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DEEP-SEA DRILLING METHODOLOGY

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Introduction

The technology developed and used in the Deep Sea Drilling Project and the Ocean Drilling Program include innovative drilling methods, sampling tools and procedures, *in situ* measurement tools, and seafloor observatories. Drilling technology for the new Program, Ocean Drilling in the 21st Century, is now under development for use by 2006. This new technology will be used to drill deeper into the seafloor than is currently possible in the Ocean Drilling Program. The first drilling target of Ocean Drilling in the 21st century is the seismogenic zone offshore Japan, a location deep in the Earth (10–14 km) where earthquakes are generated.

Drilling Technology

The Deep Sea Drilling Project and the Ocean Drilling Program use the same basic drilling technology, the open hole method. Drilling is the process of establishing a borehole. The open hole method uses a single drill pipe that hangs from the drill ship's derrick, a tall framework positioned over the drill hole used to support the drill pipe. The drill pipe is rotated using drilling systems the drill floor of the ship. Surface sea water is flushed through the center of the pipe to lubricate the rotating bit that cuts the rock and then flushes sediment and rock cuttings away to the seafloor (**Figure 1**). Open hole refers to the resulting borehole which remains open to the ocean during drilling. This method is also called a riserless drilling system. Important parts of the deep-water drilling system are a drilling derrick that is large enough to hang a long length of drill pipe reaching deep ocean and sub-seafloor depths (up to 8 km); a system that rotates the drill pipe; a motion compensator that isolates the ship's motion from the drill pipe; and a pump that flushes sea water through the drill pipe.

Open hole methods are successfully used in all of the Earth's oceans (**Figure 2**). The Ocean Drilling Program's achievements include drilling in very deep water (6 km) and to > 2 km below the seafloor (**Table 1**). Although there have been many achievements using these methods, there are also limitations. The open hole method cannot be used to drill depths > 4 km below the seafloor. Although the exact depth limit of the Ocean Drilling Program is not yet known, it is likely limited to 2–4 km. This limitation exists because when drilling deep into the seafloor, the drill fluid must be modified to a lower density so that the deep cuttings can be lifted from the bit and flushed out of the hole. In open hole methods, the drilling fluid density cannot be controlled. Another limitation of this method is that drilling must be restricted to locations where hydrocarbons are unlikely to be encountered. In an open hole, there is no way to control the drilling fluid pressure. In locations where oil and gas may exist, the formations are frequently overpressured (similar to a champagne bottle). If these formations were punctured with an open hole system, the drill pipe would act like a straw that connects this overpressured zone in the rock to the ocean and the ship. This type of puncture is called a 'blow-out' and is very dangerous. The explosion as gases are vented through the straw to the ship's drill floor could cause serious damage, or worse yet, the change in the density of the sea water as the gas bubbles are released into the overlying ocean could cause the ship to sink. With no system to control the pressure in the borehole using the open hole drilling method, there is no way to prevent a blow-out.

The new deep-sea drilling technology currently under development by Ocean Drilling in the 21st century is a closed system, also known as riser drilling. This technology has been used, in relatively shallow water, by the offshore oil industry to explore for and produce oil and gas.

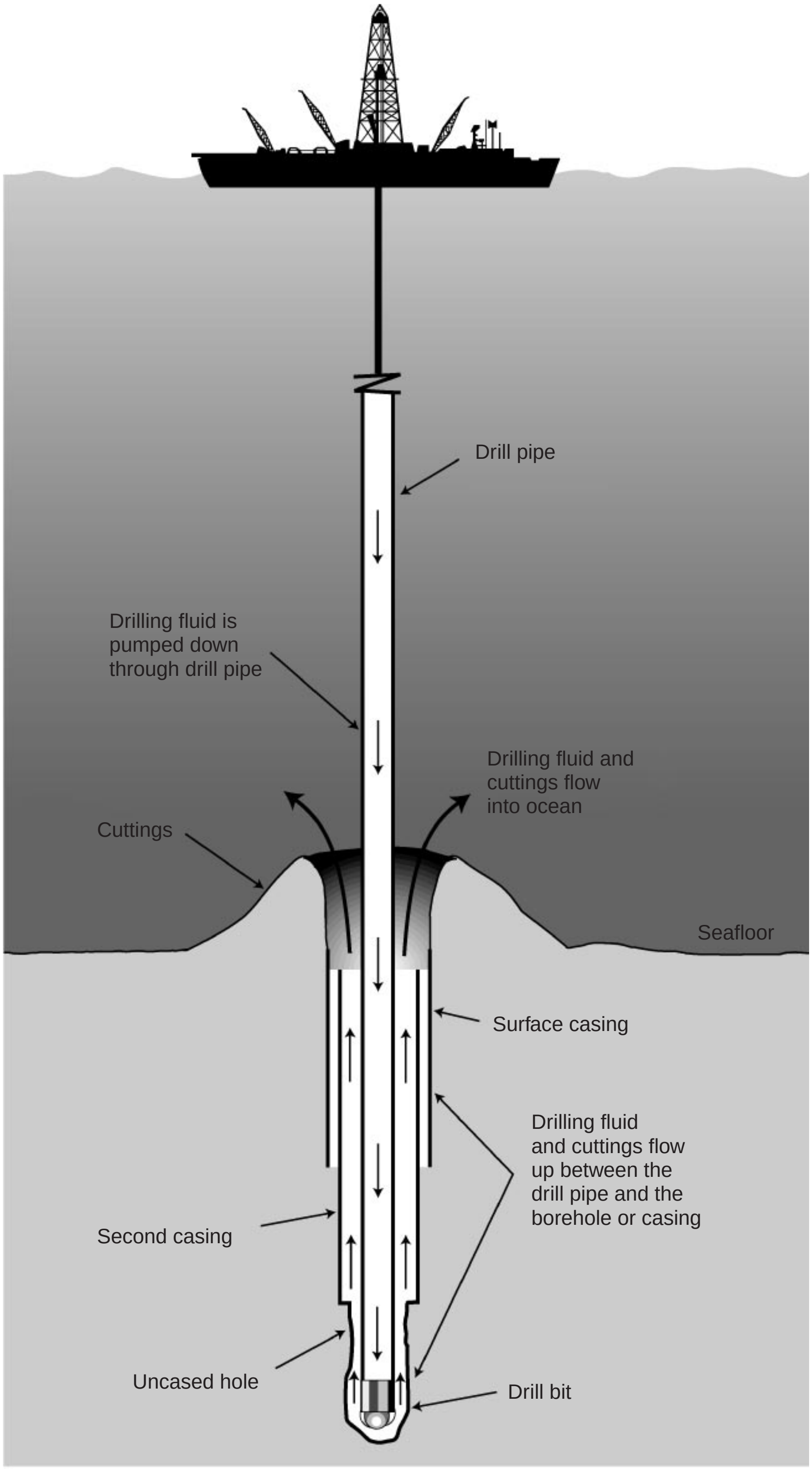

Figure 1 Diagram of a nonriser drilling system.

Riser drilling uses two pipes: a drill pipe similar to that used for open hole drilling and a wider diameter riser pipe that surrounds the drill pipe and is cemented into the seafloor (**Figure 3**). The system is closed because drill fluid (sea water and additives) is pumped down the drillpipe (to lubricate the bit and flush rock cuttings away from the bit) and then returned to the ship via the riser. With riser drilling,

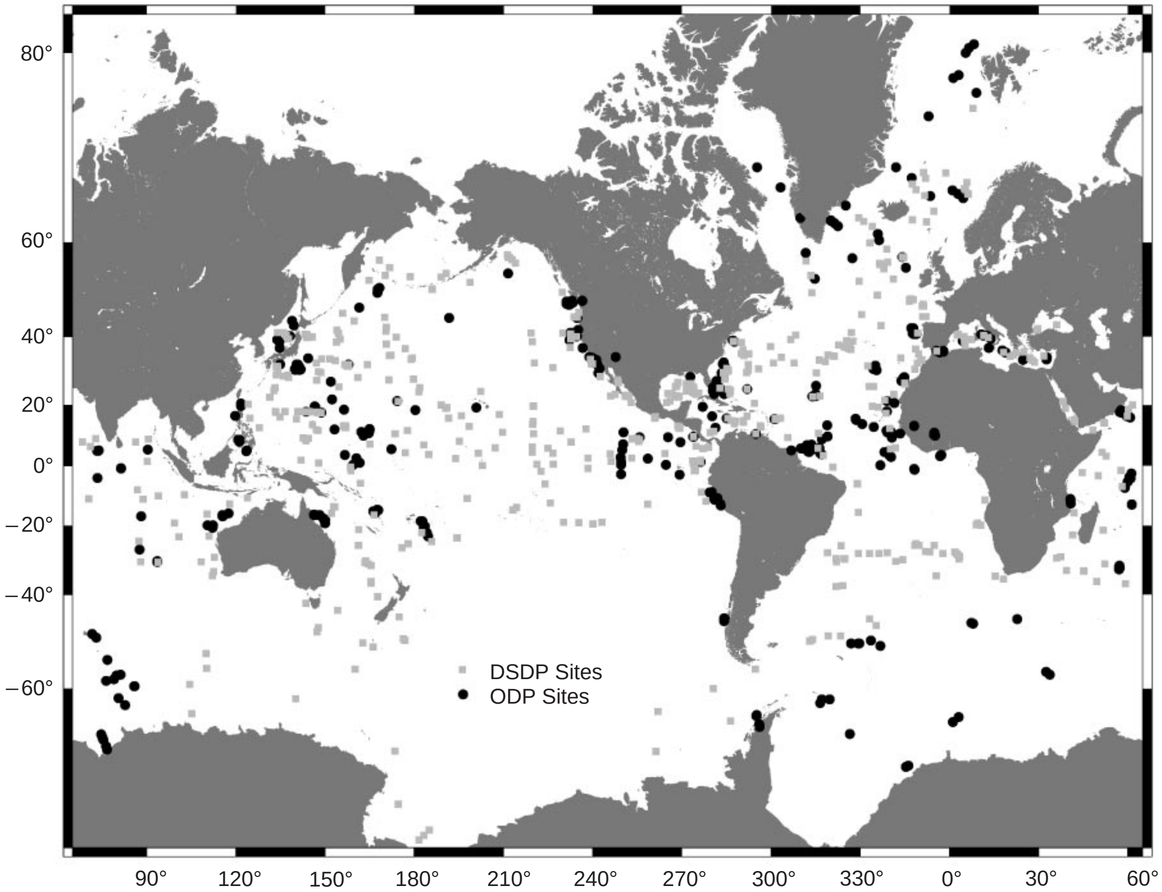

Figure 2 Map of all the sites drilled by the Deep Sea Drilling Project (DSDP) and the Ocean Drilling Program (ODP).

the drill fluid density can be varied and borehole pressure can be monitored and controlled, thus overcoming the two limitations of open hole drilling. The single limitation of riser drilling is water depth. The current water depth limit of riser technology is approximately 3 km. This water depth limit occurs because the riser, filled with drill fluid and cuttings, puts a large amount of pressure on the rock greater, in fact, than the strength of the rock, thus the rock breaks apart under this riser pressure, causing the drilling system to fail.

Deep-sea Sampling

Scientific ocean drilling not only requires a borehole, but more importantly the recovery of high-quality core samples taken as continuously as possible. Recovering sediment and rock samples from below the seafloor in deep water requires the use of wireline tools. Wireline tools are pumped down the center of the drill pipe to the bottom (called the bottom hole assembly) where they are mechanically latched into place near the drill bit in preparation for sampling. Different types of tools are advanced into the geological formation and take a core sample in different ways, depending on the type of sediment or rock. After the tool samples the rock formation, it is unlatched from the bottom hole assembly with a mechanical device, called an overshot, that is sent down the pipe on a wire. The overshot is used to unlatch the wireline tool, return it to the ship, and recover the core sample.

In the Ocean Drilling Program, three standard wireline core sampling tools are used, the advanced piston corer, the extended core barrel, and the rotary core barrel.

The piston corer is advanced into the sediment ahead of the drill bit using pressure applied by shipboard pumps through the drill pipe (**Figure 4A**). The drill fluid pressure in the pipe is increased until the corer shoots into the sediment. After the corer is shot 10 m ahead of the bit, it is recovered using the wireline overshot. The drill pipe and bit are then advanced by rotary drilling another 10 m, in preparation for taking another core sample. The piston corer is designed to recover undisturbed core sam-

Table 1 Fact sheet about the *JOIDES Resolution*, the research vessel used by the Ocean Drilling Program

Total number of days in port		445 days
Total number of days at sea		4751 days
Total distance travelled		507 420 km
Total number of holes drilled		1445 holes
Deepest water level drilled	Leg 129	5980 m
Deepest hole drilled	Leg 148, Hole 504B (South-eastern Pacific Ocean, off coast of Ecuador)	2111 m
Total amount of core recovered		180 880 m
Most core recovered on single leg	Leg 175 – Benguela (Aug. 15–Oct.10, 1997)	8003 m
Northernmost site drilled	Leg 113, site 911	latitude 80.4744°N longitude 8.2273°E
Southernmost site drilled	Leg 151, site 693	latitude 70.8315°S longitude 14.5735°W
Year and place of constitution	1978	Halifax, Nova Scotia, Canada
Laboratories and other scientific equipment installed	1984	Pascagoula, Mississippi
Gross tonnage		9719 tons
Net tonnage		2915 tons
Engines/generators		Seven 16 cyl index Diesel 5@2100 kW (2815 hp) 2@15500 kW (2010 hp)
Length		143 m
Beam		21 m
Derrick		62 m
Speed		11 knots
Crusing range		120 days
Scientific and technical party		50 people
Ship's Crew		65 people
Laboratory space		1115 m^2
Drill string		8838 m

ples of soft ooze and sediments up to 250 m below the seafloor. In soft to hard sediments, the piston corer can achieve 100% recovery. However, because the cores are taken sequentially, sediment between consecutive cores may not be recovered. To ensure that a continuous sedimentary section is recovered, particularly for paleoclimate studies, the Ocean Drilling Program drills a minimum of three boreholes at one site. The positions of the breaks between consecutive core samples are staggered in each borehole so that if sediment is not sampled in one borehole at a core break depth, it will be recovered in the second or third borehole.

The extended core barrel is a modification of the oil industry's rotary corer and is designed to recover core samples of sedimentary rock formation (**Figure 4B**). Typically, the extended core barrel is deployed at depths below the seafloor in which the sediment is too hard for sampling by the piston corer. The extended corer uses the rotation of the drill string to deepen the borehole and cut the core sample. The cutting action is done with a small bit attached to the core barrel. An innovation of this tool is an internal spring that allows the core barrel's smaller bit to extend ahead of the drill bit in softer formations. In hard formations, where greater cutting action is needed, the spring is compressed and the small core bit rotates with the main drill bit.

The rotary core barrel is a direct descendant of the rotary coring system used in the oil industry and is similar to the extended core barrel when it is in its retracted mode. The rotary corer is designed to recover core samples from medium to very hard formations, including igneous rock. The corer uses the rotation of the drill string and the main drill bit to deepen the hole and cut the core sample (**Figure 4C**).

In all drilling operations, there are times when the drill pipe must be recovered to the ship, for example, to change a worn bit or to install different bottom hole equipment. Before pulling the pipe out of the borehole, a re-entry cone (**Figure 5**). is dropped down the outside of the drill pipe where it free

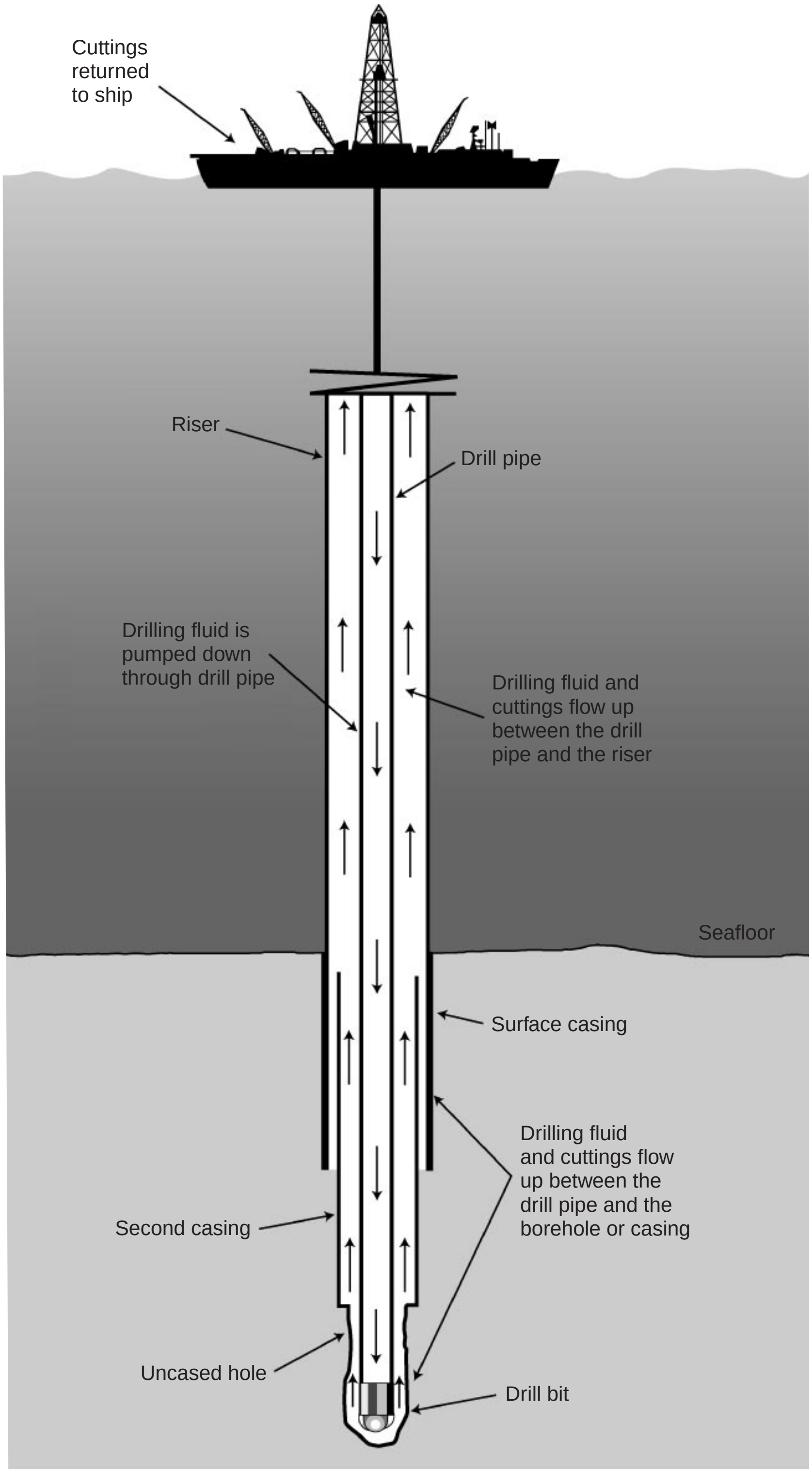

Figure 3 Diagram of a riser drilling system.

falls to the seafloor. The cone is used as a guide to re-enter the borehole with a new bit or equipment. The cone is a very small target in deep water (1–6 km) and ancillary tools are needed to locate it for re-entry into the borehole. The cone is first located acoustically, using seafloor transponders. To precisely pinpoint the cone a video camera is lowered with the drill pipe to visually pinpoint the

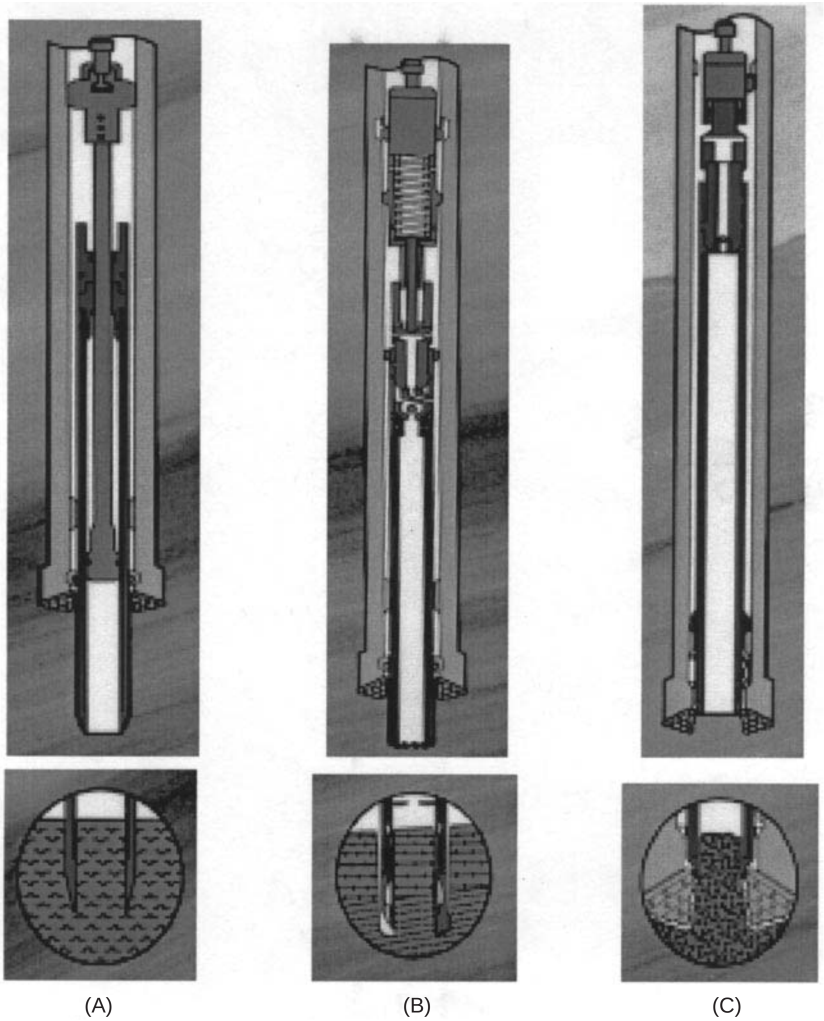
(A) (B) (C)

Figure 4 Diagrams of the Ocean Drilling Program's coring tools. (A) Advanced piston corer; (B) extended core barrel; (C) rotary core barrel.

location and drop the drill pipe back into the borehole.

Special corers are used to sample unusual and difficult formations. For example, gas hydrates, ice-like material that is stable under high pressure and low temperature, commonly occur in deep water below the seafloor and require special samplers. Gas hydrates have generated a lot of public interest since they can contain methane gas trapped within their structure, which is thought to be a potential future energy source. However, when gas hydrate is sampled, it must be kept at *in situ* pressure conditions to maintain the integrity of the core. Thus a pressure core sampler is used to sample hydrates. The sampler is similar to the extended corer in that it has its own bit, but it has an internal valve that closes before the sampler is removed from the formation. The closed valve maintains the sample at *in situ* pressure conditions.

A new coring system that will sample and maintain cores at *in situ* temperatures and pressure is under development by a European consortium, led by the University of Berlin. The system will include a variety of coring tools to sample gas hydrates in a full range of lithologies (soft sediment to hard rock). It will also include a system for nondestructive physical and chemical analyses and sampling under pressure and at controlled temperatures, once the samples are recovered to the ship from below the seafloor. The system is ideally suited to study gas hydrates and the Earth's deep biosphere.

Drilling Measurements

Once sampling is completed, logging tools are lowered into the borehole to measure the *in situ* geophysical and chemical properties of the formation. In the Ocean Drilling Program, logging tools,

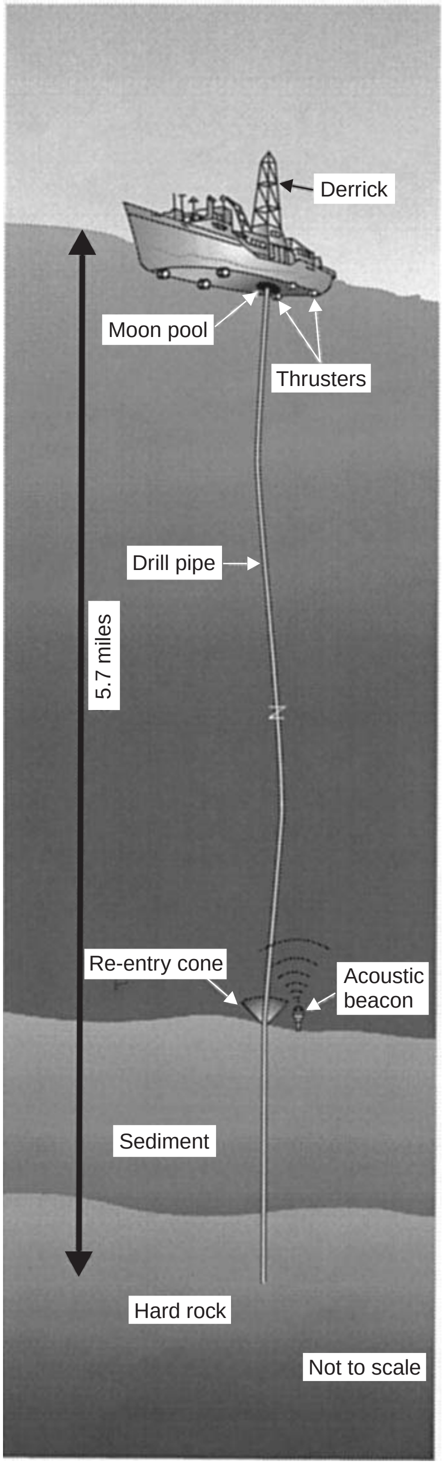

Figure 5 Diagram of the ship, drill pipe, and re-entry cone used in the drilling process.

developed for use in the oil industry, are leased from Schlumberger. The origins of logging go back to 1911 when the science of geophysics was new and was just beginning to be used to explore the internal structure of the Earth. Conrad and Marcel Schlumberger, the founders of Schlumberger, conceived the idea that electrical measurements could be used to detect ore (precious minerals). Working at first alone and then with a number of associates, they extended the electrical prospecting technique from the surface to the oil well. Now, the use of electric prospecting, called logging, is widely accepted as a standard method in oil exploration.

Logging tools are lowered into the borehole using a cable that also transmits the data, in real time, to the ship. The term logging refers to the type of data collected. For example, a borehole log is a record or ledger of the sediment and rock encountered while drilling. Logs are geophysical and chemical records of the borehole. The logging tools typically comprise transmitters and sensors or a sensor alone encased in a robust stainless steel tube. Examples of tool measurements include electrical resistivity, gamma ray attenuation, natural gamma, acoustic velocity, and magnetic susceptibility. Log data provide an almost continuous record of the sediment and rock formation along length of the borehole.

Log data are of high quality when collected in the open hole, outside of the drill pipe. The most common method for deploying logging tools is to deploy a device that releases the drill bit from the drill pipe once all drilling and sampling operations are completed. The drill bit falls to the bottom of the borehole and is left there. The drill pipe is retracted and only 75–100 m of pipe are left at the top of the

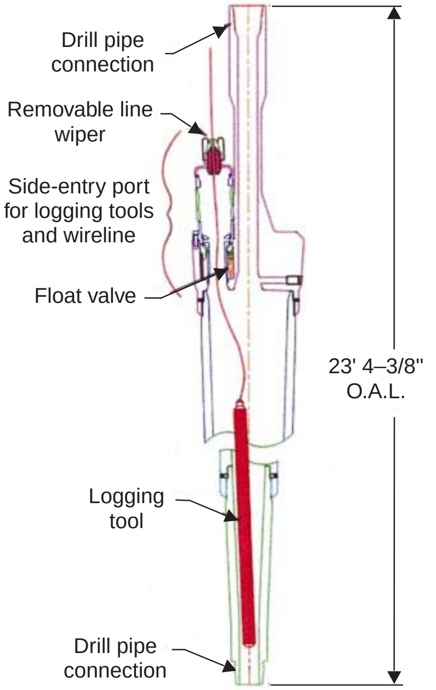

Figure 6 Diagram of the side-entry sub technology.

borehole to keep the upper, loose part of the borehole stable. Logging tools are lowered through the drill pipe to the bottom of the borehole. Log data are acquired by slowly raising the tool up the borehole at a constant speed. When boreholes are unstable and the walls are collapsing into the open hole, another method is used, unique to the Ocean Drilling Program. In unstable conditions, the drill pipe cannot be retracted to within 75 m of the seafloor without borehole walls collapsing and blocking or bridging the hole. In these situations, after the bit is released, the logging tools are lowered inside the drill pipe to the bottom of the hole. The drill pipe is retracted only enough to expose the logging tools to the open hole, while protecting the remainder of the borehole walls. Then, drill pipe is retracted at the same speed as logging tools are pulled up through the borehole. The technology developed that allows for this unique operation is called the side-entry sub (**Figure 6**). When inserted as a part of the drill string, the cable, to which the tools are attached, exits the drill pipe at the side-entry sub, positioned well below the ship. In the way, the logging cable does not interfere with removal of drill pipe.

Data in the borehole are also collected using wireline-deployed tools. Sediment temperature is measured with a temperature sensor mounted inside the cutting edge of the piston corer. In addition, other tools are deployed that do not recover a sample. They are pushed into the sediment ahead of the drill bit, left in place for 10–15 min to record temperature, and then pulled back to the ship, where the data are downloaded and analyzed. Special wireline

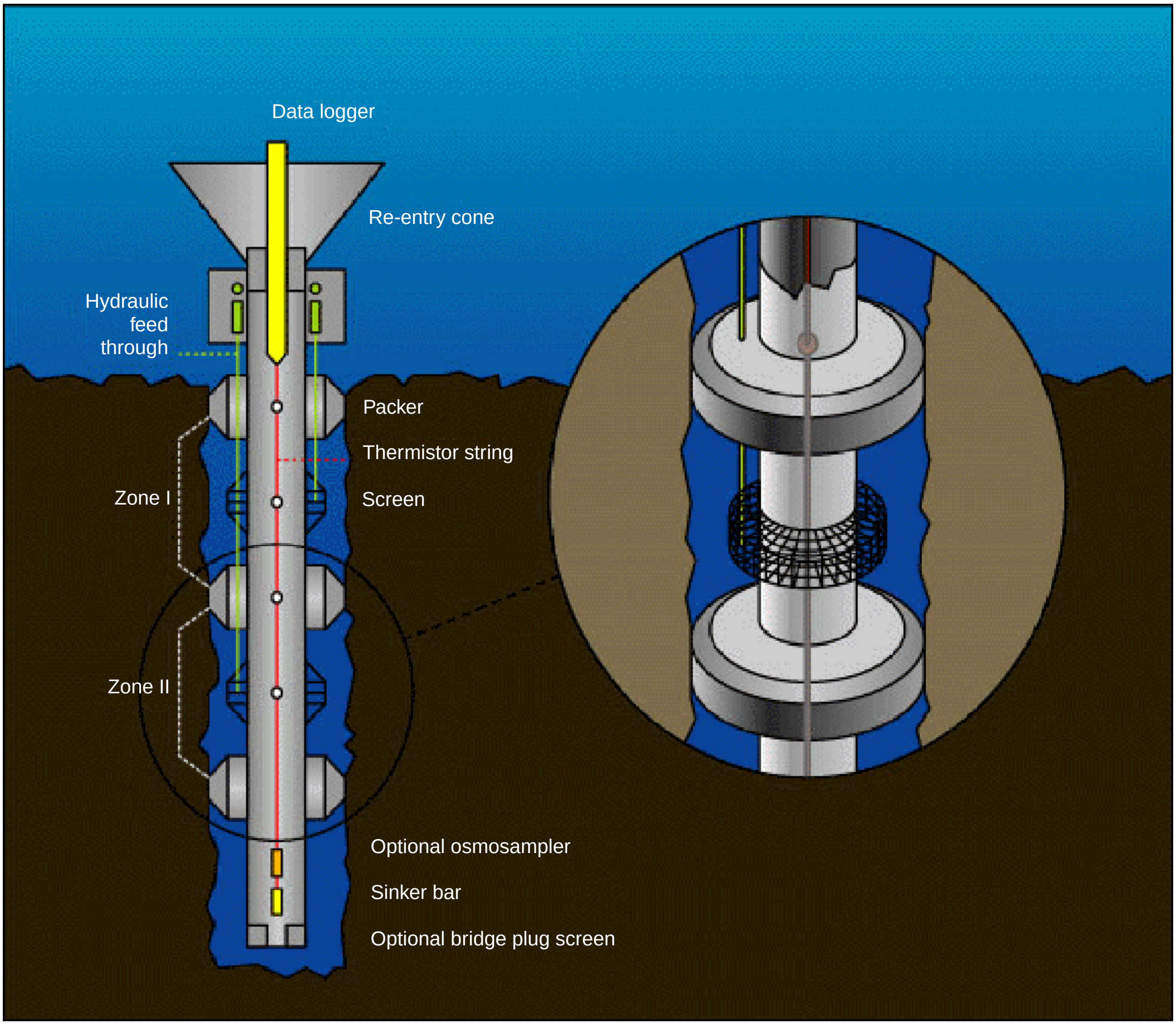

Figure 7 Diagram of the advanced CORK system used to seal instruments in the borehole.

tools have also been used to measure pressure and fluid flow properties of sediment and rock.

Deep Seafloor Observatories

The CORK (Circulation Obviation Retrofit Kit) is a seafloor observatory that measures pressure, temperature, and fluid composition – important parameters for the study of the dynamics of deep-sea hydrologic systems. CORKs are installed by the Ocean Drilling Program for measurements over long periods of time (months to years). Since 1991, observatories have been installed on the deep seafloor in different settings, for example at mid-ocean ridge hydrothermal systems and at active margins.

The CORKs are installed by the drill ship. After a borehole is drilled, a CORK is installed to seal instruments in the borehole away from the overlying ocean (**Figure 7**). The CORK has two major parts: the CORK body that provides the seal and an instrument cable that hangs from the CORK into the borehole. A data recorder is included with the instrument cable. The data recorders have sufficient battery power and memory for up to 5 years of operation. Data are recovered from CORKs using manned submersibles or remotely operated vehicles. The instruments in the CORK measure pressure and temperature spaced along a cable that extends into the sealed borehole. The CORK also includes a valve above the seal where borehole fluids can be sampled.

The Ocean Drilling Program installs another type of long-term seafloor observatory for earthquake studies. Seismic monitoring instruments are installed in deep boreholes located in seismically active regions, e.g. off the coast of Japan. These data are used to help established predictive measures to prevent loss of life and damage to cities during large earthquakes.

Deep-sea seismic observatories contain a strainmeter, two seismometers, a tilmeter, and a temperature sensor. The observatories have replaceable data-recording devices and batteries like CORKs, and are serviced by remotely operated vehicles. Eventually real-time power supply and data retrieval will be possible when some of the observatories are connected to nearby deep-sea fiber-optic cables.

Summary

Deep-sea drilling applies innovative sampling, instrument, and observatory technologies to the study of Earth system science. These range from the study of Earth's past ocean and climate conditions using high-quality sediment cores, to the study of earthquakes and tectonic processes using logging tools and seafloor observatories, to exploring gas hydrates (a potential future energy source) using specialized sampling tools.

The Ocean Drilling Program continues until 2003. A successor international scientific ocean drilling program will begin in 2003 with the operation of at least two specialized ships: a riser drill ship, operated by Ocean Drilling in the 21st century in Japan and a non riser drill ship, operated by a US organization.

See also

Deep Submergence, Science of. Deep-sea Drilling Results. Manned Submersibles, Deep Water. Remotely Operated Vehicles (ROVs).

Further Reading

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DEEP-SEA DRILLING RESULTS

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Introduction

Modern scientific ocean drilling commenced over forty years ago with the inception of Project