OAR/NURP

Figure 2-39a

US Navy submersible *Asherah*–1964.

OAR/NURP

Figure 2-39b

NOAA submersible *Nekton*.

OAR/NURP

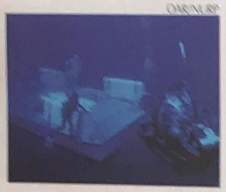

Figure 2-39c

Access to the sea.

During the 1960s, modern submersibles and self-contained diving changed the study of the oceans. Instead of grabbing samples blindly, scientists could pick the specific samples they needed. They could take delicate samples without damaging them and living organisms without killing them. For many types of research, they no longer needed samples. Instead, they could directly observe the geology, organism behaviors, and other phenomena in their natural setting.

Submersibles and Self-Contained Diving

How have submersibles and self-contained diving changed the study of the oceans?

What are the three types of submersible that have been used for underwater research?

What are the advantages and disadvantages of submersibles and scuba?

Imagine trying to study terrestrial Earth from a balloon high in the atmosphere above the clouds. To learn what you can, you lower hooks and traps, grab things, and haul them up to study. Your views and impressions would come from whatever you happened to snag. Chances are, your ideas of what a forest or desert is like would be way off.

Until the 20th century, scientists studied the ocean floor essentially the same way. One of the biggest changes in the 1900s was opening the underwater world. Although diving and submersible technologies date back more than a thousand years, until the 20th century these were neither practical nor widespread. (See Underwater Exploration Historical Timeline at the end of this chapter for more about the history of undersea exploration.)

Modern submersibles and self-contained diving changed the study of the oceans. Instead of grabbing samples blindly, scientists could pick the specific samples they needed. They could take delicate samples without damaging them and living organisms without killing them. For many types of research, they no longer needed samples. Instead, they could directly observe the geology, organism behaviors, and other phenomena in their natural setting.

Submersibles. Over the years, scientists have used three basic types of submersible for research. The first was the bathysphere (from the Greek *bathys* meaning *deep*). Pioneered in the 1930s by William Beebe and Otis Barton, this submersible was essentially a steel ball with a window. It had an oxygen recirculating system so scientists could breathe and an umbilical that provided communications and power.

The bathysphere operated only vertically, raised and lowered by a cable from a ship. Since it dangled, it tossed up and down with the mother ship in rough seas, making it uncomfortable for the occupants. Although the bathysphere is no longer used because of its limitations, it allowed the first deep-water visits by scientists. In 1932, Beebe and Barton reached 661 meters (2,170 feet) in the bathysphere in the waters off of Bermuda.

The bathysphere gave way to the bathyscaphe (from the Greek *scaphe* meaning *boat*). In essence, a bathyscaphe is a more sophisticated bathysphere, with the sphere attached to a large float instead of a cable and ship. Bathyscaphes operate much like blimp air ships. The float contains a liquid that's buoyant in water, such as gasoline, and heavy ballast. By releasing some of the ballast or the buoyant liquid, the bathyscaphe rises or descends. Small electric motors drive propellers to give it horizontal mobility. However, the horizontal motion is limited.

Bathyscaphes aren't widely used today because they're difficult to operate and limited in what they can accomplish. Their big advantage, however, is that they are the deepest diving submersibles ever made. Probably the best known bathyscaphe is the *Trieste*, which is the only submersible to have descended to the bottom of the Challenger Deep.

The state of the art today is the deep-diving submersible. These are typically two- and three-person vessels that dive in moderate to deep depths, though not as deep as a bathyscaphe. However, they don't require the bulky float tanks of a bathyscaphe and they have excellent horizontal maneuverability. They're far less fragile than bathyscaphes, making them easier to launch and use in rough seas. These characteristics make them suitable for far more varied

Figure 2-40

A steel ball with a window.

Pioneered in the 1930s by William Beebe and Otis Barton, the bathysphere was essentially a steel ball with a window. It had an oxygen recirculating system so scientists could breathe and an umbilical that provided communications and power. The bathysphere operated only vertically, raised and lowered by a cable from a ship. Since it dangled, it tossed up and down with the mother ship in rough seas, making it uncomfortable for the occupants. Although the bathysphere is no longer used because of its limitations, it allowed the first deep-water visits by scientists.

Courtesy of Space and Naval Warfare Systems Center of San Diego

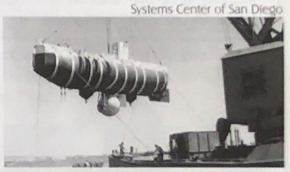

Figure 2-41a

Bathyscaphe *Trieste*.

A bathyscaphe is a more sophisticated bathysphere, with the sphere attached to a large float instead of a cable and ship. Bathyscaphes operate much like blimp air ships. The float contains a liquid that's buoyant in water, such as gasoline, and heavy ballast. By releasing some of the ballast or the buoyant liquid, the bathyscaphe rises or descends. Small electric motors drive propellers to give it horizontal mobility. However, the horizontal motion is limited.

OAR/NURP

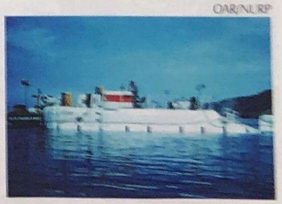

Figure 2-41b

***Trieste II*.**

THE *TRIESTE*

In 1960, under the leadership of Dr. Andreas B. Rechnitzer, a graduate of the Scripps Institution of Oceanography, U.S. Navy Lieutenant Don Walsh and Jacques Piccard carried out what is probably the most dangerous and daring deep dive to date. Piccard and Walsh descended in the bathyscaphe *Trieste* to the bottom of Challenger Deep in the Mariana Trench.

This is the one and only time man has visited the deepest known part of the ocean, a record depth of 10,914 meters (35,807 feet).

While landing on the bottom, Piccard claims to have seen a fish, a shrimp, and a jellyfish through a tiny view port, proving that life exists even at this depth. Although this was more than four decades ago, Challenger Deep has not been visited by man since.

Courtesy of Space and Naval Warfare Systems Center of San Diego

Figure 2-42

Trieste.

Project leader Dr. Andy Rechnitzer organized the journey of Jacques Piccard and Don Walsh aboard the bathyscaphe *Trieste* to Challenger Deep.

Courtesy of Historical Diving Society, USA

Figure 2-43

Augustus Siebe hard-hat diving equipment.

In the middle of the 19th century the first practical dive equipment emerged. This equipment was hard-hat (helmet) diving that supplied air from the surface through a hose. An Englishman named Augustus Siebe introduced the first commercially successful line of hard-hat equipment in 1840. Seibe's equipment looked very much like the basic helmet equipment still used today.

types of research. Some deep-diving submersibles have robotic arms that allow the pilot or scientist to grasp samples or perform experiments outside the sub.

Self-contained diving. For centuries, humans experimented with ways to stay underwater for longer than a single breath. Different types of bell to support divers and crude diving apparatus date back as far as 375 A.D.

Despite these efforts, however, it wasn't until the middle of the 19th century that the first practical dive equipment emerged. This equipment was hard-hat (helmet) diving that supplied air from the surface through a hose. An Englishman named Augustus Siebe introduced the first commercially successful line of hard-hat equipment in 1840. Seibe's equipment looked very much like the basic helmet equipment still used today.

Although Seibe's surface-supplied hard-hat diving became the basis for underwater labor (construction, salvage, ship maintenance), this type of dive equipment was limited for underwater research. It was heavy and required a support team and vessel. Although science was conducted in hard-hats to a limited degree, it was not ideal. What was needed for scientific diving was a lightweight, self-contained system—what we call scuba today.

Another Englishman, Henry Fleuss, introduced the first workable scuba in 1878. His unit recirculated pure oxygen. Caustic soda absorbed the carbon dioxide the diver exhaled, and the diver replaced consumed oxygen as needed from a pressurized cylinder. Although this system worked, it soon proved limited for scientific diving. The most substantial obstacle was that divers can't use

IMPORTANT RESEARCH SUBMERSIBLES

The *Alvin*, operated by Woods Hole Oceanographic Institution and owned by the US Navy, is considered the world's most productive submersible. Refurbished and upgraded numerous times over its career, *Alvin* is scheduled to be replaced by a new vehicle. In its present configuration, *Alvin* is capable of diving to 4,500 meters (14,764 feet). During its career, *Alvin* made over 150 dives per year. Dr. Robert Ballard used the *Alvin* for the first visits to the wreck of the *Titanic*.

©Woods Hole Oceanographic Institution (All)

Figure 2-44a

***Alvin*, 1956.**

Figure 2-44b

***Alvin*, 1977.**

Figure 2-44c

***Alvin*, 2001.**

Harbor Branch Oceanographic Institution in Fort Pierce, Florida, owns and operates two Johnson *SeaLink* submersibles. These manned submersibles are devoted primarily to marine research with an operating depth of 914 meters (3,000 feet). The forward 12.7-centimeter (5-inch) thick acrylic sphere accommodates the pilot and observer, allowing panoramic visibility. A second chamber in the rear can hold two additional scientists. Both *SeaLinks* have manipulator arms, suction devices, plankton samplers, active sonar, and broadcast quality video cameras for use by scientists in their research.

Courtesy of Harbor Branch Oceanographic

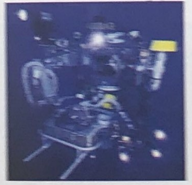

Figure 2-45

Johnson SeaLink.

Nautile is a three-person French submersible operated by the Institute of Research and Exploitation of the Sea. This submersible also has a small, tethered ROV (remotely operated vehicle) named *Robin* that can inspect and image areas inaccessible to *Nautile* itself.

Ifremer

Figure 2-46

Nautile.

MIR-1 and *MIR-2* are three-person submersibles operated by the Shirshov Institute of Oceanology in Russia. Both submersibles have an operating depth of 6,000 meters (20,000 feet). The MIR submersibles have the second-deepest rating of all deep submersibles. (The Japanese submersible *Shinkai* leads with a depth rating of 6,500 meters [21,325 feet]). The *MIR* submersibles were featured in the movie *Titanic*.

OAR/NURP

Figure 2-47

MIR-1.

Operated by the Hawaii Undersea Research Laboratory at the University of Hawaii, *Pisces IV* and *V* both have a maximum operating depth of 2,000 meters (6,280 feet). International Hydrodynamics of Vancouver, Canada, built both *Pisces*. Scientists commonly use them for studies along the undersea volcano Lo'ihi, on submerged banks in the main Hawaiian Islands and on the banks and sea-mounts in the Northwestern Hawaiian Islands.

OAR/NURP

Figure 2-48

Pisces V.

Constructed by Nuytco Research in Canada, *DeepWorker* is a new breed of small, lightweight submersible. *DeepWorker* allows one or two explorers at a time descend to 610 meters (2,000 feet). Due to its small size, *DeepWorker* easily travels by trailer and launches much like a regular support vessel from a small support ship. With this capability, *DeepWorker* makes research by submersible more accessible by lowering logistical costs.

Courtesy of Phil Nuytten

Figure 2-49

DeepWorker.

Courtesy of Historical Diving Society, USA

Figure 2-50

Fleuss rebreather, 1878.

Henry Fleuss introduced the first workable scuba in 1878. His unit recirculated pure oxygen. Caustic soda absorbed the carbon dioxide the diver exhaled, and the diver replaced consumed oxygen as needed from a pressurized cylinder. Although the system worked, it soon proved limited for scientific diving.

pure oxygen deeper than approximately 10 meters (33 feet). This is because oxygen becomes toxic beyond a certain pressure. Despite this limitation, Fleuss' design went on to become the basis for early combat-diver equipment and submarine escape apparatus.

Frenchman Jacques Cousteau introduced the first practical scuba in 1943. Working with a compressed-gas engineer named Emile Gagnan, Cousteau developed a scuba system that delivered compressed air (not oxygen) to a diver. By automatically adjusting the breathing air pressure and providing air only when the diver inhaled, this new, self-contained equipment was easy to operate, reliable, and provided a reasonable underwater duration. It was relatively lightweight, simple, and required minimal support compared to hard-hat diving. This opened a new door to the underwater world. Divers swam freely like fish instead of walking awkwardly on the bottom. Within 20 years, scuba was in use by the military, science, and as a fast-growing recreation.

Today scientists use both submersibles and scuba for underwater research. Both tools have their place, with respective advantages and disadvantages. The primary advantages of submersibles compared to scuba are depth and duration. Submersibles can descend far deeper than scuba divers. Most of the ocean's volume is within reach of research submersibles, but out of reach of scuba. Submersibles can also continue for much longer than scuba dives. Four hours is a long scuba dive. Sometimes, a submersible needs longer than that just to reach the working depth!

Figure 2-51a & b

Open-circuit scuba equipment.

Frenchman Jacques Cousteau introduced the first practical, open-circuit (meaning the diver's exhalation is breathed into the water as bubbles) scuba in 1943. This is basically the same equipment used today by recreational and scientific divers.

2-51a Cousteau image Courtesy of Historical Diving Society, USA

Figure 2-51a

Original Cousteau Aqualung.

Bob Wohlers

Figure 2-51b

Modern scuba equipment

The primary disadvantages of submersibles compared to scuba are cost, logistics, and accessibility. Submersible diving is substantially more expensive than scuba diving, so research from a submersible doesn't take place on a whim. Submersibles generally need support vessels and a team for launching, retrieval, and maintenance. Finally, due to their size, there are places submersibles can't go, either because they're too big or too difficult to transport.

The primary advantages of scuba over submersibles are cost, simplicity, portability, size, and dexterity. Although the leading-edge scuba technologies can be very expensive, standard compressed air scuba is so inexpensive that it is a common recreation. Compressed-air scuba is simple, making training and maintenance relatively simple compared to a submersible.

Scuba is very portable. With scuba, scientists can dive from a wide range of vessels that would be unable to support a submersible. Similarly, they can go places with scuba that would be nearly impossible for submersible diving—like an underwater archaeological site in the middle of a dense rainforest. Because scuba equipment is compact, it gives specially trained divers access to small areas underwater where submersibles cannot go.

Although many research submersibles have robot claws and other devices scientists can use, none of these replace the human hand for many tasks and procedures. When a scientist needs to delicately lift a fragile archaeological find, it is much easier to do this by hand than with a robotic arm.

While scuba is very versatile, its drawbacks compared to submersibles are depth and duration. Working with conventional compressed-air equipment, scuba is limited to no more than about 40 or 50 meters (130 to 165 feet). Even with the leading-edge, highly sophisticated scuba using synthetic breathing gases, the practical working depth limit is no more than about 150 meters (492 feet). While there is a tremendous amount of research possible in this range, the vast majority of the ocean lies deeper.

Scientists cannot stay under water on scuba as long as in a submersible. Because they're exposed to the water and pressure, divers have temperature, decompression, and endurance considerations. Even with the most effective dive suits, in all but very warm water, a diver will eventually become cold. While breathing gas under pressure, a diver's body absorbs excess gas. The diver must surface in stages (decompression stops) that allow this gas to dissipate, or decompression sickness may result. The longer a diver remains under water, the longer it takes to surface.

Even without temperature or decompression considerations, fatigue is a factor. Water is denser than air, so every move underwater requires more effort than out of water. Breathing through

Figure 2-52a

Preparing a submersible for work underwater.

Figure 2-52b

Submersible and diver at depth.

Scientist at work outside of submersible.

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Figure 2-53

Submersibles versus scuba.

SUBMERSIBLES VERSUS SCUBA

	ADVANTAGES	DISADVANTAGES
Submersibles	Greater depth Duration	High cost Large size Logistical complexity
Scuba	Simplicity Portability Low cost	Limited depth Short duration

scuba requires more energy than breathing at the surface. These may be small effort differences, but over time they add up, tiring the diver.

Therefore, even within scuba depths, if a scientist needs to stay down for hours to observe something, a submersible may be the best tool. Temperature, decompression, and fatigue may make diving impractical even in relatively shallow water.

Because of these relative advantages and disadvantages of submersibles and scuba, the hardsuit first emerged in the 1913. Essentially wearable submersibles, hardsuits try to strike a balance between the advantages and disadvantages of each. Hardsuits protect the diver from pressure and temperature and are far smaller and more mobile than conventional submersibles. They allow the diver to go deeper than with scuba, though not as deep as a conventional submersible. The drawbacks are cost and logistical complexity, which, while less than a conventional submersible, are greater than for scuba diving. The state of the art in hardsuits is the Nuytco Newt Suit.

[illegible]

Figure 2-54a

1935 hardsuit.

Pictured is an early one-atmosphere, armored hardsuit.

Courtesy of Phil Nuytten

Figure 2-54b

Modern one-atmosphere hardsuit.

Because of the relative advantages and disadvantages of submersibles and scuba, the hardsuit first emerged in the 1913. Essentially wearable submersibles, hardsuits try to strike a balance between the advantages and disadvantages of each. Hardsuits protect the diver from pressure and temperature and are far smaller and more mobile than conventional submersibles. They allow the diver to go deeper than with scuba, though not as deep as a conventional submersible.

ROVs, AUVs, Electronic Navigation, and Satellites

What other technology has expanded underwater research?

How have Loran-C and GPS benefited seafaring and oceanography?

What are three types of sea surface observations that satellites can make to benefit oceanographers?

Among the many scientific and technological advances in the last half of the 20th century, electronics and space travel provided at least four other important contributions to oceanography. These were the inventions of the Remotely Operated Vehicle (ROV), Autonomous Underwater Vehicle (AUV), electronic navigation, and ocean observation satellites.

The ROV is another technology that has expanded underwater research. An ROV is essentially a small, unmanned submarine with propellers, a video camera, and an umbilical to the surface. The operator at the surface controls the ROV remotely by watching the video image. ROVs range in size from a lawn mower to larger than a car, depending on their purpose. Some are basically underwater "eyes," while others have robotic arms, claws, and other tools.

ROVs became common beginning in the late 1970s and early 1980s as a bridge between the capabilities of submersibles and scuba. ROVs can match the depth and duration of submersibles, yet they're far more compact and inexpensive. This makes them usable from vessels and in locations that cannot support submersibles. They're not affected by pressure or temperature, so they're suitable for long observations without the expense of a submersible.

ROVs are also very useful for both submersible and scuba operations. For example, researchers may send an ROV down ahead of a submersible or diver to check the location. This confirms the location before committing to launching a manned submersible or exposing a diver. Sometimes ROVs work with submersibles and divers, providing light and other support. There are specialized ROVs operated from submersibles. In exploring the *Titanic* from *Alvin*, Dr. Robert Ballard used such an ROV to view inside the wreck. There was no way this could have been done by a submersible.

Another important tool used by oceanographers is the Autonomous Underwater Vehicle (AUV). AUVs are untethered robotic devices, propelled through the water by self-contained power systems and controlled and piloted by an onboard computer. AUVs are launched from the surface and are maneuverable in three dimensions. Under most environmental conditions, this level of control permits AUVs to follow precise preprogrammed under-

NURP/NOAA

Figure 2-55

Cave diver towed by ROV.

NURP/NOAA

Figure 2-56

ROV *Phantom*.

Courtesy of Harbor Branch Oceanographic

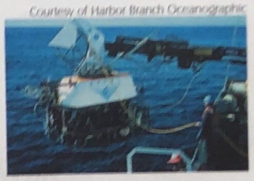

Figure 2-57

ROV Ventana.

The ROV Ventana, built for the Monterey Bay Aquarium Research Institute (MBARI), is a highly sophisticated vehicle with data collection sensors, a high definition camera, and animal collection devices.

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water paths. Sensors within an AUV sample the ocean along these paths. AUV development began in the early 1960s. The first AUVs were either too large, inefficient, expensive, or a combination of all three. In the 1980s, AUV technology matured, but it is essentially still in its infancy.

Unlike tethered ROVs, AUVs must carry their brain and brawn with them. In the 1980s this requirement left them waiting for advances in computer technology and energy storage. However, during the last 20 years the brains and brawn have begun to arrive. Today AUVs are under development or are operational all over the world. Many oceanographers believe AUVs will be the next generation of important oceanographic tools capable of collecting all types of critical data.

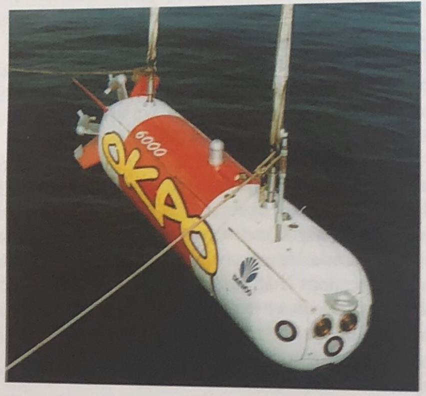
Daewoo Corp.

Figure 2-58

The OKPO AUV.

The torpedo-shaped OKPO is an example of a modern Autonomous Underwater Vehicle (AUV). The OKPO can dive to a depth of 6,000 meters (19,685 feet), travel at a speed of 3 knots, and operate independently of its mothership for 10 hours. This AUV is used for a number of purposes, including deep-sea mineral exploration, search and survey for sunken vessels, and oceanographic data measurements.

Another important breakthrough has been the invention of electronic navigation. After the invention of the chronometer, ships could determine their location accurately enough for navigational purposes. Plus or minus 2 kilometers (about a mile) is not much of an issue when you're in the open ocean. However, it is a huge difference if you're studying an archaeological shipwreck or a small, local, underwater community. Also, cloudy weather and haze sometimes meant that ships couldn't take a navigational fix for days at a time.

The first electronic navigation emerged in the late 1960s. Initially called LORAN (for LOng RAnge Navigation), it became known as Loran-C. Loran-C was based on radio signal transmitters along the coast. A ship that received signals from two or more transmitters could determine its position by plotting the signal directions and determining where they intersected. As electronics became more sophisticated, Loran-C receivers handled the plotting with software and simply displayed the latitude and longitude of the vessel.

Loran-C changed navigation. Instead of accuracy within a kilometer (about half a mile), ships knew their location within a few meters. Loran-C also provided navigation information 24 hours a day in any weather. (This was the primary reason for its invention—to make shipping safer.)

Loran-C was a big step for navigation, but it had its limits. For one, it was only functional where there were Loran transmitters. Many countries, especially remote, less developed ones, didn't have them. Secondly, Loran-C accuracy varied with distance from the transmitters. The farther away the vessel is, the less precise the position, and when a vessel is too far from shore, Loran-C doesn't reach it at all.

For these reasons, during the 1990s, GPS (Global Positioning System) largely replaced Loran-C. Developed and implemented by the US military, GPS is similar in concept to Loran-C, but provides signals from a series of orbiting satellites instead of transmitters on shore. GPS overcame the limits of Loran-C because it works everywhere (on land and at sea) and because it is much more accurate. With modern GPS receivers, accuracy within 1 or 2 meters (3 to 6 feet) is common. The most sophisticated ones display the ship's location, speed, and direction on top of a sea chart.

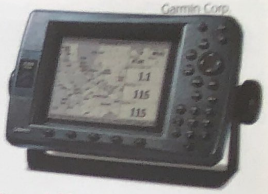
Garmin Corp.

Figure 2-59

Modern GPS.

GPS navigation is very important for oceanography because with it, scientists know where they are when they take samples or conduct a search. They can reliably return to a specific study location, and can provide this information to other scientists who need to conduct research in the same location.

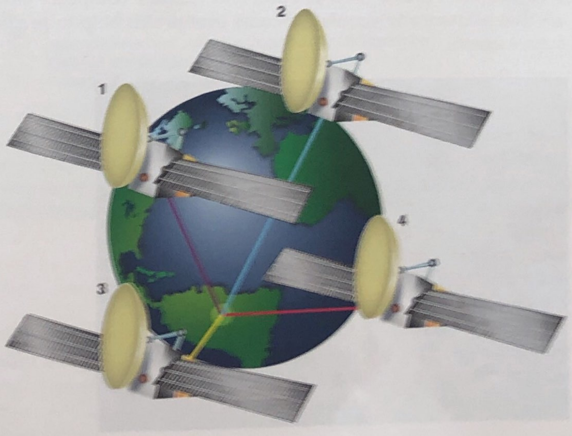

Figure 2-60

How GPS works.

A process called triangulation accurately determines a position on Earth using GPS (Global Positioning System). Satellite 1 transmits a signal that contains data on its location in space and the exact time the signal left the satellite. The GPS receiver collects and interprets this signal and is able to determine the distance from the satellite to the receiver. This creates an "area" of possible locations of the receiver. The process is repeated for satellites 2 and 3. Where the three signals meet at the GPS is its location expressed in specific coordinates. A fourth satellite signal is required to obtain the elevation of the GPS unit.

Electronic navigation has been very important for oceanography because with it, scientists know where they are when they take samples or conduct a search. They can reliably return to a specific study location, and can provide this information to other scientists who need to conduct research in the same location. Loran-C and GPS benefited seafaring and oceanography by making navigation significantly more accurate and easy.

In recent years, satellites have become an important tool for oceanographers. Satellites are objects that orbit a larger object, such as a planet. While there are natural satellites, including the moon, hundreds of man-made satellites also orbit the Earth. Satellites now assist oceanographers with global observations of the oceans, providing long-term, continuous measurements of variables, such as sea-surface height, shape, temperature, and color, over the entire planet. With this capability, they can detect algae blooms and river plumes, monitor pollution, and assist oceanographers in understanding the influence and effect of the oceans on the global climate system. They are a wonderful way for oceanographers to look at very large areas of the world in a very short period of time.

To obtain information about the oceans, scientists often go to sea and take measurements from ships or retrieve data from anchored or free-drifting buoys. Satellite observations complement the measurements taken at sea. Together, they provide oceanographers with varying data for studying global circulation and climate events such as El Niño. The information gathered from satellites is also used to build and validate computer models that numerically simulate climate events and help to predict future events.

NASA

Figure 2-61

The SeaStar satellite with the SeaWIFS instrument.

The Sea-viewing Wide Field-of-view Sensor (or SeaWIFS) instrument is part of the SeaStar satellite. The SeaStar is an excellent example of a satellite used by oceanographers. It provides information on subtle changes in ocean color, which indicate the presence and concentration of microscopic marine plants called phytoplankton. The greener the water, the more phytoplankton is present.