



Petroleum Extension Service of The University of Texas at Austin

A PRIMER OF OILWELL DRILLING

Seventh Edition

THE UNIVERSITY OF TEXAS AT AUSTIN · PETROLEUM EXTENSION SERVICE



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He is a third generation oil man following his father (UT, BS-PGE, '50) who was a highly regarded petroleum engineer in Texas as the principal owner of Viking Drilling Company in San Antonio and his paternal grandfather who was a field superintendent in Oklahoma, East Texas and on the Texas Gulf Coast for Stanolind (later Amoco) Oil Company. As with most oilfield families, his mother (UT, BS-HEc, '49) made sandwiches for the crews, curtains for the tool pusher's trailer, created a home, and raised the kids.

About the Author



This book is an introduction to the art and science of drilling oilwells. While this book focuses on well drilling in the *oil* and gas industry, it is important to note that *wells* can be drilled for a variety of purposes. Not all wells are used to extract oil and gas from the earth. Wells are also drilled to produce fresh water for irrigation and to supply water to cities. Some wells are drilled into deep layers of rock to dispose of hazardous waste. Greenhouse gases, such as carbon dioxide, can be captured and injected into underground layers for permanent disposal. The same well drilling methods can be applied to all these uses.

Drilling *rigs* are large and noisy. They operate numerous pieces of enormous equipment (fig. 1). The purpose of a drilling rig is only to drill a hole in the ground. Although the rig is big, the hole it drills is relatively small. The purpose of the drill hole is to *tap* an oil or gas *reservoir* often thousands of feet or hundreds of metres below the surface of the earth. The drill hole is usually less than one foot (30 centimetres) in diameter at final depth.

1

Introduction



Figure 1. Drilling rigs are large to accommodate the size of the drilling equipment and pipes.

The story of modern oilwell drilling began at the start of the industrial revolution. Workers wanted better ways to illuminate their homes when they returned from the factories. The steam-powered industrial machines increasingly used in factories also required good quality lubricant oils.

Responding to the demand for reliable lighting, companies began making oil lamps, which were brighter than candles, lasted longer, and were not easily blown out by errant breezes. The best source of oil to burn in the early oil lamps was sperm whale oil. Whale oil was clear, almost odorless, light in weight, and burned with little smoke.

While everyone preferred whale oil, by the mid-1800s it was so scarce that only the wealthy could afford it (fig. 7). Whalers in the New England region of the United States had nearly hunted sperm whales into extinction. There was a demand for something to replace whale oil.

Oil seeping out of shallow accumulations is a common, worldwide phenomenon. The area around Baku, Azerbaijan, had been known from ancient times to hold oil and natural *gas seeps*. The first modern oilwell was drilled in Baku in 1846. This well was drilled to a depth of 69 feet (21 metres). By 1872, due mainly to lamp oil demand, the Baku area had so many wells that it became known as the “Black City.”

2

History



Figure 7. Whaling ships in New Bedford, Massachusetts. The barrels in the foreground are filled with whale oil.

SOURCE: NOAA, DEPT. OF COMMERCE

3

Cable-Tool and Rotary Drilling

Cable-tool drilling and rotary drilling techniques have been available since people first began making holes in the ground. Rotary rigs dominate the industry today, but cable-tool rigs drilled many wells in the past. Over 1,600 years ago, the Chinese drilled wells with various primitive yet efficient cable-tool rigs, which they continued to use into the 1940s. To quarry rocks for the pyramids, the ancient Egyptians drilled holes using hand-powered rotating bits. They drilled several holes in a line and stuck dry wooden pegs in the holes. Then they saturated the pegs with water. The swelling wood split the stone along the line made by the holes.

Most wells today are drilled with rotary rigs based on the Hamil Brothers' design at Spindletop.

CABLE-TOOL DRILLING

A steam-powered cable-tool rig was used by Drake and Smith to drill the Oil Creek site in Pennsylvania. The early drillers in California and elsewhere also used cable-tool rigs. The principle of cable-tool drilling is the same as that of a child's seesaw. When a child is on each end of a seesaw, it moves it up and down. The rocking motion demonstrates the principle of cable-tool drilling.

To explore the concept further, one could tie a cable to the end of the seesaw and let the cable dangle straight down to the ground. Next, a heavy chisel with a sharp point could be attached to the dangling end of the cable. By adjusting the cable's length so the end of the seesaw is all the way up, the chisel point hangs a short distance above the ground. Releasing the seesaw lets the heavy chisel hit hard enough to punch a hole in the ground. Repeating the process and rocking the seesaw causes the chisel to drill a hole. The process is quite effective. A heavy, sharp-pointed chisel can slowly force its way through rock, bit by bit, with every blow (fig. 15).

A cable-tool rig operates much like a seesaw with a powered *walking beam* mounted on a derrick. The walking beam is a wooden bar that rocks up and down on a central pivot. At Drake's rig, a 6-horsepower (4.5-kilowatt) steamboat engine powered the walking beam. As the beam rocks up, it raises the cable attached to a chisel, or bit. Then, when the walking beam rocks down, heavy weights above the bit, called *sinker bars*, provide weight to ram it into the ground. The bit punches its way into the rock, and repeated lifting and dropping make the bit drill into the earth. The driller lets out the cable gradually as the hole deepens. The derrick provides space to raise the cable and pull the long drilling tools out of the hole using one of several winches called the *bullwheel*.

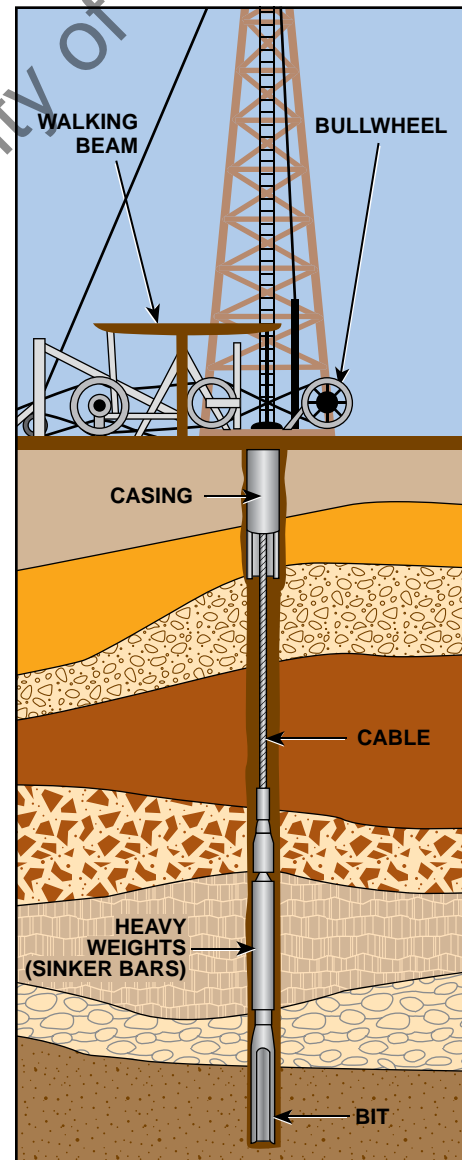


Figure 15. A cable-tool rig

4

Rotary Rig Types

A variety of rotary drilling rigs might be used depending on the location and geography of the reservoir.

Offshore, the ocean environment plays an important role in rig design. Rigs may be broadly divided into two categories: rigs that work on land (fig. 25) and rigs that work offshore (figs. 26 and 27).

One type of offshore drilling facility is a *platform*. Although drilling occurs from platforms, most companies use platforms for production of oil and gas rather than for drilling. Because this book concentrates on drilling and not platforms, more information about platforms is available in another PETEX publication: *A Primer of Offshore Operations*.

If a platform is designed for drilling, the rig on the platform operates just like a land rig. Several wells can be drilled from the same platform, and the rig is moved or *skidded* over to the next slot in the platform to begin a new well.



Figure 25. A land rig

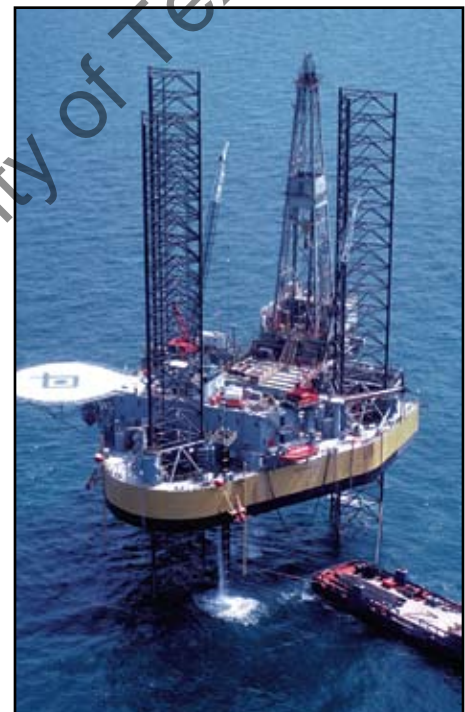


Figure 26. An offshore jackup rig



Figure 27. An inland barge rig

Whether on land or offshore, and regardless of size, all rigs require personnel to operate them. There are people employed by companies involved in drilling work all over the world. They drill wells on land and ice, in swamps, and on water as small as lakes or as large as the Pacific Ocean. Drilling is demanding work, continuing 24 hours a day, 7 days a week, in all kinds of weather (fig. 46).

Drilling is also increasingly complex. The technical complexity is so great that no single company is diverse enough to perform all the required work. Consequently, many companies and individuals are involved in drilling a well, including operating companies, drilling contractors, and service and supply companies.

5

People and Companies



Figure 46. Workers on a drilling rig

COURTESY OF ENERMAX, INC. PHOTO BY BRET BOTTLER

The location of the well, or drill site, varies as the surface geography of the earth varies. In the industry's early days, geologists and wildcatters were able to find oil and gas in places readily accessible. As people began using more hydrocarbons, the oil industry extended its search for oil and gas worldwide. Today, companies might drill wells in the frozen wilderness, remote desert, marshes, jungles, rugged mountains, and deep offshore waters. A drill site is anywhere oil and gas exists or might exist.

7

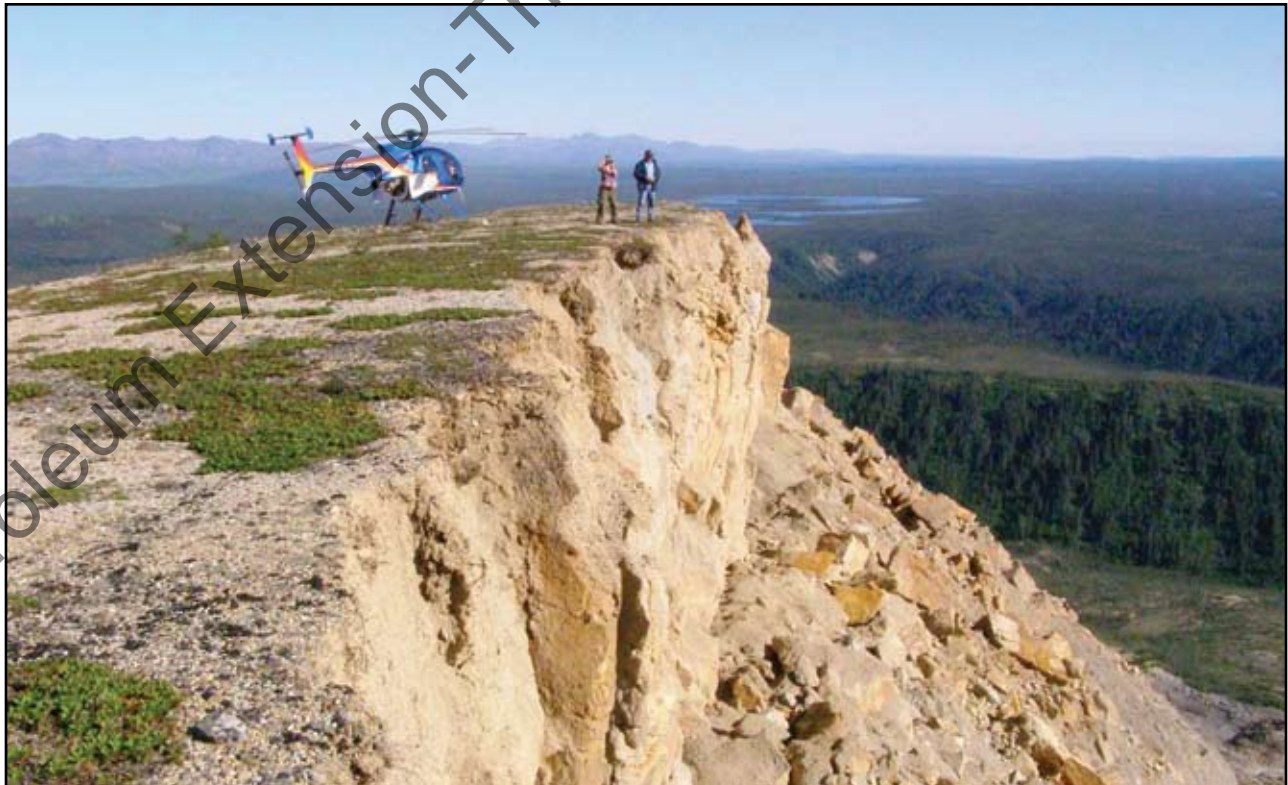
The Drill Site

CHOOSING THE SITE

The operating company considers several factors when deciding where to drill. A key factor is the company knows or believes that hydrocarbons exist in rocks beneath the site. Sometimes, an operator drills a well in an existing field to increase production from it. In other cases, an operator drills a well on a site where no one has previously found oil or gas.

Where no production has occurred, a company often hires geologists and geophysicists to find promising sites (fig. 74). Geologists and geophysicists are called *explorationists* because they explore areas to determine where hydrocarbons might exist. Major companies have an explorationist staff, while independent companies might hire consultants or buy information from companies that specialize in geological and geophysical data.

Figure 74. Geologists working at a prospective petroleum area at the Peel Plateau in the Yukon



COURTESY OF GOVERNMENT OF THE YUKON. PHOTOGRAPH BY TIFFANI FRASER

Rigging up an offshore drilling rig is usually not as complicated as rigging up a land rig. Most offshore rigs can be moved over water with almost no need to disassemble major parts. Onsite, the offshore rig is stabilized by placing rig supports on the ocean floor for bottom-supported rigs or, by anchors, anchor chains, and wire or polyester rope for floaters. Only the dynamically positioned floaters require no additional support to stay in position during drilling.

To move most land rigs, crewmembers must disassemble many of its components. Disassembly is required so the parts can be transported to the next location and then reassembled. For safety, rigging up usually takes place only during daylight hours. Even with lighting after dark, there is too much heavy equipment to move safely during rig-up.

On most land rigs during rigging up, the rig parts are put back together so the rig can drill a hole. It involves unloading and hooking up the rig engines, the *mud tanks* and pumps, and other equipment on the site. One of the last steps, and one of the more dramatic, is raising the mast from horizontal—the position in which it was transported—to the vertical drilling position. The first rig component positioned by the crew is the rig’s substructure, which is the base, or foundation.

SUBSTRUCTURES

A substructure is the framework located directly over the hole; it is the foundation of the rig. The bottom of the substructure rests on level ground. The crew places a work platform on top of the substructure called the rig floor. The substructure raises the rig floor to approximately 10 to 40 feet (3 to 12 metres) above the ground. Elevating the rig floor provides room under the rig for special high-pressure valves and a *blowout preventer (BOP) stack* that the crew connects to the top of the well’s casing. The exact height of a substructure depends on the space needed for this equipment. A cellar also provides more space for the equipment.



Rigging Up

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The main function of a rotary rig is to drill a hole in the ground, or to *make hole*. Making hole with a rotary rig requires qualified personnel and a large amount of equipment. There are four main categories of equipment systems used in making hole: power, hoisting, rotating, and circulating.

POWER SYSTEM

Every rig needs a source of power to run the hoisting, circulating, and rotating equipment. In the early days of drilling, steam engines powered most rigs. In the 1860s, Colonel Drake powered his rig with a wood-fired steamboat engine. Until the 1940s and 50s, steam engines drove almost every rig (fig. 95).

Steam is a tremendous power source. For example, steam catapults are used today on modern aircraft carriers to launch aircraft. The major problem with using steam power on drilling rigs was that the boilers were heavy and difficult to move. Also, the steam lines to the steam engines were heavy and withstood high pressures and temperatures. Steam power also required large volumes of water and fuel.



Figure 95. In the foreground is a coal-fired boiler that made steam to power the cable-tool rig in the background.

9

Rig Components

10

Normal Drilling Operations

Normal drilling operations include drilling the hole and adding a new joint of pipe as the hole deepens. It also involves tripping the drill string out the hole to put on a new bit and then running it back to the bottom (making a *round trip*). Other key steps include running and cementing the large-diameter steel casing used to seal selected intervals of the hole.

DRILLING THE SURFACE HOLE

Engineers create a well plan and a wellbore architecture for every well before it is drilled. A typical wellbore architectural diagram for an onshore well is shown in figure 160. The wellbore diagram shows the hole and casing sizes needed to drill the well to its desired depth.

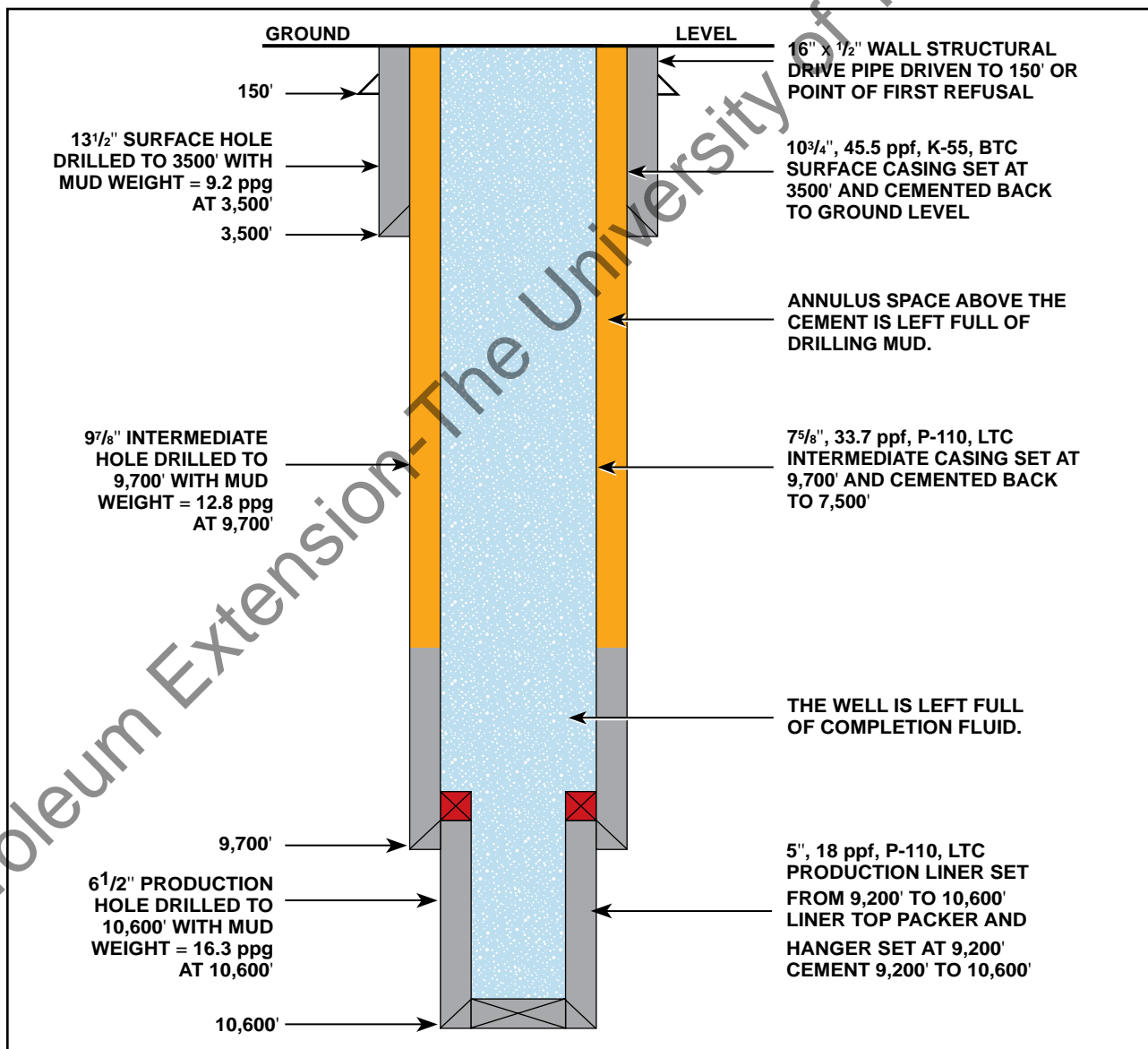


Figure 160. Typical wellbore architecture

11

Formation Evaluation

Formation evaluation is the process used by operators to determine if rock layers contain hydrocarbons. Formation evaluation can determine if sufficient quantities of hydrocarbons are present and if the rock has enough permeability to allow a commercial completion. The techniques addressed in this chapter are the examination of cuttings and drilling mud, well logging, drill stem testing, and coring.

EXAMINING CUTTINGS AND DRILLING MUD

One of the oldest formation evaluation techniques is to simply look at the cuttings and the drilling mud returning from the bottom of the hole (fig. 200). A geologist or trained technician who examines the returning drilling mud and cuttings is called a *mud logger*.

The rock type can be identified from the cuttings. This is important because reservoirs typically fall into broad categories by rock type. For example, reservoir rocks are often sandstone and limestone, which develop the correct combination of porosity and permeability needed to contain hydrocarbons and allow them to flow. A rough idea of the porosity of a rock can be determined by viewing cuttings under a microscope. If a rock contains oil, trace amounts of oil will coat the cuttings even after they have been circulated in drilling fluid and brought to the surface.

Oil is a polarizing compound. It will have a fluorescent shine when viewed in a black light box. The oil stain on cuttings can be confirmed by flushing the oil off the cuttings with a solvent. The streaming solvent will also fluoresce under the black light. In this way, an oil stain can be differentiated from other rock mineral that might also fluoresce. Using this method to determine the presence of oil does not work if an oil-based mud is used as a drilling fluid.



Figure 200. A handful of cuttings made by the bit

Once the formation evaluation is done, the operator must decide if the well should be completed as a producing oil or gas well. If the well does not contain hydrocarbons, or not enough to pay for the completion, the well will be *plugged and abandoned (P&A)*.

PLUGGING AND ABANDONING A WELL

To P&A a well, the drilling rig pumps several cement plugs through the drill pipe. The cement plugs are used to isolate and seal unprofitable hydrocarbon zones from nonhydrocarbon-bearing zones and to seal freshwater zones from saltwater-bearing zones. The intervals between cement plugs are left full of drilling mud. At this time, it might be possible to cut off and recover some of the intermediate casing string (if one is present) for use in other wells. The surface casing string is always left in place and sealed at the bottom and top by either cement plugs or a combination of mechanical and cement plugs. The surface casing will be cut off below the ground level or mud line and a *cap* placed on the stub. If the well is on land, the well site will be environmentally restored after the drilling rig has been moved off the location.

COMPLETING A PRODUCING WELL

The drilling rig is used to run and cement production casing as described previously. The blowout preventers are removed and a production wellhead is attached to the top of the casing. The production wellhead seals the tops of the various casing strings in the well, provides a place to suspend and seal *production tubing* as needed, and provides the valves that control flow out of the well. Figure 209 shows a typical land wellhead or *Christmas tree*.



Figure 209. This collection of valves and fittings is a *Christmas tree*.

12

Completing the Well

There are several special operations used in oilwell drilling: directional drilling, fishing, and *well control*.

DIRECTIONAL DRILLING

No well is ever perfectly vertical. Even wells meant to be drilled vertically will wander a few degrees from vertical and move in different directions. Routine measurements are taken during drilling to determine if a well is deviating from vertical by more than the allowed amount (normally less than 5 degrees). If so, careful drilling practices, such as changing the placement of stabilizers in the BHA or adjusting the *rotary speed* or weight on bit, will bring the well back within the tolerances normally allowed for vertical wells.

Directional drilling is used when a well is intentionally deviated to reach a *bottomhole location (BHL)* that is different from the *surface location (SL)*. Directional drilling is done for many reasons. The BHL might be under an obstruction such as a building or lake where rigging up over the required BHL is not possible. It might be necessary to drill several wells from a fixed place, such as an offshore platform or an onshore drilling island (fig. 215), to different bottomhole locations.

Part of an existing well might become blocked with lost drilling tools that are unrecoverable, or a well might have been drilled into an unproductive part of the reservoir. It is possible to set a plug in the lower part of the well and deviate, or *kick off*, the well to a new BHL. Some reservoirs are more efficiently produced by wells drilled at a very high angle. These wells are known as *horizontal wells* because the inclination angle from vertical reaches 90 degrees or more.

Older directional drilling methods placed inclined wedges, called *whipstocks*, in the well to force the bit to move in the desired direction. In soft sediments, it is possible to place a large bit nozzle or jet in the desired direction and simply erode the well's starting path. Although time consuming, these methods are still used at times.

The two faster and often more reliable methods of directional drilling are:

- *Slide drilling* with a motor
- Drilling with a *rotary steerable assembly*

13

Special Operations

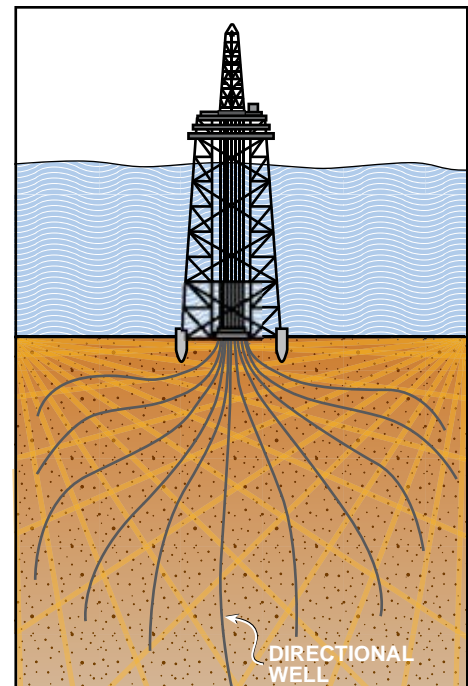


Figure 215. Several directional wells tap an offshore reservoir.

14

Rig Safety and Environmental Concerns

Safety training is part of everyday life for all hands on a drilling rig. There are safety meetings at the beginning of every tour and before each new part of a job. Outside training, such as well control schools and helicopter safety training for offshore crews, is also required for drilling personnel. The equipment used to drill a well is technical and complex, and those who run the equipment must be well trained.

The International Association of Drilling Contractors (IADC) keeps a list of detailed statistics on accident rates in the drilling industry. The annual statistics can be viewed at IADC's Web site (www.iadc.org). One statistic is the total number of any type of accident that occurs for every one million man-hours worked. This number has declined slightly from 2002–2007 at an average of 11.16 accidents per one million man-hours worked. A normal number of hours one person might work on a drilling rig is about 3,100 man-hours in one year. So, a five-person crew will work roughly 15,500 man-hours in one year. Using the average accident rate shown above, the number of accidents that might be estimated to occur in one year in the five-person crew is 0.18 or less than one. This calculation suggests the average drilling crewmember is a safe worker.

The total number of man-hours actually worked in the worldwide drilling industry is enormous and increases as more rigs are added to the world fleet. Table 3 shows the annual man-hours worked and the total accident frequency rate from the IADC data base. Although safety can always be improved, these statistics suggest the industry is becoming safer because the accident rate has decreased with the increasing work time.

Table 3
IADC Annual Work Time and Accident Statistics

Year	Total Man-Hours	Accident Frequency	Total Accidents
2007	446,335,455	10.24	4,572
2006	418,954,216	10.85	4,547
2005	369,693,317	11.72	4,332
2004	336,122,663	11.29	3,794
2003	301,959,960	11.16	3,369
2002	281,350,992	11.72	3,297

SOURCE: IADC

Drilling has developed into a specialized and technologically advanced business. The size of the equipment is enormous. The technical challenges to overcome as wells become deeper and are drilled in increasingly hostile environments are equally enormous. The technology of the most advanced drilling rig is computer-controlled and can be monitored from any office in the world. The guidance systems used in directional drilling rival those found on modern jet aircraft or spacecraft.

The energy business is the largest business in the world. This will continue because the standard of living in most countries is now tied to the ability to find and use energy efficiently. Well drilling continues to be an important part of the efficient use of energy, regardless of whether the well is producing hydrocarbons or water, or permanently disposing wastes by injecting them into deep layers in the earth.

The drilling industry must have people who are trained, motivated, and, most importantly, interested in the business, the science, and the art of drilling.

15

Conclusion

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