Techniques and Technology of Exploration in the Gulf of the Farallones

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Summary and Introduction

Although the oceans occupy 71 percent of the Earth's surface, they continue to be largely shrouded in mystery. From the surface it is impossible to see into the ocean depths, and actually going into those depths is both costly and hazardous. Because the oceans are crucial to our survival, we must try to understand the interactions of their complex physical and biological systems. In pursuit of this understanding, scientists seek many kinds of information—the depth, composition, temperatures, and movements of the water; the shape and composition of the sea bottom; and the types and abundances of the animals and plants living in the water and at the bottom. Some of these kinds of information can be obtained at the surface from ships, others require the lowering of cameras and sampling devices, and still others are best acquired through exploration in submersible vehicles, both manned and unmanned. Exploration in the Gulf of the Farallones has made use of a wide variety of such techniques.

When collecting multiple sets of geophysical and geological data over a wide area of the sea floor, precisely determining the location of an object or feature is critical. Navigation was therefore the common denominator that linked all data types together in a spatial frame of reference. Four types of navigation sensors were used to determine the locations of objects and features on the sea floor—Global Positioning System (GPS) satellites, Loran-C, and two ranging navigation systems (Del Norte and Benthos). The output from the GPS, Loran-C, and Del Norte systems was fed directly into a navigation program running on a microcomputer. This program provided important real-time location information, which was relayed to computers in onboard science laboratories and the ship's bridge. The Benthos system was a stand-alone system, which had its own program and display and ran separately from the integrated navigation system.

Two types of equipment using sound waves—sidescan sonar and seismic-reflection systems—were used to map the sea floor in the gulf. Images from three different sidescan systems were cut and pasted together to create "mosaics," which provide excellent map views of the area of sea floor studied in the gulf. Both 3.5-kilohertz (kHz) and 4.5-kHz high-resolution seismic-reflection systems were used to profile and look at the shallow subbottom (uppermost 50 m/160 ft) of the sea floor. A 10-kHz system was also used to provide accurate bathymetric information.

A towed seabed gamma-ray spectrometer belonging to and operated by the British Geological Survey, called the EEL because of its eel-like appearance, was used to measure the radioactivity of the sea floor. The gamma detector can measure both natural and artificial radioactivity in surficial sea-floor material to an effective maximum subbottom depth of about a foot. As the probe is towed, data are sent up the towing cable to a shipboard computer and recorded continuously.

Physical samples of the sea bottom were taken with two devices. A gravity corer, driven into the bottom by a heavy weight, was used to obtain round cores about 10 cm (~ 4 inches) in diameter and as much as 3 m (~ 10 ft) long. This type of coring device was used where the sediment was expected to be soft and muddy. The other sampling device used was a Van Veen grab sampler, which works very much like a clam shell. When the two sides of the shell touch the sea floor they close and scoop up a sample. This device was used where the sea floor was expected to be sandy, because sand would not easily be penetrated by or retained in a gravity corer.

Instrument packages were attached to lines moored to the sea floor to measure the velocity and direction of ocean currents in the Gulf of the Farallones. These instrument packages also measured water clarity, conductivity, salinity, and temperature.

A camera sled designed and built by the U.S. Geological Survey was towed from a research vessel along a preplanned trackline to take pictures of the sea floor in the gulf. Video was recorded continuously and still photographs were taken every 10 to 15 seconds. The images of the sea floor obtained with the camera sled were used to visually verify information collected from both sidescan-sonar mapping and physical sampling.

Visual observations were also made with *Sea Cliff*, a manned deep-submergence vehicle (DSV) operated by the U.S. Navy. *Sea Cliff* also had the capability to take physical samples with the use of mechanical arms. The Navy's unmanned Advanced Tethered Vehicle (ATV) was also used to obtain additional video and photographs of the sea floor. The ATV can be remotely "driven" to a specific site, and it proved to be the most precise way used so far in the Gulf of the Farallones to view objects on the sea floor

Navigation

When collecting multiple sets of geophysical and geological data over a wide area of the sea floor, precisely determining the location of an object or feature is critical. Navigation was therefore the common denominator that linked all data types together in a spatial frame of reference. Selection of a location for core sampling or conducting a camera transect was often based on information derived from sidescan-sonar mosaics and geophysical data. Thus, the navigation used in creating sidescan-sonar mosaics required the accuracy to allow a research vessel to return to a precise location to collect new data.

Four types of navigation sensors were used to determine the locations of objects and features on the sea floor—Global Positioning Satellites (GPS), Loran-C, and two ranging navigation systems (Del Norte and Benthos). The output from the GPS, Loran-C, and Del Norte systems was fed directly into a navigation program running on a microcomputer. This program provided important real-time location information, which was relayed to computers in onboard science laboratories and the ship's bridge. The Benthos system was a stand-alone system, which had its own program and display and ran separately from the integrated navigation system. The following are short descriptions of each of these systems:

Global Positioning Satellite (GPS)—This system consists of a constellation of navigational satellites and associated ground control equipment designed and maintained by the U.S. Department of Defense. Signals are broadcast on two frequencies on a continual basis. Simultaneous reception of the data transmitted by a minimum of four satellites allows receivers to determine distances to the satellites and therefore an accurate position on the Earth's surface. The accuracy of a GPS position can be within 35 m (~100 feet).

Loran-C—This system is a long range land-based radio-navigational system that consists of sets of stations, called a chain, covering many coastal and island areas in the northern hemisphere. A chain comprises a master station and two to four secondary stations that can be at distances of 1,000 to 1,500 miles from the master station. The accuracy of a Loran-C position is between about 100 to 500 m (328 to 1,640 ft). Loran-C stations are permanent fixtures and are maintained by the U.S. Coast Guard.

Del Norte ranging navigation—This system is similar to the Loran-C system in that it also uses radio-frequency communication to fixed stations on land. Two distinct differences between the Loran-C and Del Norte systems are: (1) Del Norte stations are set up by shore personnel for the duration of work, and (2) the Del Norte system is considered a short-range navigation system, short-range meaning the ship must be within line of sight of the shore stations. To maximize the range of the system, the stations are placed on hills and located away from electromagnetic sources and physical obstructions. The shipboard system "interrogates" each land station, which means the ship sends a signal to a station and waits for a reply. Each station has a distinct code; thus, when it replies to an interrogation the shipboard system can differentiate between stations. The distance from the ship to a shore station is calculated by using the two-way travel time of the signal. By distances from three or more stations, the ship's position is calculated by simple triangulation. The accuracy of a position determined by a Del Norte system is about 1 to 10 m (~3 to 30 ft).

Benthos long-baseline acoustic navigation—This system requires the positioning of six transponders at known locations on the sea floor. The array of transponders is called a transponder net. Benthos navigation is similar to Del Norte navigation in that it involves interrogating a transponder from the ship and receiving a subsequent reply from the transponder. The difference with the Benthos system is that the transponders and receivers are under water and the signal and reply are acoustic (sound waves, not radio waves).

Geophysics

Seismic-reflection

An integral part of the data collection scheme in the Gulf of the Farallones was the acquisition of bathymetric and shallow subbottom (upper 50 m/160 ft) profiles to help assess the character and stability of the sea floor. Data collected were primarily 3.5-kHz and 4.5-kHz high-resolution seismic-reflection profiles and 10-kHz bathymetric profiles. The following are short descriptions of each of these systems:

3.5-kHz high-resolution seismic-reflection system—This system is housed in a towfish body that is towed from a ship just below the ocean surface. Data are recorded both digitally and on a graphic line-scan recorder that displays and prints a cross-section view of the ocean floor directly below the towfish. The 3.5-kHz profiling system provides high resolution and shallow penetration, which yields details of the upper 25 to 30 m (~80 to 100 ft) of the sea floor.

4.5-kHz high-resolution seismic-reflection system—This system is part of the SeaMARC1A system (see below). It is a down-looking transducer mounted on the SeaMARC1A towfish along with transducers for sidescan sonar (fig. 1) and produces profiles similar to the 3.5-kHz system described above.

10-kHz echo-sounder system—This system is similar in design to the 3.5-kHz system. It is also housed in a towfish body and is towed from a ship at a depth similar to the 3.5-kHz towfish. Shipboard instrumentation consisted of a graphic recorder that printed out analog 10-kHz data on wet paper. Owing to its narrower beam, the 10.5-kHz system provides detailed bathymetric information with little if any subbottom penetration.

Sidescan sonar

Three different sidescan sonars were used to conduct surveys on the Continental Shelf and Slope in the gulf (fig. 2). The sidescan-sonar imagery, called a mosaic (fig. 3), provides a plan view of the sea floor. Sidescan-sonar mosaics are acoustic images of the sea floor. Acoustic energy transmitted from a sidescan transducer mounted on a towfish is "backscattered" from the sea floor, producing an image composed of light and dark tones. The shades of gray ranging from black to white that define the nature of the sea floor on the mosaic represent varying energy levels of acoustic backscatter. Many complex factors determine how sound is backscattered and reflected from the sea floor. Steep slopes, rough bottom, sea floor hardness, and sediment type all affect the level of backscatter. Sidescan data were collected in digital form and were processed aboard ship. The following are short descriptions of each of these systems:

SeaMARC1A deep-towed sidescan-sonar system—This system, which operates at a frequency of 27 to 30 kHz with a swath width of up to 5 km (3.1 miles), was used in water depths from 90 m (300 ft) to 300 m (900 ft). In the Gulf of the Farallones this system was used to construct a regional sonar mosaic and to map distribution of radioactive waste barrels. The data were processed onboard ship and the output, strips of paper, were pasted together on a geographic coordinate system to create a sea floor mosaic.

AMS-120 sidescan-sonar system—This system operates at a frequency of 120 kHz with a swath width of up to 0.75 km (0.5 miles). In the gulf, it was used for imaging both the Continental Shelf and uppermost Slope. The high resolution and relatively wide swath capabilities of this system make it ideal for working in water depths of less than 150 m (500 ft).

Huntec sidescan-sonar system—This system, which operates at a frequency of 100 kHz with a swath width of 0.2 km (650 ft), was used in the shallower shelf depths (less than 100 m). It provided the highest resolution, 10 cm (3.9 inches), of all three sidescan-sonar systems used in the gulf.

Radioactivity measurement

British Geological Survey EEL (towed seabed gamma-ray spectrometer)—The EEL, named for its eel-like appearance, measures the radioactivity of the sea floor. The detecting probe of the EEL is towed on the sea floor inside a 30-m (100 ft) length of plastic (PVC) hose, which protects the instrument. In addition to a gamma-ray detector, the probe also houses pressure (depth) and temperature sensors and a microphone that picks up the sound made by the EEL moving across the seabed. The gamma detector can measure both natural and artificial radioactivity in surficial sea-floor material to an effective maximum subbottom depth of about 30 cm (12 in). As the probe is towed, data are sent up the towing cable to a shipboard computer and recorded continuously. To receive accurate data the EEL must stay in contact with the sea floor as it is towed. The length of towing cable is altered, using a remote control, to maintain the probe on the seabed as water depth changes or to accommodate changes in the speed of the survey vessel. A clear reduction in the signal from both the gamma-ray detector and the microphone is seen if the probe loses contact with the seabed.

Physical Sampling

Several devices were used in the Gulf of the Farallones to collect sea-floor samples. Each device was attached to a cable and lowered by winch to the sea floor. The following are short descriptions of each device and the methods used to process the samples collected:

Gravity corer—This device is a carbon steel barrel that is attached below a lead weight stand (fig. 4), which drives the barrel into the sea floor. The weight used to drive the corer can vary from less than 100 pounds to as much as 2,000 pounds. The barrel is lined with a clear polybuterate tube that is approximately 10 cm (4 inches) in diameter. When the core is recovered, the clear liner is pulled out of the barrel and capped at both ends. The cores recovered in the gulf ranged in length from less than 1 to as much as 3 m (3 to 10 ft), depending on the sediment type at the site. A gravity core preserves the internal structure of the sediment and is used at sites where sediment is soft and relatively unconsolidated. Gravity cores were "logged" with a gamma-ray device onboard ship to determine compressional (p-wave) velocity and magnetic susceptibility. The cores were then cut into 150-cm (5 ft) sections (fig. 5). These sections were then split lengthwise into two halves. One half was used as a "working" half, and the other archived as a reference. Each core was visually described at sea and radiographed (X-rayed). X-raying provides a nondestructive means of observing internal structure and sedimentary and biogenic features within the cores. A small sample of core was also taken for laboratory analysis to determine particle-size distribution. Geotechnical analyses to determine the strength and sea floor stability of the sediment were performed on all cores back in the onshore laboratory following the survey.

Van Veen grab sampler—This device was used where sea-floor sediment was too coarse and dense (dominantly sandy) for gravity coring (fig. 6) . A Van Veen is a type of grab sampler that works like a clam shell. When this grab sampler comes in contact with the sea floor, the clam shell closes and sediment is scooped into the device. The Van Veen is also able to collect a good sample of the benthic fauna present both on and within the sea floor.

Oceanographic Measurements

Measurements of water movement (velocity and direction), temperature, clarity, and salinity were made from moorings consisting of several devices (fig. 7). An array of six current meter moorings were deployed across the shelf and slope in the gulf. All instruments at a site were attached to a single mooring and either a single or dual acoustic release package was used to connect the mooring to the anchor. The vertical length (depth) of the longest mooring was about 1,900 m (6,200 ft) and the shortest mooring was about 80 m (260 ft). The following are short descriptions of each of the devices attached to moorings:

Vector-averaging current meter (VACM)—These devices measured the average current direction and speed every 3.75 minutes. In addition to measuring currents, some current meters were outfitted with a transmissometer (to measure water clarity), conductivity cells (to measure conductivity used to calculate the salinity of the water), and temperature sensors (to measure water temperature). All these properties are important to understand the structure of the water column.

Sediment traps—These devices capture sediment suspended in the water column as it settles. Intervalometers that dispense layers of white Teflon beads at a specified time interval (monthly) were used in the sediment traps for time control to allow determination of local sediment rates within a particular trap.

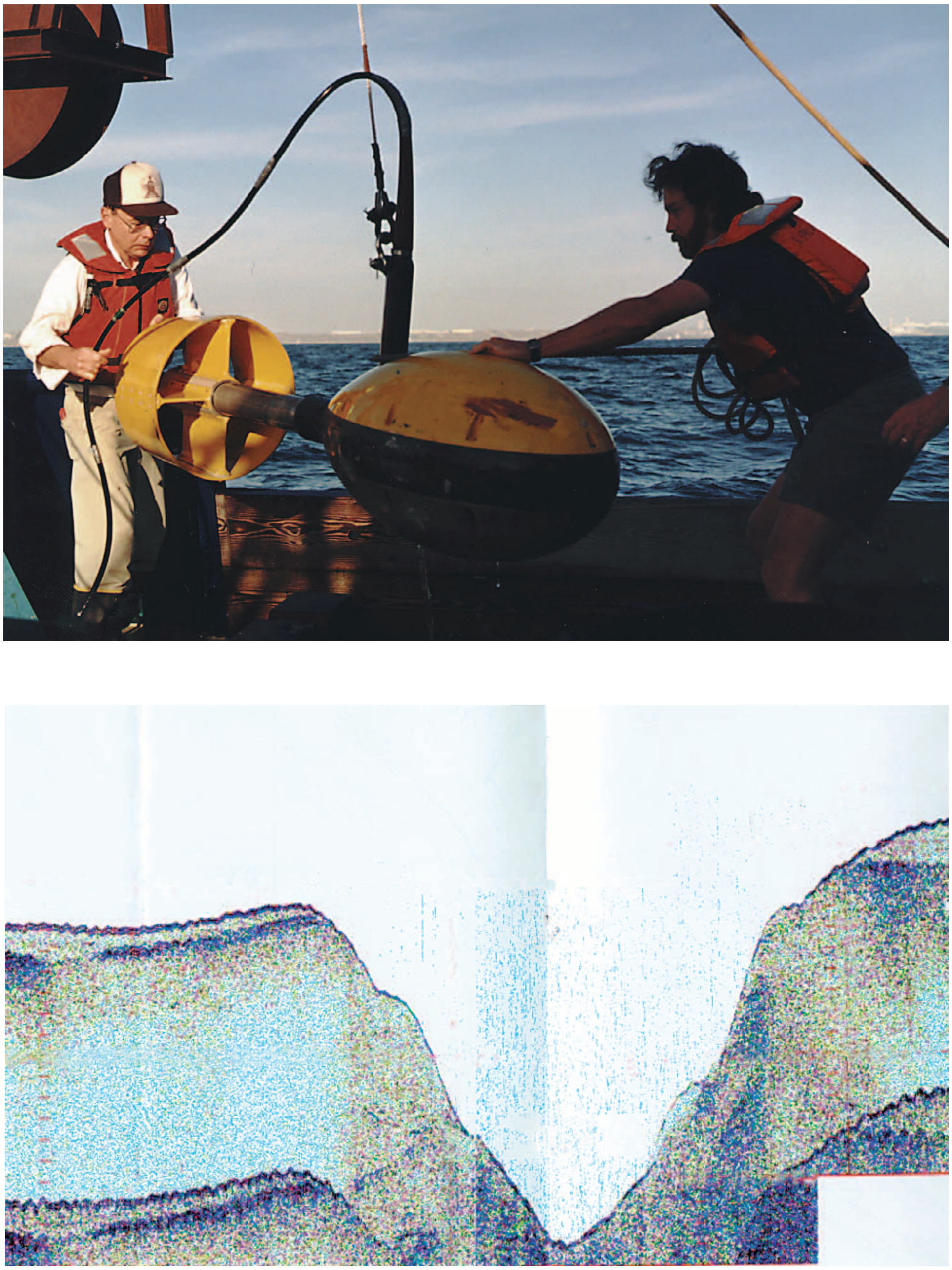
Visual Observations

Visual observations of the sea floor in the Gulf of the Farallones were made using a camera sled to take photographs and video of the sea floor and by manned and unmanned submersibles. The submersibles were also used at times to collect sea floor samples. The following are short descriptions of each of these methods:

Camera sled— A camera sled designed and built by the USGS was towed from a research vessel along a pre-planned trackline to take pictures of the sea floor in the gulf (fig. 8). Video was recorded continuously and 35-mm still photographs were taken every 10 to 15 seconds. The still photos and videos obtained allowed scientists to visually verify the nature of the sea floor that had been deduced from acoustic surveys. Sea floor photography provided valuable information on the sedimentary and biologic features present on the sea floor in the gulf. The camera sled also provided a safe way to verify the presence of low-level radioactive waste barrels whose locations had been derived from acoustic surveys.

Deep Submergence Vehicle (DSV) Sea Cliff—Visual observations and verification of location of some low-level radioactive waste barrels was done using this 9.6-m (31.5 ft.), 58,000-pound, three-person deep submergence vehicle (DSV), operated by the U.S. Navy (fig. 9). The vehicle was equipped with a television camera, video recorder and monitor, flood lights, a 35-mm still camera, sonar, and underwater and surface communications. *Sea Cliff* is also equipped with mechanically operated arms that were used to collect sea floor samples and to manipulate instrumentation.

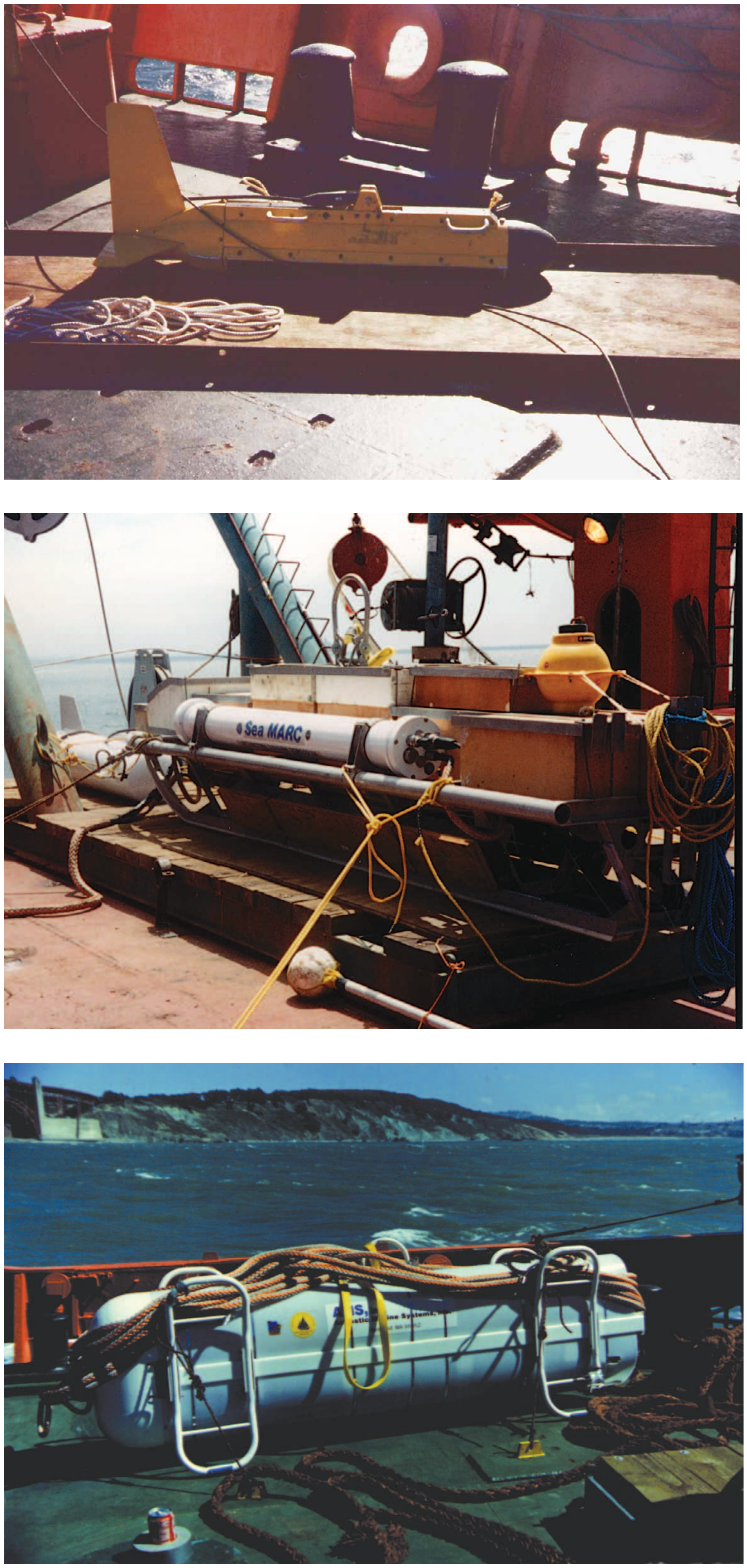
Advanced Tethered Vehicle (ATV)—The U.S. Navy's Advanced Tethered Vehicle (ATV) is a remotely operated vehicle with deep-diving capability (fig. 9). It has manipulator arms, video and camera packages, and search sonar. The ATV is operated from a control room onboard ship. The search sonars allow for target acquisition at ranges of several hundred meters. The ATV is then driven by joystick to the target using the search sonar. Video cameras allow target identification and sample collection with the use of the manipulator arms. The ATV provided the most precise and safe way used in the gulf to view and verify specific targets on the sea floor.



A

B

Figure 1. *A*, Acoustic towfish used for both 3.5-kHz and 10-kHz high-resolution seismic-reflection systems. *B*, Example of a record from a 3.5-kHz system.



A

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C

Figure 2. The three sidescan-sonar systems that were used to map the sea floor in the Gulf of the Farallones: *A*, Huntec; *B*, SeaMARC1A; *C*, AMS 120.

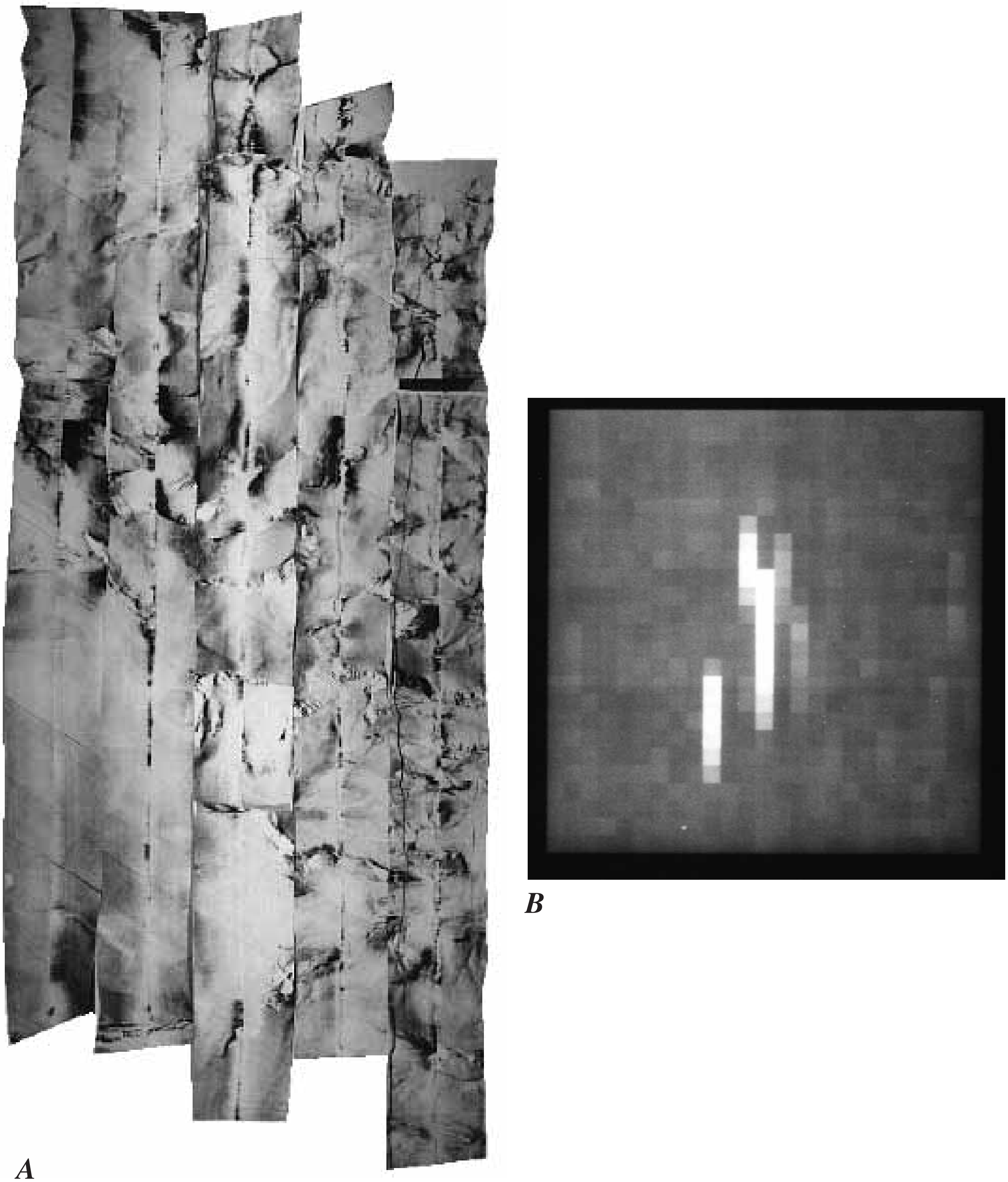


Figure 3. *A*, Sidescan-sonar mosaic; each "strip" represents the data from one trackline. *B*, An individual record.

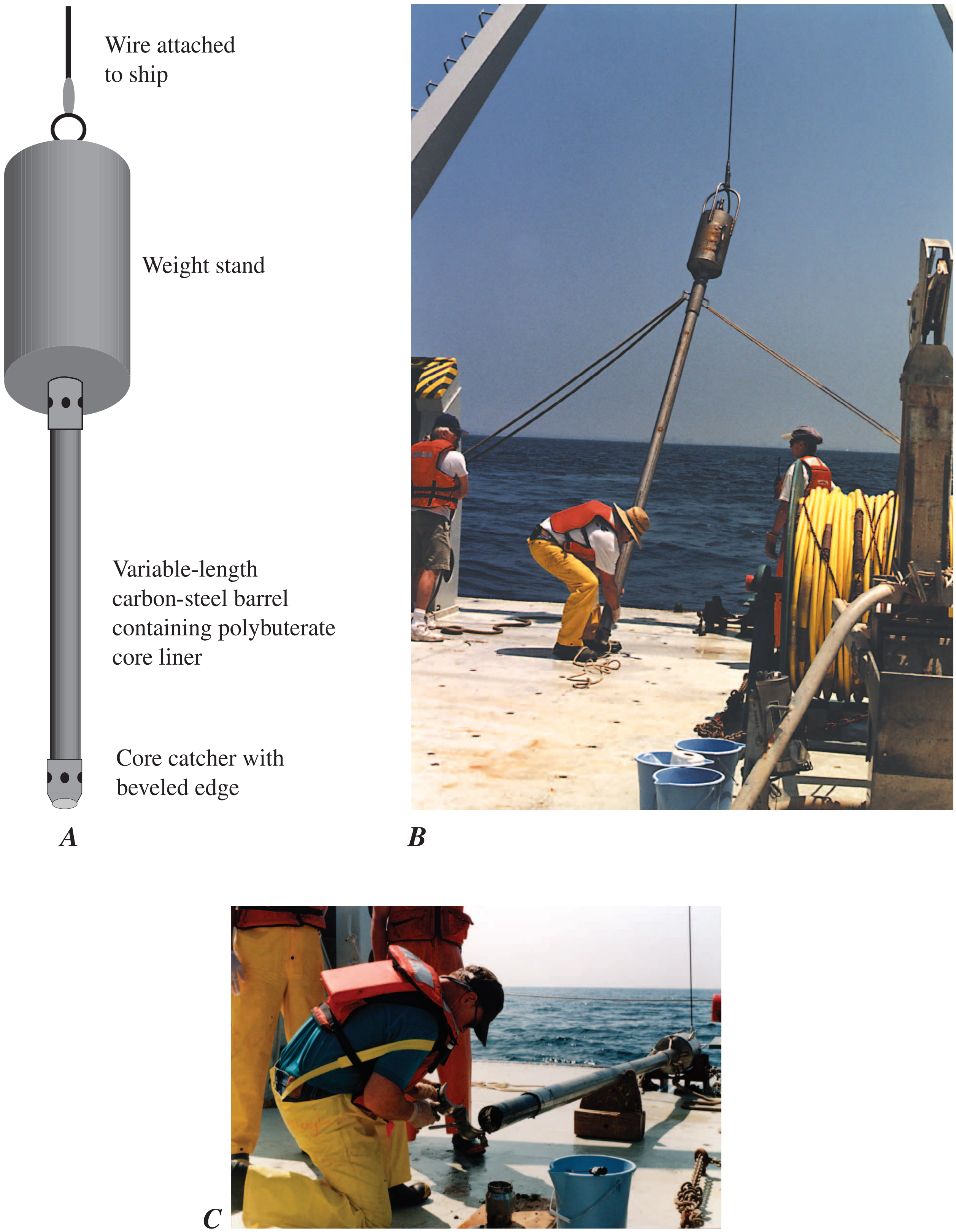


Figure 4. *A*, Schematic diagram of a gravity corer. *B*, Gravity corer being launched from a ship. *C*, Polybuterate core liner being extracted and cut into sections.

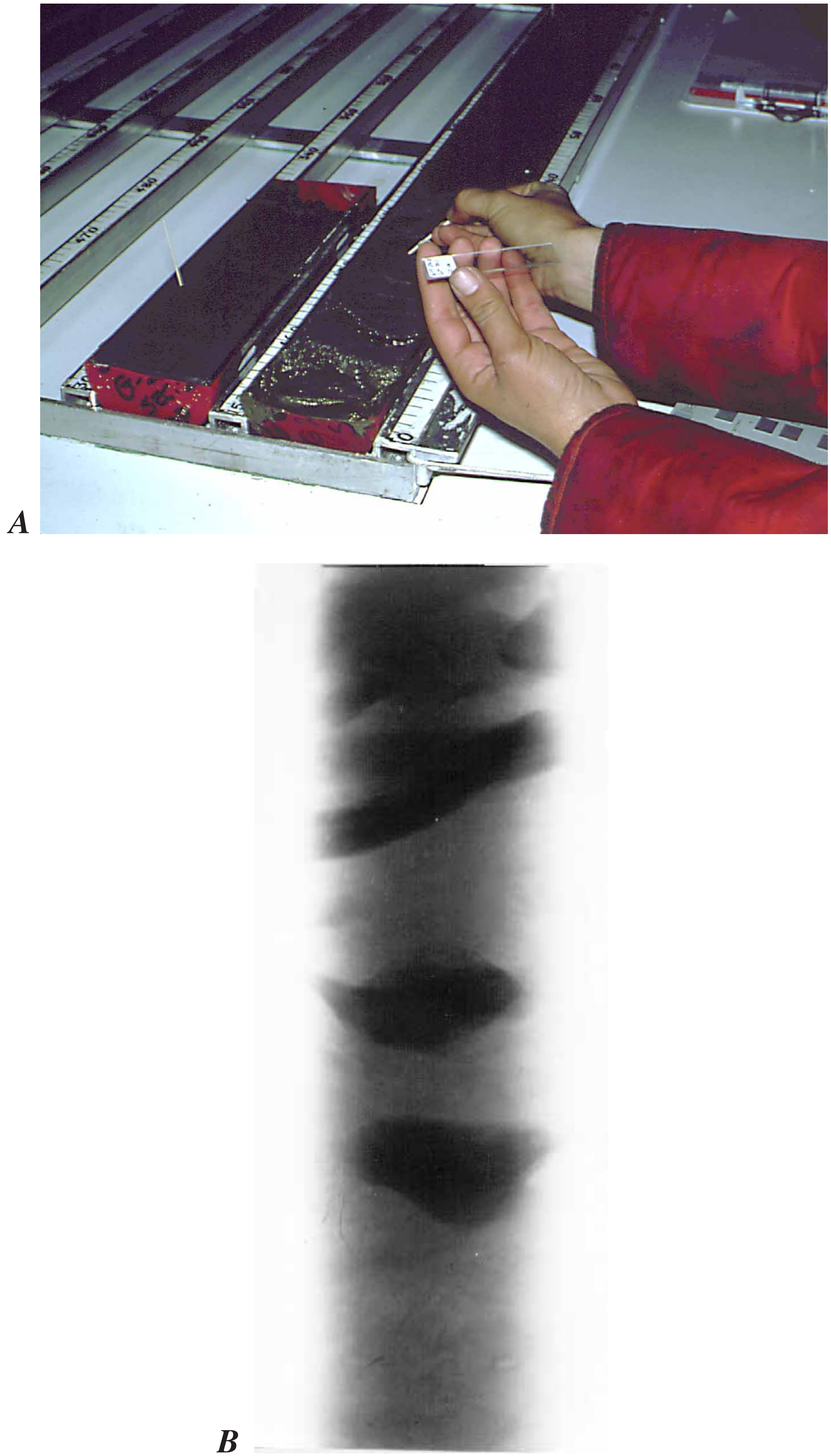


Figure 5. Gravity cores are split lengthwise and described onboard ship and later X-rayed onshore: *A*, Split core being sampled; *B*, X-ray of a gravity core.

Figure 6. *A* and *B*, Van Veen grab sampler. This type of sampler is used when sampling coarse sand. *C*, Sand and brittle stars recovered using a Van Veen sampler.

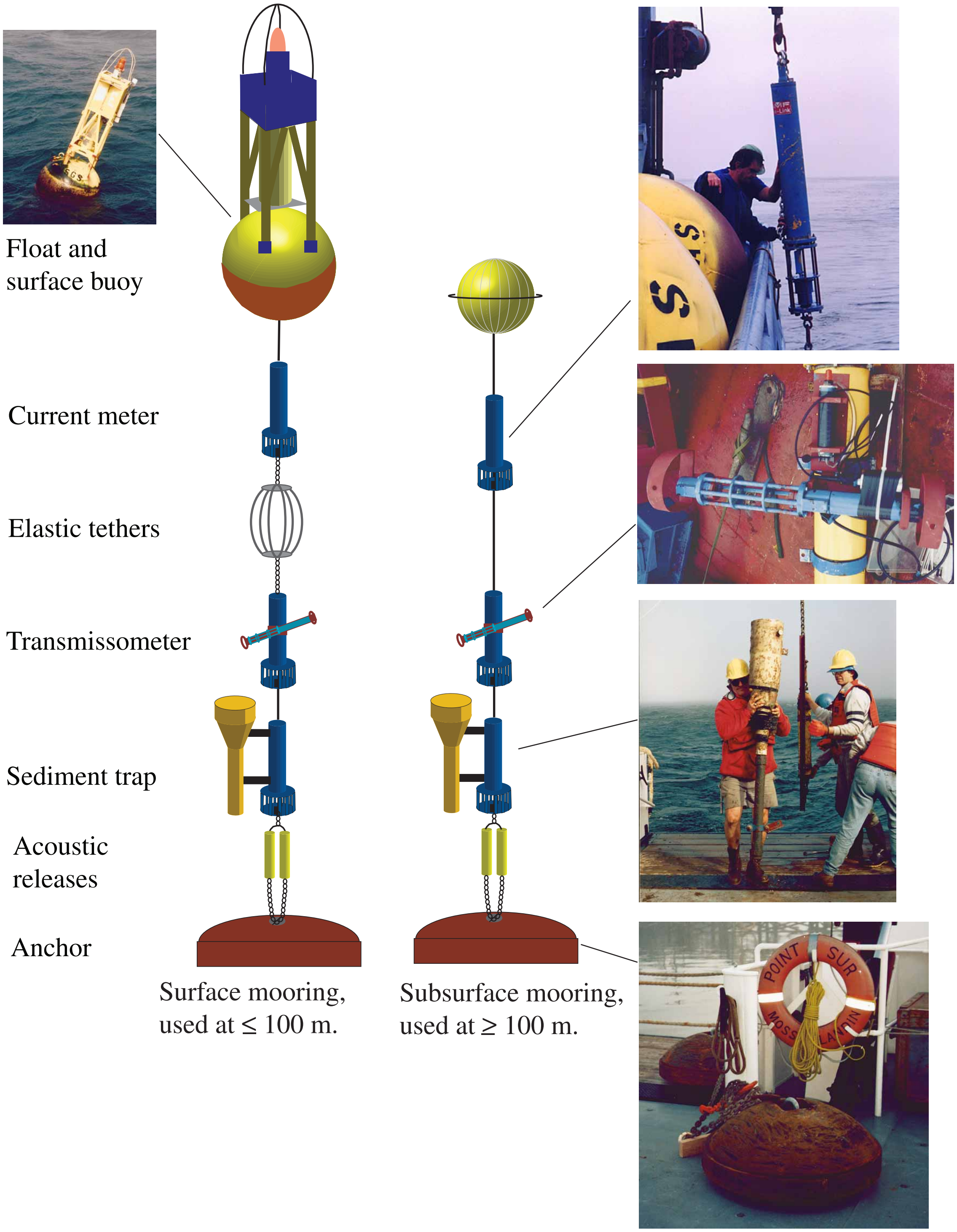
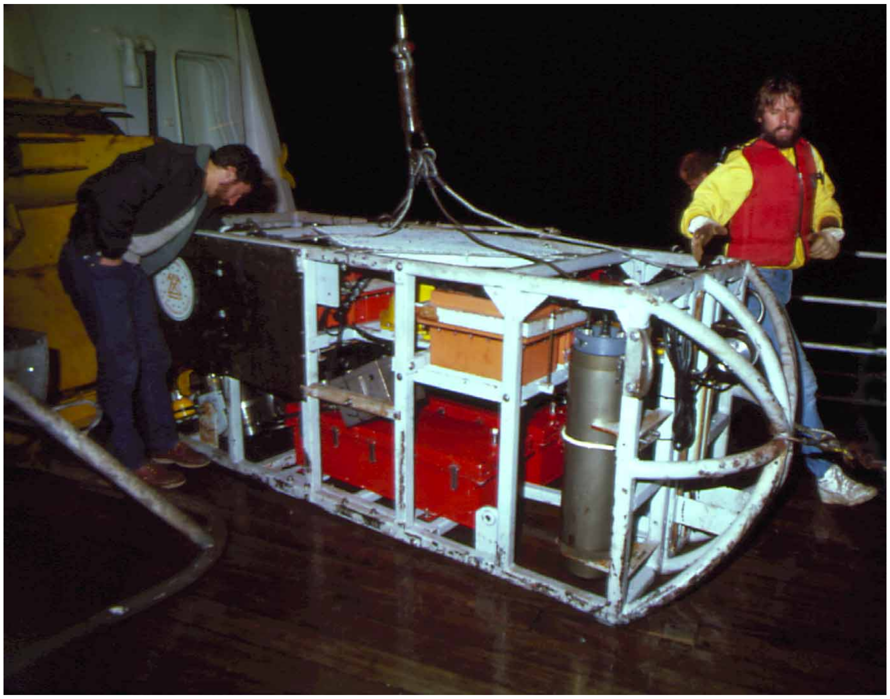
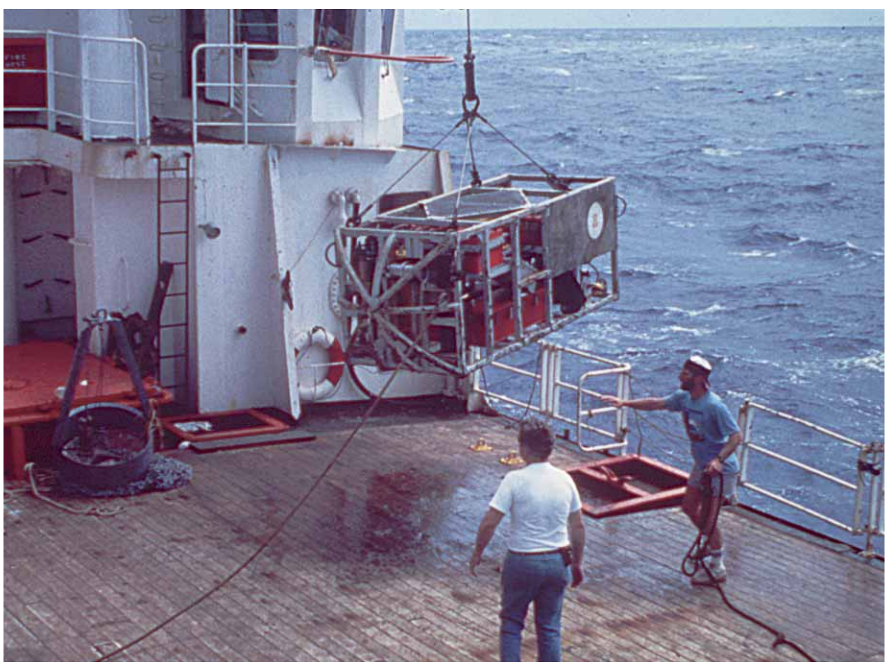


Figure 7. Examples of current moorings used in the Gulf of the Farallones. Instruments on these moorings measured the speed and direction of ocean currents, as well as water clarity, conductivity, salinity, and temperature.



A



B

Figure 8. *A*, U.S. Geological Survey camera sled equipped with both video and still cameras to photograph the sea floor. *B*, Sled being launched from ship.

A *B* *C*

Figure 9. The *Laney Chouest* (*A*), the support vessel for the U.S. Navy's Advanced Tethered Vehicle (ATV) (*B*) and deep submergence vehicle (DSV) *Sea Cliff* (*C*).