be relatively consistent over time, especially when compared to that of other planets. On the other planets, and even on Earth's own moon, surface temperatures fluctuate much more widely during the course of a year, and in some cases, between day and night. Earth's relatively consistent temperature, maintained largely by its vast ocean, distinguishes it from its neighbors in the solar system and helps make it a habitable planet.

The ocean also affects global climactic conditions as a key component of the hydrologic cycle—the interactive cycling of water between the ocean, continents, and the atmosphere. In the hydrologic cycle, heat energy from the sun causes liquid water to evaporate and be introduced into the atmosphere as water vapor. Evaporation takes place from the surface of all bodies of water, as well as from soil and living organisms. Water vapor rises into the atmosphere, cools, and condenses to form the tiny water droplets that combine to make up clouds. When the amount of water in the atmosphere reaches a critical level, precipitation occurs and some of the evaporated water is returned to Earth. Because the ocean covers over 70 percent of Earth's surface, most precipitation falls there and mixes with seawater. Precipitation that falls onto land either evaporates directly back into the atmosphere, is absorbed by the soil, or flows into streams. Small streams combine to form larger streams and rivers, which eventually flow into a lake or the ocean. All along the way, water is reintroduced into the atmosphere through evaporation, and the cycle continues. See Figure 5.

The salinity of the ocean, important for the survival of its inhabitants, is maintained through the hydrologic cycle. When rainwater falls on land, it erodes and dissolves salts and minerals from rocks and soil. These leached salts are carried by runoff through streams and rivers, and many eventually reach the ocean. It is estimated that some four billion tons of dissolved salts are carried into the ocean each year. At the same time, water that evaporates from the ocean leaves it salts behind, increasing the salt concentration of the remaining seawater. The ongoing introduction of salts into the ocean through these processes is offset by other events. Fresh water continually enters the ocean as precipitation and salts are deposited on the ocean floor at about the same rate as they are introduced into the ocean by rivers and streams. The balance between these opposing processes has caused the salinity of ocean water to remain essentially the same through recent geologic history.

Within the last few decades, scientists have developed a fairly clear understanding of the role the ocean and the hydrologic cycle play in weather formation. One interesting result has been the explanation of the effects of El Niño. El Niño is an unusually warm ocean current that develops in the western Pacific Ocean, usually around Christmas time (hence the name, which means The Child). The warm surface water temperatures associated with El Niño lead to alterations in the movement of air masses and the development of irregular ocean currents. Changes in the normal formation of weather conditions result, and the entire world is eventually affected. In the mid-1980s, El Niño was responsible for weather extremes from severe drought conditions in Australia to heavy rains and flooding in parts of South America.

The effects of El Niño provide evidence of the integral role the ocean plays in the lives of human beings. As marine explorer Jacques-Yves Cousteau stated in 1980, “The very survival of the human species depends upon the maintenance of an ocean, clean and alive, spreading all around the world. The ocean is our planet’s life belt.” The importance of the ocean is often overlooked, however, even as people around the world alter their activities in response to daily weather conditions regulated in large part by the ocean.

Similarly, the important impact that humans have on the ocean is generally underacknowledged. The pollution that results from certain human activities has the potential to permanently alter the delicate ecological balance in the ocean and thereby undermine its capacity to sustain life. For this reason, Jacques-Yves Cousteau and many other noted scientists advocate protection of the world ocean from overuse and from various forms of pollution. A 1971 United Nations report defined marine pollution as “the introduction by man, directly or indirectly, of substances or energy into the marine environment, resulting in such deleterious effects as harm to living resources; hazards to human health; hindrance to marine activities, including fishing; impairment of quality for use of seawater; and reduction of amenities.”

One familiar ocean contaminant is oil. Oil seeps, in which crude oil exudes from the ocean bottom, are common occurrences in some areas. Natural degradation processes occur after an oil seep that, given time, generally bring about recovery of the affected area. Ocean pollution, on the other hand, arises from human activity that introduces an “unnatural” amount of oil, thereby overwhelming the capacity of the environment’s degradation and recovery mechanisms. Oil is introduced into ocean water primarily during transportation activities. While in transport, oil may be released by “normal” leakage, accidents, or improper equipment cleaning methods.

Immediate damage to marine life results from an oil spill and occurs at the interface between the ocean and the atmosphere, where the oil forms a layer or “slick.” As the Exxon Valdez accident of 1989 clearly demonstrated, seabirds, sea otters, and other aquatic animals that must surface for air are extremely vulnerable to the effects of spilled oil. The oil adheres to their feathers, skins, and coats and severely limits their mobility. They often become easy prey for predators or starve because they can no longer hunt successfully. Those that survive and are rescued must be individually cleaned and treated.

Compounding the threat of the oil slick itself is the fact that the hydrocarbon components of oil are extremely toxic to most forms of marine life.

As oil that remains in the marine environment breaks down into its various components, some of the more volatile compounds evaporate into the atmosphere and others decay relatively quickly through natural processes. Other compounds, however, dissolve into the water or settle to the ocean bottom where they can enter the food chain if ingested by organisms. Through the food chain, these toxins are concentrated and their destructive effects are multiplied over time. Humans, at the top of the food chain, may be affected through this route.

Several techniques are used to contain and recover spilled oil. One technique involves specially equipped boats that skim the oil from the ocean's surface; floating booms can be placed around an oil slick in an attempt to contain it; chemical dispersants are sometimes sprayed over an oil slick to break down the oil and cause it to degrade faster; and, at times, the oil is even ignited. A new and promising technique is being developed that involves oil-eating bacteria. In many cases, however, efforts to clean up an oil spill meet with only limited success, and some clean-up techniques can pose greater threats to the environment than the oil spill itself. Ignition of an oil spill, for example, causes air pollution; chemical dispersants cause clumps of toxic material to sink to the ocean bottom where they are likely to be consumed by oysters, clams, and crabs.

Spilled oil that is not contained before it reaches shorelines can spoil beaches and thereby threaten the habitat of shorebirds, sand crabs, and other beach-dwelling creatures. Were possible, pools of oil are removed through the use of absorbents such as hay; rocks and other objects are scrubbed by hand.

Ocean dumping (the disposal of waste products at sea) is another major form of ocean pollution. The shallow waters off the coasts of many countries are often used as dumping grounds for various wastes. The choice to dump garbage at sea, as opposed to in a landfill, is usually based on economic reasons, as land is generally deemed more valuable than the ocean. The United States alone dumps over 45 million tons of waste into the ocean each year, and much of the material may be detrimental to the environment.

Among the many pollutants disposed of through ocean dumping is a wide variety of plastics. In 1988, almost 50 billion pounds of plastic were produced, and the amount is increasing. During the 1988 National Coastal Cleanup, 62 percent of the trash collected was plastic. In one survey from 1985, plastic made up 86 percent of the trash observed floating in the North Pacific Ocean. This points to one of the problems inherent in dumping plastics at sea—most of it floats. Another problem is its durability. Plastics are relatively immune to the natural process of decomposition, meaning that plastics put into the ocean can float around and cause problems for many years. Animals of all kinds die as a result of being tangled in plastic debris, and many animals mistake plastic for food and die as a result of ingesting it.

Ocean dumping also impacts humans in a variety of detrimental ways. Floating debris can damage recreational and fishing vessels. Insurance companies estimate that over $50 million has been awarded for boat repairs that resulted from damage incurred by debris. Refuse that washes ashore pollutes beaches and deters tourists, thereby reducing tourism revenues. The state of New York lost an estimated $1 billion in tourism revenue when medical waste and other rubbish washed up on beaches there. Incredible amounts of Federal and state revenue are spent to keep beaches clean and free of ocean debris. In 1988, for example, $1,275,354 were spent to maintain a three-mile stretch of beach in Santa Monica, California.

Recent legislation has been aimed at restricting the ocean dumping that takes place in all navigable waters of the United States. Annex V of the Marpol Treaty designates how far out in the ocean certain materials must be dumped, and makes it illegal to dump any plastic anywhere in U.S. waters. While this type of legislation will undoubtedly have a positive effect, it represents only a small step toward alleviating the problems associated with ocean dumping. There are several other things being tried to improve the situation, the most promising being the reduction of plastics use and recycling. Improvement may also come from the development and use of naturally degradable plastics.

The ocean can be viewed as an integral component of the global environment. It affects temperatures and climactic conditions worldwide and is largely responsible for making Earth a habitable planet. The ecologically significant characteristics of the ocean stem from the delicate balance of its many natural systems. Human activities that disrupt this balance threaten to alter the environmental conditions upon which we depend for survival. Therefore, knowledge about the ocean and informed decision-making regarding its use are essential for the maintenance of a life-sustaining planet. ●