

## Evolution of directional drilling since 1900

Directional drilling is the science of controlling or correcting a wellbore, along a predetermined trajectory, to one or more underground targets or locations at given horizontal displacements (HD) and true vertical depths (TVD) from the point of origin. The central advantage of drilling directionally is that significantly more of the production formation is exposed to the well, compared to vertical wells (**Figures DD-1 and DD-2**).

These techniques have been integral parts of the oil and gas industry since the 1920s. Operators must maintain wellbore verticality, construct curves (inclination builds and/or drops) and maintain tangents all in a specific direction. Applications include drilling to difficult-to-access locations and at river crossings as well as drilling relief wells, sidetracking, drilling multiple wells from one surface location or main wellbore (multilaterals) and drilling with wellbores having inclinations up to and exceeding 90°. High-inclination wells (80°+) are considered horizontal and have significantly augmented production due to their increased reservoir exposure as compared to their low-angle counterparts. Extended-reach (ER) wells push the horizontal limits of directional drilling even further.

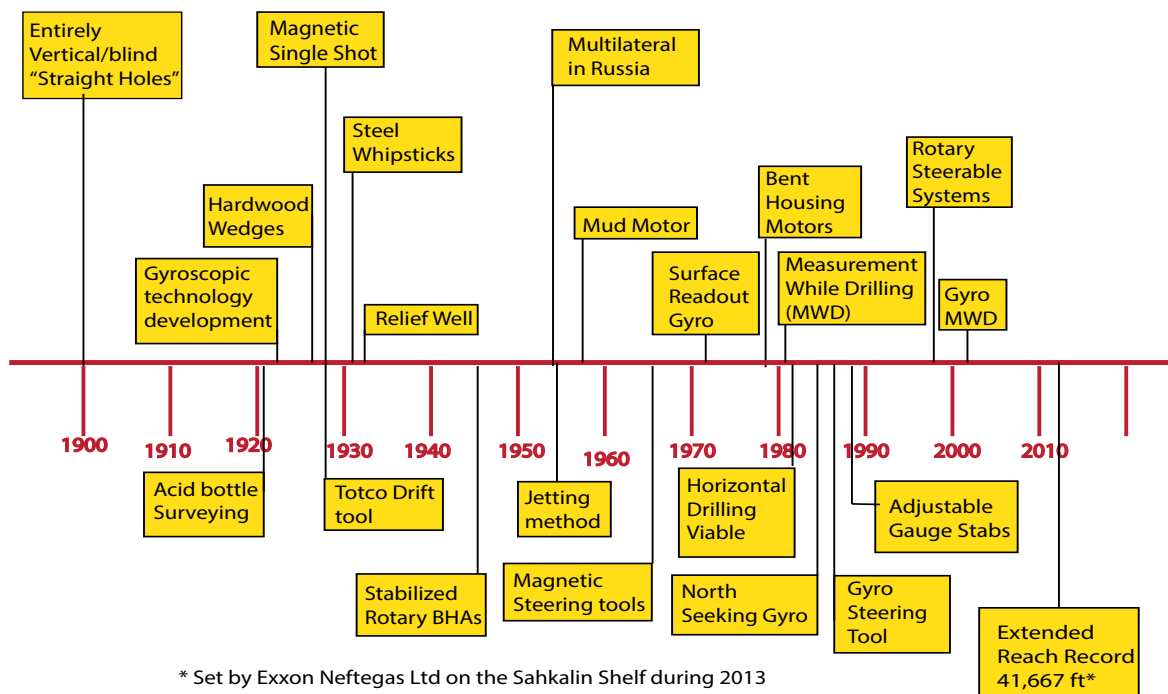
Directional drilling has found a respected place in oilfields worldwide. Historically, engineers have used established methods based on years of prior experience to advance the science toward modern techniques. Directional drilling techniques were designed to improve the mechanics of de-

viated wells so that multiple boreholes could be drilled from one location and at various angles. These techniques allow drilling to contact larger quantity of oil and gas reserves, thereby minimizing associated drilling costs, as well as environmental impact.

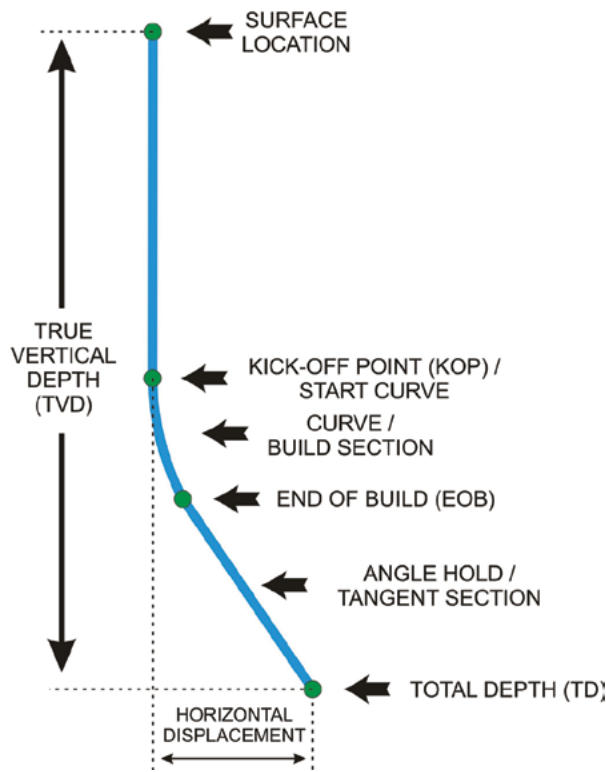
### 1900-1920s

Directional drilling has come a long way since its origins. Through most of the 1800s, wells ostensibly went in only one direction—straight down. It was in the 1920s that the industry first became aware of wellbore deviation of apparently vertical holes. Once these holes could be surveyed, operators discovered that, having had no prior method for measuring inclination or direction, they had unknowingly drilled holes with up to 50° +/- of inclination. Deviation tendencies caused by formation dips, faults, bedding planes, etc., acting on the drill bit were causing the drift away from vertical. The bending characteristics of the drillstring, coupled with the amount of weight applied to the bit, were also factors affecting the desired outcome. Ultimately, surveys consisting of depth, inclination and direction would be used to accurately calculate a well's position.

The acid bottle technique, developed in the late 1800s in South African diamond mines to survey boreholes, became in the 1920s, the first method to be utilized solely for measuring inclination. A glass bottle filled with acid was lowered into the borehole where the acid would settle at an angle in the bottle lying parallel to the angle of inclination. After some time, the acid etched the glass, which allowed calcu-



**Figure DD-1:** Evolution of directional drilling.



**Figure DD-2:** Key parameters in directional drilling.

lation of the wellbore's inclination at a given depth. In the 1920s, Totco developed the mechanical drift recorder, which could only measure borehole inclination but was more accurate than the acid bottle and other early techniques.

Unfortunately, neither of these methods shed light on the direction of well drift. The drive for wellbore control techniques and improved surveying methods was partly accelerated by the possibility that wells were drifting across lease lines. This led to court decrees that lease holders only owned deposits found within the downward vertical projection of their lease lines. Few at the time possessed technology enabling control of well drift. Among those leaseholders who did, some could not resist the temptation to produce oil from an unaware neighbor.

Another method, developed by George Maas, used an acid-etch test tube in parallel with a compass needle that would lock into cooling gelatin, to record both inclination and direction. A vacuum flask was used to protect the gelatin from external heat in the borehole. This development was first described around 1912, yet the heat-shield principle is still used in modern survey instruments.

In 1926, Sun Oil enlisted Sperry Corporation to use gyroscopic-based technology to make survey instruments for accurately measuring borehole inclination and direction. The rotating gyroscopes provided accurate measurements across three different axes and allowed drillers to accurately determine a borehole's azimuth and inclination.

The first magnetic single-shot and multi-shot instruments, which measured both inclination and direction, were developed in 1929 by H. John Eastman. These instruments used sensors employing magnetic compass needles and plumb bobs. They also featured mechanical timers that triggered a simple camera to record the survey on photographic film. The science of controlled directional drilling did not come about until the development of these magnetic single-shot and multi-shot instruments.

There were three natural consequences of these accurate surveying methods: intentionally deviating wells to precise bottomhole locations; restricting vertical wells to at most a few degrees in inclination; and limiting the resultant wellbore drift. The first deliberately deviated wells were drilled in the late 1920s. Hardwood wedges were used, pushing the bit to one side of the hole and producing a deflection to direct the wells from vertical toward an intended direction.

### 1930s

In 1930, a French inventor named René Moineau discovered the principle of the progressive cavity pump which led to the development of downhole positive displacement motors (PDMs). PDMs would eventually become the most effective and commonly used deviation tools in the industry.

Records from two wells drilled in Huntington Beach, California, in 1930 are the first records from directionally controlled boreholes drilled from an onshore location to oil/gas deposits under the ocean (offshore). The steel whipstock was the main deflection tool used from the 1930s until the 1950s. Early whipstocks were simply lowered into the borehole, oriented with the whip face in the desired direction and mechanically anchored at the bottom of the main wellbore (**Figure DD-3**). When the wellbore drifted off course, a whipstock was set and drilling operations would be diverted along the whip face. No attempts were made to retrieve these whipstocks and they were typically abandoned in the well. Beginning in 1932, directional wells were regularly drilled along the beachfront beneath the ocean. In 1933, the Signal Hill field was developed in Long Beach, Calif.

The orientation of directional tools, including whipstocks, was accomplished by using a visual surface reference and maintaining the tool facing while it was lowered into the hole. Another method entailed running in a survey instrument so that it landed in a special mule-shoe key designed to

align it with the tool facing (**Figure DD-4**). This was recorded as a reference to the magnetic direction or high side of an inclined wellbore and the deviation tool could then be turned to the desired facing/direction.

In 1934, a blowout occurred in a field owned by Humble Oil Company of Conroe, Texas. A gas kick from a high-pressure zone ignited, and the entire rig was engulfed in flames. After many months and attempts to bring the fire under control, other nearby rigs had to be closed down and the entire field was threatened. H. John Eastman, with his experience using whipstocks and surveying instruments, used a mobile drilling truck to drill a directional relief well close enough to the blowout well, killing the blowout on the first attempt. The oil industry subsequently accepted directional drilling as a reliable technique (**Figure DD-5**).

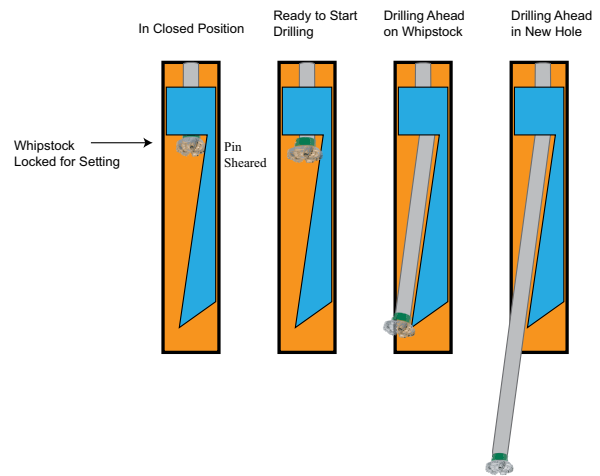
### 1940s-1960s

It's likely that basic stabilized rotary bottomhole assembly (BHA) designs with drill collars for weight and stiffness, together with stabilizers precisely positioned for inclination control while drilling, originated in the 1940s. Historically, it had been possible to control the angle of directional wells during rotary drilling by correct design of the assembly and use of suitable drilling parameters. The three basic principles included holding inclination (locked/packed), building inclination (fulcrum) and dropping inclination (pendulum). Drill collars, when used without stabilization, tended to buckle and cause unwanted deviation and poor hole quality. Multiple stabilizers were positioned to increase the stiffness or to promote the natural bending of the drill collars, thereby pointing the drill bit or applying a side force to encourage the wellbore in a specific trajectory.

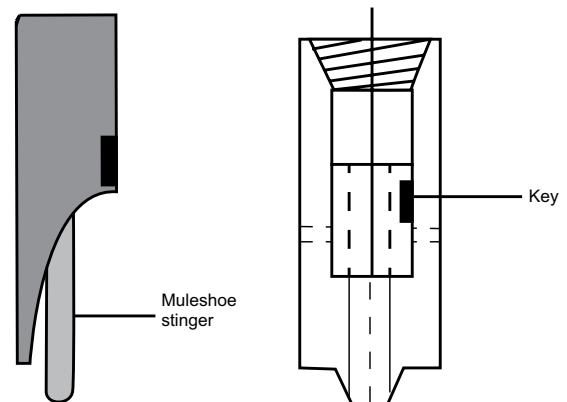
Control of hole direction had traditionally been poor with basic rotary assemblies. Roller-cone bits usually walked to the right (clockwise), and directional control was previously limited to using well-stabilized assemblies to reduce this tendency. The normal prior practice with non-steerable assemblies was to lead the well an estimated amount to the left of the plan, thereby compensating for anticipated turns.

Magnetic instruments naturally needed to be seated in a nonmagnetic environment if they were to run inside the drillstring to accurately measure direction. In the 1940s, nonmagnetic drill collars (NMDC) were placed in the lowest possible position of the drillstring with a crow's foot baffle plate inserted below it. This allowed the drilling fluid to pass through the drillstring and, at the same time, provide a convenient seat for the survey instrument.

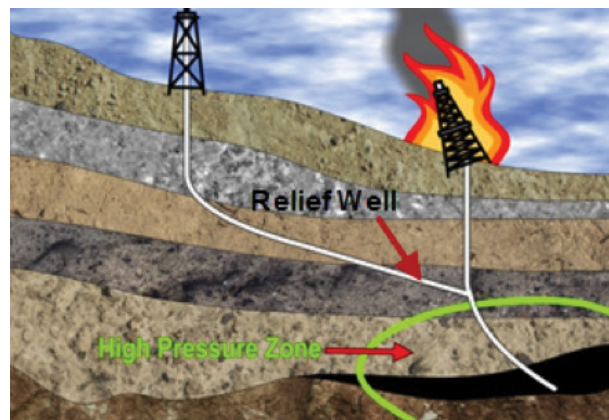
Gyroscopic surveying, developed as early as 1929, was continuously improved from the 1940s to the 1960s. Gyros were also used to measure inclination, azimuth and the



**Figure DD-3:** Wellbore deviation with whipstocks.



**Figure DD-4:** One method to orient directional tools was running in a survey instrument to land in a special muleshoe key designed to align it with the tool facing.



**Figure DD-5:** Directional drilling is well accepted as a reliable technique to drill relief wells to kill blowouts. First recorded application was in 1934.

deviation tool orientation. While magnetic instruments are dependent on the Earth's natural lines of magnetic force, gyros use a gyroscopic compass to maintain a fixed-reference direction and to measure relative changes in direction at selected depths with the aid of a timer. This surveying technology enabled even more directional drilling applications, as it could be used in magnetic environments, e.g., for accurately sidetracking from inside the casing in a vertical hole where magnetic toolfaces would otherwise be impossible to orient or when drilling suffers from magnetic interference from nearby wells.

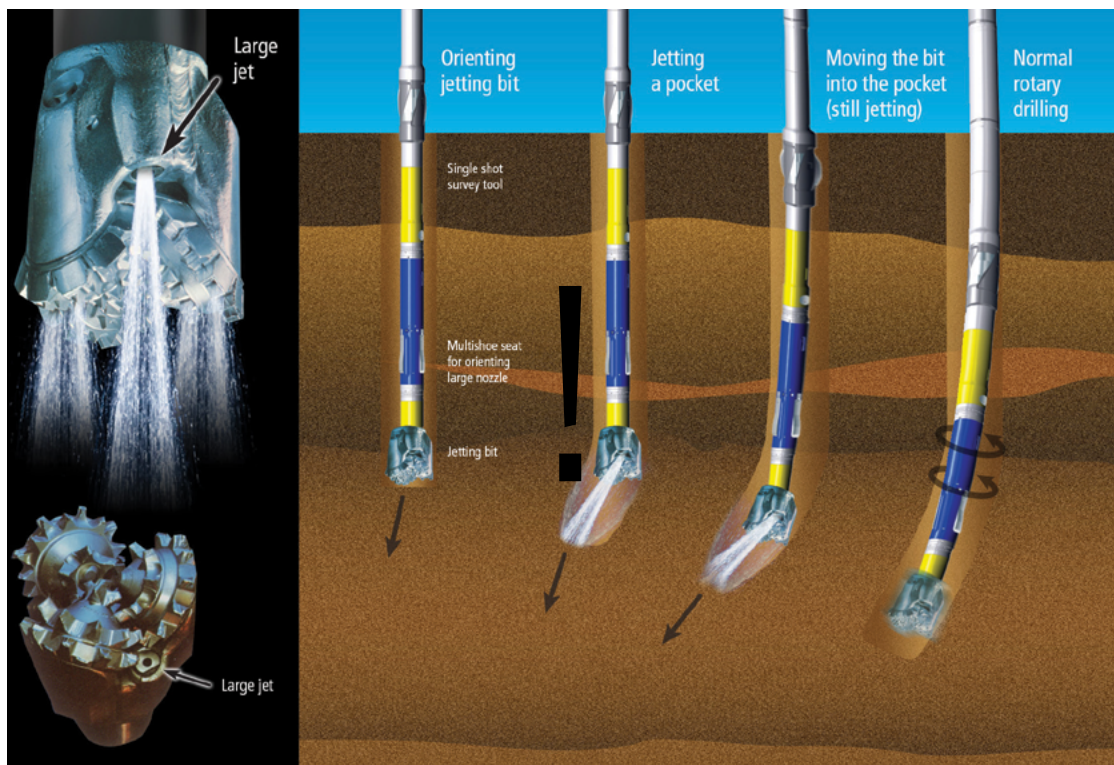
The jetting technique was developed in the mid-1950s. Rarely used in the 21st century, it is still a valid and inexpensive deviation method for soft formations. A special jet bit may be used, but it is also common practice to use a standard soft formation tri-cone bit with one very large nozzle and two smaller ones. The idea is to point the big jet in the desired direction. With the majority of flow passing through the large-bore nozzle (big jet), the hole preferentially washes in the direction of the large nozzle and forms a pocket. Drilling can continue with the assembly following the direction of the pocket (**Figure DD-6**).

While jetting is not common today, it can be useful tight an-

ti-collision scenarios exist in surface holes. Other notable points about jetting include:

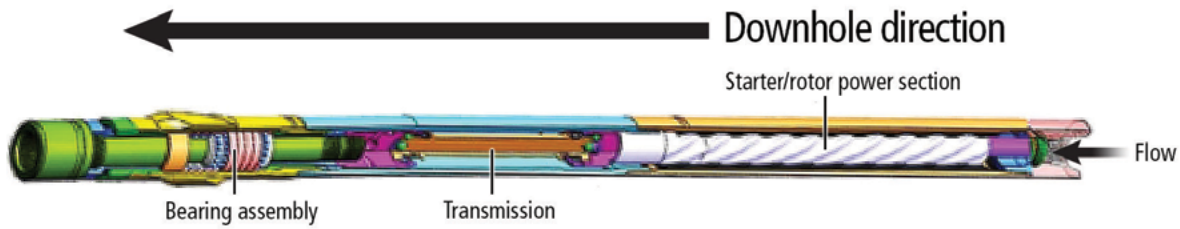
- It is relatively inexpensive compared to conventional deflection tools;
- It allows surveys to be taken closer to the bit than any other deflection method;
- Jetting dogleg response can be inconsistent and difficult to predict;
- Effectiveness is reduced as bit diameter and BHA tubular diameter increase;
- Hole-opening runs are often required, as jetting is often performed in 8 ½ in. and 12 ¼ in. holes.

The first downhole drilling motors or mud motors were designed and manufactured by Dyna-Drill in 1958. The motor was based on the 1930 Moineau design for progressive cavity pumps. The mud motor's molded elastomeric insert, which is bonded to the inside of a cylindrical steel case, comprises the stator of the pump or motor unit. A helical rotor with one or more lobes rotates eccentrically within the stator (which contains one more lobe than the rotor). When differential pressure (i.e., mud flow through this power section) is applied across the assembly, the rotary power extracted from the rotor/stator assembly functions as a motor driving the drill bit. Many power section configurations have been developed, from those that generate high bit speeds



**Figure DD-6:** Jetting was developed in the mid-1950s. Rarely used today, it is still a valid and inexpensive deviation method in soft formations. Courtesy Baker Hughes Inc.

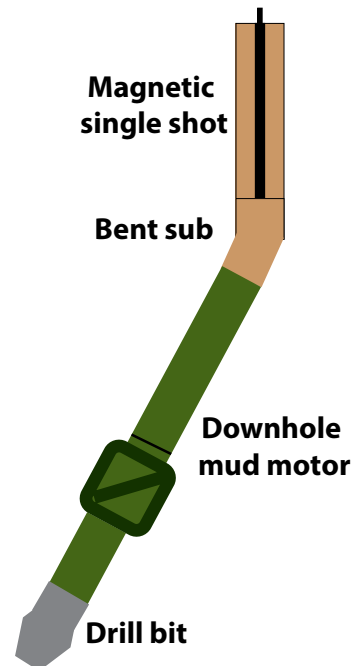




**Figure DD-7:** Downhole drilling motors were introduced by Dyna-Drill in 1958. Courtesy Baker Hughes Inc.

but are limited to relatively low torque, to those allowing for slower-bit speeds but at a much higher-torque output (**Figure DD-7**).

Mud motors were first used for directional control of boreholes in the 1960s. A bent sub (a short component for connecting two longer collars) was positioned directly on top of the mud motor (**Figure DD-8**). This directional drilling assembly would normally be used whenever the wellbore reached a depth that required deviating, normally to initiate/drill a curve or correct the wellbore. With the drillstring not rotating (rotary drive locked), drilling was accomplished by the motor-driven drill bit. This bit still rotated as long as there was mud flow and the ability to make new hole by sliding the drillstring. This would in effect kick off the wellbore in the direction of the bent-sub toolface. The BHA was usually pulled back out of the hole to prevent twisting off (breaking) the motor due to high stresses caused when trying to rotate the bent-sub configuration. Basic rotary assemblies would be run to continue controlling the well path until another motor run was necessary.



**Figure DD-8:** By the 1970s, mud motors dominated directional drilling. As above, they were used with a bent-sub for directional kick off.

Mud motors were sometimes used in vertical applications where high bit speeds were desirable. They had the added benefit of minimizing erosion and wear on the drillstring and casing strings since the drillstring would not need to be turned as fast due to the reduction of the surface revolutions per minute (RPM). The majority of mud motors were used in directional (deviated) wells. In these wells, one run with the bent-sub configuration could accomplish the same goal as multiple runs with other methods of steering the bit, but with greater accuracy, thus reducing time and cost.

The rebel tool was introduced in the 1960s. It was one of the first directional drilling tools to control the direction of lateral wellbore trajectory while rotating and could be set up on surface for a left or right tendency. Inconsistent reliability of these tools led to their declined use in the industry.

### **1970s**

Magnetic-steering tools were first used in 1969 but became more common in the 1970s. The steering tool was also used

to measure drift, direction and toolface during semi-continuous drilling and with downhole directional data available in real time on surface. An instrument assembly containing a magnetic survey package was sent downhole connected by a wireline. It was seated in a mule-shoe orienting sub (also called Universal Bottomhole Orienting sub or UBHO) that was connected to the top of a mud motor, thereby aligning it with the motor's toolface. A coder converted data measurements to electrical pulses and transmitted the measurements to the surface through a shielded electric conduit to digital or video displays. Measurements were thus available immediately in real time at the surface for use in directionally controlling the wellbore. Even though these early steering tools provided the directional driller with valuable data in real time, the tools would have to be pulled out of the drill-