6. Life Cycle of Oil and Gas Fields

- Oil and gas field development starts with the exploration activities.
- The results of such studies merely provide information about the potential location of the reservoir, its area, depth, and some characteristics such as faults and fractures.
- Based on the information available, a location (normally at the center of the potential reservoir) is selected to drill the first exploration well, called ***wild cat***.
- The design of this well is based on experience since no data are yet available for proper design of the well.
- If hydrocarbons (oil and/or gas) are found, the well is tested to determine the production potential; otherwise, the well is considered a ***dry well*** and is abandoned.
- If the wild cat is successful, more exploration wells will be drilled and tested.
- Preliminary reservoir simulation studies coupled with economic evaluations are made at this stage to determine whether the discovery is commercially viable.
- Once a decision is made to develop the field, extensive simulation studies will be conducted to examine various development and production strategies with the objective of determining the optimum development and production plan, which yield the maximum recovery and best economics.
- Following this, well completion designs will be made with the objective of having wells work for the entire life of the field, providing maximum recovery in the most economic and safe manner.
- Drilling operations then start according to schedule. Each drilled well is tested and evaluated, and the drilling program could be modified based on the data collected. To accelerate revenue, all or part of the surface production and processing facility should be on location to produce wells as they are drilled and completed.
- Production data (production rates, pressures, temperatures, gas–oil ratio, and water cut, if any) are collected for a period of time and then compared against the (predicted) data from reservoir simulations.

- Normally, no match would be obtained. Then a process called history matching is performed where the reservoir simulations are modified until the simulation data match the actual production data.
- It should be noted that several operations, such as pressure maintenance, improved/enhanced recovery, and artificial lift, might be implemented during the production life of the field.
- When no more hydrocarbons can be economically produced, the field is abandoned. Wells have to be killed, filled with layers of cement and sand, and the surface casing capped. This process is governed by either company or government regulations.

6.1. Drilling Engineering and Operations

- The preparation stage of field development includes setting the production strategy, determining the locations of the wells in the field, and designing the well completions)
- Then, the drilling-related activities begin. The drilling program is first designed. The drilling sites in the field are then prepared for the equipment and materials to be moved in, and the drilling operations begin.
- The drilling program consists of three main stages: **(1)** drilling the hole to the target depth, **(2)** setting the various casings, and **(3)** cementing the casing.

6.2. Drilling the Well

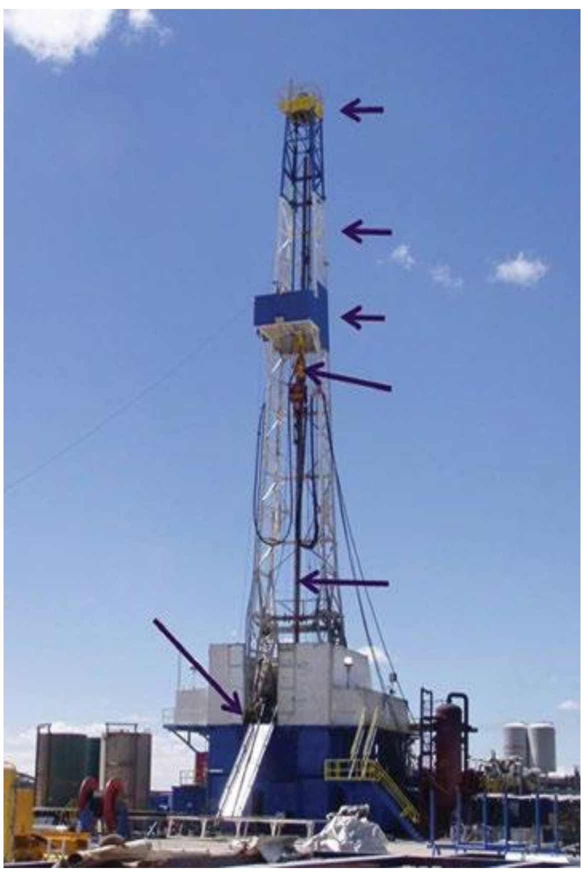
Well drilling has gone through major developments of drilling methods to reach the modern method of **rotary drilling**.

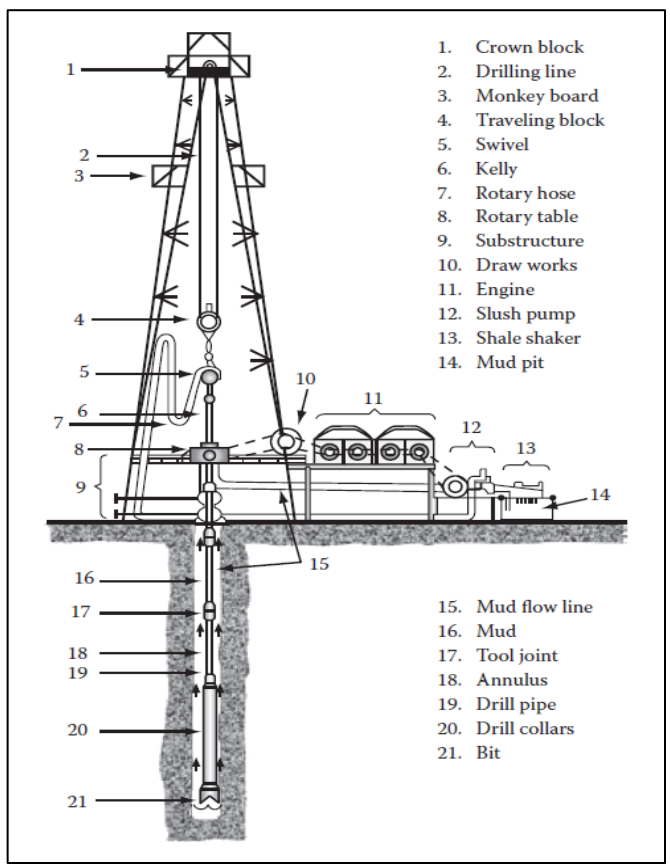
- In this method, a drilling bit is attached to the bottom end of a string of pipe joints known as the **drilling string**.
- The drilling string is rotated at the surface, causing rotation of the drilling bit. The rotation of the bit and the weight applied on it through the drilling string causes the crushing and cutting of the rock into small pieces (cuttings).

- To remove the cuttings from the hole, a special fluid, called the **drilling fluid or the drilling mud**, is pumped down through the drilling string, where it exists through nozzles in the bit as jets of fluid.
- At the surface, the mud is screened to remove the cuttings and is circulated back into the drilling string.
- The drilling operation is performed using huge and complex equipment known as **the drilling rig**.

6.3. The Drilling Rig

- Figure below shows a schematic of a rotary drilling rig.
- It consists of two main sections: the substructure (bottom section) and the derrick (top section). The substructure, which ranges from 15 to 30 ft in height, is basically a rigid platform that supports the derrick.





❖ The rig is composed of several systems and components. The major systems are as follows:

1. **Power system:** It consists of diesel-engine-driven electric generators to supply electric power to the various systems and components of the rig. About 85% of the power generated is consumed by the drilling-mud circulating system.
2. **Hoisting system:** The function of this system is to lower and raise the drilling string into and out the well. The main components of the system are the crown block, the draw works, the traveling block, the hook, the swivel, the elevator, the drilling line, and the deadline anchor.

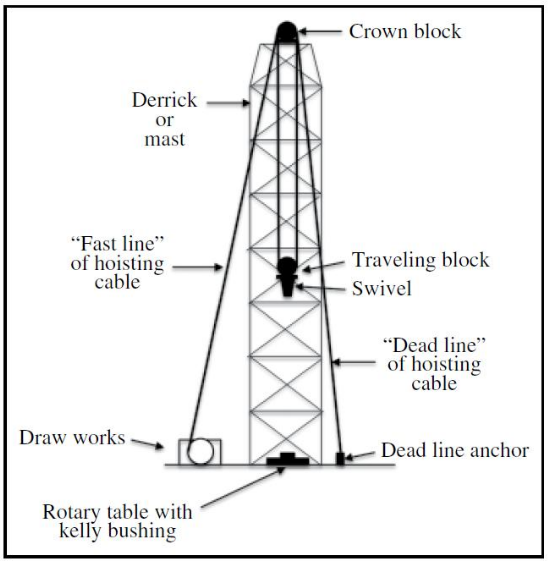


Figure: Illustration of the hoisting system.

3. **Rotating system:** The system consists mainly of a motor-driven rotating table that is used to rotate a pipe with a square or hexagonal cross section, called the kelly, while allowing it to slide through. The kelly is suspended by the hoisting system and is connected at its bottom to the drill pipe and the bit.

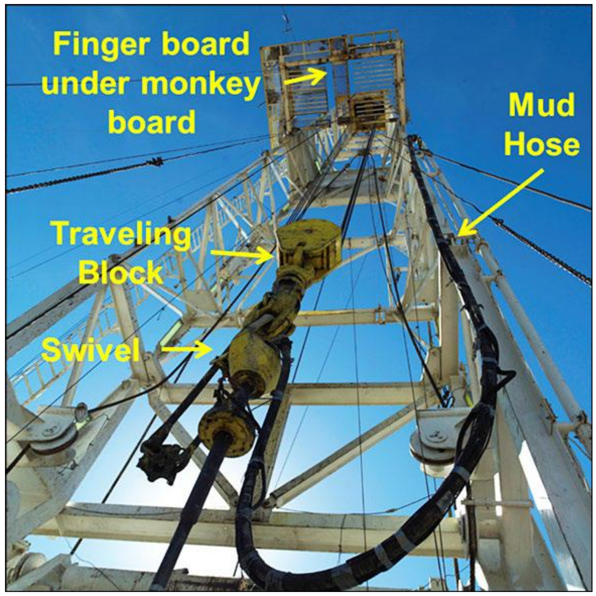


Figure: View up a derrick.

4. **Circulating system:** The system consists mainly of drilling-mud storage tanks, high-pressure pumps, circulating hoses and pipes, and a shale shaker. Its function is to circulate the mud through the well to bring the cuttings to the surface.

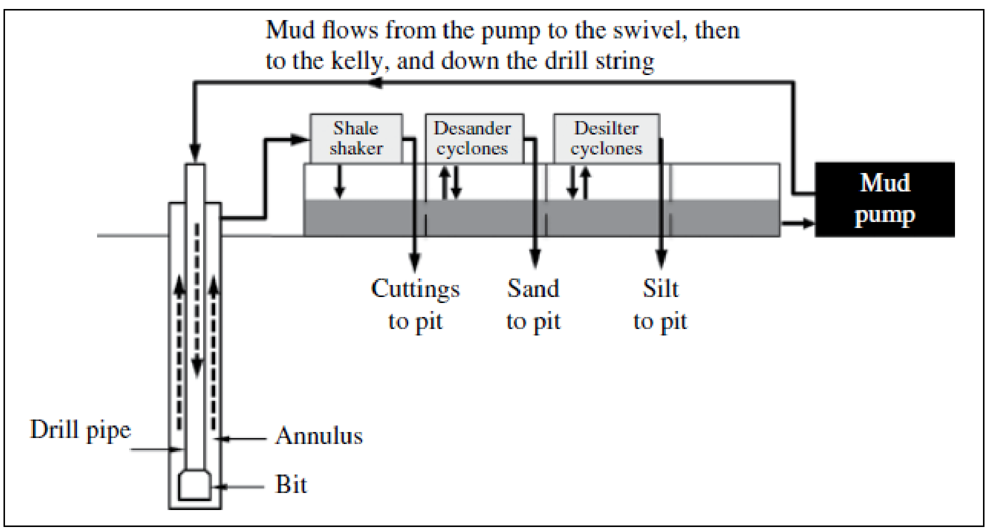


Figure: Illustration of the circulation system.

5. **Drilling bit:** The drilling bit is the device that does the actual drilling by crushing and cutting the rock as it rotates with some force applied by the drilling string. There are different types and shapes used for different types of rock.

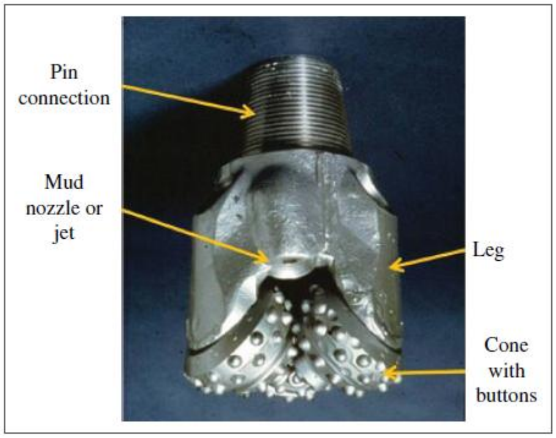


Figure: Roller-cone or tricone drill bit.

6. **Well control system:** it prevents the uncontrolled flow of formation fluids from the well bore.

Kick: the flow of formation fluids into the well in the presence of drilling fluid (occurred when formation fluid pressure greater than hydrostatic pressure of mud drilling).

Well control system functions are:

1- Detecting the kick (by pit: volume indicator or flow indicator)
2- Closing the well at the surface.
3- Circulating the well under pressure to remove the formation fluids.
4- Diverting flow away from rig personal.

Well control system consists of:

a- Blow out prevent (BOP): a high-pressure valve which seal off the top of the well.

Blow out preventers (BOP): the main task of blow out preventers is to ensure a means to close the annular between drill pipe and casing.

b- Chock manifold: a high-pressure circulating system used for circulating kick.

Well control system

7. **Well Monitoring system:** A system of devices records or display measure the following parameters, Depth, Penetration rate, Hook load, Rotary speed, Rotary torque, Pump rate, Pump pressure, Mud density, Mud salinity and Gas content.

6.4. Drilling Fluid (Mud)

The drilling fluid is a very important element of the drilling operation. Its importance stems from the many essential functions it serves. Some of these functions are as follows:

1. Transporting the cuttings from the bottom of the hole to the surface
2. Cooling of the bit and lubrication of the drill string
3. Exerting hydrostatic pressure to overbalance the pressure of the formation and thus prevent flow of formation fluids into the well
4. Supporting the walls of the hole to prevent it from caving in
5. Enhancing drilling by its jetting action through the bit nozzles

Types of Drilling Fluid:

1- Water – based muds.

2- Oil- based muds.

3- Gas – liquid mixture:

4- Gas systems.

Composition of drilling fluids:

1- A continuous phase (liquid) such as water and oil.

2- A dispersed gel- forming phase Such as Bentonite or colloidal organic matter.

3- Inert an active dispersed phase: they lead to the thickening of the drilling fluid, such as Barite, sand, weighting material, and cuttings.

4- Various chemicals necessary to control mud properties with in desired limits. Maintains the properties of the drilling fluid or restores the properties of the drilling fluid if it loses it.

Drilling fluid properties:

The most important properties of drilling fluids are:

1. **Density** is the mass of a unit volume and is measured in several units: gm/cm^3, lb/ gal, lb/ft^3, kg/m^3.

Mud density is the single- most important factor in controlling formation pressure throughout the wellbore. For a balanced well, the formation pressure must not exceed the hydrostatic pressure exerted by the mud column.

2. **Mud Viscosity:** Mud viscosity measures the drilling mud's resistance to flow. The greater resistance is the higher viscosity. It must be high enough for the mud to keep the bottom hole clean and carry cuttings to the surface.
3. **Gel Strength:** Determines the ability of the drilling fluid to develop a gel structure as soon as it stops moving. Its purpose is to hold cutting and mud solids in suspension when circulation is stopped.
4. **Mud PH Level:** The PH level of drilling mud should be monitored in order to maintain sufficient alkalinity and reduce pipe corrosion.

Notes:

- Less than 7 acidic.
- greater than 7 alkaline solution.
- Ordinary drilling fluids have a pH range of 7 to 8.

- As for chemically treated drilling fluids, it ranges from approximately 8 to 12.5.

5. **Sand Content:** It is the volume percentage of solid particles present in the drilling fluid, with a diameter ranging from: 0.074 to 4 mm; Because less than this range will be dispersed in the liquid like clay, while the largest of it will be trapped on the surface by the shale shaker, and this percentage should not exceed 3% in the liquid because if it increases, it will affect all the properties and processes of drilling and drilling means where it causes problems Numerous such as Valves erosion, drill pipe and even nozzles.
6. **Filtration**: It is the penetration of a part of the free liquid phase into the permeable layers due to the pressure difference between the pressure of the drilling fluid column and the pressure of the formations.
7. **Stability:** The stability of the drilling fluid means that the fluid maintains its homogeneity, that is, it does not separate into its components during stopping rotation or stagnation.

6.5. Casing the Well

- The casing is a steel pipe that is placed in the drilled hole (well).
- Normally, four strings of casing of different diameters are installed in the well at various depths that are specified by the geologist. These are the **conductor**, the **surface casing**, the **intermediate casing**, and the **production casing**. The conductor has the largest diameter and shortest length of the four casing strings; the production casing has the smallest diameter and longest casing.
- In designing casing strings, weight and grade must be selected such that the casing string will not fail under all loads to which it will be subjected during drilling, setting casing, and production.
- To set a casing string, the drilling operation is stopped when the desired depth is reached and the drill string and the pit are pulled out of the hole. The casing string is then lowered into the hole, joint by joint, using the hoisting system of the rig, until the total length of casing is in the hole.

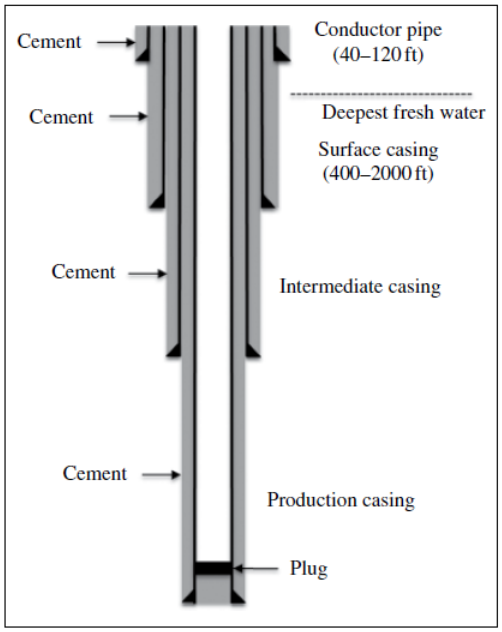


Figure: A wellbore diagram for a vertical well.

- The casing is then cemented to the wall and drilling operation is resumed until the target depth for the next casing string is reached.
- Normally, before setting the production casing, the petroleum formation is logged and evaluated. The casing will be set only if the logging results indicate the presence of a productive formation. Otherwise, the well will be abandoned.

Function of casing:

1. To support the wall of the hole and prevent it from collapsing.
2. To prevent contamination of fresh water.
3. To exclude water from the producing formation.
4. To confine production to the wellbore.
5. To provide a means for controlling pressure.
6. To facilitate installation of the subsurface equipment.

6.6. Cementing the Casing

- Cementing is the process of mixing cement slurry (a mixture of cement, water and additives) down the casing and up the annular space behind the casing where it is allowed to set, thus bonding the pipe to the formation.
- To cement the casing, the annulus between the casing and the wall of the hole must be filled with cement.
- To achieve this, the required volume of the cement slurry (a mixture of cement, water and additives prepared on location) is pumped through the casing.
- A special rubber plug is normally inserted ahead of the cement to separate it from the mud and prevent any contamination of the cement with mud.
- Another plug is inserted after pumping the specified volume of cement. This is followed by pumping a fluid (normally mud) to displace the cement. When the first plug reaches the bottom, pumping pressure is increased to rupture the plug and allow the flow of cement behind the casing.
- When the top plug reaches the bottom, the cement must have filled the annulus to the surface. The cement is then left undisturbed until it sets and acquires enough compressive strength before resuming the drilling operation for the next casing string.
- Once the casing is cemented, it becomes permanently fixed into the hole. It is very important to have a good cement bond between the casing and the wall of the hole. For this purpose, a special log (cement bond log) is conducted to check the integrity of the cementing operation. Failure to have a good cementing job will necessitate expensive remedial cementing operations.

Cementing purpose:

1. To bond the casing to the formation.
2. To prevent the flow of fluids from formation behind the casing.
3. To provide support for the casing.
4. To protect the casing from corrosive attack by formation fluid.

Example} Drill String, How many stands of drill pipe are needed to prepare a drill string that is 10 000 ft long? A stand is three pipes, and each pipe has a length of 30 ft. Assume one stand of drill collar and neglect elongation of pipe.

Answer} Length of drill string = 10 000 ft = length of drill collar + length of drill pipe

Length of drill collar = 90 ft

So Length of drill string = 10 000 ft = 90 ft + length of drill pipe

Length of drill pipe = 9910 ft

One stand of drill pipe = 90 ft

Therefore, we need 9910 ft/ (90 ft/stand) = 110.1 stands of drill pipe.

110 stands of drill pipe would be short, so 111 stands would be needed.

Example} Volume in the annulus, Calculate the volume in the annulus between a section of pipe with outer diameter OD = 4.5 in., length L = 1500 ft, and the casing with inner diameter = 7 in., Express your answer in ft^3.

Answer

Radius of casing = r_c and radius of pipe = r_p:

$$V = \pi r_c^2 L - \pi r_p^2 L$$

$$= \pi \left(r_c^2 - r_p^2 \right) L$$

$$= 3.14159\left(0.292\,\text{ft}^2 - 0.188\,\text{ft}^2\right) \times 1500\,\text{ft} \approx 235.2\,\text{ft}^3$$

Example} Drill time, The top of a formation of interest is at a depth of 5000 ft and the ROP of the drill bit is 250 ft/day. How long will it take to drill to the top of the formation?

Answer}

Time to drill = 5000ft / (250ft/day) = 20days

6.7. Well Spacing and Infill Drilling

- The distance between wells and the area drained by a well correlate to well spacing (Figure below).
- In the United States, a typical spacing is expressed in terms of acres. For example, the term "40 acre spacing" refers to vertical wells that can drain an area of 40 acres.
- A square mile contains 640 acres, so there are 16 areas with 40 acres each in a square mile. Therefore, the number of wells that can be drilled in a square mile with 40 acre spacing is 16.
- vertical gas wells may be drilled on 160 acre spacing, which means that only four wells must be drilled to drain a square mile. If additional wells are needed to adequately drain a reservoir, more wells can be drilled in the space between existing wells. This is called **infill drilling**.

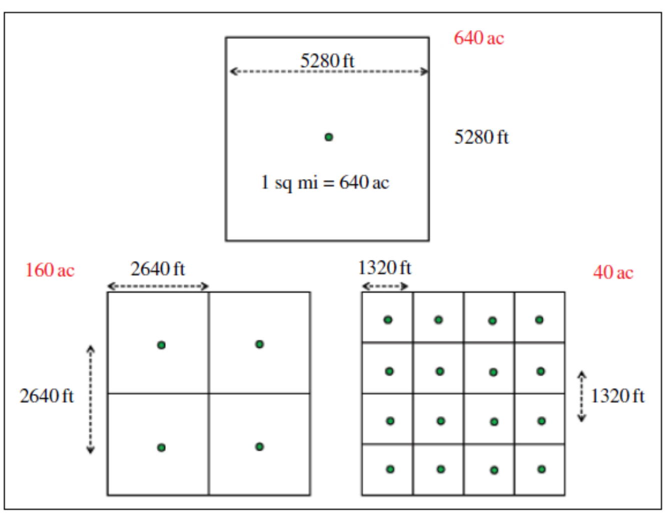


Figure: Well spacing.

6.8. Directional Wells

- Modern technology makes it possible to drill wells with a variety of trajectories as shown in Figure below.

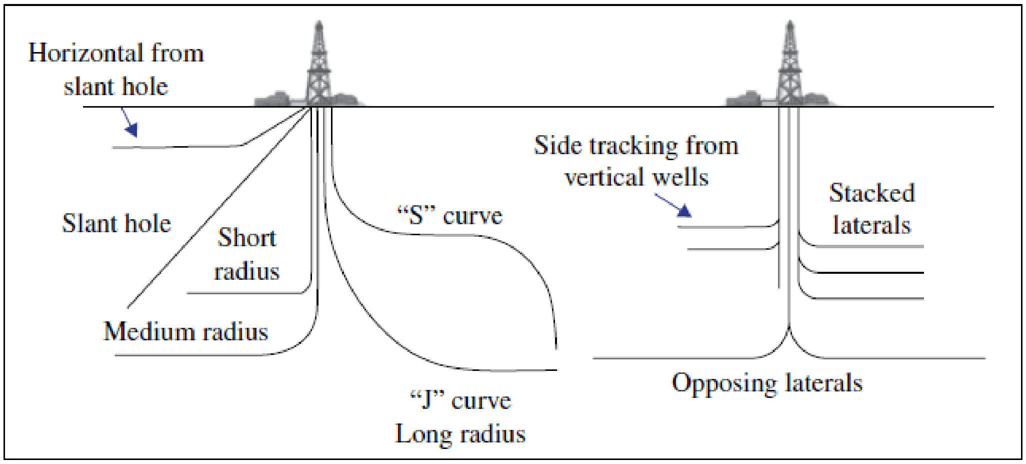


Figure: Directional wells and multilateral wells.

- Two common shapes for directional wells are the "S" and the "J" curves. Both shapes have a kickoff point (KOP), which is the depth at which the wellbore trajectory begins to deviate from vertical.
- An "S"-curve wellbore is designed to offset the drilling position before returning to a vertical orientation into the target formation. The "J" curve gives a deviated wellbore trajectory into the target formation.
- Directional wells can be drilled to follow the orientation of a geologic formation. This improves access to the formation when production tubing is perforated within the formation.
- A sidetrack diverts the direction of the well. This can be done for many reasons, such as avoiding a piece of broken drill pipe or to reach a different reservoir. A multilateral well has multiple segments branching from the original well. The original well is called the trunk, and the segments are called laterals or branches.

- Multilateral wells are used in offshore environments where the number of well slots is limited by the amount of space available on a platform. They are also used to produce fluids from reservoirs that have many compartments.

6.9. Extended Reach Drilling

- Extended reach drilling (ERD) refers to drilling at one location with the objective of reaching a location up to 10 km away that may otherwise be inaccessible or very expensive to drill. ERD wells are justified in several circumstances.
- For example, an ERD well may be able to access an offshore location from an onshore location, it may be drilled from a well site location that minimizes environmental impact, or it may be drilled from a well site location that minimizes its impact in a densely populated area.
- Horizontal, extended reach, and multilateral wellbores that follow subsurface Formations are providing access to more parts of the reservoir from fewer well locations.
- Extended reach wells make it possible to extract petroleum from beneath environmentally or commercially sensitive areas by drilling from locations outside of the environmentally sensitive areas.