

DRILLING METHODS

This continuing education unit reviews drilling methods common to drillers, with an emphasis on water well drilling methods. For completeness mention is made of methods or tools used in the oil & gas industry. Often methods or tools first employed in the oil or gas drilling industry eventually find their way into the water well drilling field. As well mention is made of drilling methods employed in the geotechnical or environmental drilling sector. However the coverage of the methods and tool of the geotechnical or environmental sector is not exhaustive.

Many drillers adopt their chosen method of both hole-making and hole clearing and become experts over time. Long and successful careers are had by working within the method of drilling/hole clearing chosen. These drillers identify themselves by their chosen methods: “cable tool driller” “mud rotary driller,” “environmental/geotechnical driller.” Large companies look for these specialists when seeking new employees.

Other drillers, by choice, or happenstance are exposed to several methods of making hole and hole clearing. These drillers become comfortable using different approaches depending upon hole size, engineering specifications, equipment availability and geology.

The material below reviews the range of hole making and hole clearing approaches in common use in the drilling industry.

Hole making methods

Making hole includes breaking rock in consolidated formations and stirring sediments in unconsolidated formations. While hole making is most commonly carried out by mechanical means, other means may also be employed such as high frequency vibration and hydraulic pressure.

MECHANICAL HOLE MAKING METHODS

CABLE TOOL

Cable tool had its beginnings 4000 years ago in China. It was the earliest drilling method and has been in continuous use for about 4000 years. The Chinese used tools constructed of bamboo and well depths of 3000 ft. are recorded. However, wells of this depth often took generations to complete.

Cable tool rigs are sometimes called pounders, percussion, spudder or walking beam rigs. They operate by repeatedly lifting and dropping a heavy string of drilling tools into the borehole. The drill bits breaks or crushes consolidate rock into small fragments. When drilling in unconsolidated formations, the bit primarily loosens material.

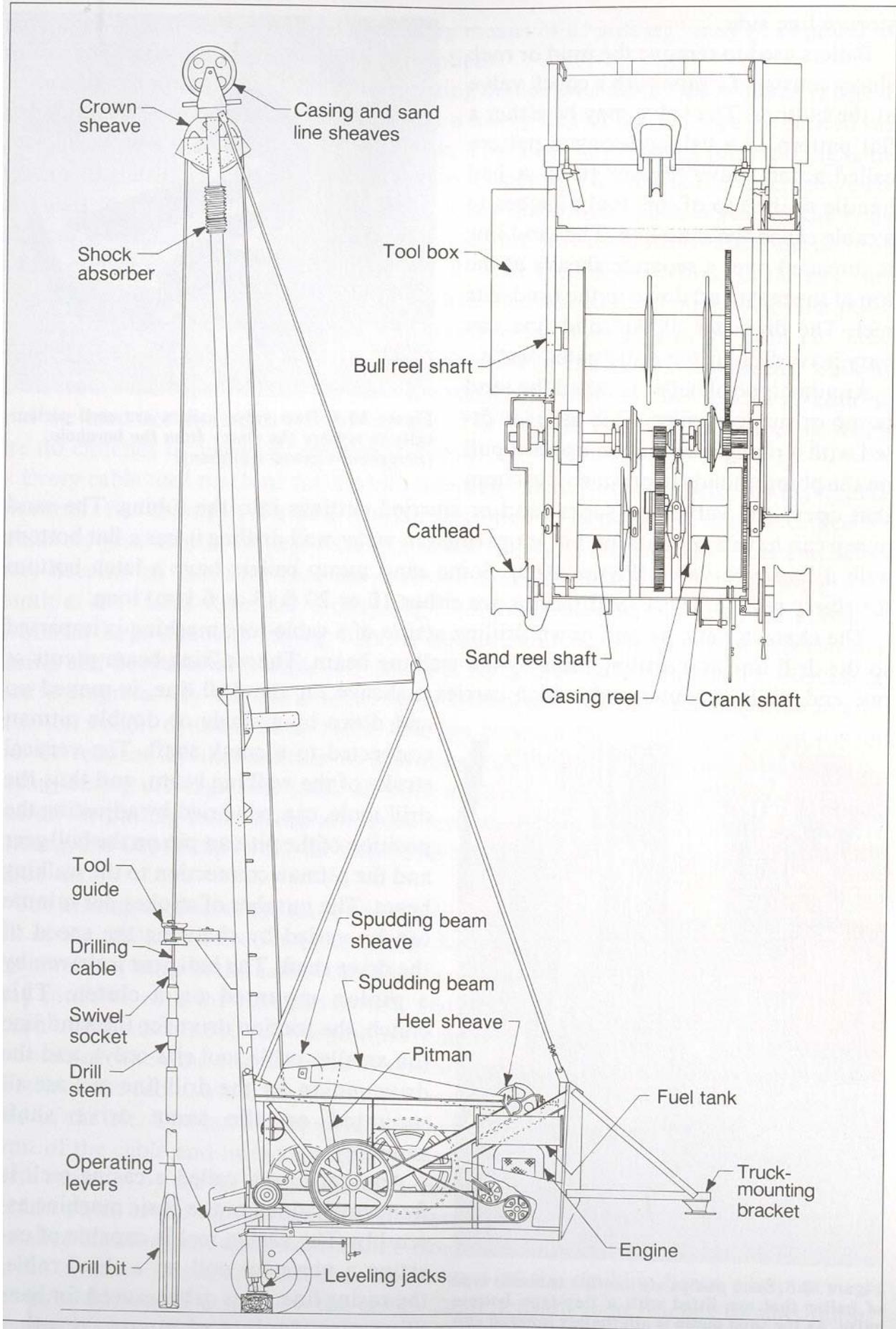


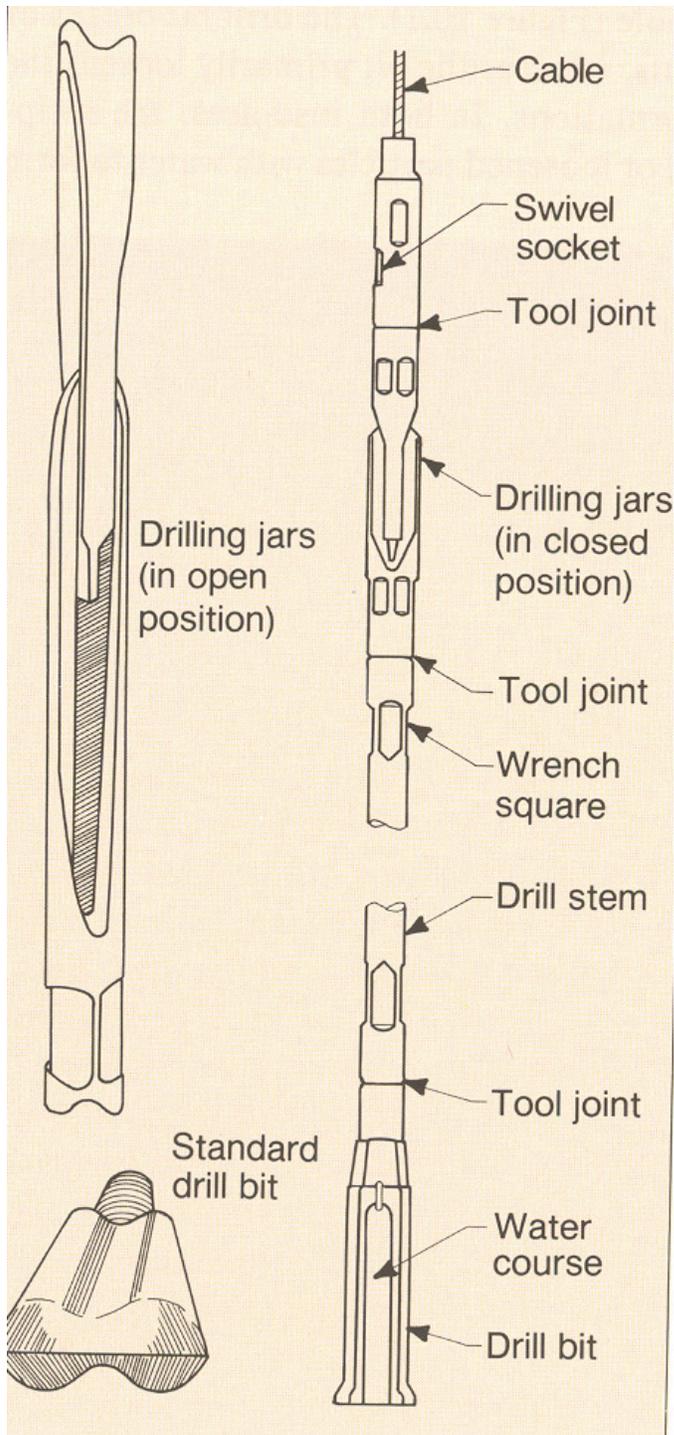
Figure 10.3. Engineering drawing of a Bucyrus-Erie Model 22-W shows how the drill line is reeved in a typical cable tool rig. The spudding action is imparted to the drill line by

Water, either from the formation or added by the driller, mixes the crushed or loosened particles into a slurry at the bottom of the borehole. An experienced cable tool driller feels when the accumulated slurry has reached the point where it is reducing bit penetration to an unacceptably slow level. At this point slurry is removed from the borehole by a bailer. Once the slurry is removed, the bit is reinserted into the hole and drilling continues.

Cable Tool Drill String Components:

For a cable tool drill to operate the drill string must have these four components:

- **Drilling cable - lifts tools, turns tools, controls tool motion.**
- **Swivel socket - connects cable to tools, allows cable to unwind.**
- **Drill stem - provides weight, steadies and guides bit.**
- **Drill bit - penetrates formation, crushes and reams, mixes cuttings. Many cable tool drillers now employ Tungsten Carbide studded bits to aid in hard rock penetration.**



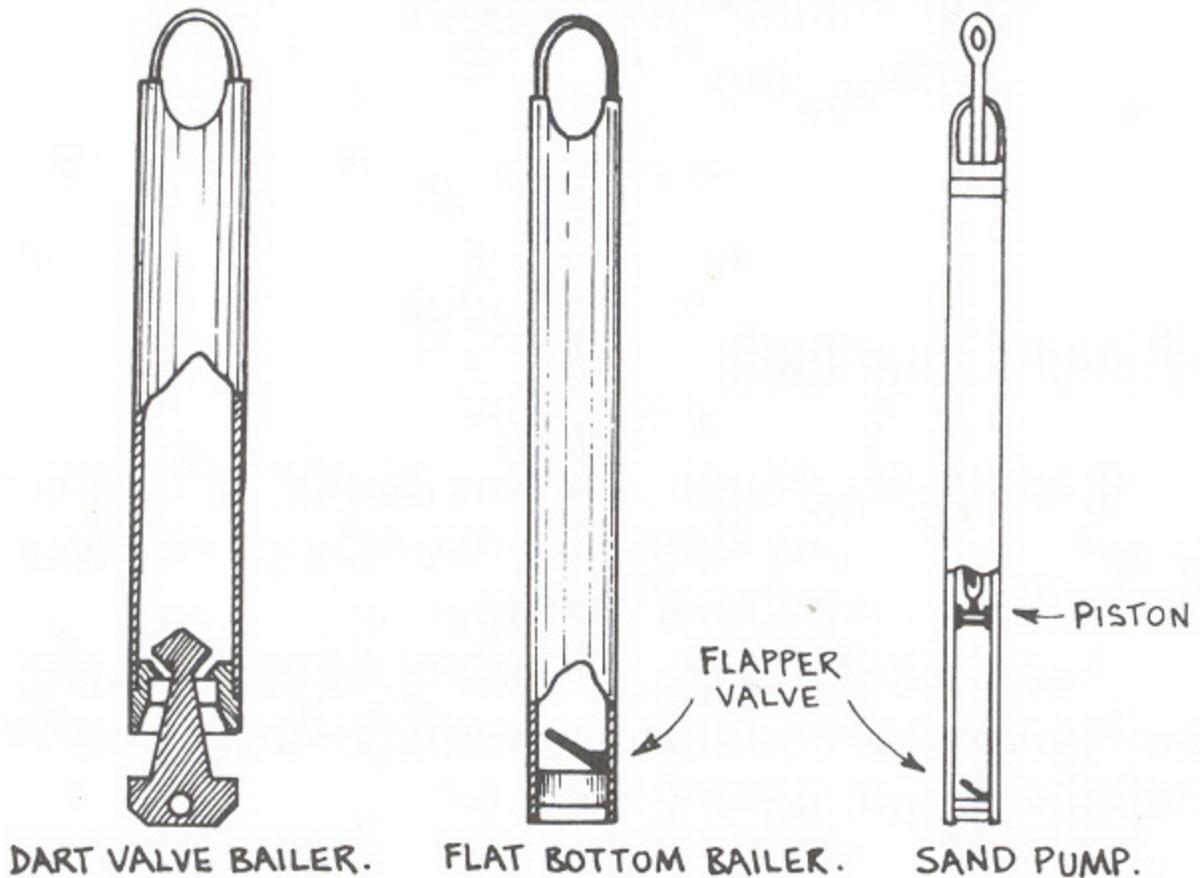
Tool joints connect the drill string components. Depending on formation the driller may add drilling jars to the drill string. The hammering action provided by

the jars frees tools that become jammed. Jars play no part in the drilling process.

Cable Tool Bailer

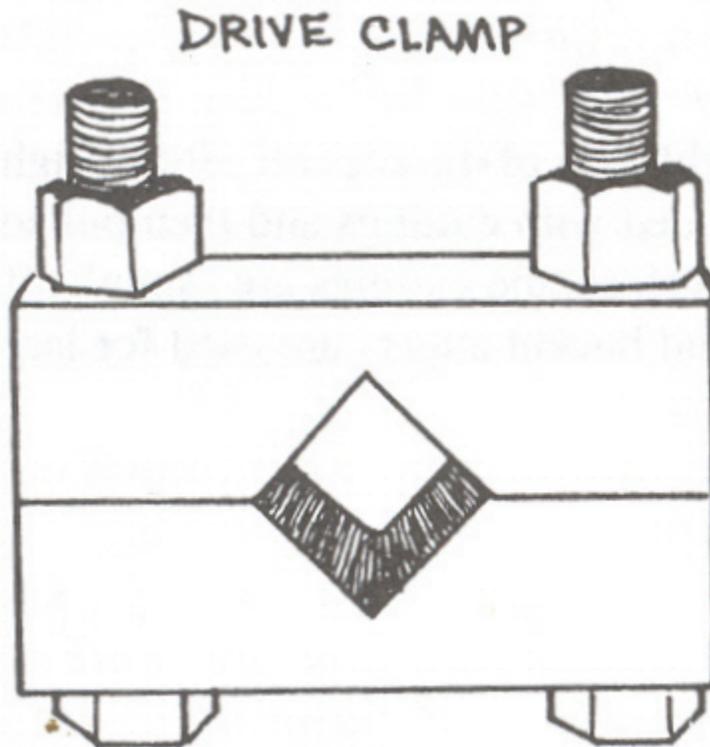
Bailers: Bailers are used to clear cuttings from the hole. Bailers are run on a separate "bailing line" when the drill string is out of the hole. The bailer is attached to an eye in the end of the line.

Selection of the most suitable type of bailer will depend on how well the cuttings are mixing. The **dart valve** bailer will only pick up well-mixed cuttings.



A bailer is run on a separate bailing line and is inserted after the drill string is removed from the hole. The bailer is used to remove slurry from the hole so that efficient penetration can continue.

Cable Tool Casing Driving Equipment

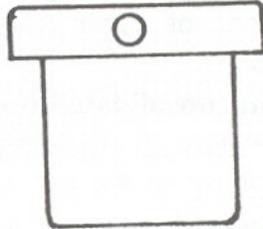


The driving of casing is an integral part of cable tool drilling. The driving force is provided by a drive clamp attached to the drill string. A wrench square is forged in the drill stem to allow for the attachment of the drive clamp.

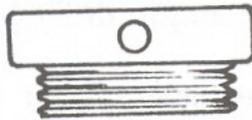
A drive shoe is attached to the bottom of the first length of casing to be driven. The drive shoe is manufactured with a hardened cutting surface at the leading edge. When fully driven into a consolidated formation a seal is created between the drive shoe and the formation.

A drive head is fitted or screwed to the top of the casing, to protect the casing from damage when being driven.

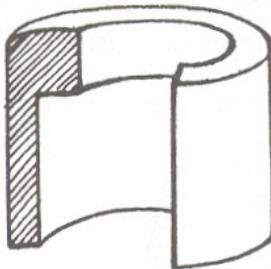
INSIDE DROP
DRIVE HEAD



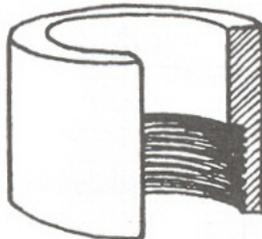
SCREW TYPE
DRIVE HEAD



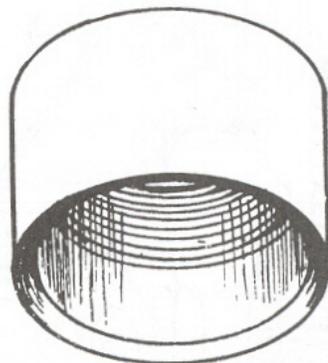
OUTSIDE
DROP DRIVE
HEAD



HEAD FOR
PIN-UP
CASING



Casing which is to be driven is fitted with a **drive shoe**.



DRIVE SHOE

A drive head is fitted to the top of the casing to protect it against damage when being driven.

Cable Tool Operation

The drilling motion of the cable tool drilling machine must be synchronized with the gravity fall of the tools for effective penetration. Effective drilling action is obtained when the engine speed is synchronized with the fall of the tools and the stretch of the cable, while paying out the correct amount of cable to maintain proper feed of the bit. A shock absorber is installed at the crown sheave to provide resiliency in the system. The shock absorber dampens vibration and protects the derrick and machine from severe shock stresses. The shock absorbers rebound helps to lift the tools sharply after they strike bottom.

Every cable tool machine has certain limits as to the depth and diameter of boreholes it is capable of drilling. This limit is a function of the total weight of the drill string plus the cable needed to drill to either maximum depth or maximum casing diameter.

The usual process is to drive the casing initially using the hammering action of the drive clamps attached to the wrench square near the top of the drill stem. The clamps act as the hammer face and the tools provide the weight for driving the casing. After the casing is driven into the formation, the material is removed by inserting the bit, adding water and operating the drill bit until a slurry is formed from the cuttings. The bailer is then used to remove the slurry and this process is repeated

with the driving of casing the insertion of the drill bit, the operation of the bit until a slurry is formed and the bailing of the slurry until the casing reaches a desired depth.

While drilling, a depth may be reached where casing cannot be driven further without risking damage to it. If this point is reached and sufficient water has not yet been found, the casing diameter will then be reduced and drilling will continue inside the smaller casing. Drillers anticipating the need to telescope casing downward will begin drilling a borehole of a larger size to accommodate telescoping down during the drilling process.

Advantages of the cable tool:

- 1. Highly suitable for remote settings. The cable tool's low fuel consumption, small needs for water and other materials and reliability make it an excellent choice for remote site locations.**
- 2. Low capital investment and cheap maintenance. Capital costs of new cable tool rigs are generally significantly less than the costs of new rotary drilling machines of similar capacity. As well, cable tool maintenance is less expensive than parts for the less mechanical, more hydraulically equipped rotary systems.**
- 3. Particularly suited to water poor areas. Cable tool drilling more easily identifies each water bearing formation penetrated, even those of small yields.**
- 4. Efficient use of personnel. Cable tool rigs are often operated by a single person.**

Disadvantages of Cable tool drilling:

- 1. Productivity measured in hole produced per day is low compared to other drilling methods in similar formations.**
- 2. Hard rock penetration rates very low.**

Despite many new drilling developments, cable tool remains a useful and competitive drilling technique in some drilling applications.

AUGER DRILLING

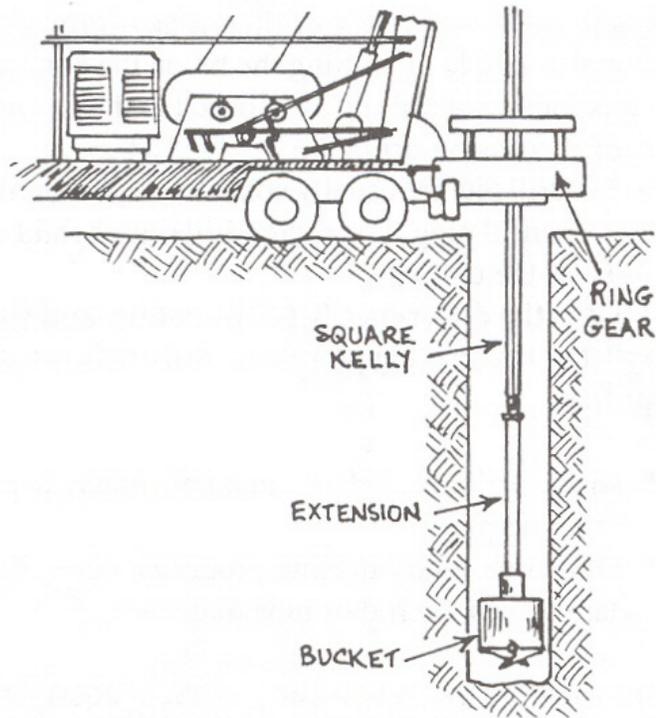
Often used for site investigation, environmental and geotechnical drilling and sampling, and boreholes for construction purposes, auger drilling can be an efficient drilling method.



The advantages of auger drilling include low operating costs, fast penetration rates in suitable formations and no contamination of samples by fluids. Augers come in continuous flight, short flight/plate augers and bucket augers. Continuous flight augers driven by top head rotary machines (shown above) carry their cuttings to the surface on helical flights. Continuous flight augers with hollow stems are often used for sample recovery in environmental, geotechnical operations.

Short flight/plate augers and bucket augers are used for large diameter holes. The cuttings are lifted out of the hole and then removed before drilling continues.

Bucket augers: The cuttings are picked up in the bucket, hoisted to the surface and dumped through the hinged bottom of the bucket. Extensions are added as the hole gets deeper.



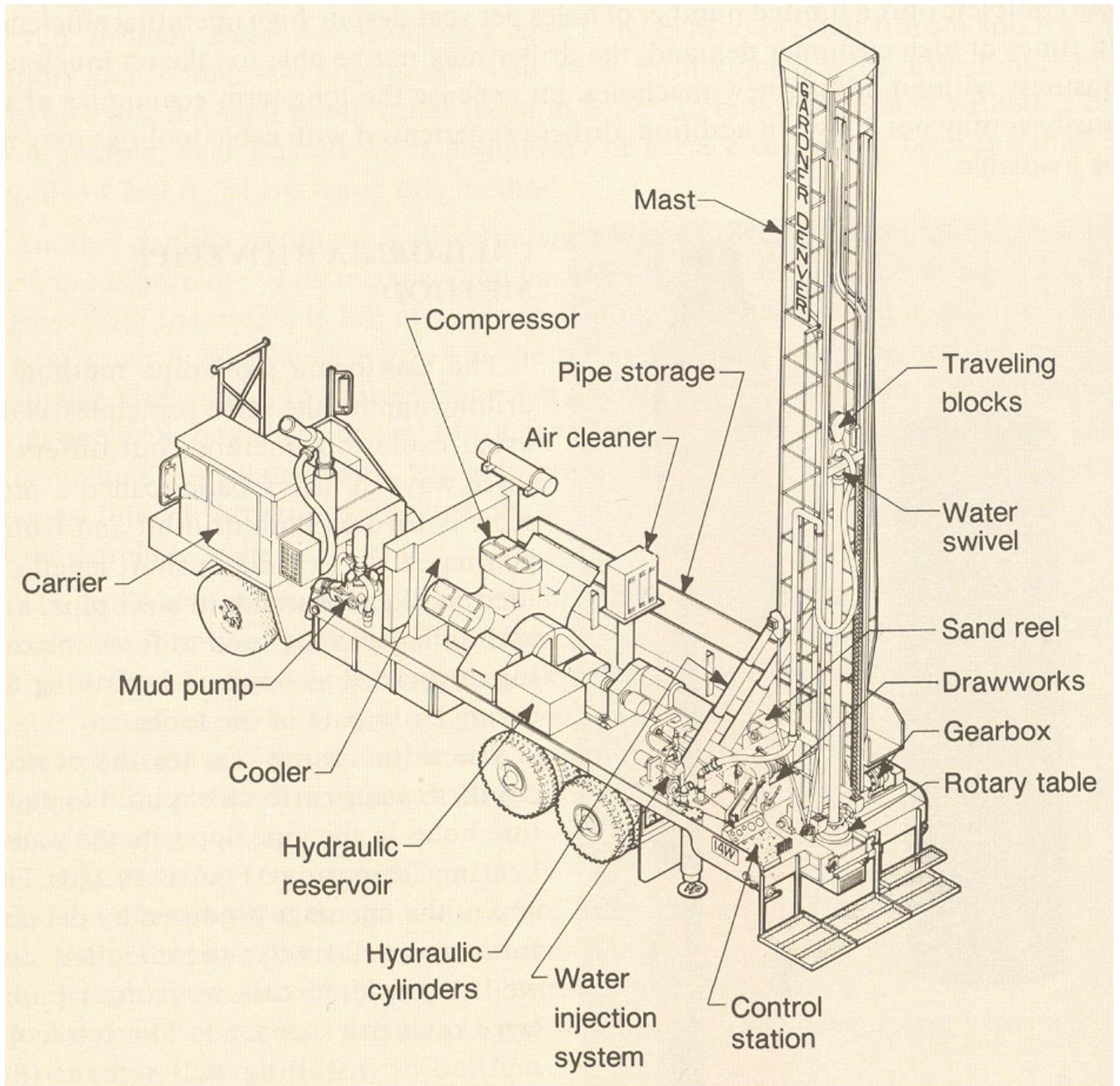
Rotary Drilling

Rotary drilling uses a sharp, rotating drill bit to dig down through the Earth's crust. Much like a common hand held drill, the spinning of the drill bit allows for penetration of even the hardest rock. The idea of using a rotary drill bit is not new.

Archeological records show that as early as 3000 B.C., the Egyptians may have been using a similar technique. Leonardo Di Vinci, as early as 1500, developed a design for a rotary drilling mechanism that bears much resemblance to technology used today. Despite these precursors, rotary drilling did not rise in use or popularity until the early 1900's.

Although rotary drilling techniques had been patented as early as 1833, most of these early attempts at rotary drilling consisted of little more than a mule, attached to a drilling device, walking in a circle! It was the success of the efforts of Captain Anthony Lucas and Patillo Higgins in drilling their 1901 'Spindletop' well in Texas that catapulted rotary drilling to the forefront of petroleum drilling technology.

While the concept for rotary drilling - using a sharp, spinning drill bit to delve into rock - is quite simple, the actual mechanics of modern rigs are quite complicated. In addition, technology advances so rapidly that new innovations are being introduced constantly. The basic rotary drilling system consists of four groups of components. The prime movers, hoisting equipment, rotating equipment, and circulating equipment all combine to make rotary drilling possible.



1. Prime Movers

The prime movers in a rotary drilling rig are those pieces of equipment that provide the power to the entire rig. Steam engines provided the power to the early drill

rigs. Gas and diesel engines became the norm after World War II.

Recently, while diesel engines still compose the majority of power sources on rotary rigs, other types of engines are also in use; more so in the oil and gas industry than in the water well sector. Natural gas or gasoline engines are commonly used, as are natural gas or gasoline powered reciprocating turbines, which generate electricity on site. The resulting electricity is used to power the rig itself. The energy from these prime movers is used to power the rotary equipment, the hoisting equipment, and the circulating equipment, and on large rigs may be used as well to provide incidental lighting, water, and compression requirements not associated directly with drilling.

2. Hoisting Equipment

The hoisting equipment on a rotary rig consists of the tools used to raise and lower whatever other equipment may go into or come out of the well. The most visible part of the hoisting equipment is the derrick, the tall tower-like structure that extends vertically from the well hole. This structure serves as a support for the cables (drilling lines) and pulleys (draw works) that serve to lower or raise the equipment in the well.

For instance, in rotary drilling, the wells are dug with long strings of pipe (drill pipe) extending from the surface down to the drill bit. If a drill bit needs to be changed, either due to wear and tear or a change in the subsurface rock, the whole string of pipe must be raised to the surface. In deep wells, the combined weight of the

drill pipe, drill bit, and drill collars (thicker drill pipe located just above the bit) may be in excess of thousands of pounds. The hoisting equipment is used to raise all of this equipment to the surface so that the drill bit may be replaced, at which point the entire chain of drill pipe is lowered back into the well.

The height of a rigs derrick can often be a clue as to the depth of the well being dug. Drill pipe traditionally comes in 20ft sections, which are joined together as the well is dug deeper and deeper. This means that even if a well is 1200 feet deep, the drill string must still be taken out in 20 foot sections. However, if the derrick is tall enough, multiple joints of drill pipe may be removed at once, speeding up the process a great deal.

3. Rotating Equipment

The rotating equipment on a rotary drilling rig consists of the components that actually serve to rotate the drill bit, which in turn digs the hole deeper and deeper into the ground. The rotating equipment consists of a number of different parts, all of which contribute to transferring power from the prime mover to the drill bit itself. The prime mover supplies power to the rotary, which is the device that turns the drill pipe, which in turn is attached to the drill bit. A component called the swivel, which is attached to the hoisting equipment, carries the entire weight of the drill string, but allows it to rotate freely.

The drill pipe (which, when joined together, forms the drill string) consists of 20ft sections of heavy steel pipe. The pipes are threaded so that they can interlock together. Drill pipe is manufactured to meet specifications laid out by the American Petroleum

Institute (API), and others, which allows for a certain degree of homogeneity for drill pipes across the industry.

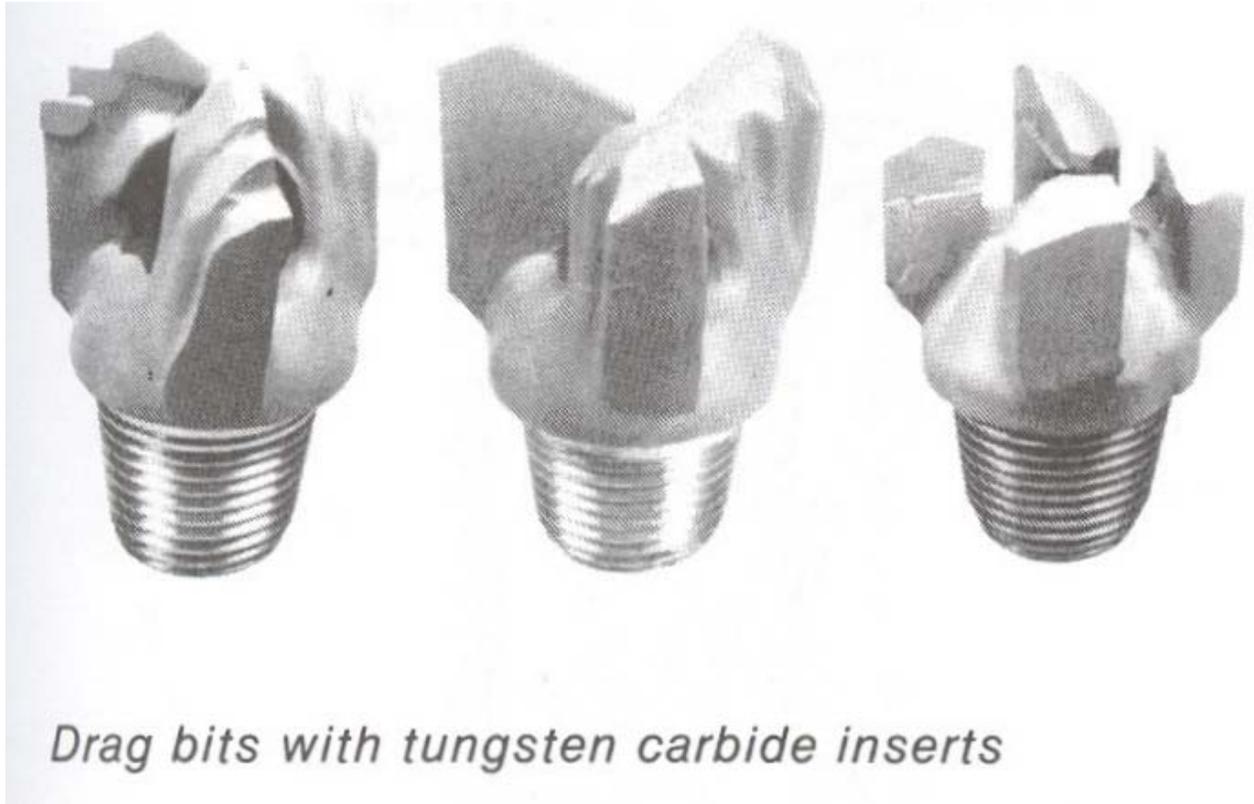
Below the drill pipe are drill collars, which are heavier, thicker, and stronger than normal drill pipe. The drill collars help to add weight to the drill string, right above the bit, to ensure there is enough downward pressure to allow the bit to drill through hard rock. The number and nature of the drill collars on any particular rotary rig can be altered depending on the down hole conditions experienced while drilling.

Rotary Drill Bits

The drill bit is located at the bottom end of the drill string, and is responsible for actually making contact with the subsurface layers, and drilling through them. The drill bit is responsible for breaking up and dislodging rock, sediment, and anything else that may be encountered while drilling. There are dozens of different drill bit types, each designed for different subsurface drilling conditions. Different rock layers experienced during drilling may require the use of different drill bits to achieve maximum drilling efficiency. It can be a long process to change bits, due to the fact that the whole drill string must be removed; but using the correct drill bit, or replacing a worn bit, can save a great deal of time during drilling. Drill bits are chosen given the underground formations expected to be encountered.

There are four main types of drill bits, each suited for particular conditions.

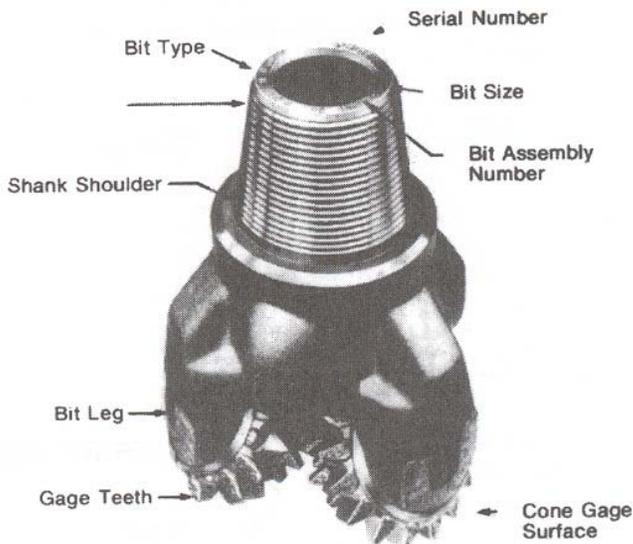
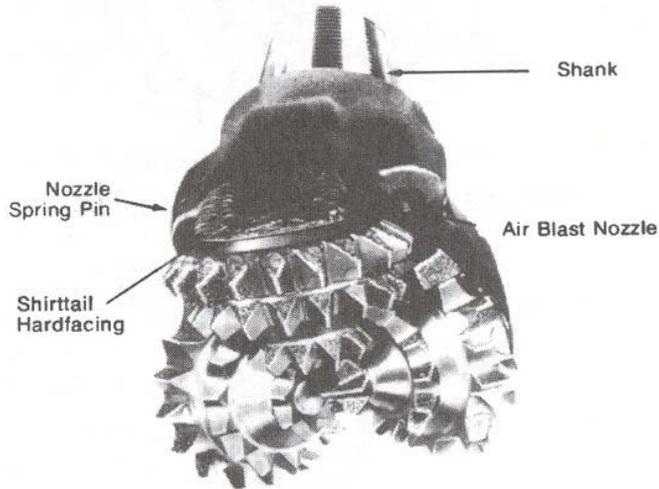
- 1. Blade or Drag Bits forged steel with tungsten carbide cutting surfaces for drilling unconsolidated formations. Also called wing bits or fishtail bits were the first rotary bits. They are available in 3 way or 6 way designs. Their cutting action is through a shearing action on the formation.**



Drag bits with tungsten carbide inserts

- 2. Steel Tooth Rotary Bits, tricone being the most common type. Rock or roller cone bits, as they are often known, were invented in the early 1900's and have evolved over the years. They are the most common drill bit type for all drilling industry sectors. Long tooth roller cone bits are used for soft formations with short toothed bits used for hard formations. The cutting action is through a crushing and chipping action. Tungsten carbide studs are used in place of**

teeth used for particularly abrasive formations like dolomite, granite, chert, basalt, and quartzite.



3. **Polycrystalline Diamond Compact Bits** have polycrystalline diamond inserts attached to the carbide inserts found in Insert Bits. (primarily oil&gas industry)

4. Diamond Bits have industrial diamonds implanted in them, to drill through extremely hard rock formations. Diamond bits are forty to fifty times harder than traditional steel bits, and can thus be used to drill through extremely hard rock without dulling overly quickly.

Bit types 1&2 are most commonly used in the water well drilling industry. Bit type 3, in addition to the oil and gas industry, also has applications in the directional drilling sector. Bit type 4 is used in geophysical drilling for coring applications

Regardless of the drill bit selected continuous cutting removal is essential to rotary drilling. It is an awareness of this fact that lead to the development of alternative means to achieve continuous cuttings removal in all geologic formations. Whatever circulation method chosen, the purpose of fluid circulation is to keep the hole clean and the bit turning freely against the bottom.

4. Circulating System

The final component of rotary drilling consists of the circulating system. There are a number of main objectives of this system, including cooling and lubricating the drill bit, removing debris and cuttings, and coating the walls of the well with a mud type-cake. The circulating system consists of drilling fluid, which is circulated down through the well hole throughout the drilling process. The components of the circulating system include drilling fluid pumps, compressors, related plumbing fixtures, and specialty injectors for the addition of additives to the fluid flow stream.

Basic Rotary Operation

Rotary drilling as opposed to percussion drilling cuts by rotating a bit at the bottom of the hole. In addition to rotation, downward pressure must be exerted and continued as the bit cuts its way through the formation.

Part of the art of rotary drilling is to match the bit type and pull down pressure with the formation and the use of drilling fluids to maintain circulation to keep the hole clear of cuttings and the bit lubricated and cool.

The most common methods of imparting the rotary drive to the bit are:

1. A rotating table which turns the drill string via a kelly bar passing through the table and attached to the top joint of the drill string.

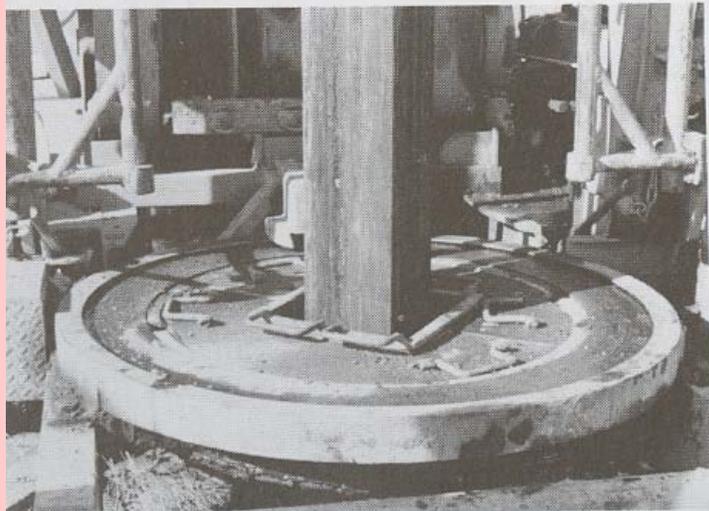
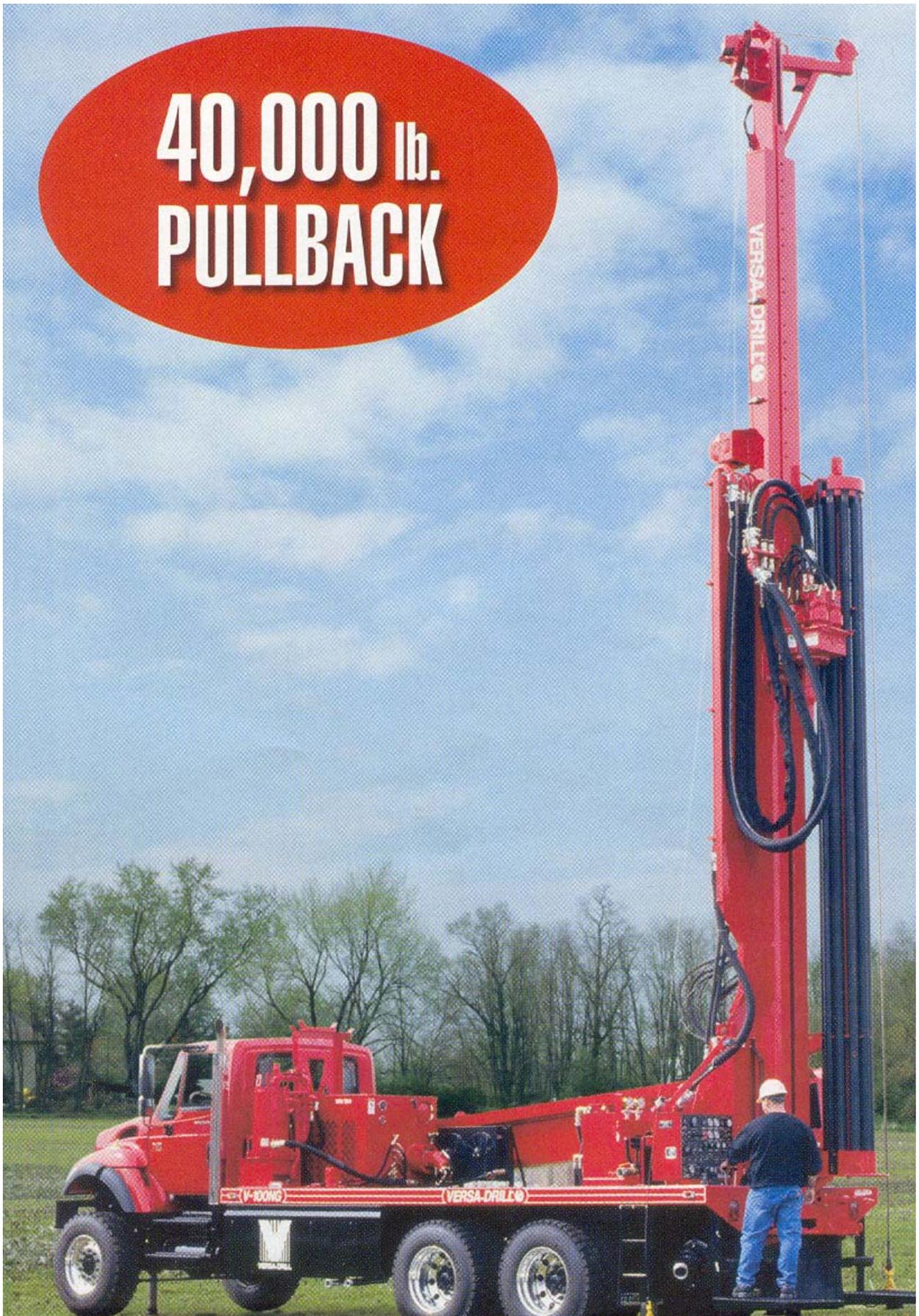


Figure 10.20. A rotary table rotates the kelly, which is connected to the top of the drill string. The kelly can be square, hexagonal, or round with flutes cut into the outer wall. (*Huron Drilling*)

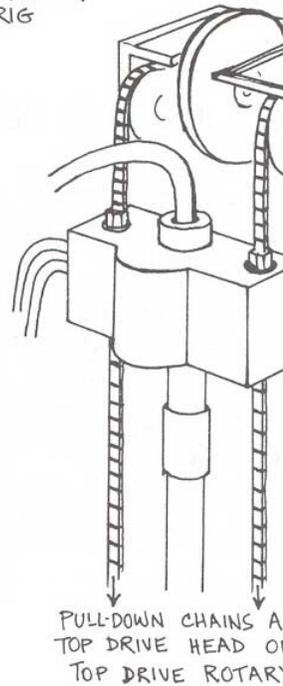
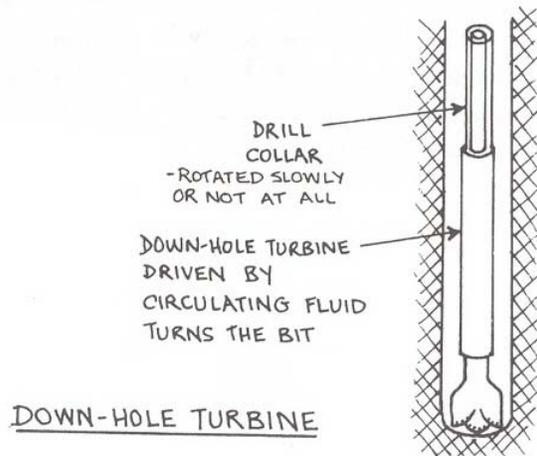
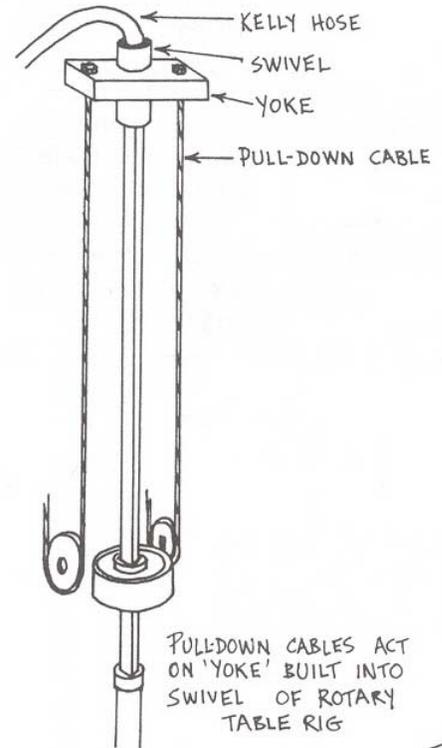
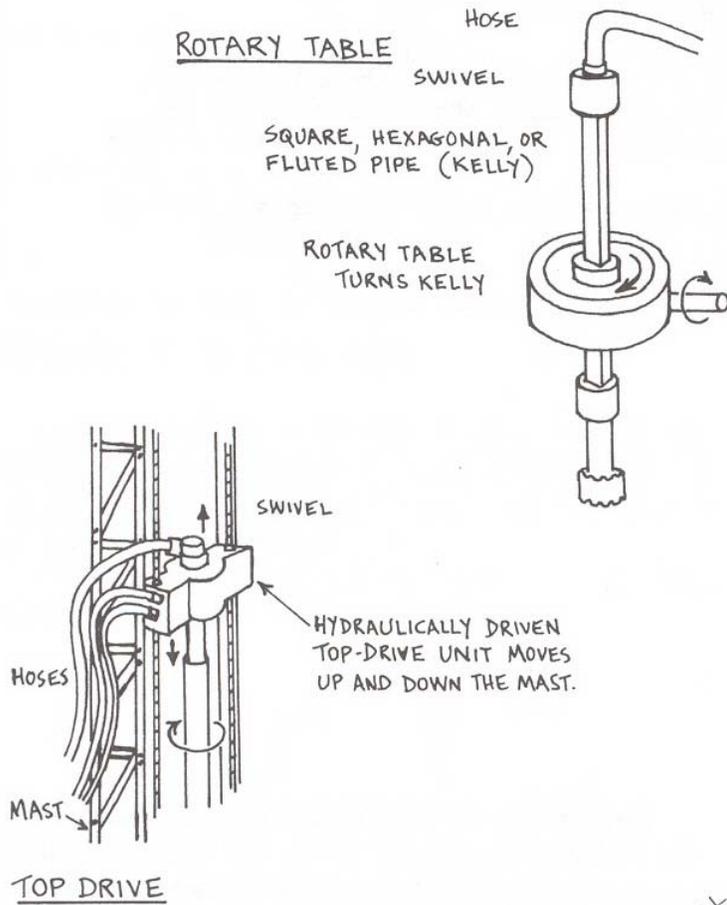
2. Rotating the drill string directly by a hydraulic unit attached directly to the top of the drill string.

**40,000 lb.
PULLBACK**



3. Downhole motors (also called down hole turbines) are widely used in the oil and gas industry, and impart the rotational force directly at the drill bit. The earliest down hole bit driving device was the turbodrill, patented in 1873.

...rotating the bit, using a down-hole turbine drive.



4. Dual rotary rigs which operate upper and lower top head drives impart rotary cutting motion to both the drill bit and casing.

Methods of feeding the bit:

Pull down pressure is that force used to impart downward energy to the drill string.

This force can be created simply by the weight of the drill string including drill collars and stabilizers attached immediately behind the bit. If sufficient weight is attached to the drill string due to the size and depth of the hole, the string weight by itself may provide sufficient downward force on the drill bit to insure continued penetration.

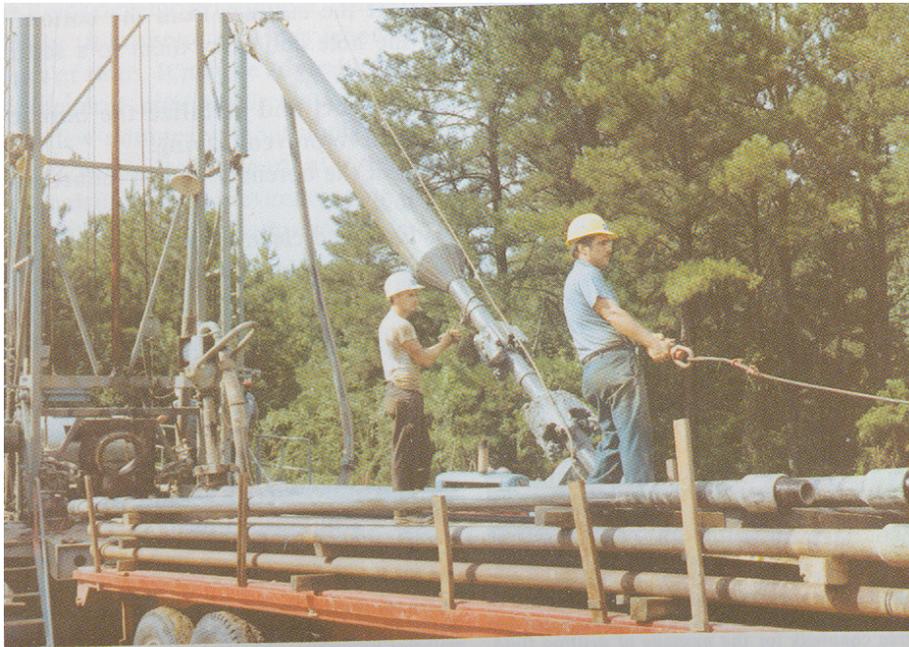


Figure 10.17. Heavy collars added to the drill string above the bit help keep the borehole straight.

When beginning a new hole and often times during drilling operations pull-down pressure from the drill rig is applied. This pull-down force is achieved by a screw, cable, chain arrangement or by hydraulic motors. Hydraulically powered pull-down actions are usually

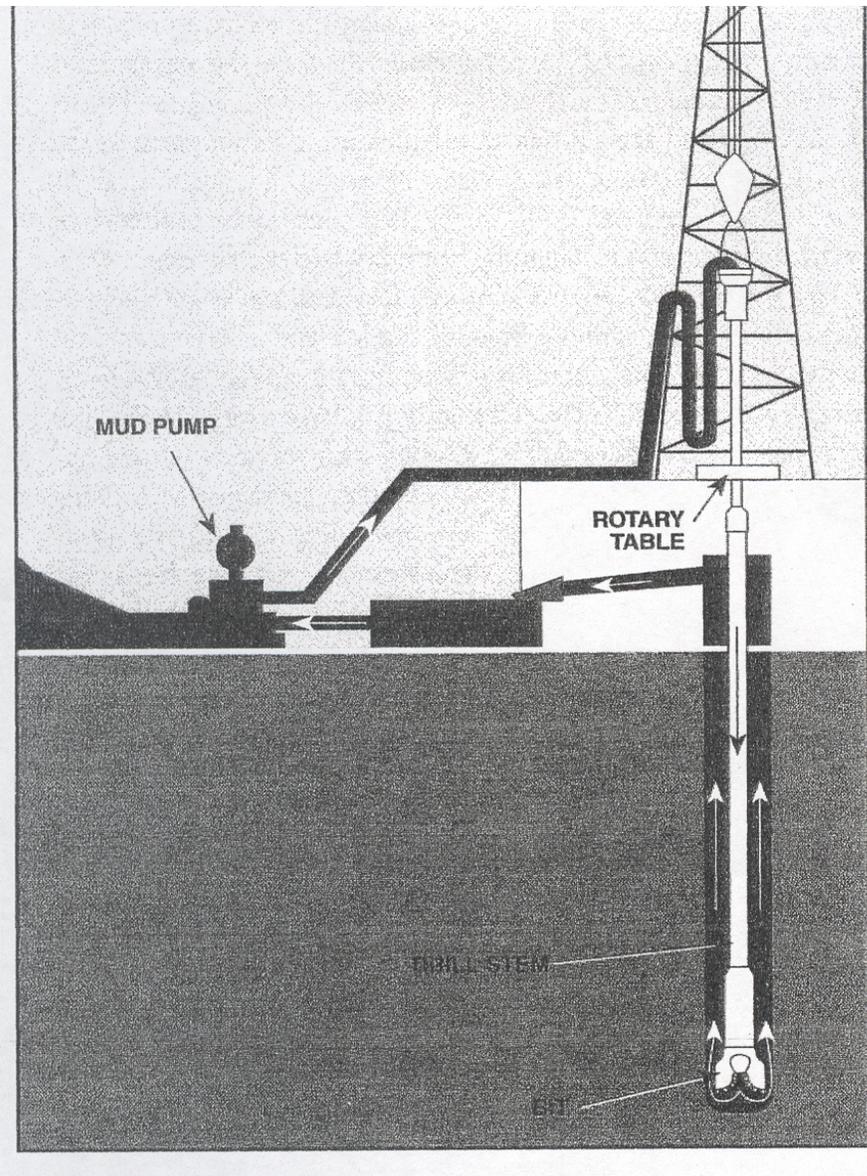
found on more recently manufactured drill rigs, with screw, cable and chain pull down arrangements more commonly found on older rotary rigs.

The driller controls the pull-down pressure and thus the speed of penetration. It must be noted as said in the beginning of this text that part of the art of rotary drilling is the matching of pull-down pressure to the formation. Excessive pull-down pressure can damage drill bits, drill pipe and the trueness of the borehole. Thus applying more pull-down pressure is not always the best drilling practice.

Rotary Fluid Circulation

Rotary drilling requires one of several methods of fluid circulation to clear cuttings from the borehole. Several types of rotary drilling methods are best classified by the type of drilling fluid used, and/or the way in which the fluid is circulated through the borehole.

Direct circulation- Mud Rotary



In direct circulation rotary drilling fluid (water or water with additives-mud) is pumped down the drill pipe and out through the ports or jets in the drill bit. The fluid then flows up the annular space between the hole and the drill pipe carrying cuttings in suspension to the surface.

The drilling fluid, much like the bit, is custom designed and chosen depending on what type of subsurface conditions are expected or experienced. The drilling fluid chosen must have a number of properties to allow it to accomplish its tasks.

It must be light and thin enough to circulate through the drill bit, cooling the bit as it drills as well as lubricating the moving parts. The fluid must be heavy enough to carry drill cuttings away from the bit and back to the surface. In addition, the drilling fluid must be thick enough to coat the borehole with a cake, which serves to temporarily seal the walls of the well until casing can be installed.

In direct circulation drilling the circulating system consists of a starting point, the mud pit, where the drilling fluid ingredients are stored. Mixing takes place at the mud pit or in a drum or mixer used for this purpose. After mixing or the addition of additives the fluid is forced through pumps up to the swivel and down all the way through the drill pipe, emerging through the drill bit itself. From there, the drilling fluid circulates through the bit, picking up debris and drill cuttings, to be circulated back up the well, traveling between the drill string and the walls of the well (also called the 'annular space').

At the surface the fluid is channeled into settling pits or tanks where most of the cuttings settle out. Clean fluid is picked up from the opposite end of the settling area. If portable mud pits are employed, a series of baffles is used to aid in the settling process. The drilling fluid is then re-circulated down the hole. The process is repeated until drilling is completed.

Direct circulation is the most popular of the rotary drilling methods.

The drilling fluids most often used in direct circulation rotary drilling contain clay additives (bentonite) or polymer based additives. A combination of the two additives is also used. Drilling muds remove cuttings while cooling and lubricating the drill bit. The drilling fluid also stabilizes the borehole by the creation of a wall cake. While these 3 functions, cooling, clearing, & stabilizing are essential for successful hole completion, in water well drilling the overuse of additives can make the removal of the drilling fluid residues more difficult during well development.

Reverse mud circulation

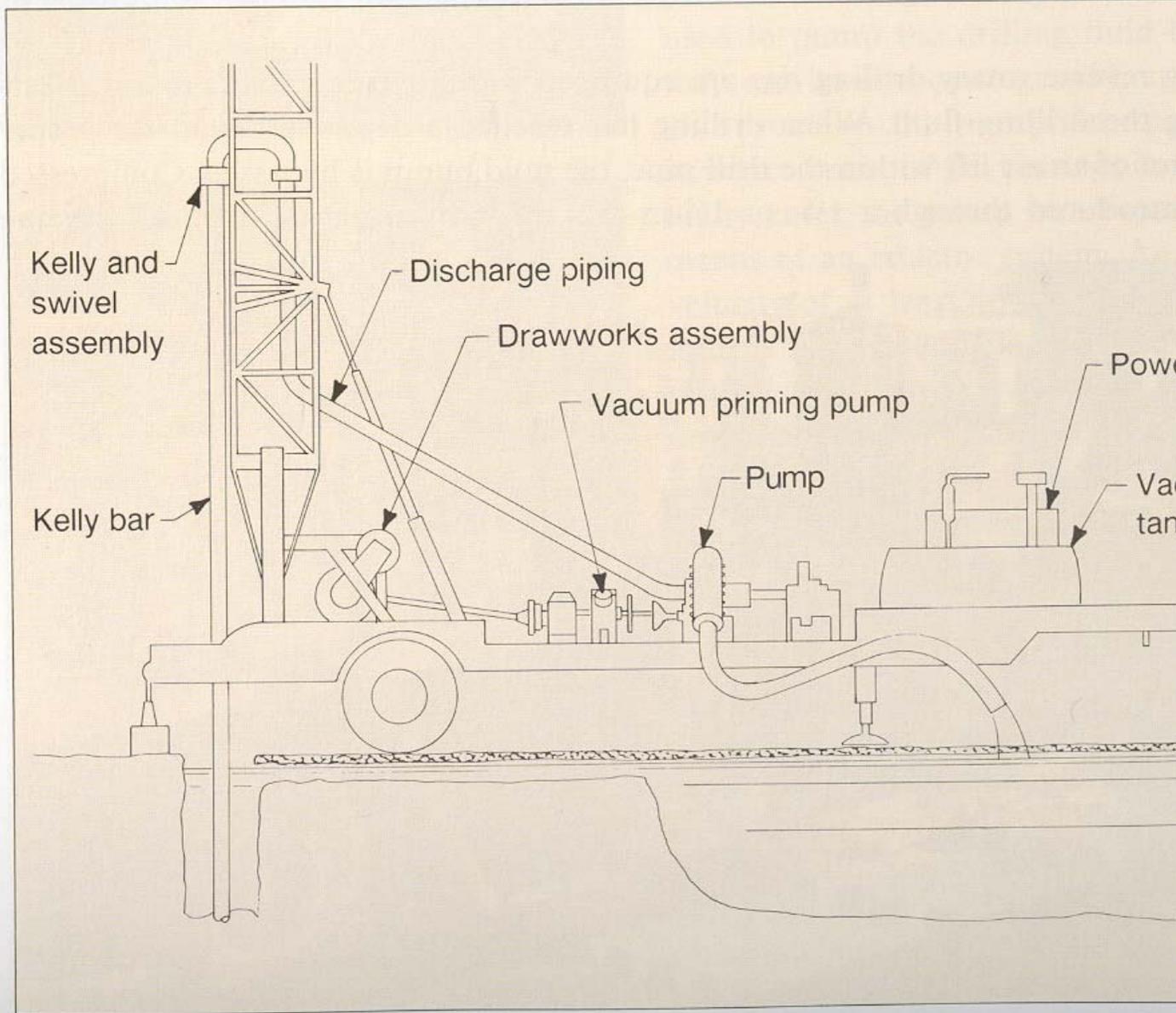


Figure 10.26. In a reverse rotary circulation system, the drilling fluid flows from the mud pit into the borehole outside the drill rods, then passes upward through the bit into the drill rods after the cuttings. After flowing through the swivel and mud pump, it passes into the mud pit where it

Reverse circulation drilling was developed to allow for larger borehole drilling without the limiting factors of drilling fluid pump capacities. Rotary rigs designed for reverse circulation have larger capacity mud pumps and air compressors to allow for increased pressures needed to insure the removal of cuttings from large boreholes. These drill rigs are far larger than those used for domestic purposes. Centrifugal mud pumps

are often used instead of positive displacement because the cuttings will more easily circulate through a centrifugal type pump than through a positive displacement pump.

Reverse circulation rotary drilling is a variant of the mud rotary method in which drilling fluid flows from the mud pit down the borehole outside the drill rods and passes upward through the bit. Cuttings are carried into the drill rods and discharged back into the mud pit.

Reverse circulation requires a lot of water and sediment handling, as the boreholes are large in diameter. Stability of the borehole wall depends on the positive pressure from the fluid in the borehole annulus. If the positive pressure is not sufficient, the borehole wall or parts of it might collapse, trapping the drill string.

In reverse circulation rotary method, the drilling fluid can best be described as muddy water rather than drilling fluid; drilling fluid additives are seldom mixed with the water to make a viscous fluid. Suspended clay and silt that recirculates with the fluid are mostly fine materials picked up from the formations as drilling proceeds. Occasionally, low concentrations of a polymeric drilling fluid additive are used to reduce friction, swelling of water-sensitive clays, and water loss. Since fewer drilling muds are used no wall cake is created and the stabilization by the borehole fluid is needed.

To prevent caving of the hole, the fluid level must be kept at ground level at all times, even when drilling is suspended temporarily, to prevent a loss of hydrostatic pressure in the borehole. The hydrostatic pressure of the water column plus the velocity head of the

downward moving water outside the drill pipe are what support the borehole wall. Erosion of the wall is usually not a problem because velocity in the annular space is low.

A considerable quantity of make up water is usually required and must be immediately available at all times when drilling in permeable sand and gravel. Under these conditions, water loss can increase suddenly, and if this causes the fluid level in the hole to drop significantly below the ground surface, caving usually results. Water loss can be addressed by the addition of clay additives, but this action is only taken as a last resort.

Often to aid the upward movement of water through the drill string, air is injected, lifting the contents to the surface. Another reason to use air is the fact that the suction pump lift is limited in its capacity to create enough vacuum to start up the water movement after a rod change. When air lifting is used to assist in reverse mud drilling this method becomes similar to the reverse air rotary drilling method discussed below.

Reverse mud is a cost effective method for drilling bore holes of 24" and greater. This method is most successful in unconsolidated formations.

Advantages of Reverse Circulation Mud Rotary

- 1. The near-well area of the borehole is relatively undisturbed and uncontaminated with drilling additives and the porosity and permeability of the formation remains close to its original hydrogeologic condition.**

2. Large-diameter holes can be drilled quickly and economically
3. No casing is required during the drilling operation.
4. Well screens can be set easily as part of the casing installation.
5. Most geologic formations can be drilled, with the exception of igneous and metamorphic rocks.
6. Little opportunity exists for washouts in the borehole because of the low velocity of the drilling fluid.

Disadvantages include the following:

1. Large water supply is generally needed.
2. Reverse-rotary rigs and components are large and expensive.
3. Large mud pits are required.
4. Some drill sites are inaccessible because of the rig size.
5. For efficient operation, more personnel are generally required than for other drilling methods.

Direct air rotary drilling (*down the hole hammer drilling discussed in separate section*)

In air rotary drilling, air alone lifts the cuttings from the borehole. A large compressor provides air that is piped to the swivel hose connected to the top of the Kelly or drill pipe. The air, forced down the drill pipe, escapes through small ports at the bottom of the drill bit, thereby lifting the cuttings and cooling the bit. The cuttings are blown out the top of the hole and collect at the surface around the borehole.

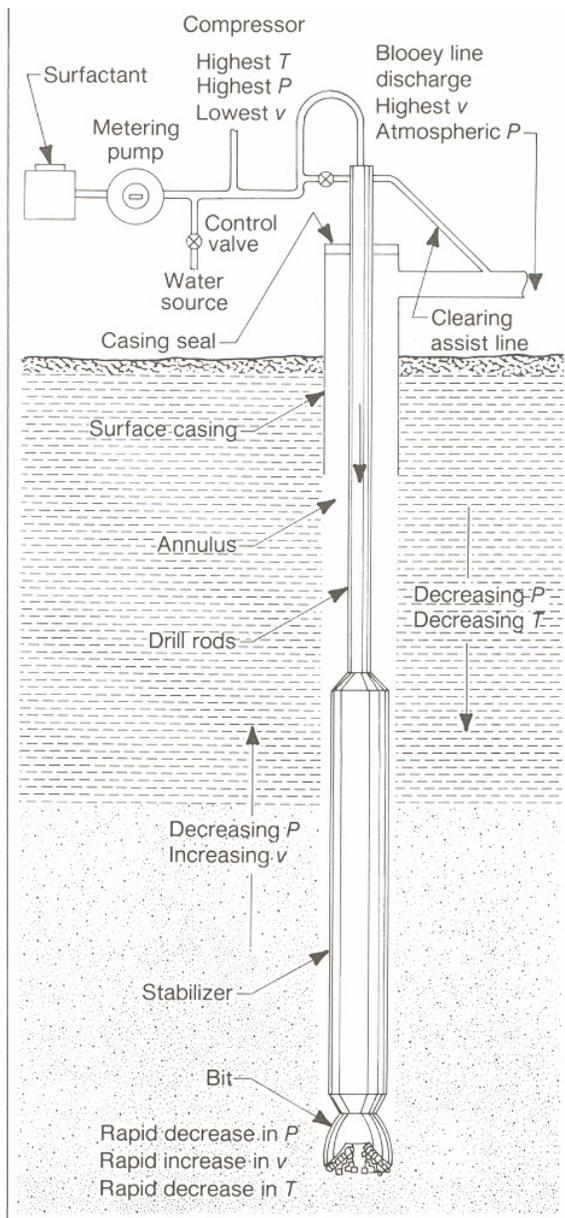


Figure 11.30. Basic components of an operating air rotary circulation system showing the pressure and volume conditions in the drilling fluid at various sites. Greatest pressure and volume changes generally occur at the bit, which is the most critical point in an air drilling-fluid system.

Air is low in density. It is also low in viscosity, having a viscosity approximately 2% that of water. Therefore the up-hole or bailing velocity must be at least 20 times as high as the velocity required when using water. Air drilling has many advantages:

- 1. Good hole cleaning**
- 2. excellent information on what's happening down the hole.**
- 3. immediate indication of water shows with the opportunity to determine quantity and quality of water encountered**
- 4. low pollution risk**
- 5. fast penetration**
- 6. high bit life**
- 7. air is readily available.**

Air drilling can be done only in semi-consolidated or consolidated materials. In rigs equipped with both mud pumps and air-drilling capacity compressors, drillers may switch to air drilling once the consolidated formation is reached.

Additives to the air line create stiff foam and add to the lifting capacity. Drilling with foam has these advantages:

- low density fluid**
- high viscosity gives good cleaning in large diameter holes**
- low air consumption**
- low bailing velocity eliminates erosion of the walls of the hole.**
- foam will build wall stability and inhibit swelling of clays**



Figure 11.34. The liquid-volume fraction determines how the foam looks as it leaves the borehole. If the foam is relatively dry, it collects around the top of the borehole (left). If the LVF tends to run away on the surface of the water brought up the borehole. (*Nelson Well Service Company*)

Roller-type rock bits, similar those designed for drilling with water-based fluid, can be used when drilling with air. Tricone rock bits are commonly used. Button bits are also used successfully. Field test have shown faster penetration rates and longer bit life when using air and compared with water-based drilling fluids.

The path for fluid circulation when drilling using direct rotary air is somewhat the same as for mud rotary drilling:

Air travels from compressor to the Kelly or swivel down the drill pipe through nozzles in the bit and exit along the borehole walls outside the drill pipe.

Drill bit nozzles for air rotary drilling are available in sizes to suit the down-hole conditions, velocity requirements, hole depth and compressor capacity.

Disadvantages of Direct Air Rotary Drilling

- **cost to purchase sufficient capacity compressor**
- **cost of maintenance & repair of compressor**

Reverse air drilling

This method is most successful when drilling in soft sedimentary rock and unconsolidated sand and gravel.

This method requires adequate water to be successful. The air is used to assist in the transport of cuttings up the drill pipe by creating a partial vacuum which helps to draw the water and cuttings in suspension. Both reverse mud and reverse air require larger settling ponds as there is no recirculation of fluid, the water is drawn from the producing zones that have been accessed.



A tremie pipe is inserted inside the drill pipe with a check valve on the bottom of the tremie. Once the formation has produced water reverse air drilling can be begun. As drill rods are added, lengths of tremie pipe are also added until the tremie is submerged more than 20 ft. Air is introduced into the tremie which aerates the column of water within the drill rod. The now aerated column is less heavy than the fluid outside the drill pipe.

An air-assisted lift is created up the drill pipe, drawing cuttings from the borehole through the bit ejecting them at the exit hose attached to the top of the swivel and into the holding pond.

Reverse air drilling is seen as an excellent approach for municipal supply wells. Engineers often specify this method of drilling be used once the water bearing formation is reached because there is little change of contaminants being introduced into the borehole. Also there is less danger of reducing the permeability of the near well area because no drilling fluids are used once reverse air drilling is commenced.

The reverse air method is seldom used in small diameter wells.

Reverse air drilling Advantages

Rapid removal of cuttings

No plugging of the aquifer with drilling fluids

No use of mud pumps during the air drilling stage

Extended bit life

Easier estimates of formation yield

Loss of circulation zones not a factor

Samples easily obtained

Disadvantages of Reverse Air Drilling

Restricted to semi consolidated and well-consolidated materials.

High initial and maintenance costs of compressors

Hole must be producing water

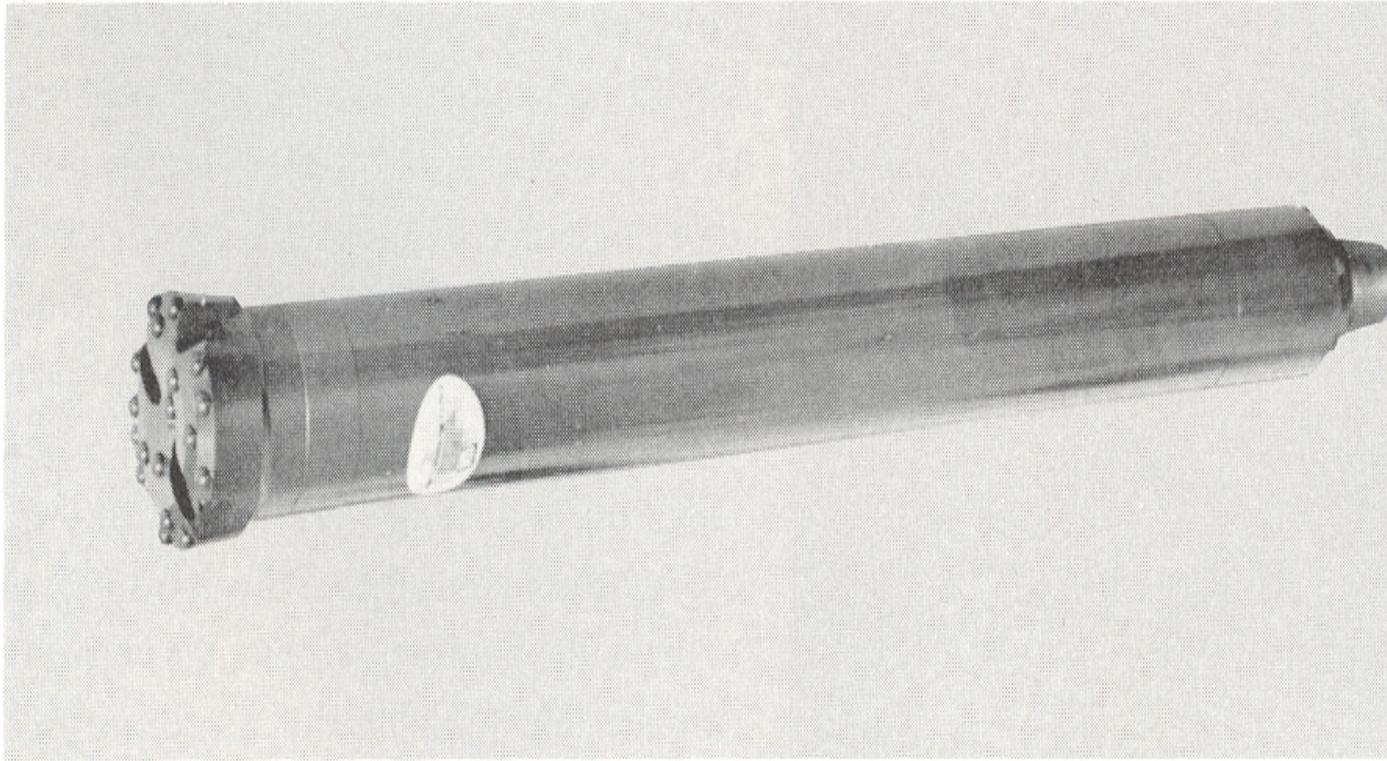
Large settling pit needed

**Extra work required to add and remove tremie line during tripping in and tripping out
slower pace of drilling
plugging of string
broken tremie or dislodged check valve**

Down the hole air hammer

To drill effectively in hard formations, rotary bits require very high pull down pressures. These pressures may be beyond the design capabilities of small to medium drill rigs. And, as was stated earlier, excessive pull down pressures may damage the drill string and deflect the trueness of the hole. If the hard rock formation is near the surface, even larger rigs have trouble with penetration as the weight of the drill string is not relatively great when drilling is beginning.

The down hole hammer is an air activated percussive drilling bit which operates in the manner of the jack hammer commonly seen in surface construction. Constructed from alloy steel with heavy tungsten-carbide inserts that provide the cutting or chipping surfaces. These inserts are subject to wear and may be replaced or reground improve penetration rates. Corrosion (rust) is the DHH's greatest enemy. It must be kept well lubricated at all times. And it should be opened and inspected after every 100 hours of continuous operation.



The DHH rotates to insure uniform penetration. During application the bit face remains in constant contact with the bottom of the formation. Rather the piston arrangement behind the bit face impacts the face repeatedly, fracturing the formation. After each piston stroke air is exhausted from the bit face, clearing cuttings and exiting the cuttings out of the borehole on the outside of the drill pipe. Because of the rapid cuttings removal, the DHH hits a clean surface with each stroke, making its operation far more efficient than the traditional cable tool which strikes through slurry or previously broken cuttings.

Reverse circulation down hole hammers are also available. The return air and cuttings are directed up the center of the hammer when reverse DHH's are used.

Advantages of Down the Hole Hammer

- fastest hard formation penetration method**
- aquifer not tampered with by muds**
- extended bit life**
- cold weather non factor**
- easy yield estimates**
- no mud pumps**

Disadvantages of Down the Hole Hammer

- initial costs of air compressors**
- maintenance and repair costs of compressor and DHH**

Jet Drilling

Drilling in unconsolidated formation with high water availability allows jet drilling to be a viable drilling method. Often employed in drilling shallow irrigation wells, jet drilling is achieved by water circulation down through the rods washing cuttings from in front of the bit. The cutting flow up the annular space and in a settling pit so that the water can be recirculated.

Jetting in semi consolidated formations may be assisted by using a hammering technique to “chop” through hard bands. This technique is a combination of jetting and percussion. A fish-tail type rotary bit may be used and the pipe rotated to “cut the hole. All hydraulic (water based) drilling requires that the hole be kept full off water until it is cased.

A variation of the jetting method is the wash down method where the wash pipe is inserted within the well screen in an arrangement whereby water under pressure is pumped through the wash pipe at the bottom of the screen. The jetting action allows the screen to sink to the desired location without any predrilling.

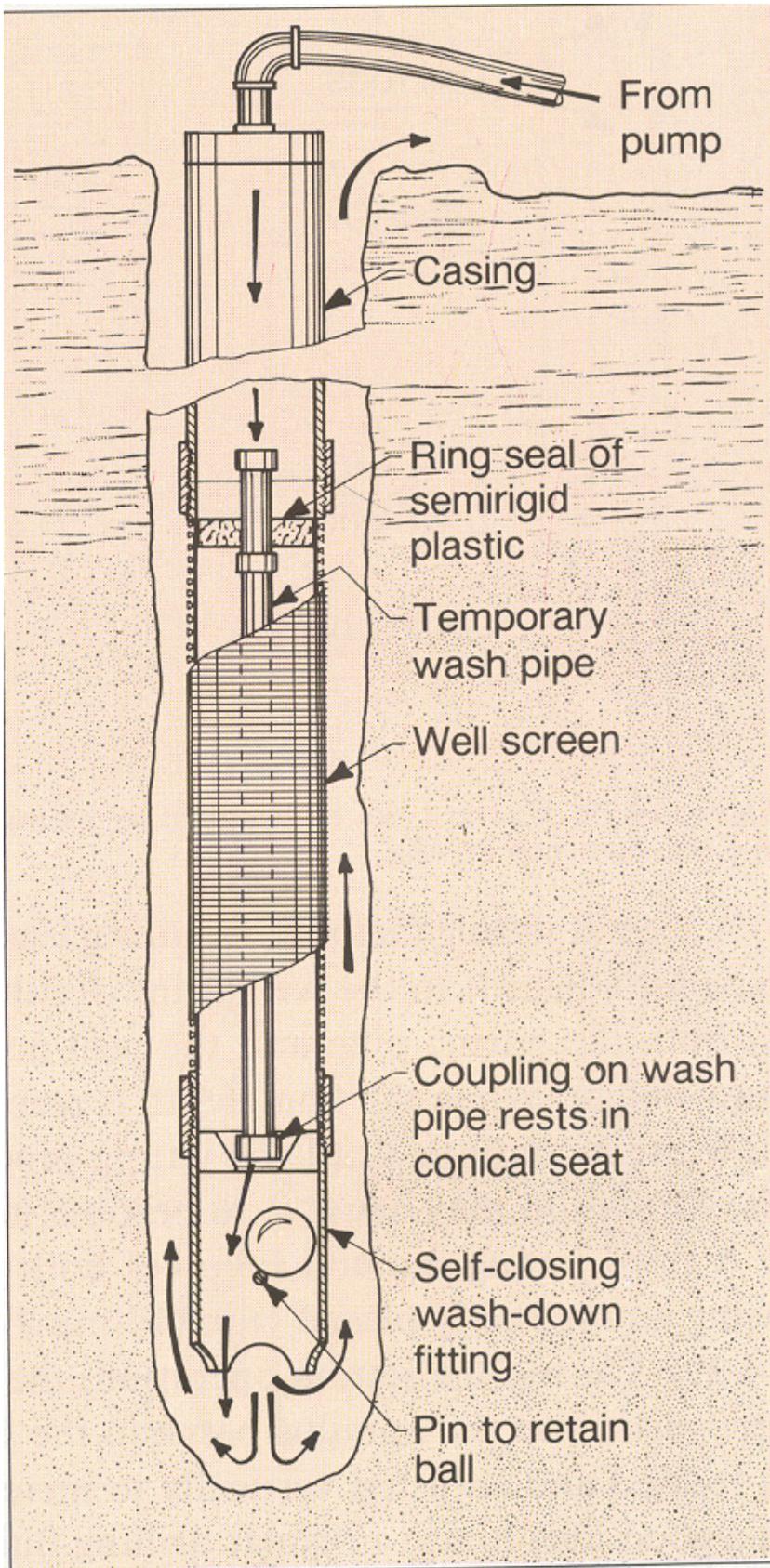


Figure 14.28. Small-diameter screens can be washed into place by jetting through a wash pipe and wash-down bottom with floating-ball valve.

Wells have been jetted to depths of 1000 feet and drillers have used jetting or washing techniques to place screens in completed boreholes to insure placement at the precise level desired.

END OF TEXT