Drilling Technology in Nontechnical Language
Second Edition

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PennWell®

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DRILLING GEOLOGY

Overview

This chapter will examine geology as it relates to drilling operations. It is necessary to understand something about the physical and chemical characteristics of rocks in order to understand drilling processes and problems. The chapter also describes the basic principles of hydrostatic pressure exerted by a fluid at depth, as this is important for drilling operations.

This brief chapter will cover some important concepts that should be understood for the chapters that follow.

Origins of Rock

When the earth first formed, it consisted of molten rock. As the surface of the planet cooled down, the planet surface solidified. Rocks formed by molten rock cooling and solidifying are called *igneous rocks*. Basalt and granite are examples of igneous rock (fig. 1–1).

Water and gases form the oceans and atmosphere. The gravitational pull of the sun and moon and solar heating cause movements of the atmosphere (weather) and the oceans (tides and currents). The movements of air, water, and ice erode rocks, releasing rock particles. These effects are called *weathering*.

Particles of rock, from tiny grains to huge boulders, can be carried long distances by wind and water. Eventually the forces carrying the rock particles are reduced, and the rock fragments fall to the earth's surface, or to the bottom of a water body, forming thick beds of material called *sediments*. As the water or wind slows down, the largest fragments are

Geologists, being geologists, do not use the engineering convention; rather, to a geologist, compressive stress is positive and tensile stress is negative. This is reasonable, since in the earth's crust (rock), stresses are normally compressive and only rarely tensile. In a normally stressed situation, the greatest stress, called sigma 1 (σ_1), is the vertical stress. The smallest stress, denoted sigma 3 (σ_3), is normally horizontal, and the intermediate stress, σ_2, is also horizontal, with little or no difference between σ_2 and σ_3. However, in some cases, σ_2 or σ_3 can be vertical. Understanding the stress state is very important to planning wells, which is the reason for covering it here.

Wells are sometimes drilled straight down vertically. However, most wells deviate from vertical to a greater or lesser degree, and wells may even be planned and drilled so that they finish up horizontal in the reservoir. In deviated (and especially highly deviated or horizontal) wells, these stresses can become a significant factor in designing the well, and deciding on the procedures needed to drill through it successfully can be challenging.

Of particular interest to the drillers is the ability of the rock to withstand pressure inside a hole drilled in it. This is called the *fracture pressure*. Imagine that a hole is drilled into a chunk of rock. Inside the hole is liquid. If pressure in this liquid is continually increased, at some point the rock will start to break. Fluid will leak into the rock, creating growing fractures that extend away from the hole and into the rock. The fluid pressure creates tensile forces in the rock around the hole, which eventually causes tensile failure. However, the compressive stresses around the rock will act to support the rock against the pressure. As most rocks are weak against tensile forces, the fracture pressure will be very close to the lowest compressive stress imposed on the rock, σ_3.

As rock compressive stresses generally increase with greater depth, the fracture pressure also tends to increase with depth.

Hydrostatic Pressure Imposed by a Fluid

Fluid pressures are fundamental to many aspects of oil well drilling. If downhole pressures are not kept under control, an uncontrolled release of oil and gas to the surface (called a *blowout*) can result that might lead to loss of life, massive environmental damage, damage to underground reservoirs, and damage to the rig and other surface facilities.

very close to each other. At a depth of 2,000 m, the gap between the crystals is about 10 nanometers. By the time the shale is buried to a depth of 5,000 m, this gap has closed to about 1.5 nanometers (1.5×10^{-9} m or 0.0000000015 m).

Shale has tiny pores that are connected by tiny passages. It takes a long time for the water and the oil produced within the shale source rock to migrate out of the rock, squeezed out by pressure. The actual mechanism by which the oil leaves the source rock is uncertain, but it is thought that the oil is initially in solution in the water under the high pressures that exist in the source rock.

Primary Migration

The first two conditions necessary for the birth of a reservoir are the existence of an organic-rich source rock and the conditions necessary for oil to be generated—temperature (the oil window) and time. If the oil cannot migrate out of the source rock, it stays locked within the shale and cannot be produced.

The third element required is that the source rock lies next to a permeable rock or a channel that allows the oil to migrate. In most cases, a permeable sandstone deposit provides this conduit, but it can also be provided by fractures in the rock or ancient reefs (limestone structures made up of coral skeletons with very high permeability). Fractures often allow migration vertically upwards, and this mechanism has led to many large oil accumulations, such as those found at shallow depths in Venezuela and northern Iraq.

A gently sloping formation bed can carry the oil for long distances horizontally until a trap stops migration and allows accumulation. Therefore, a reservoir can be located many miles away from the source rock that generated the oil.

Structural Traps

As the oil and gas undergoes primary migration away from the source rock, it must find a structure that has the right conditions to trap the oil and stop it from reaching the surface (fig. 2–2).

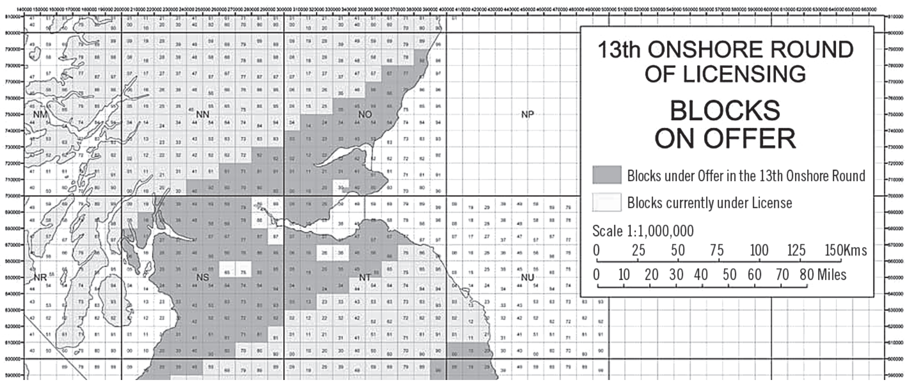

Fig. 3–1. Part of the UK onshore licensing map

Small companies sometimes pay for a block, invest enough to identify good prospects, and then look for larger companies to buy in as partners. If this works, then the new partner will likely fund the first one or two wells, "carrying" the small company, to become a partner on the block. In this way, the small company can then increase its value many times with a relatively small investment.

An exploration well is drilled to gain information. It is usually a false economy to try to drill an exploration well to later produce oil. A producing well cannot be properly designed until the reservoir is known in sufficient detail (pressures, fluids and gases present, permeability, how well consolidated the reservoir rock is, and many other factors). Many things about the subsurface conditions cannot be predicted on the first well. This means that the well design may have to change if unexpected conditions are encountered while drilling. Exploration wells should be minimum-cost wells designed to obtain essential information and be abandoned afterwards.

Well Proposal

For this example well, an angular unconformity structure is present (as was discussed in chapter 1), providing a potential trap for oil and gas. The geologists believe that it will contain a gas cap on top, with a column of oil and water below. It was decided to drill a well into the edge of the gas cap and follow the bedding plane down through the oil and into the water, so that several facts (the *well objectives*) could be established (fig. 3–2):

General information

General information included in a drilling program includes the following:

1. Which country, which exploration block (blocks are usually numbered), name of drilling rig, program issue date, who the program was written by, and who approved it
2. Which offset wells were used for data input
3. A statement on shallow gas (e.g., whether likely to be present or not)

Well objectives

It is important to differentiate between primary objectives (those that the well must meet) and secondary objectives (those that are desired if they can be obtained for little extra effort or cost).

A graph is normally given, showing the anticipated well depth at each day of the operation. The actual progress can be plotted on the same graph, to show whether the well is on target, behind the curve (late), or ahead of the curve (early). The flat spots on the graph show where drilling stops to run casing into the well at the end of each hole section (fig. 3–7).

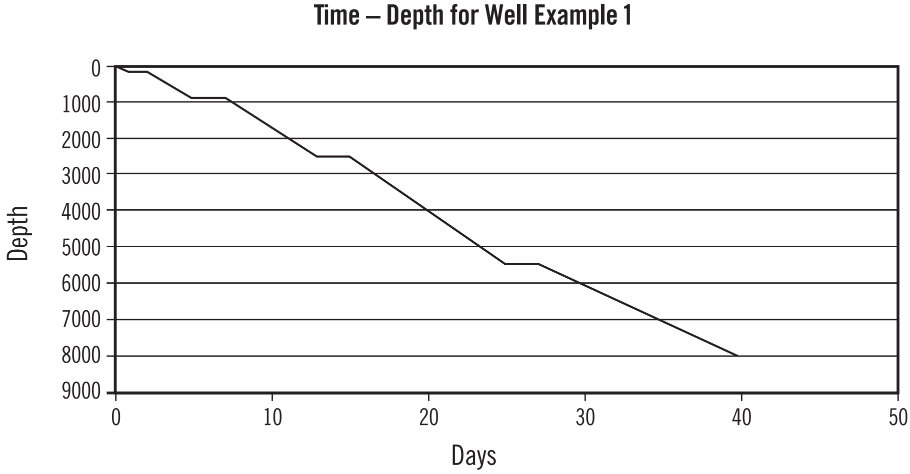

Fig. 3–7. Graph of time vs. depth for an example well

The drillers measure the distance from the drill floor down to the top of the conductor pipe. Depths in the well while drilling are referenced back to the drill floor, so the conductor shoe depth = length of conductor in the ground + distance from drill floor to the top of the conductor.

The derrick has several large sheaves at the top end. Steel wire rope, called *block line*, passes over these sheaves and around another set of sheaves on a massive pulley. By winching in or out on the block line with an electrically powered drum, the pulley—called the *traveling block*—moves up and down the derrick. Below the traveling block is a large steel hook that can lift whole strings of casing pipe, support the drill string while drilling, and perform many other tasks. A large land rig would probably be strong enough for the traveling block to support up to 500 tons (508 tonnes), using block line of commonly 1⅝″ (495 mm) diameter with a tensile strength of over 100 tons (101 tonnes). (Block line may vary in size from 1″ [25 mm] to 1¾″ [44 mm] diameter.)

With the rig ready to start operating, the diverter must be attached to the conductor, which was hammered into position by the location preparation crew (fig. 3–11). The diverter contains a large rubber seal that is forced under hydraulic pressure to squeeze in around the drillstring and seal around it. Underneath this seal are usually two large pipes, at least 10″ in diameter, which should lead away from the rig in opposite directions with no bends or changes in internal size. Occasionally only one line will be fitted, leading off downwind of the prevailing wind. If a kick is experienced while drilling below the conductor pipe, the flow is diverted away from the rig by closing the diverter and opening the valve on the pipe leading downwind.

On top of the diverter is a section of pipe (called a *bell nipple*) that has an outlet to the side. This side outlet directs mud flow from the rig along a channel to the solids control equipment and then back to the mud tanks, from where the pumps circulate it back down the hole.

The space between the inside of the well and the outside of the drillstring is called the *annulus.* Mud coming out of the bit flows upwards in this annulus, lifting drilled cuttings to the surface. It comes out of the flowline outlet (as shown on fig. 3–11) and is directed to equipment that separates the drilled solids and the mud, so that clean mud can be pumped back down the hole.

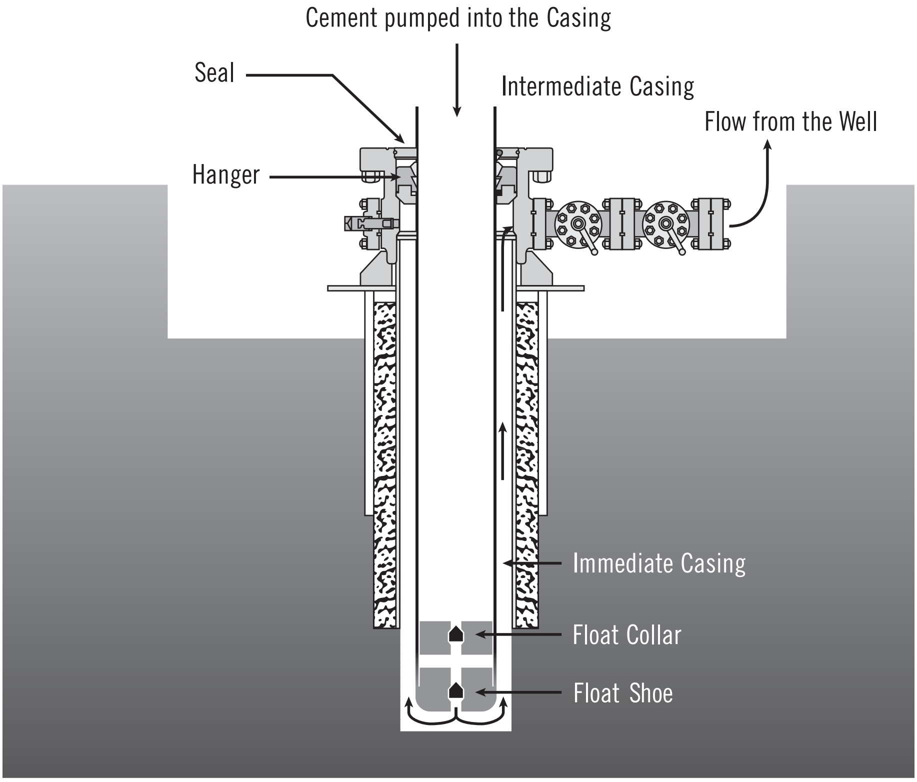

Fig. 3–21. Cementing the intermediate casing

With the casing hanger landed in the profile inside the casinghead housing, seals on the outside of the hanger create a pressure-tight seal between the hanger and the housing. Figure 3–21 also displays valves leading out from the casinghead housing. These are called *side outlets*.

After the casinghead housing is attached to the surface casing, valves are attached to these side outlets. Now when landing the intermediate casing, these valves are open to allow mud to flow from the well when pumping cement down the casing. Hoses are attached to the outsides of these valves, and the hoses take returns from the well to the rig mud tank system. This is illustrated in figure 3–21.

With the casing landed and the hoses attached, mud is circulated down the casing. Gradually the flow rate is increased, while watching the tank levels very carefully to detect the start of any mud losses down

Where a 5″ production tubing connects to a 5″ liner, the inside of the conduit from the reservoir to the surface will all be the same diameter and is all therefore accessible from the surface with wireline and other tools. This type of design is called a *monobore completion*.

In a horizontal well, the target location is not directly underneath the rig, so the well must be drilled along an accurate path to the target. Once in the reservoir, the well must remain a certain distance above the oil-water contact but not so far above it that it approaches the gas-oil contact.

The BHA navigates through the reservoir by measuring the characteristics of the reservoir while drilling, using logging tools that are constructed inside a drill collar. These techniques are called, logically, *logging while drilling (LWD)*. The logging tool for this job measures electrical resistivity—the closer it approaches water, the lower the resistivity measured. As the reservoir was repeatedly logged during the exploration and appraisal drilling, the engineers have a good picture of how the resistivity varies with depth. (*Appraisal drilling* refers to drilling done after a discovery is made by an exploration well to further appraise the discovery.)

Initially, the well is drilled vertically. At the kickoff point, the rotary drilling assembly is pulled out. (A *rotary drilling assembly* is a configuration of drill collars and other downhole tools that drills by rotating the drillstring from the surface, as opposed to an assembly that powers the bit with a downhole motor.) Next, a special directional drilling assembly is run in the well (see fig. 4–6). This is designed to exert a side force at the bit, so that the bit starts to drill away from vertical. The direction that the well drills towards is determined by aligning the side force in the appropriate direction.

The direction of the well relative to true north is called the *azimuth*, and it is usually measured in degrees clockwise. True east will be 090°.

The angle between the wellbore center and vertical is called the *inclination*. The horizontal section of the well, if it is exactly horizontal, will have an inclination of 90°. A vertical well has an inclination of 0°.

There are various tools and techniques used to deviate the wellbore. Directional drilling techniques are covered in more detail in chapter 8, "Directional and Horizontal Drilling."