Let us speak Drilling

A little history

"If you can't get to the oil, let the oil get to you" would be a succinct way of describing the beginnings of oil production. Hydrocarbons that form deep in the subsurface and do not meet any traps, migrate to the surface and then seep through rocky outcrops, produced the first oil fields. The shores of the Caspian Sea are thought to be the cradle of the oil industry because, during the IXth century, oil is thought to have been produced in the Baku region of Azerbaijan. Marco Polo who visited the Azerbaijani capital in 1264 described "*seepages from which oil flows abundantly*". At the end of the XVIth century, trenches 35 meters deep were dug to collect the seep oil, but the first great industrial adventure was the production of bitumen in Péchelbronn, Alsace. The primitive production technique consisted of digging a trench 3.5m deep around the source, letting the oil seep to the surface and then collecting it.

To access seep oils that were a little deeper, a mining technique developed, which consisted of digging underground galleries. Unfortunately production was often delayed by accidents and, in many cases, people had to resign themselves to abandoning the flooded galleries as the pumps at that time were not powerful enough to extract the water. Not only that, but at a certain depth gas pockets would continuously appear, causing fatal explosions.

Figure 1 –Colonel Drake's oil well in Old Creek near Titusville, Pennsylvania

The increasing demand for oil in the first half of the XIXth century could not be met by the low irregular supply of seep oil. If there were surface seepages, they were a sign that the hydrocarbons were formed at a greater depth and then percolated to the surface. Gaining direct access to deep-lying hydrocarbons through a well appeared to be the solution for the future. The most historic date is still that of August 27, 1859 when *Colonel Drake* dug a well using a drill bit suspended by a cable and driven by a steam engine (

Figure 1). Having drilled to a depth of just 23 meters, he succeeded in bringing the black gold to the surface at the unprecedented rate of 10 barrels[1] per day. However, the limitations of the percussion technique soon came to light: slow penetration rates, the need to stop drilling to extract debris and

[1] One barrel equals 159 liters

major constraints in terms of depth. It was the discovery of rotary drilling, which consisted of rotating a bottomhole tool designed to crush the rock via a metal drill string, which really laid the foundations of the modern oil industry.

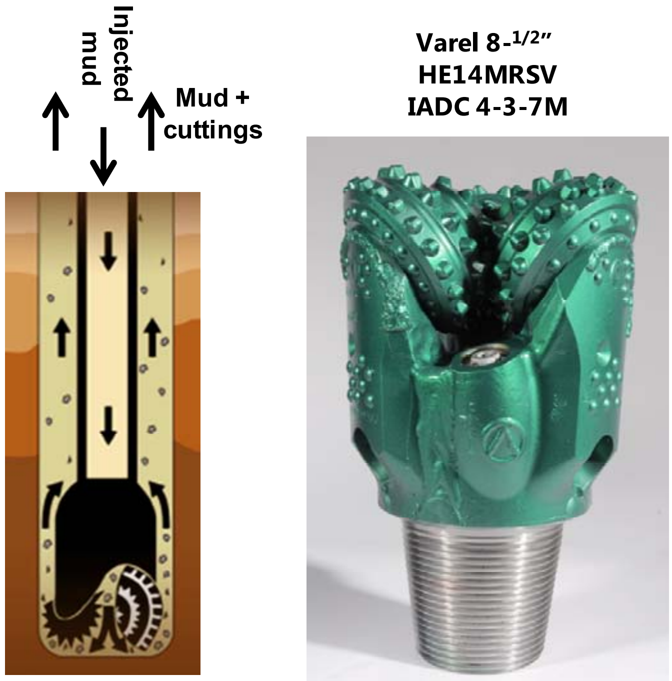

Figure 2 – Rotary drilling and example of a drill bit (courtesy of Varel)

Rotary drilling is thought to have been used since ancient times but, despite numerous projects (one of which is attributed to Leonardo da Vinci), it did not gain any real popularity until the second half of the XIXth century. The idea[2] was to pump a fluid inside a metal pipe to carry the debris up to the surface through the annular space (**Figure 2**). In the end, it was only at the beginning of the XXth century that the first rotary mode oil wells were drilled in soft rock in Texas and California. The invention of the steel drill bit[3], which crushes the rock into little chips[4], allowed for drilling through increasingly hard formations at ever-increasing depths, as early on as the 1920s.

The well

In view of the heterogeneity of the layers drilled through (differences in terms of the hardness of the rock and of the pressure of the fluids) between the surface and the oil or gas-impregnated rock (whether reservoir or source rock), it is impossible to drill a well of uniform diameter. It must be drilled in several sections and, once completed, the sections are covered by a steel tube (called casing) which is cemented in place. When finished, a well is therefore a telescopic structure, starting out with a diameter of about 80 cm, shrinking to about 10 cm when it finally reaches the oil or gas-impregnated rock. A typical well will include on average four sections of cemented casing. At the level of the oil or gas layer the casing is perforated to allow fluid to flow into the well and rise to the surface under the action of its natural pressure inside uncemented tubing (**Figure 3**).

The assembly of the cemented casing sections creates a seal which prevents the hydrocarbons from coming into contact with (and therefore contaminating) the different formations through which they pass, in particular the water-bearing surface layers. This is known as *well integrity*.

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[2] The patent of the Englishman Robert Beart was based on an idea from a Frenchman called Flauville.

[3] The drill bit is a real crushing tool made up of three toothed wheels. To begin with, the teeth were steel spikes, but were later replaced by harder materials such as tungsten carbide and diamond that could cut through the hardest rocks.

[4] These chips of rock are so called *cuttings*

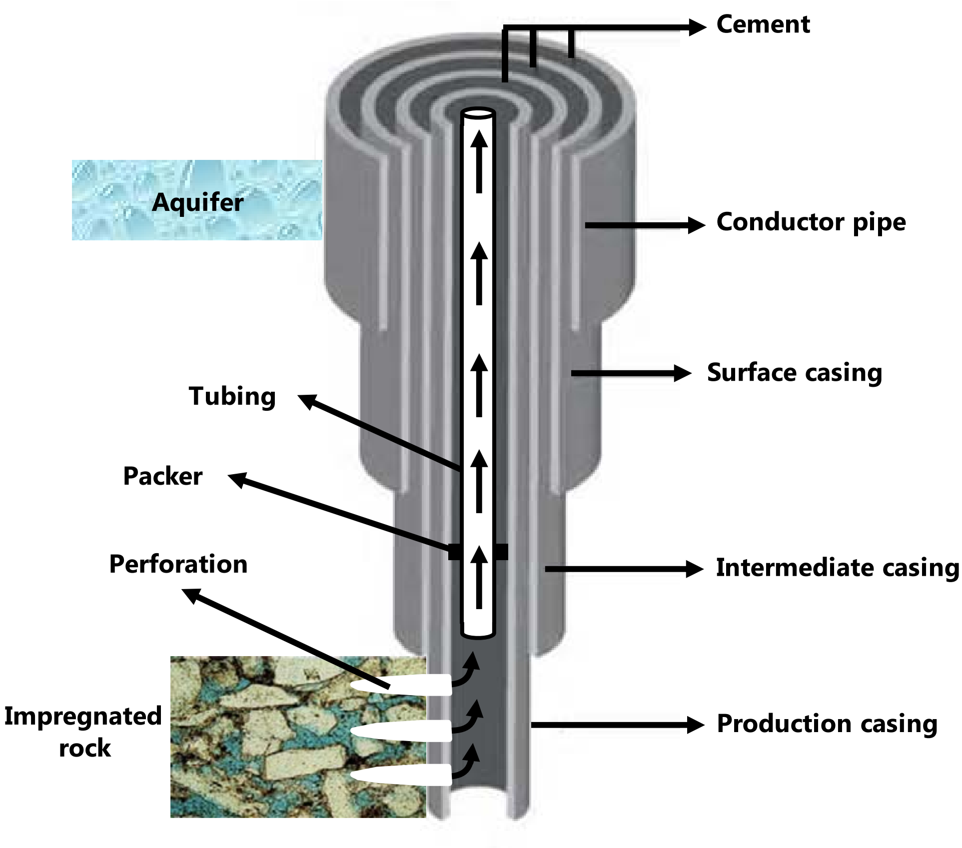

Figure 3 – Typical well architecture.
The cemented casing assures the well seal and protects the water-bearing surface layers
The production fluid flows up through the tubing.

The first vertical developments

The first onshore fields[5] were produced using a large number of vertical wells clustered together and located in the immediate vicinity of the surface seeps (

Figure 4). By highlighting the concept of an anticline trap, geologists added some logic into well location techniques and contributed to rationalizing the number of wells drilled. However, it was the discovery of oil fields in the North Sea and in the Gulf of Mexico in the mid-1970s that really revolutionized drilling techniques, moving first toward deviated and then horizontal wells.

Deviated and horizontal wells

In order to develop offshore oil and gas fields, the number of platforms must be reduced. This constraint gave rise to the *cluster* concept which consists of drilling several dozen wells from a single platform and then deviating the trajectory of the borehole in terms of both inclination (angle of the well axis relative to the vertical) and in terms of azimuth (angle of the trajectory relative to geographical North).

[5] Except for the case of the shallow waters of Lake Maracaibo in Venezuela

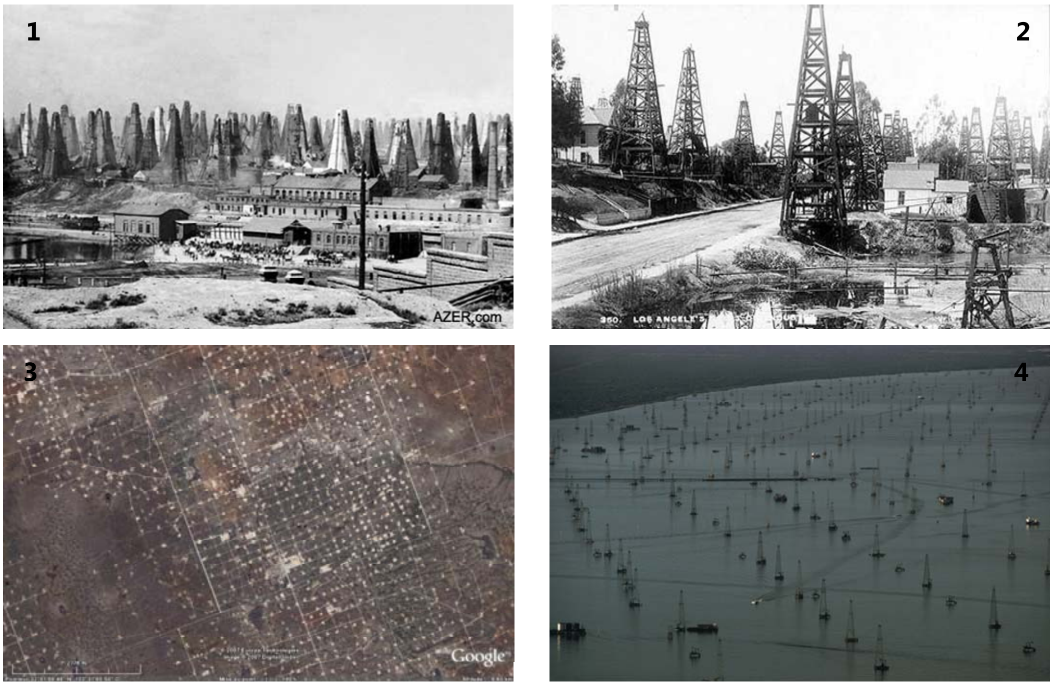

Figure 4 – Typical examples of production
using vertical wells in the first half of the XXth century
1. Baku region (Azerbaijan) 2 and 3 – California 4 – Maracaibo Lake

From points very close together at the surface (the start of the boreholes are just two to three meters apart), this technique means that the oil- or gas-impregnated rock can be reached at distances (this horizontal distance is called "departure") of several km (**Figure 5**).

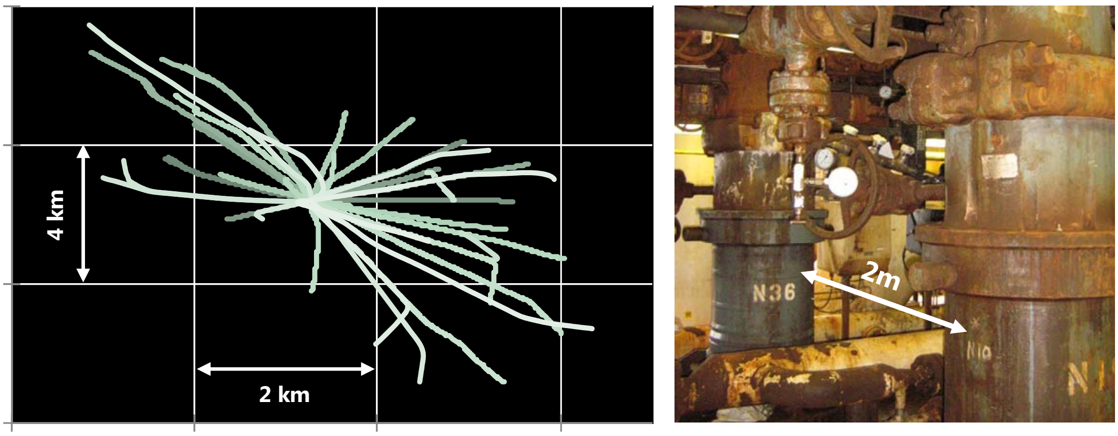

Figure 5 – Example of a cluster in the North Sea
Left: plan view. Many wells are deviated in different directions
Right: the start of two wells just two meters apart at the surface

Controlling the borehole trajectory means first having a specific drill string assembly which can create the required deviation. This is the role of the directional downhole motor (**Figure 6**) comprising a helical screw attached to the end of the drill string and driving the rotation of the drill bit using the movement of the drilling mud[6]. By slightly bending (one to three degrees on average) the end of the

[6] Contrary to traditional rotary drilling, this technique does not require the drill pipes to be rotated.

drill string assembly between the motor and the drill bit, the borehole is drilled in a curve and its trajectory can be selectively deviated in terms of both inclination and azimuth. A well trajectory would therefore turn progressively by a few degrees every 100 meters.

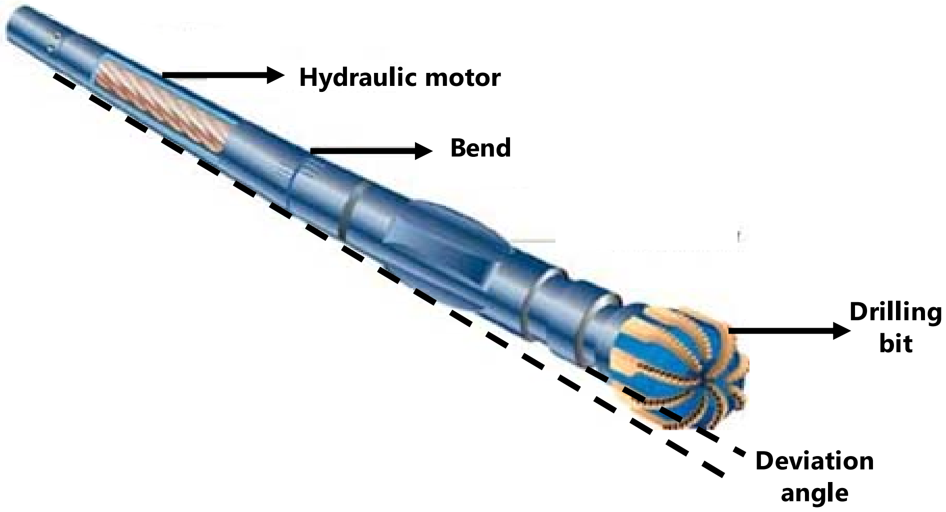

Figure 6 – Directional downhole motor

Using this technique different shapes of borehole can be drilled, the most common being the **J-shape** which tends toward a continuous inclination, the **S-shape** which, once the borehole has been inclined, aims to bring the trajectory back to the vertical and finally the **H-shape,** where the aim is to "land" in the impregnated rock at an angle of 90° and then continue drilling horizontally for several hundred or even thousand meters. The well inclination and azimuth are estimated constantly using sensitive measuring instruments which are an integral part of the drill string. Apart from the possibility of accessing distant targets, deviated and particularly horizontal wells, considerably increase the surface of the borehole exposed to the oil and gas as the distance of rock drilled through is markedly longer.

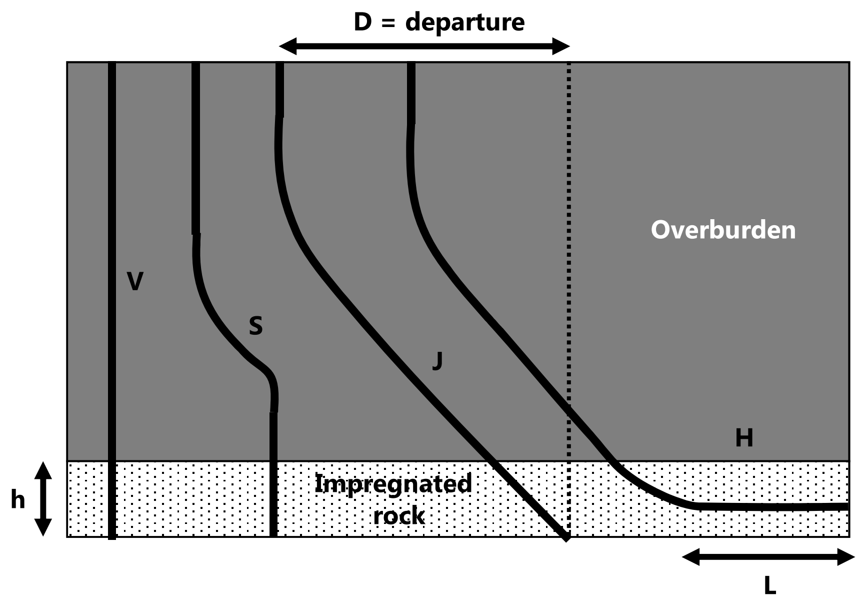

Figure 7 – Different well trajectories (V= vertical, S-shape, J=inclined, H=horizontal)
Compared with the vertical borehole, the inclination creates an offset, but more importantly increases the borehole surface area exposed to the impregnated rock

So for a given oil or gas layer thickness, a well inclined at 70° will double the length of a vertical well (**Figure 7)**. For horizontal wells, the linear portion can sometimes be 20 to 40 times the vertical height of the reservoir, if not more.