Technical Area: 3 Drilling Drawbacks

Item: 3-1 Countermeasures against lost circulation during mud drilling

1: Objectives
To be able to explain and advise for how to prevent from lost circulation and countermeasures against it during mud drilling.

2. Contents
- Phenomenan of lost circulation
- countermeasure against lost circulation

3. Teaching Methods
(1) Explain phenmenan of lost circulation and lost circulation formation.
(2) Explain how to remedy for circulation loss.

4. Materials
3-1M1 Drilling Chap. 6 P218-219

Oil water emulsion:

2 to 4 L(1/2-1 gal) soluble oil in 100 L(25 US gal) water.
(Some milky type oils require only 1 to 2 Litres of oil in 1000 L or 250 US gal water.)

Section 5 Overcoming lost circulation using muds

- Lost circulation formations
- Remedies for circulation loss

Lost circulation is one of the more serious problems that can arise during drilling. Circulation is said to be lost when the mud flows into surrounding formations instead of returning up the annulus. This may be due to natural fissures or fractures in the formation, porous sands or gravels, or cavernous limestones. Fractures induced by excessive hydrostatic pressure in the hole can also cause lost circulation.

Lost circulation formations

These are permeable or porous formations which allow flow from the drill hole.

Loss of circulation into natural permeability usually occurs at or near the bit as the formation is drilled. If a total circulation loss does not occur immediately, the loss is likely to increase as a longer section of permeability is opened up.

Circulation loss into fractures created by hydraulic pressure occurs quite often. It can follow the penetration of a low strength formation or the accidental over-pressuring of a formation during drilling operations.

Sometimes a formation may be fractured as the mud density is increased to control high pressure in another formation. Circulation loss is likely to be followed by drill string sticking. (Refer to Chapter 12)

The string should be hoisted well clear of the bottom immediately upon any indication of circulation loss.

Remedies for circulation loss

There are five possible courses of action to take when mud circulation is lost.

1. Wait, to allow mud to gel in the formation.
2. Add circulation loss materials to block the formation permeability.
3. Drill on without return circulation.
4. Gunk squeeze, cement, or case.
5. Circulate low density fluids - air or foam.

In formations where the fluid loss is through permeability, consisting of fine cracks or intergranular spaces, the colloidal material in the drilling fluid will plug the permeability.

If drilling has been proceeding with a high colloid content in the fluid, the best initial action possible is to wait. A waiting period may allow the fluid to gel in the formation and provide a seal sufficient to allow circulation to be restored.

When extremely unstable formations or those containing open fractures, joints or caverns are encountered, stronger measures are necessary if the loss is to be overcome.

A variety of lost circulation materials can be added to the mud.

Commercial additives include fine flakes of paper or mica. These specially prepared flakes do not hinder the normal mud circulation functions, but when the mud carries these materials into small openings in the walls of the hole, the flakes wad up to block the opening.

Bridging agents, comprising fibrous or large flakes of material, are available for use when larger openings are encountered.

In order to provide the bridge, very fine sized material as well as coarser material is required. The coarser material establishes an initial bridge by lodging in the formation, and the finer sized materials are responsible for reducing the opening down to the point where the mud particles can form a filter cake.

It is important that the bridging agents used should be sized so that bridging and sealing take place within the formation, and not on the face of the hole, where it will be dislodged by the down hole equipment. It follows then, that coarser materials are required to bridge large fractures, while finer materials are adequate for bridging smaller openings. A high viscosity bentonite mud, containing a small percentage of fine mica, will seal most porous sands or gravel beds.

When a polymer drilling fluid is used as the circulating medium, it is important to remember that such systems contain no solids or wall building materials. When drilling porous and permeable formations with a polymer system, water loss control is almost completely a function of the viscosity of the system. Loss of fluid to permeable formations other than to voids, caverns or large fractures can be effectively controlled by raising the viscosity. Losses due to large cracks and fissures in the formation necessitate the addition of lost circulation bridging agents and bentonite, in order to effect a seal.

If a lost circulation zone is encountered unexpectedly and a driller has no commercial lost circulation material on hand, he may improvise.

Almost any granular flake or fibrous material can be used to provide a wad to block a lost circulation zone.

Local supplies of materials usually can be located readily such as:

- bran, husks, chaff or straw
- bark or wood chips
- cotton, feathers or even bedding, including fibre or wool matresses.

Large fractures are the most difficult to bridge, because the restrictions imposed by the water ways of the bit limit the size of the lost circulation material which can be used. Therefore, when large fractures are responsible for lost returns, alternative materials and techniques must be adopted.

Gunk squeeze

The gunk squeeze is a method of sealing off a zone of lost circulation by spotting a large amount of clay in the zone and forcing it into the formation, where it swells or hydrates and fills up any cracks or crevices.

A very high concentration, (6 - 7 kg/L or 50-60 lbs/gal), of bentonite, is mixed with diesel oil. The clay will not swell while in the diesel but will remain in its original state.

The gunk mixture may be lowered into the hole, in a sealed bag or container which can be ruptured when opposite the lost circulation zone. Alternatively, the"gunk" can be circulated into position, keeping it isolated from water by slugs of diesel fuel, before and after the gunk.

The material is forced by pressure into the formation. At the same time, it comes into contact with the water in the mud, or, with water pumped down the annulus. This water causes the clay to swell after it penetrates the formation. This swelling continues for a number of hours and seals off the zone restoring circulation.

When the material comes into contact with water in the hole, it thickens considerably in a short period of time (5 minutes). However, since it is being forced into the lost circulation zone, it should not cause any serious pumping problems.

Rather than bentonite, diamond drillers often use a biodegradable polymer as the base for a gunk mixture. When mixed with water (in quantities much greater than for a standard mud mix), the powdered polymer forms a thick jelly-like material which is poured directly into the hole. The hole is then pressurised to force the gunk mixture into the lost circulation zone.

Note: Drillers should never use chemical pollutants such as oil or organic matter in a borehole, where contamination of potable aquifers is likely. Local regulations may absolutely forbid there use.

Other solutions

If the lost circulation zone cannot be blocked or if the insertion of lost circulation material is undesirable, drilling sometimes may proceed without return circulation. The cuttings are carried away into the formation cavities. It may be necessary to occasionally pump a slug of viscous mud to clear the bottom of the hole.

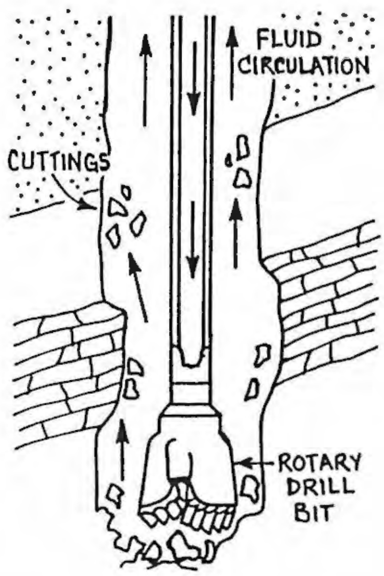
While"dense" fluids such as mud or water may be lost, lighter fluids such as foams may allow return circulation to be achieved.

Failing all these possible solutions to lost circulation problems, casing can be placed to seal off the problem zone.

Section 6 Rotary and down-hole hammer drilling

- Rotary mud-circulation drilling
- Muds for shallow rotary drilling
- Drilling into artesian pressure
- Mud mixtures for sub-artesian drilling
- Rotary drilling with air circulation (RAB)
- Air circulation in wet holes
- Mist and aerated fluids
- Air-lift and stiff foams
- High pressure air
- Casing in rotary holes

Rotary mud-circulation drilling



We talk about this type of drilling as being:

1. **Rotary**
2. **Mud-Circulation**
3. **Drilling**

The order of procedure when working in a mud filled hol is:

1. Start the rotation

Rotating the pipe slowly breaks the gel of the mud ar allows for lower circulation pressures.

2. Start the mud pump

The circulation cleans the hole and the bottom of tl hole as the bit is lowered.

Technical Area: 3 Drilling Drawbacks
Item: 3-2 Countermeasures against lost circulation during DTH drilling

1: Objectives To be able to explain and advise for how to prevent from lost circulation and countermeasures against it during DTH drilling.
2. Contents - Phenomenan of lost circulation - countermeasure against lost circulation
3. Teaching Methods (1) Explain phenmenan of lost circulation and lost circulation formation. (2) Explain how to remedy for circulation loss.
4. Materials See 3-1M1

Technical Area: 3 Drilling Drawbacks

Item: 3-3 Countermeasures against bore wall collapse during mud drilling

1: Objectives

To be able to explain and advise for how to prevent from bore wall collapse and countermeasures against it during mud drilling.

2. Contents

- Prevention of bore wall collapse
- countermeasure against borehole collapse

3. Teaching Methods

(1) Explain phenomenan of borehole collapse.
(2)Explain the measures for stabilization of bore wall.

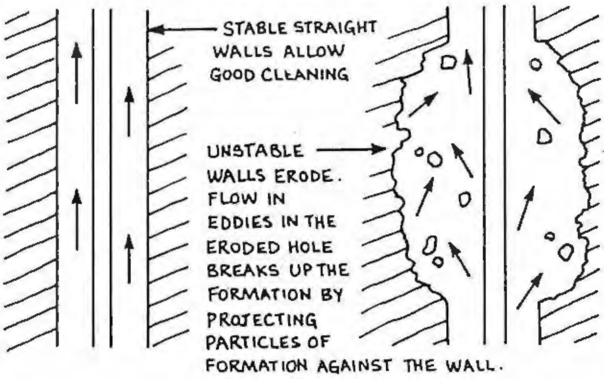
4. Materials

3-3M1 Drilling Chap. 6 P215-P218

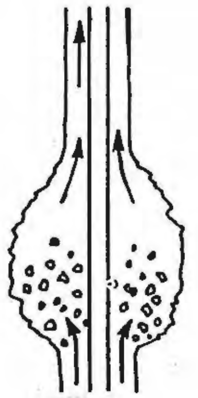
Many things can go wrong with the formation of the gel and the cake. Experience in examining filter cakes formed during filtration tests shows how soft and ineffective as a seal poor filter cakes can be.

The filter-press cake is formed under static conditions. Formation of a satisfactory stabilising gel and cake in a flowing mud stream is more difficult.

Stabilisation makes the hole itself secure. Lack of stability, once developed, gets worse when the fluid is flowing.



The lower flow velocity in the enlarged hole, allows cuttings to"drop out" and accumulate. When flow is stopped, the accumulated cuttings drop down the hole, causing the drill string to become stuck.

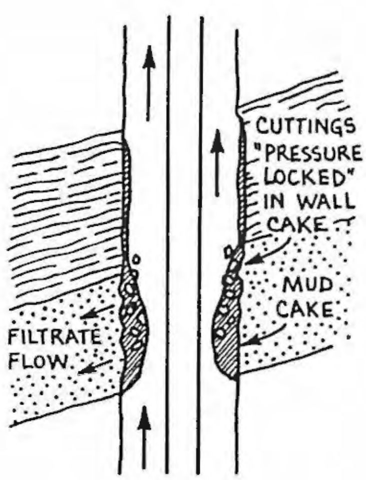


Pressure in a circulating fluid

1. Over-balance pressure

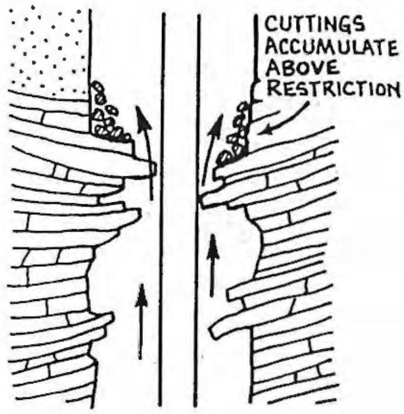
The desirable overbalance pressure causes flow into permeable formations. Poor quality fluids form thick mud cakes which"trap" cuttings.

The hole pressure holds the cuttings in the wall cake. More cuttings accumulate where the flow velocity drops above the restriction.



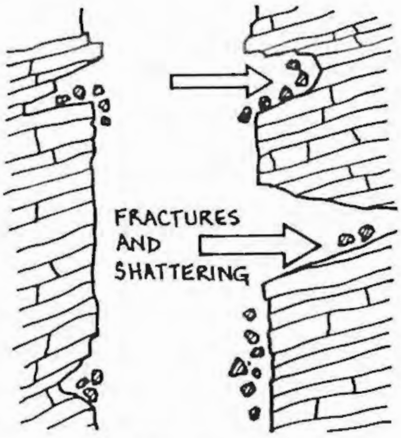
2. Under-balance pressure

Under-balance allows plastic formations to be sque into the hole. The"tight" hole interferes with cleaning. I cause high circulation pressures lower in the hole.



3. Pressure surges

The most severe pressure surges come from drilling and bailer movements. Dropping the tools causes a pressure surge. Lifting the tools causes a low pressure su High pressure surges also come from starting the pum building up pressure too quickly.

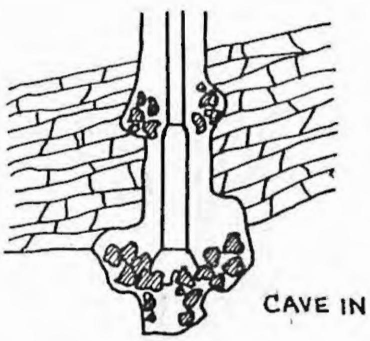


HIGH PRESSURE SURGES CAUSE FORMATION SHATTERING AND FLUID LOSS.

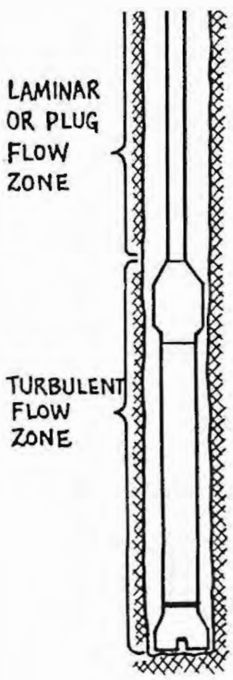
Low pressure surges come from sudden drops in the fluid level in the hole.

Turbulent flow will exist all the way up a diamond drill hole, but in a standard rotary hole, turbulence is unusual except near the bit and drill collar.

Avoid high up-hole velocities when drilling or reaming with the turbulent flow zone in an unstable part of the hole.



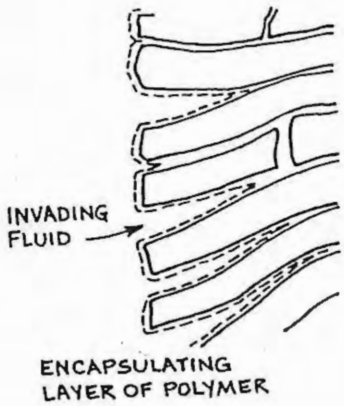
LOW PRESSURE SURGES CAUSE FLUID INFLOWS AND CAVE-INS.



Stability in a circulated hole

Control over the wall building properties of the drilling fluid must be exercised carefully when the hole is being cleaned by circulation. Turbulent flow, in particular, will dislodge and flush away any pieces of poor quality filter cake. Without the protection of the filter cake, the walls of the hole will be eroded.

When the protection of the filter cake is continually being eroded by the mud flow, sensitive formations require special protection. Shales and clays must be protected against"invasion". The invading fluid gets in between the layers of the formation, hydrating the shale and causing it to"flake off".



Some polymer muds provide a protective colloidal coating which seals off the microscopic cracks. Unsealed cracks allow water into the shale or clay. The coating, or **encapsulation** layer, made up of polymer molecules, is also formed around cuttings from shale or clay formations. Encapsulation of chips prevents them from breaking up and mixing into the mud. They reach the surface and collect in the sampling pits.

Maintaining correct hole size

Many points raised in previous pages could be seen as recommendations in favour of keeping the hole to its right size.

A hole of uniform size with external flush pipe turning in it, will be cleaned by a constant velocity mud flow. Steady continuous cleaning is the aim.

Preventing hole reduction by formation swelling

The formation must be held by pressure and prevented from hydrating. Weighted fluids are used to balance formation pressures.

Low water loss fluids or encapsulating fluids in combination with salt water mud inhibit hydration.

For "trol" type polmeric compound muds:

Mix the polymer in fresh water, 8 kg (7lbs) polymer to 1000 L (100 US gals) water. Add salt to bring S.G. to 1.15. Use 200 kg (170 lbs) salt to 1000 L (100 US gal) water.

Preventing hole enlargement by erosion of unconsolidated formations

Fluids of high gel strength will effectively bond and hold unconsolidated materials provided that any clays present do not soften and break up. A thin tough filter cake built over the formation assists stability.

Pressure against the filter cake must be kept exactly constant. Any change in pressure will"surge" the gelled material and cause it to collapse into the hole.

Bentonite base mud:

In 1000 L(100 US gals) of fresh water mix 25kg (20 lbs) of high yield bentonite. Hydrate for 12 hours.

Polymer base mud:

In 1000 L(100 US gals) of water mix 3kg (2 1/2 lbs) of "trol" type polymer. To provide tight wall cake first hydrate, then mix in 20 kg (18 lbs) high yield bentonite.

Stability and lubrication

Steady movement of the pipes and rods as well as steady lifting of cuttings, are components of stability. When cuttings become"balled up" or if drilling is too fast and cuttings"overload" the annulus, stability is likely to be lost.

Rods moving unevenly or vibrating in the hole, will cause shock waves in the fluid, leading to loss of wall stability. A fluid which provides good lubrication, will assist stability as well as assisting hole making. Where stability and lubrication are required, polymer-oil muds are used.

A typical polymer-oil mud:
In 1000 L (100 US gal) of fresh water
Mix: 5 kg (4lbs) "trol" type organic polymer
20 litres (5 US gal) of soluble oil
100 litres (25 US gal) diesel fuel
Stir until oil is emulsified.

NOTE: In some places, the use of diesel or other oils in muds may be prohibited. Check with the local Authorities before using any mud system contaning oil.

Lubrication, without any need for hole stabilisation, is often required in diamond drill holes where lubrication contributes to movement of the core into the barrel as well as rod stability.

Oil-in-water emulsions have been shown to provide:

1. increased drilling rate.
2. longer bit life (up to 10 times).

Where combined with a polymer and some clay solids, emulsion muds provide tough, low permeability filter cakes.

Oil-water emulsion drilling fluids are prepared using soluble oils. For additional lubrication, particles of grease can be mixed into the fluid.

Oil water emulsion:

2 to 4 L(1/2-1 gal) soluble oil in 100 L(25 US gal) water.
(Some milky type oils require only 1 to 2 Litres of oil in 1000 L or 250 US gal water.)

Section 5 Overcoming lost circulation using muds

- Lost circulation formations
- Remedies for circulation loss

Lost circulation is one of the more serious problems that can arise during drilling. Circulation is said to be lost when the mud flows into surrounding formations instead of returning up the annulus. This may be due to natural fissures or fractures in the formation, porous sands or gravels, or cavernous limestones. Fractures induced by excessive hydrostatic pressure in the hole can also cause lost circulation.

Lost circulation formations

These are permeable or porous formations which allow flow from the drill hole.

Loss of circulation into natural permeability usually occurs at or near the bit as the formation is drilled. If a total circulation loss does not occur immediately, the loss is likely to increase as a longer section of permeability is opened up.

Circulation loss into fractures created by hydraulic pressure occurs quite often. It can follow the penetration of a low strength formation or the accidental over-pressuring of a formation during drilling operations.

Sometimes a formation may be fractured as the mud density is increased to control high pressure in another formation. Circulation loss is likely to be followed by drill string sticking. (Refer to Chapter 12)

The string should be hoisted well clear of the bottom immediately upon any indication of circulation loss.

Remedies for circulation loss

There are five possible courses of action to take when mud circulation is lost.

1. Wait, to allow mud to gel in the formation.
2. Add circulation loss materials to block the formation permeability.
3. Drill on without return circulation.
4. Gunk squeeze, cement, or case.
5. Circulate low density fluids - air or foam.

In formations where the fluid loss is through permeability, consisting of fine cracks or intergranular spaces, the colloidal material in the drilling fluid will plug the permeability.

If drilling has been proceeding with a high colloid content in the fluid, the best initial action possible is to wait. A waiting period may allow the fluid to gel in the formation and provide a seal sufficient to allow circulation to be restored.

When extremely unstable formations or those containing open fractures, joints or caverns are encountered, stronger measures are necessary if the loss is to be overcome.

A variety of lost circulation materials can be added to the mud.

Commercial additives include fine flakes of paper or mica. These specially prepared flakes do not hinder the normal mud circulation functions, but when the mud carries these materials into small openings in the walls of the hole, the flakes wad up to block the opening.

Bridging agents, comprising fibrous or large flakes of material, are available for use when larger openings are encountered.

In order to provide the bridge, very fine sized material as well as coarser material is required. The coarser material establishes an initial bridge by lodging in the formation, and the finer sized materials are responsible for reducing the opening down to the point where the mud particles can form a filter cake.

It is important that the bridging agents used should be sized so that bridging and sealing take place within the formation, and not on the face of the hole, where it will be dislodged by the down hole equipment. It follows then, that coarser materials are required to bridge large fractures, while finer materials are adequate for bridging smaller openings. A high viscosity bentonite mud, containing a small percentage of fine mica, will seal most porous sands or gravel beds.

When a polymer drilling fluid is used as the circulating medium, it is important to remember that such systems contain no solids or wall building materials. When drilling porous and permeable formations with a polymer system, water loss control is almost completely a function of the viscosity of the system. Loss of fluid to permeable formations other than to voids, caverns or large fractures can be effectively controlled by raising the viscosity. Losses due to large cracks and fissures in the formation necessitate the addition of lost circulation bridging agents and bentonite, in order to effect a seal.

If a lost circulation zone is encountered unexpectedly and a driller has no commercial lost circulation material on hand, he may improvise.

Almost any granular flake or fibrous material can be used to provide a wad to block a lost circulation zone.

Local supplies of materials usually can be located readily such as:

- bran, husks, chaff or straw
- bark or wood chips
- cotton, feathers or even bedding, including fibre or wool matresses.

Large fractures are the most difficult to bridge, because the restrictions imposed by the water ways of the bit limit the size of the lost circulation material which can be used. Therefore, when large fractures are responsible for lost returns, alternative materials and techniques must be adopted.

Technical Area: 3 Drilling Drawbacks

Item: 3-4 Countermeasures against bore wall collapse during DTH drilling

1: Objectives
To be able to explain and advise for how to prevent from bore wall collapse and countermeasures against it during DTH drilling.

2. Contents
- Prevention of bore wall collapse
- countermeasure against borehole collapse

3. Teaching Methods
(1) Explain phenomenan of borehole collapse.
(2)Explain the measures for stabilization of bore wall.

4. Materials
See 3-3M1

Technical Area: 3 Drilling Drawbacks

Item: 3-5 Countermeasures against jamming of drilling tools

1: Objectives
To be able to explain and advise for how to prevent from jamming of drilling tools and countermeasures to recover it.

2. Contents
-Prevention of jamming
- Countermeasure against jamming

3. Teaching Methods
(1) Explain causes of jamming such as colllapse, key seasts, under gauge, dog-leg etc. using manual.
(2) Explain countermeasure against jamming.

4. Materials
3-5M1 Drilling Chap. 12 P514-517

Overcoming downhole problems

The problems in deep hole drilling occur because:

- small mistakes bring disaster.
- larger forces are involved.
- the hole is open longer.
- long drill strings are subject to vibration and have many joints.
- hole stability is more critical.
- direction control is difficult as well as critical.
- cuttings take longer to clear.
- small difficulties quickly become problems which take a long time to remedy.

Drillers have more worries. There is more at stake and drillers must be able to think further ahead. If problems are to be avoided, their **inspections** must be more thorough and they must know what to look for. Long periods of heavy loading require more robust machinery, drill strings and bits.

Section 3 Key seats and differential sticking

- Causes of stuck pipe/rods
- Differential pressure sticking
- Key seat sticking
- Recovering stuck pipe

Causes of stuck pipe/rods

Getting the drilling tools or the drill rods or pipe stuck in the hole is a fear which most drillers share. Getting stuck leads to much lost drilling time while efforts are made to free the stuck tools. The forces exerted can lead to drill string failures. The problem then becomes more complex with a "stuck fish" in the hole.

Often the driller is warned of impending sticking by:

(a) increasing drag as the drill string is raised or lowered, or
(b) increasing torque, or
(c) vibration during drilling.

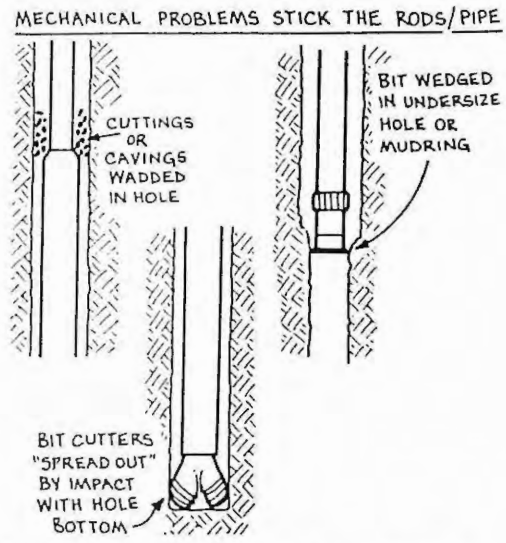
These increases in resistance to movement of the drill string are **indicators** of a developing problem. Stuck tools surely represent a problem, but, in fact, they too are an **indicator** or a result of the real downhole problem. The real problem to be solved is the deterioration in the desired shape, cleanliness or stability of the hole.

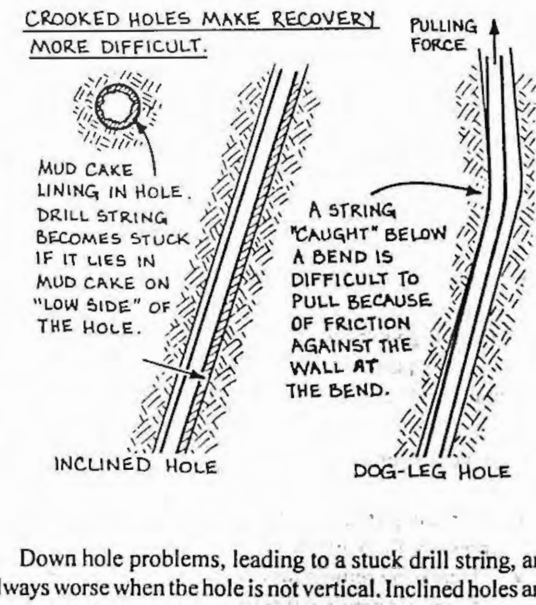
Downhole problems which can result in stuck tools fall into two groups:

1. **Fluid problems:** The wall cake building characteristics of the drilling fluid can allow thick sticky wall cakes to build up.
   Hydrostatic pressures may act to hold the tools in the wall cake.

2. **Mechanical problems:** There are many ways of forming a mechanical bind between the walls of the hole and the drill string:

- Pulling into a **key-seat** which has formed in a dog-leg in the hole.
- Cuttings or cavings building up a solid "wad" around the string.
- Problem formations swelling or otherwise moving into the hole.
- Running the tools into an undersized hole.
- Running the tools into the bottom of the hole, or into a ledge, and distorting the tools.
- Cementing the drill string.
- "Burning in" a diamond bit.





Down hole problems, leading to a stuck drill string, are always worse when tbe hole is not vertical. Inclined holes are more likely to suffer from casing failures. In an inclined hole, the drill rods may lie along the bottom of the hole. They will be pressed into any mud cake covering the wall of the hole.

Overcoming downhole problems

Crooked or dog-legged holes are the most likely to cause problems. The risk increases with the severity of the dog-leg. When drilling in "crooked hole country", a driller may have to be resigned to having some bends in the hole. He should concentrate on reducing the curvature and avoid sharp bends or dog-legs

Good drilling practices, frequent mud testing and treatment, and close monitoring of the cuttings and fluid return will allow the driller to recognise early **indicators** of down-hole problems. The driller is then in a position to prevent the problems developing or he's able to solve them quickly, before the drill string becomes stuck.

Differential pressure sticking

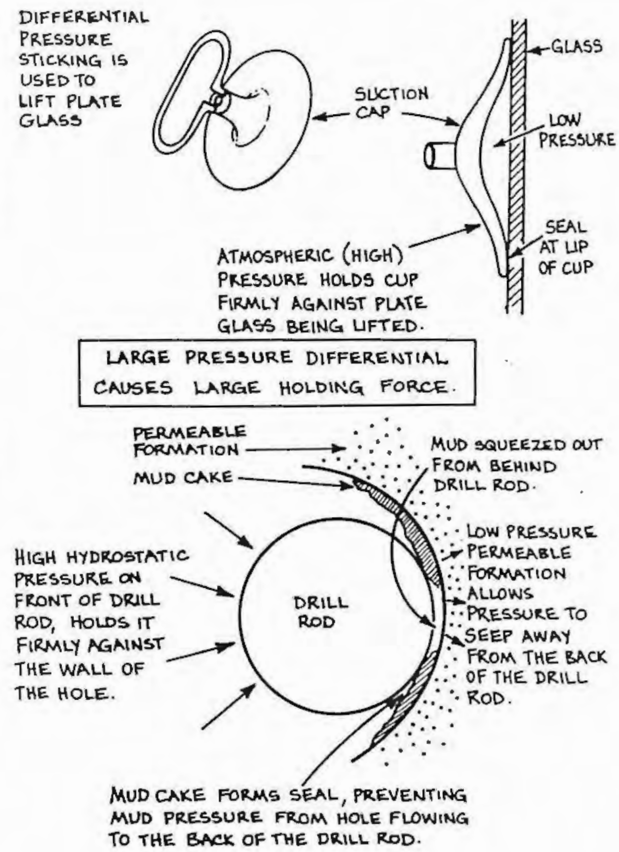
There are two major downhole problems which cause the drilling tools "to stick". The first of these is differential pressure sticking. It occurs when collars, pipe or rods are held against the wall of the hole by hydrostatic pressure.

Causes of differential stick

Differential pressure stick occurs under the following conditions:

1. When the hydrostatic pressure in the hole is greater than the formation pore pressure.
2. When the formation is permeable.
3. When a thick, poor quality filter cake has been built up over the permeable formation as a result of a slow, continuing mud filtrate loss.
4. When the rod, pipe or casing is allowed to lie stationary for several minutes against the wall of the hole.

When tools are held by differential pressure sticking, the fluid circulation in the hole is not affected in any way, but the drill string cannot be raised, lowered or rotated.



Overcoming differential stick

To reduce the tendency to become stuck by differential pressure stick:

1. reduce the contact area between drill collars or pipe and the wall of the hole by running stabilisers or using square drill collars, or pipe with external upset tool joints.
2. maintain good quality muds with low solids content, low water loss and thin tough filter cakes.
3. minimise the pressure differential by running low density muds, aerated muds or foams. Restrict penetration rates to prevent a heavy cuttings load in the mud.
4. keep the drill string moving so that it does not get a chance to "settle into" the mud cake. (The tendency to "settle in" is lower in vertical holes).
5. when rotary drilling under conditions likely to cause differential stick, some form of jarring tool or bumper sub should be run above the drill collars.

The obvious way to free a drill string held by differential pressure is to reduce or even remove the pressure differential. In shallow holes, in diamond drill holes, and in some water wells, this is the preferred procedure. Before reducing the hydrostatic head in the hole, the driller must consider the risk of causing a blow-out, collapse or caving, which could add to the problem.

When reducing the bottom hole pressure by circulating fluids of lower density or by lowering the standing fluid level, proceed cautiously, while a pull is maintained on the stuck string. Bailing and aeration of the mud are recommended techniques. Knowledge of the likely natural water table level will guide the driller in deciding how far to reduce the head.

When the pressure reduction required to release the pipe is so large that it would cause other problems, circulation of diesel oil or a commercial "spotting fluid" may break down the mud seal and release the string. When the pipe comes free, the hole should be circulated and the mud conditioned, before anything else is done.

Key-seat sticking

The second major cause of stuck pipe is **key-seating.** In deep holes, an estimated 50% of all stuck pipe problems are contributed to or caused by **key-seating.**

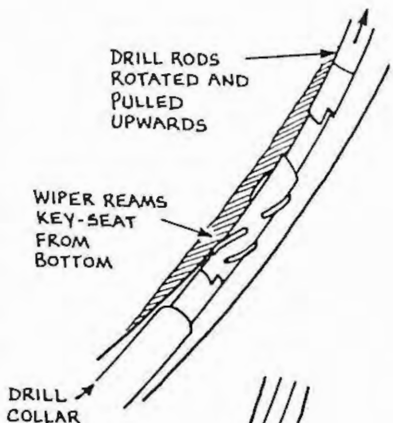
Prevention and indicators of key seats

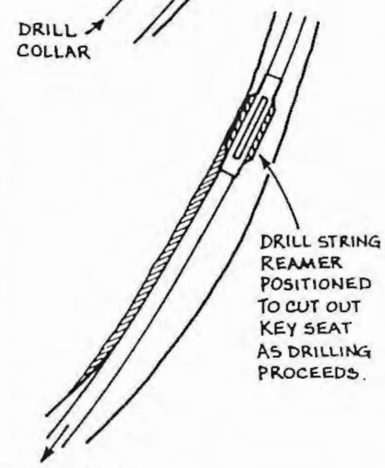
Key-seating can be detected. Wherever a dog-leg or crooked hole occurs, that section of the hole is likely to form a key-seat. The pipe rubbing on the side of the hole during tripping or rotating cuts out a side groove which just fits the pipe (see figure next). This is the key seating. Increased loading on the winch when a larger diameter section of the drill string is pulled through the groove is an indicator of a key-seat.

Key-seats can be prevented by maintaining a straight hole and by refraining from rotating for long periods without tripping the string.

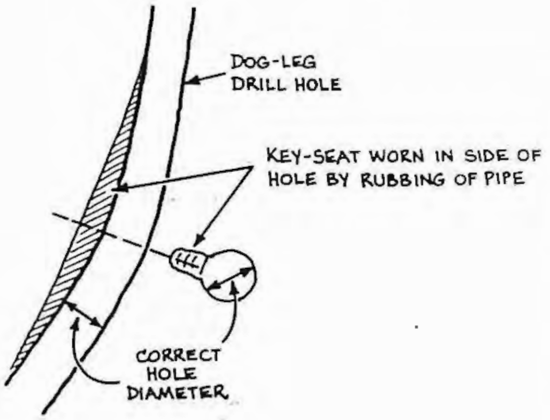
Key-seats can be removed. The key-seated interval is reamed, using a drill-string reamer, or a key-seat wiper is run immediately on top of the drill collars. The key-seat wiper is reamed upwards through the key-seat.

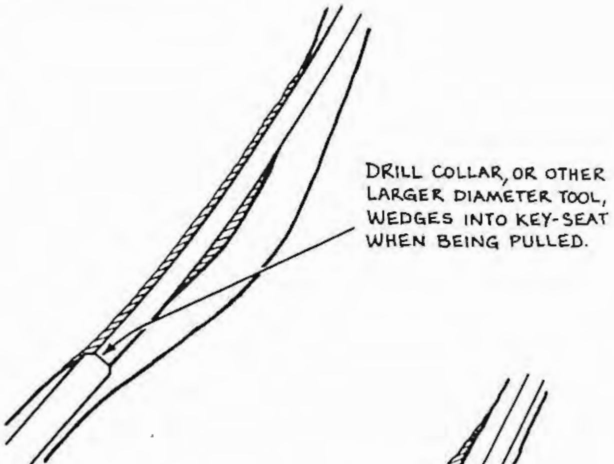
COMBINATION JAR AND KEY-SEAT WIPER

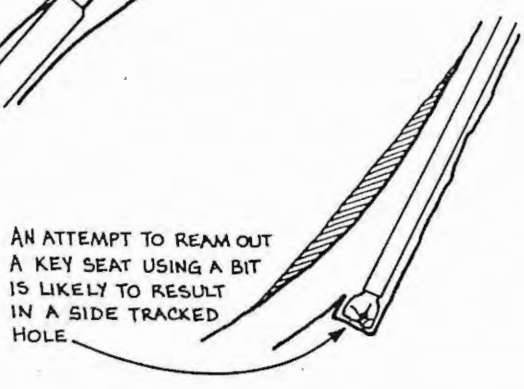




DRILL COLLAR WEIGHT PULLS REAMER INTO KEY SEAT







Any reaming operation must be conducted with care, as the drill string is subjected to repeated high loadings which may cause fatigue failures. Reaming to remove key- seats requires great care. Only top drive rigs can do this easily owing to the upward reaming procedure.

Small rotary table rigs may be forced to ream upwards using slips to drive on the drill pipe. If this technique is used, the slips must be tied to hold them in place.

Preferably, a key-seat is reamed using a reamer run between two drill collars. Stabilisers are run both above and below the drill collars to centralise the collars in the hole. As this assembly is rotated, the reamer opens out the key-seat.

Use of a drill string reamer requires considerable experience if fatigue failure is to be avoided. The reamer is positioned so that the tension in the string pulls the reamer into the key-seat.

Freeing pipe from a key-seat

The driller should avoid pulling the pipe so hard into a key-seat (or mud ring) that the string becomes immobile. The string should be lowered, then driven or pushed downwards to a point where it can be rotated.

Circulation should be established and maintained to circulate any cavings out of the hole. (Circulation helps prevent wall sticking.) The string is then pulled gently into the tight spot and rotated. The string may "roll out" of the keyseat or the sides of the key-seat may be worn away. The pipe should be marked and then pulled. The movement of the mark will then indicate whether the string is being "worked out" of the key-seat. If so, the pulling and rotating are repeated.

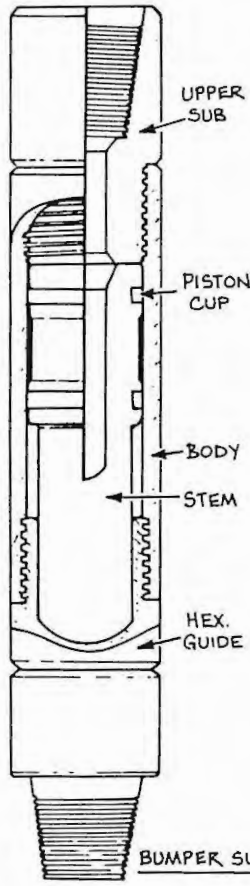
If the string remains within the key-seat, it is worked up and down alternately with rotation, in an effort to continue wearing away the key-seat.

A key-seat wiper, with or without a bumper or jarring action, at the top of the drill collars, will greatly assist this operation.

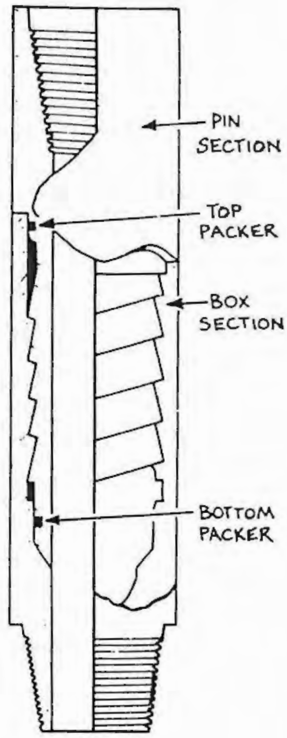
Recovering stuck pipe

When holes must penetrate problem formations or drilling must continue in holes subject to dog-legs or mud rings, the likelihood of a stuck drill string is increased. The drill string should be modified so that sticking can be more easily overcome.

- Rotary jars or a bumper sub in the string will allow use of a hammering action to free the stuck pipe.
- The drill collars or other components of the string likely to become stuck should be separated from the remainder of the string by a safety joint. This joint can be unscrewed at any time to allow use of a greater variety of methods of freeing the stuck tools.



BUMPER SUB



SAFETY JOINT

If the drill string does become stuck:

1. Establish the true nature of the downhole problem that has stuck the tools.
2. Work out where the tools are stuck.
3. Follow a systematic recovery program.

A suitable recovery program might be:

1. If the string becomes stuck when pulling out, try to work the string downwards. If it's stuck when running in, work the string upwards.
2. Establish and maintain circulation.
3. Rather than exerting a heavy pull, try to gain a little movement and keep working the string to increase the amount of movement.
4. Circulate spotting fluid to the estimated point of sticking and allow it to "soak".
5. Attempt to slowly rotate the string, being careful not to overtorque the tool joints.

If attempts to move the string must be abandoned, the string is backed off at the safety joint. When a safety joint is not present, explosives are sometimes used to achieve "back-off" at a standard joint. As a last resort, **wash over strings**, usually made up from casing, may be used to drill over the stuck tools in order to cut them free from the material holding them. The "wash-over" technique is not recommeded for recovering pipe held by differential pressure stick.

Technical Area: 4 Drilling Control

Item: 4-1 Mud control

1: Objectives
To be able to explain and advise for rolls of mud fluid to conduct effective drilling and how to keep condition of mud.

2. Contents
- Mud agent
- Function of mud
- Annular velocity
- Mud mixing
- Mud control equipment
- Mud control according to geological conditions

3. Teaching Methods
(1) Explain the use and mixing ratio of mud agent such as bentonite, polimer etc. using manual.
(2) Explain function of mud circulation such as removal of cuttings, wall stabilization, lubrication etc. using manual.
(3) Explain mud circulation equipment and system using manual.
(4) Explain how to keep mud conditions according to geological conditions.
(5) Explain how to use funnel viscosimeter and mud balance.

4. Materials
4-1M1 DDCA's Manual for Drilling Works
4-1M2 Drilling Chap. 6 P197-P208

3 DRILLING CONTROL (TA CODE 4)

3.1 MUD CONTROL (A CODE 4-1)

The roll of mud circulation is as follows:

- Prevension from wall collapse
- Removal of drill cuttings from the hole
- Prevension from flow-in of groundwater
- Prevension form lost circulation
- Cleaning and cooling of bit
- Reducing the friction of bit rotation

Bentonite is the most general mud stabilizer. Other mud additives are CMC, polimers and dispersant. Viscosiity and density of the mud shall be well controlled by using the marsh funnel and mud balance. Funnel spped shall be approximately 30 seconds and specific gravity shall be not more than 1.2. If the mud is too strong, the cutting separation becomes non effective. Furthermore, it may cause the stucking of the drill string. The separation work from the mud canal is important.

Mud circulation system is composed of mud pump, suction pit, settlement pit and so on. Drillers are required to understand the functions of each component and proper operation of the mud circulation sysmte is important to implement the smooth drilling works. ***Figure 19*** shows the standard layout of drilling Figure 19equipment including the mud pits and canals.

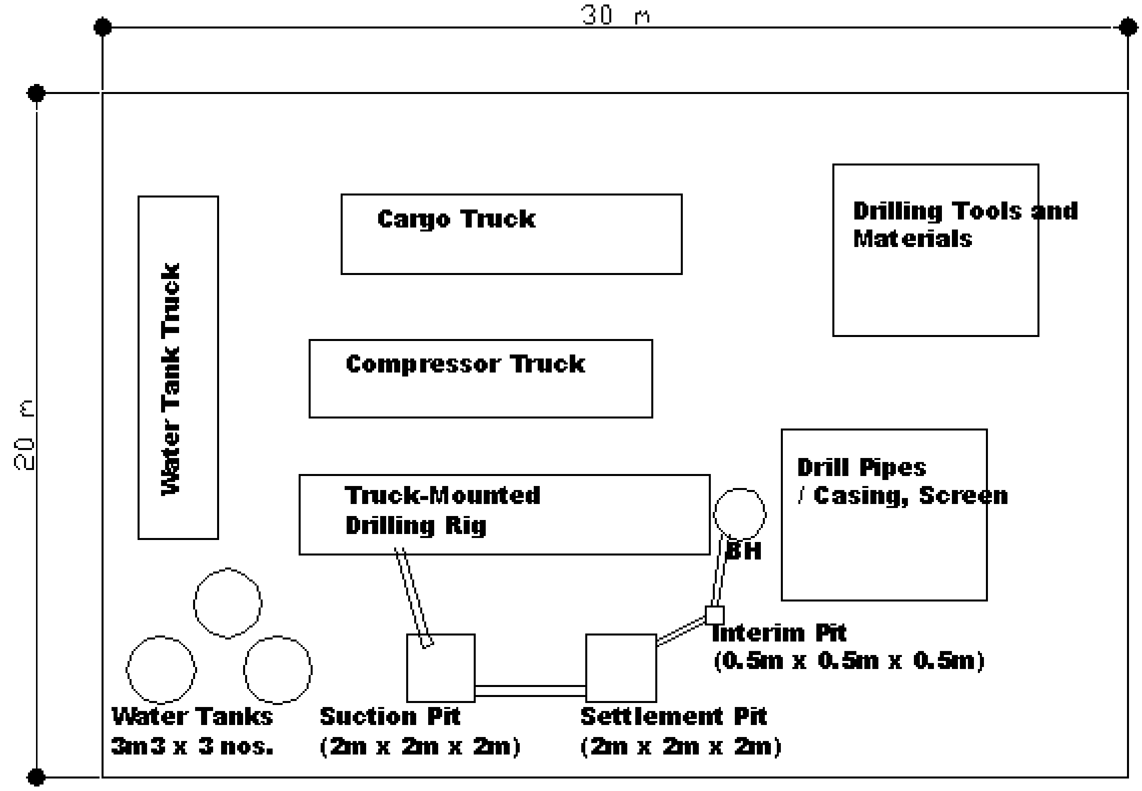


Figure 19 Standard Layout of Drilling Equipment on Site

Circulation fluids & grouting

Section 1 Fluids for cleaning and stabilising

- Properties of fluids
- Functions of a drilling fluid
- The fluids available
- Fluids under pressure
- The way flow changes some fluids
- Solutions or suspensions
- Suspensions in drilling muds
- Lubrication and protection against corrosion
- Selecting flow by its character
- Control of fluid density
- Wall stabilisation by gels

Properties of fluids

To gain efficient cleaning and stabilising in a drill hole, we take advantage of many of the properties of fluids and pumps.

Density

- Specific gravity
- Buoyancy
- Pressure
- Inertia

Flow characteristics

- Flow
- Friction
- Pulsations
- Viscosity

Lubrication

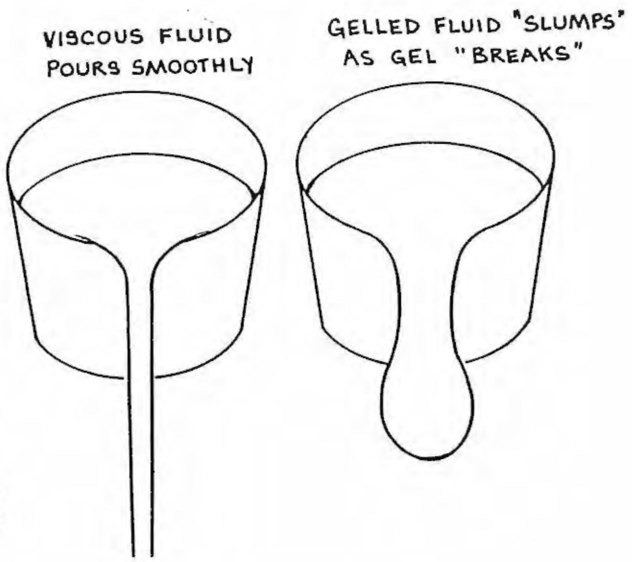
- Composition of lubricants

Pumps

- Suction and delivery
- Cavitation

In this section, we go on to study more about flow characteristics and the way that some fluids change their viscosity according to how much they are being stirred.

Many drilling fluids are described as "**thixotropic**", which means that they form a "gel" or "gel up" when allowed to stand still; and they go thin again when pumped or stirred.



Functions of a drilling fluid

A driller who knows about drilling fluids and has the skills to make them work for him has access to the most powerful drilling tool available.

A good drilling fluid will assist the driller by performing functions in five main areas. It will perform all these functions in a safe way without providing any hazard to the crew or to the environment, or causing any damage to the drilling tools and equipment.

1. Hole making functions

- cool the bit
- clear the bit and the bottom of the hole
- transmit energy to the chip making and clearing process (hydraulic energy)
- lubricate the rods/pipes and bit
- inhibit corrosion of down-hole tools and casing
- assist in running casing, reduce costs of placing casing, and in deep holes, support the weight of the casing (buoyancy).

2. Hole clearing functions

- remove cuttings from the hole
- deposit cuttings at the surface
- hold cuttings in suspension when the flow is stopped.

3. Hole stabilising and control functions

- control down-hole pressure and temperature
- provide support for unconsolidated formations, consolidate caving formations
- protect target formations or ore bodies against invasion or contamination
- restrict wall cake build up
- control circulation loss
- inhibit formation deterioration.

4. Sample transport and logging functions

- communicate accurately about what is happening down the hole. (Changes in colour, smell, feel, appearance, flow and chip content all help to convey the message. Messages carried quickly are better messages).
- preserve the core or chip samples
- deliver the sample rapidly without breakage or loss
- facilitate electric or geophysical logging.

5. Self care function

- stable - the desired properties of the fluid, once established, should be stable under normal drilling conditions
- easy to treat - if the desired properties are lost, treatment should be available to restore or adjust them
- testable - tests and testing equipment should be able to identify fluid properties and indicate any treatment required.

The fluids available

Drilling fluids may be either liquids or gases.

Liquids are relatively:

- dense, i.e. have high specific gravity.
- viscous, i.e. resist flow.
- easily handled, i.e., stay in a bucket.
- incompressible, i.e., volume changes little with pressure.

Gases are relatively:

- light.
- non-viscous.
- difficult to contain.
- compressible.

The commonly used drilling fluids are:

- **air** - compressed from the atmosphere.
- **oil** - mineral oils.
- **water** - fresh or saline water.
- **mist** - compressed air with finely divided water particles.
- **foam** - bubbles of air surrounded by soap or detergent and water film.
- **stiff foam** - a stable lattice of foam bubbles.
- **mud** - water treated with colloids and/or chemicals to provide special properties.
- **aerated mud** - mud/air mixture.

1. Air

Air, unlike liquids, is easily compressed and pressurised. High velocity through the bit nozzles, and expansion of the air at the work face, provide superior chip clearing and thus fast penetration rates.

However, the low density of air means that very high up hole velocities are essential to prevent chips settling back down the hole. An up-hole velocity for air must be at least 20 times that for water. In deep holes, or holes which make considerable amounts of water, extremely high air pressures are needed to lift cuttings to the surface.

Air is an apparently ideal fluid, in that it is cheap, readily available, and needs only compression to be a useful circulating medium. Air is no longer the ideal fluid when down-hole conditions deteriorate. However, air circulation can be modifed to overcome certain down-hole problems.

2. Water/oil

Water was the first commonly used drilling fluid. It is cheap, often readily available and its cooling properties are far superior to all other drilling fluids. Water is still used as the circulating fluid in normal circulation holes if drilling competent formations where loss of circulation and other down hole problems are not anticipated. It is commonly used in large diameter reverse circulation drilling.

Oil is never used alone as a circulating medium. Oil based muds are often used in oil and gas drilling, and oil and water emulsions are used for lubrication in slim hole drilling.

The addition of oil to water base drilling fluids has been credited with the following benefits to the overall drilling operation:

- reducton in pipe torque.
- reduction in pipe drag.
- increased penetration rate.
- increased bit life.
- reduction in bit bailing.
- alleviation of differential sticking.

3. Mist

When small inflows of water are encountered in an air drilled hole, the dampness often sticks cuttings together to form mud rings.

Injection of water, or water with a foaming detergent, wets the cuttings sufficiently to prevent sticking. The cuttings are easily blown out of the hole in a muddy spray, with only a slight increase on the original air pressure. Mist or water injection drilling is also used quite often to elminate the problems of dust at the collar of the hole.

4. Foam

Larger water inflows cause:

- water to build up in the hole and
- loss of cleaning efficiency, as the weight of water to be lifted becomes too much for the available air pressure.

Foam circulation is used to assist in lifting the water. Foam is a similar mixture to mist; however, the proportion of foaming agent is greater. Pressures are slightly higher than would be used in a dry hole.

5 Stable/stiff foam

As water builds up in air-drilled holes beyond, the capacities of misting or foaming, it is possible to continue drilling by:

- air lifting of water.
- using a stiff foam.

To air lift water, the water level in the hole must be above the half way mark. Much smaller air flow volumes are used, but higher pressure is required.

When the water level is not suitable, or if the water flow is causing instability in the surface formations, stiff foam circulation is necessary. Stiff foams are made up of foaming additives mixed with standard mud colloids and water. Stiff foams can be very effective in overcoming such down-hole problems as lost circulation. When there is a requirement to drill large diameter holes which could not be cleared adequately by air or mist, stable foam will enable continued use of the available compressor.

The foam encapsulates air bubbles, water droplets and cuttings, the trapped air tending to lighten the weight of the fluid column. Very low volumes of air are required to circulate the stiff foam, and air pressure is only slightly increased for a similar dry hole.

6. Mud

Drilling mud is made up of three principal components:

- base liquid
- active solids
- inert solids.

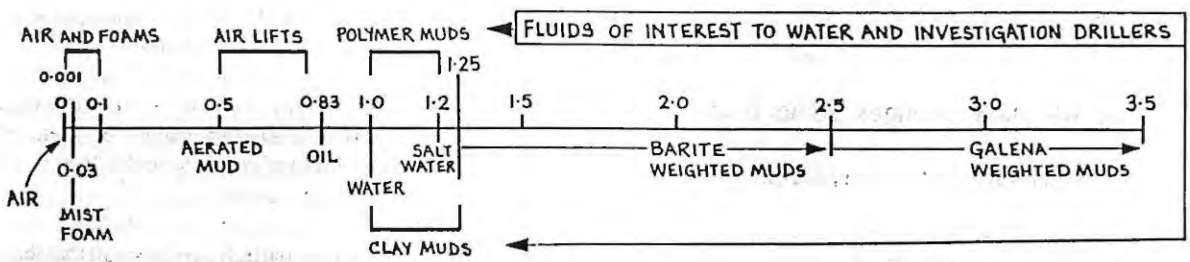
Base liquid - Oil and fresh or salt water can be used as the base liquid in drilling muds. Oil and salt water based muds are almost totally restricted to hydrocarbon drilling. Fresh water based muds are the most widely used.

Active solids - Active solids are those clays or polymers which are added to the base fluid to produce a colloidal suspension. They determine the viscosity of the mud and are known as viscosifiers.

Inert solids - Inert solids are substances added to the mud, principally as weighting material. They increase the density of the mud without appreciably affecting the viscosity. Without the presence of viscosifiers which, build the suspension, they would quickly settle out in the system.

7. Aerated mud

Air, introduced into the mud line at a pressure equal to, or higher than the mud pressure, produces aerated mud. It is used only when an increased up-hole velocity is needed to give better cuttings return in a mud drilled hole.



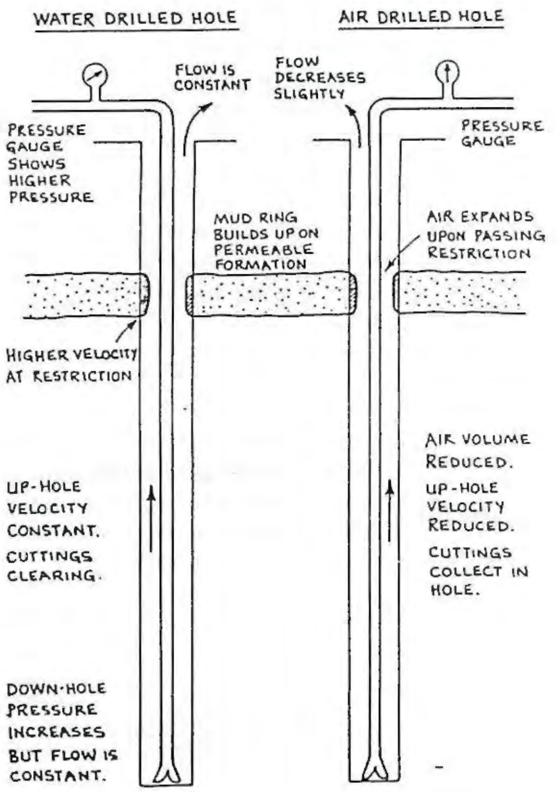
The available drilling fluids cover a wide range of specific gravities.

Fluids under pressure

Liquid pressure at the bottom of the hole gets greater as the hole is drilled deeper. But liquids behave in the same way whether under pressure or not, so changing depth does not change the performance of a liquid circulating fluid.

Gases show little change in static pressure over the depth of a drill hole, but because they are compressible, their volume can change enormously when pressure is built up to overcome a restriction to flow.

A constriction, such as a mud ring in the upper part of an air-drilled hole, can cause the deeper part of the hole to be under pressure. For example, say the down hole pressure is 500 kPa (72 psi), then the air volume will be only one fifth of its volume at atmospheric pressure (100 kPa or 15 psi). Therefore, the flow velocity (bailing velocity) will be only one fifth of the velocity at the top of the hole, **and** this lower velocity might not be enough to lift the cuttings.



The way flow changes some fluids

The rate of flow of a fluid depends on two factors:

- the pressure gradient along the flow path.
- the viscosity of the fluid.

The ability of a fluid to carry or suspend cuttings depends on four factors.

- the rate of flow of the fluid.
- the viscosity of the fluid.
- the size and shape of the cuttings.
- the specific gravities of the fluid and the cuttings.

Viscosity of the drilling fluid is doubly important for efficient drilling. The viscosities of most fluids are controlled largely by temperature. Movement of most fluids has no effect on their viscosities.

Because drillers are concerned in making sure that cuttings are lifted out of the hole and do not settle back down if the flow velocity is reduced, there is reason for seeking a fluid which has a higher viscosity when it is moving more slowly.

Colloidal Solutions of polymers or clays become thicker when allowed to stand. Such colloids are thixotropic. They become less viscous when stirred or pumped. They become more viscous as the flow velocity is decreased and 'gel' when allowed to stand.

Just as viscosity is the measure of the force required to keep a fluid flowing, **gel strength** is the measure of the force required to start a gel flowing.

The"thickness" of colloidal solutions is measured by their **plastic viscosity.**

Plastic viscosity is affected by:

- temperature
- stirring or flow rate
- solids content
- shape and size of the solid particles

Yield point is the theoretical plastic viscosity when the flow rate is zero.

Solutions or suspensions

Muds, as we have seen, are colloidal solutions. But what does this mean? To understand muds and the way they work for us, we need to know the meaning of a number of terms used to describe muds and their condition.

Mixture - A mixture is made by stirring solids or fluids together. The component parts of a mixture continue to be present and capable of being sorted out. Mixtures of fluids of differing specific gravities sort themselves by one floating on the top of the other. A mixture of petrol and water sorts itself, with the petrol floating on the water.

Suspension - A suspension is a mixture of solid particles in a fluid. Like mixtures, a suspension will separate unless the fluid viscosity is too high to allow the solid particles to settle. Cuttings in mud make a suspension.

Solution - A solution is formed when one material is dissolved in another. Unlike mixtures or suspensions, the component materials in a solution cannot be seen, even under a microscope. Solutions pass through filters without separation of their component parts.

Colloidal Solution - This is an extremely finely divided suspension where the solid particles are so small that they do not settle. The particles can be seen with a microscope and separated from the liquid by filtering.

Emulsion - An emulsion is another colloidal solution of one fluid in another. (The emulsion so formed may be fluid or solid.)

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Chemical change - When mixed, some solutions undergo a chemical change. New chemical compounds, so formed, may precipitate from the solution.

Suspensions in drilling muds

One of the desirable properties of a drilling fluid is that it will carry cuttings in suspension.

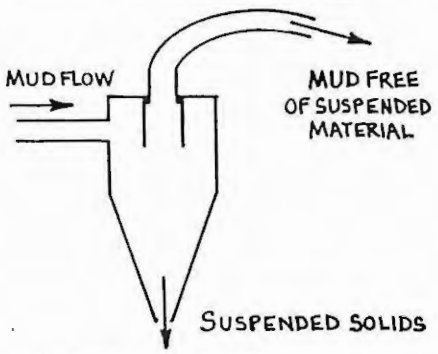
The viscosity of the fluid is increased to the point where it will"suspend" the cuttings while moving up the hole, but kept low enough to allow the cuttings to settle in the mud pits.

Particles smaller than cuttings, do not settle in the pits. Finely ground weighting material, such as barite, is retained in suspension and recirculated.

Very fine cuttings and silt will also remain in suspension and be recirculated.

Sand and silt in the mud will cause wear in the pump, pipes, valves, swivels, and drilling tools. It interferes with the efficient operation of the bit. Suspended material increases the density of the mud.

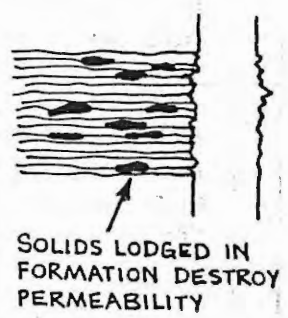
Hydrocyclones may be used to separate the suspended solids and restore the mud to its former density.



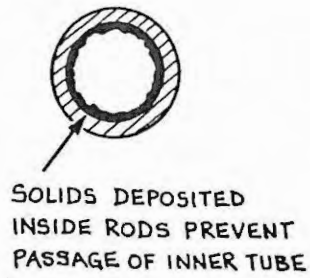
HYDROCYCLONE

Suspended materials may have very serious effects on the drilling performance.

1. Suspended solids can be carried into permeable formations where they are deposited, thus destroying the permeability.



2. Suspensions flowing through rods turning at high speeds are"centrifuged". The solids are deposited on the inside of the rods.



Lubrication and protection against corrosion

Many colloids, both clays and polymers, have a"slippery" nature. Drilling fluids made up using these colloids have a natural lubricating property. Their ability to lubricate can be improved by adding oils or soap to the mud.

Air or water and particularly mists or foams, which are mixtures of air and water, provide little lubrication. To make things worse, mists and foams greatly increase corrosion. To form good drilling fluids, oils or soaps, as well as corrosion inhibitors, should be added.

Continuous injection of oil so that a continuous oil film is maintained over the rods and tools will assist both lubrication and protection against corrosion. Addition of soluable oils and wetting agents will encourage preferential oil wetting of metal surfaces.

Corrosion - drilling equipment is subject to many types of corrosion.

Dissimilar metals - the small electric currents, generated when dissimilar metals are in contact, in a corrosive environment, cause rapid corrosion.

Pitting and crevice - localised attack concentrated by corners or grooves.

Stress - corrosion in combination with tensile stress causes deep cracking often leading to fatigue failure.

Erosion - in combination with corrosion, exposes new metal to attack and thus leads to early failure.

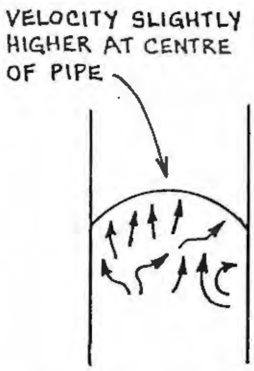
Protection against corrosion

1. Maintain a high pH environment – above a pH of 9.
2. Twice a week, apply a coating of corrosion inhibitor to all metal surfaces.

Selection of flow by its character

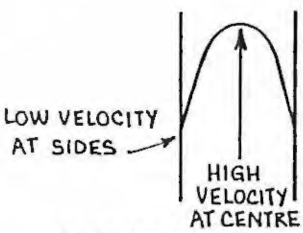
When flow is turbulent (although the fluid is constantly changing direction), the cuttings are transported rapidly. The important factor is that the velocity changes little across the pipe.

Circulation fluids and grouting



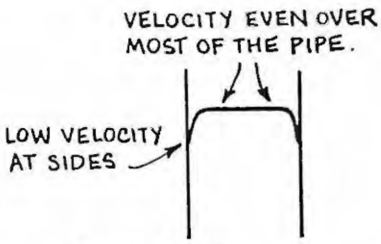
VELOCITY PROFILE WITH TURBULENT FLOW.

Laminar flow provides a higher velocity at the centre of the pipe. Cuttings can slip back by getting into the low velocity area.



LAMINAR FLOW

Plug flow, a characteristic of polymer fluids, provides even velocity over most of the flow area.



PLUG FLOW

The high velocities required for air and mist circulation ensure that turbulent flow occurs. Cuttings are transported rapidly. The turbulence maintains clean walls but can erode friable materials.

Laminar flow normally exists when clay based fluids are circulated. The low velocities at the walls allow good wall cake formation.

Polymer fluids possess the characteristic of **shear thinning**. That means that the fluid is thin where shearing is occurring, that is, at the walls of the hole.

At the centre, where **plug flow** is occurring, the fluid is more viscous and holds the cuttings in suspension. Wall cake in the pores of the formation is not disturbed and retains the 'gel' necessary to stabilise the walls.

Control of fluid density

Hole making is assisted by a low pressure bottom hole environment. But higher pressures often are necessary to balance formation pressures or stabilise the walls of the hole. Hole pressure is increased simply by increasing the fluid density.

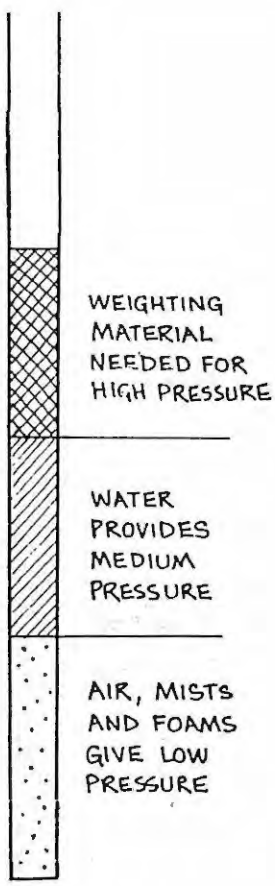
The chart earlier in this section shows the range of specific gravities possible with drilling fluids.

Penetration, as well as detection of water shows, is improved when the bottom hole pressure is lower than the formation pore pressure. Usually, the formation pore pressure is equal to the pressure of a column of water reaching to the water table. Low bottom hole pressures exist when air, mist, or aerated fluids are used.

These fluids with a low specific gravity have no stabilising effect on down hole formations or pressures.

In most holes, the standing water level is some distance below the collar of the hole. That means, that provided the hole is filled with a fluid of about the specific gravity of water, and **kept full** to the collar of the hole, the formation will be kept under a steady stabilising pressure.

Additional pressure is obtained by increasing the fluid specific gravity by adding **weight material**.



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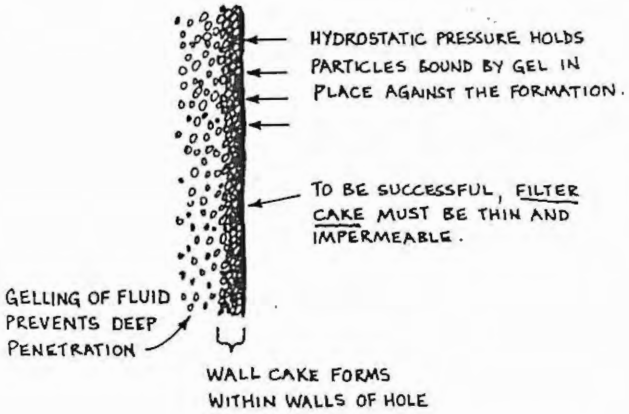
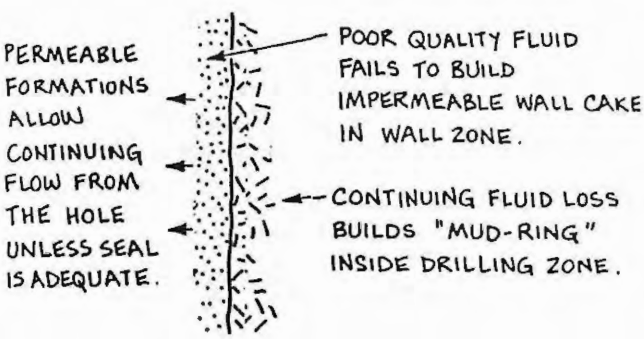
Weighting may be by materials in solution, eg salt, or by material in suspension (e.g., clay, silt or barite). Silt weighting is undesirable because silt in the fluid causes wear of equipment.

Wall stabilisation by gels

An important contribution made by colloid type drilling fluids is their ability to enter the pores of unconsolidated formations and stabilise the walls by holding the particles of formation with a"gel". The particles held by gel must be held in place by a stabilising pressure to ensure stability.





Drilling fluids, like foams or muds, build wall cake. Three steps are involved in forming the cake.

1. Some of the fluid enters the pore space in the wall. Once in the pores, it moves more slowly and "gels".
2. Solids in the fluid and the small particles making up the colloid work together to build a thin cake on the surface of the hole.
3. If the first two steps do not stop further flow into the formation, the filtering action of the filter cake allows liquids to pass and continues to build up an increasingly thick mud cake.

Section 2 Drilling muds

- Requirements for drilling muds
- Bit cooling and bottom clearing
- Mud cleans and transports
- Clays and viscosity
- Viscosity and colloids
- Hole cleaning
- Good information on"what's happening"
- Good core/cuttings and lubrication
- Clean mud
- Stable holes – pressure control
- Filter cakes
- Wall building – formation stabilisation
- Formation and aquifer protection

Requirements for drilling muds

Not all **water drillers, mineral drillers and site investigation drillers** use mud in their drilling operations. Of those who could, what would they want the mud to do? Each driller will have his own list of priorities.

A drilling mud should be selected so that it performs the five priority functions very well. With these needs satisfied, attention is then given to minor adjustments that could allow the mud to provide other functions. Any adjustments like this can only be made if they don't interfere with the priority functions.

More than anything else, drillers working in these areas must have muds that:

- are simple to mix in the quantities used (0.5 to 500 cubic metres or 20-20,000 cubic feet).
- can be tested and treated easily and cheaply.
- are non-polluting to the environment or the aquifers and formations penetrated.

A driller's mud selection and treatment is likely to be aimed at:

- good bit cooling and bottom clearing.
- clean holes.
- good information on"what's happening".
- good core/cuttings and lubrication.
- clean mud.
- stable holes – pressure control.
- wall building – formation stabilisation.
- formation and aquifer protection.

Bit cooling and bottom clearing

Contributing properties

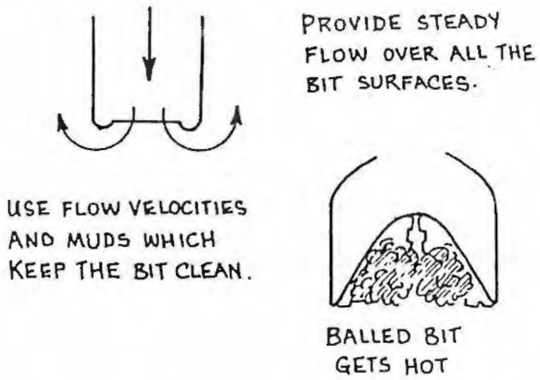
Cooling means carrying heat away. Almost any fluid moving over the bit will do this. Water does it best. Water is helped by a"wetting" agent that keeps the bit surfaces clean and wet.

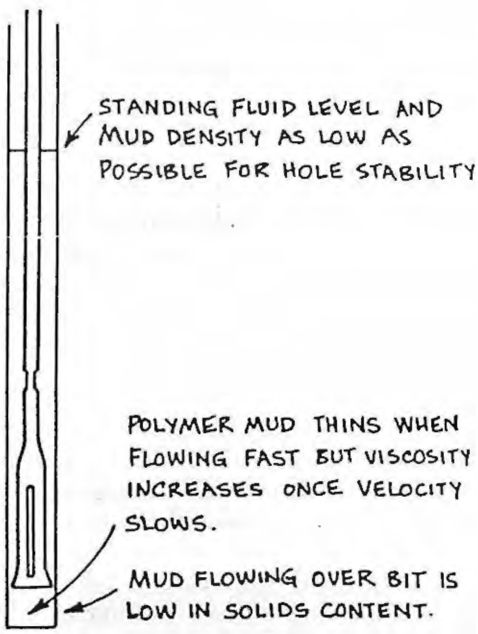
Circulation fluids and grouting

Bottom clearing is most effective when:

1. low bottom hole pressures exist.
2. fluid has low viscosity.
3. fluid has high velocity.
4. fluid is free of solids.

Once clear of the bottom, the chips should be held, and even when the velocity of the clearing fluid drops, the chips should be held suspended.





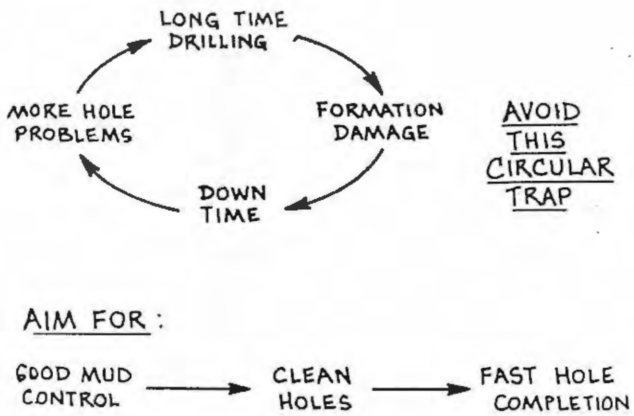
Factors that inhibit bit cooling and bottom hole clearing

- Intermittent flow stops proper cooling. Interruptions to the fluid flow can destroy a diamond bit in seconds.
- Clay built up on bit rollers lowers cooling efficiency.
- Any type of drilling is hindered by the bit working in a viscous mud with high solids content (greater than 2%).
- Dense muds slow down chip clearing because of the high bottom hole pressure.

- Similarly, more fluid than necessary in a cable tool hole,increases the bottom hole pressure.
- No viscosity at all in a cable tool fluid allows cuttings to settle quickly.

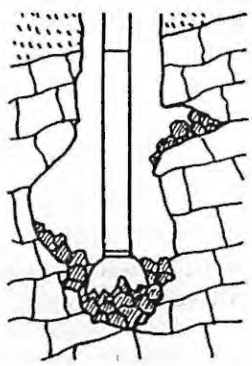
Mud cleans and transports

Many formations are affected by the drilling fluid. The longer the fluid is in contact with the formations, the more they are affected.



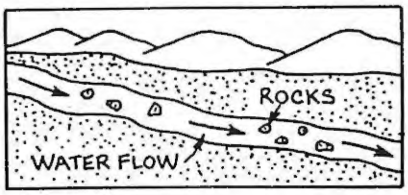
Holes are difficult to clean when they:

- are overloaded with cuttings.
- have washouts or cavings.
- are lined with sticky swelling formations or thick filter cakes.

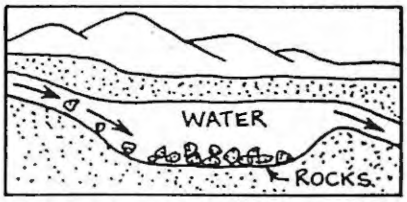


Rapidly flowing water transports rocks easily.

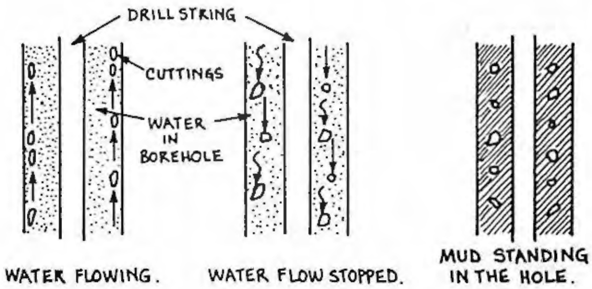
Circulation fluids and grouting



When the flow rate drops, the stream no longer carries the rocks.

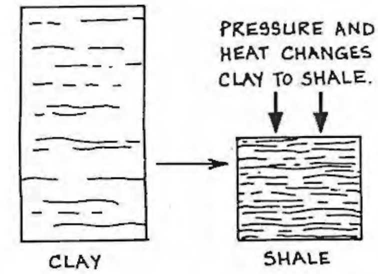


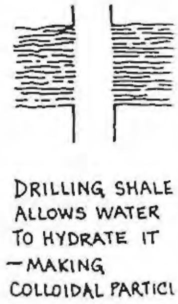
Similarly, water transports cuttings up the hole when the up-hole velocity is high enough. When circulation stops, the cuttings settle quickly. Muds having viscosity or providing buoyancy, are used to slow the settling.



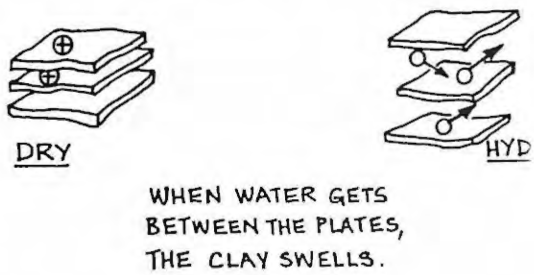
Clays and viscosity

Clays and shales cut during drilling become finely divided and hydrated. If the drilling fluid is being recirculated, the colloidal particles formed from the clays and shales add **viscosity** to the fluid. This makes a mud.

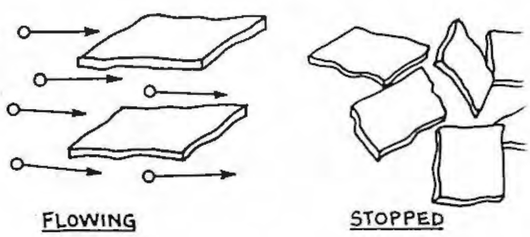




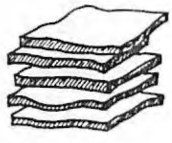
Some clays, like pottery clays, do not expand whe are placed in water. Others, like **bentonite** are made stacks of platelets. When they get wet, (become **hydr** they expand to many times their former size.

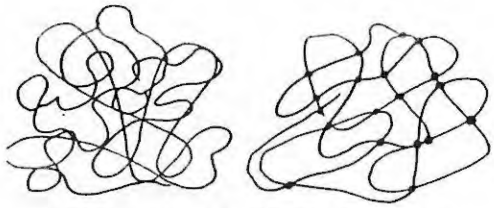


When clay platelets are dispersed through wate increased solids content causes an increase in visc While the mud is flowing, the platelets become lined u move freely, thus giving a lower viscosity. When flow the platelets become"disorganised" and form a stru which traps the water. This structure supports cutting



The presence of salt or some other chemicals i drilling water causes the bentonite to remain **aggreg**



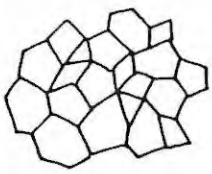


The little stacks of platelets in an aggregate suspension, will hydrate and swell if they come in contact with fresh water.

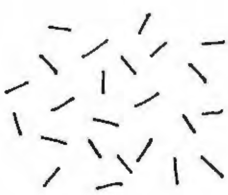
Viscosity and colloids

The viscosity of a clay mud can be changed by the addition of chemicals which change the way that the platelets of clay are arranged.

Addition of lime (or cement) to a clay mud will thicken the mud by"**flocculating**" the clay. The platelets of the clay become locked together at their edges.



Flocculated muds and muds which have become too viscous because of increased clay content, may be"thinned" by the addition of thinners or **dispersants**.



Clay muds are regarded as being"versatile" because of the way their viscosity (and other properties) can be adjusted by the mud engineer.

Drillers who must work without the assistance of a mud engineer often find that the more costly polymer muds work out"cheaper in the long run".

The **organic polymers** used in drilling consist of very large"long chain" molecules. It is these long molecules which operate to provide viscosity when the polymer is mixed with water.

- Polymers are 10-20 times as powerful as bentonite, as viscosity forming agents.
- Polymers restrict the hydration of clays and thus polymer muds require less treatment.
- Polymers provide greater change in viscosity between their flowing state and their still state. Pumping pressures are low.
- Polymers can be weighted with salt to provide a low solids weighted fluid.

Hole cleaning

Contributing properties

Hole cleaning is improved by:

- increasing up-hole velocity.
- increasing mud viscosity.
- increasing buoyancy by weighting the mud.
- preventing settling of cuttings when flow stops.

When adequate velocity is available, cuttings are more easily removed from the mud.

Mix some colloid to provide:

- gel strength, to stop cuttings settling.
- lubrication.

Use a colloid which requires little adjustment to mud properties.

Mud viscosity is an important tool. Check the viscosity regularly as a change in viscosity indicates that mud properties may need treatment.

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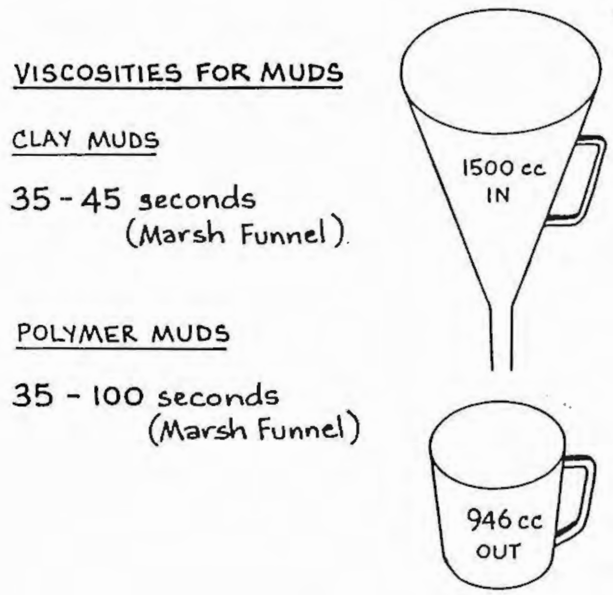
Circulation fluids and grouting



UP-HOLE VELOCITIES FOR MUDS

LOW VISCOSITY
(near water) 0.6 m/sec (120fpm).

MEDIUM VISCOSITY
(35 seconds
Marsh Funnel) 0.5 m/sec(100fpm).

HIGH VISCOSITY
(over 50 seconds
for clay mud) 0.3 m/sec(60fpm).

Factors that inhibit drilling efficiency

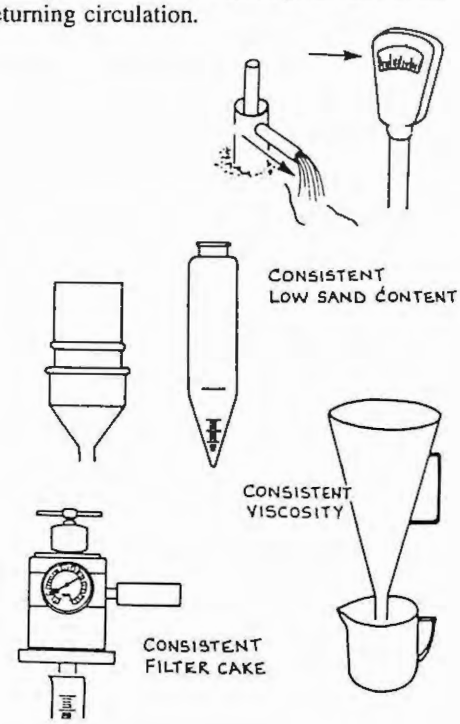
- High velocities (above 2 m per second or 400fpm)are likely to erode the walls of the hole in friable formations.
- Small pumps cannot provide adequate up-hole velocity in large holes and viscosity must be increased to compensate.
- High viscosities cause pressure surges and formation damage on:
  - starting up the pump.
  - lifting or lowering the drill string.

Changes in velocity cause cuttings to collect and possibly"pack" together. Velocity changes come from washed out holes and changes in pipe/rod diameter.

Good information on"what's happening"

Contributing properties

- Good cleaning, i.e. adequate up-hole velocity and viscosity.
- Good quality mud plus frequent observations/ checks to detect any changes.
- Sensible arrangement of gauges and flow channels so that the driller can monitor changes in gauge readings, or in color, or cuttings content of the returning circulation.



Factors that inhibit information gathering

- High solids content can mask any changes.
- Irregular flow due to poor pump operation.
- Excessive or persistent gel preventing separation of cuttings.

Good core/cuttings and lubrication

Contributing properties

Good core recovery depends on:

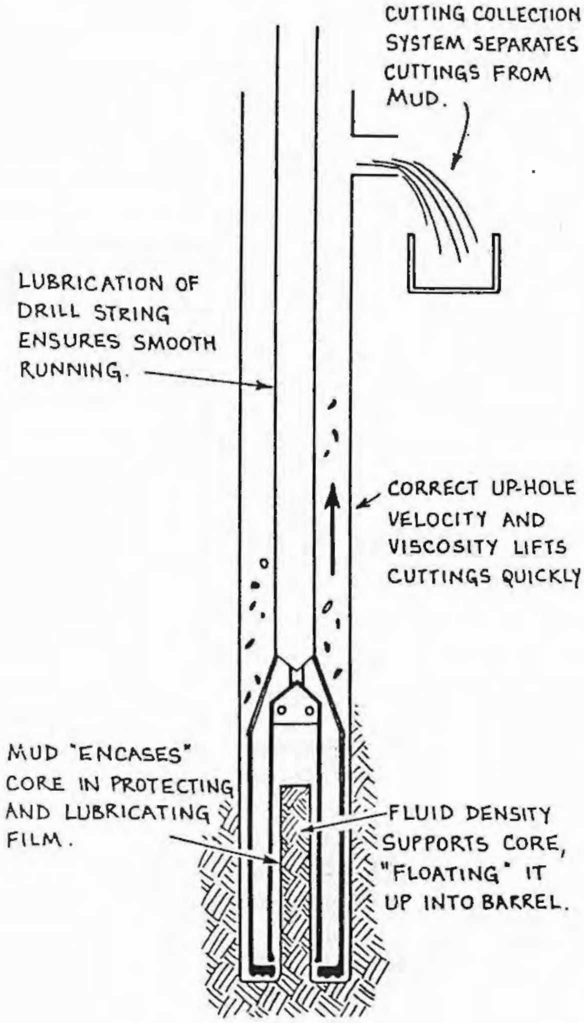
- smooth running and thus adequate lubrication of a drill string in good condition.
- Good feeding of the core into the barrel, which includes
- an unbroken core.
- no swelling of core.
- lubrication of core.
- buoyancy of core.

Protection of the core against erosion requires,

- low fluid velocity over core.
- nonagressive fluid.

Good cuttings require:

- protection against swelling or disintegration.
- transport up a hole free of drill pipe vibration.



Factors that inhibit good core recovery

- Lack of lubrication and support of drill string, allows vibration and rough operation.
- Lack of lubrication prevents correct transmission of cutting forces.
- Lack of protection against hydration, allows core to swell and cuttings to break up and become"lost" in the mud.
- Slow completion of core run, or return of cuttings, allows deterioration of sample.
- Excessive or persistent gel prevents good separation of cuttings from mud.

Clean mud

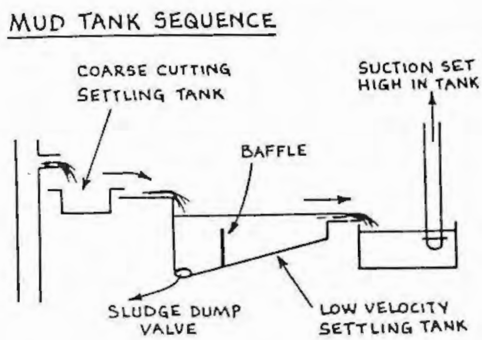
Contributing properties

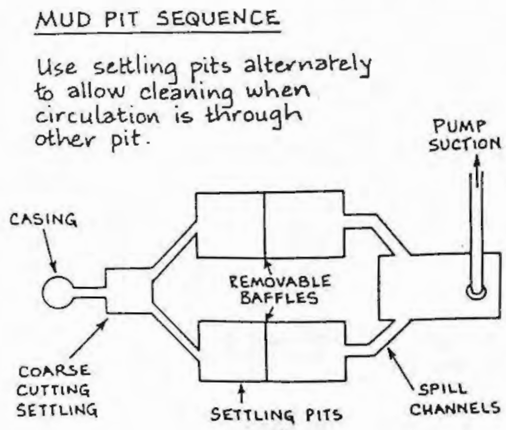
Clean mud depends on good mud properties:

- protection of the walls of the hole and the cuttings against breaking up and mixing into the mud.
- rapid transport of cuttings to minimise contact time.
- efficient separation of cuttings from the mud. (Thin light mud and mud detergent).

Good mud cleaning is accomplished with:

- effective settling pits.
- clearance of cuttings and settled sand/silt.
- desanders used where necessary.





Factors that inhibit mud cleaning

- High viscosity
- Dispersion additives which act to break up shales and clays.
- Failure to monitor sand content or density of mud.
- Attempting to"clean" pit while mud is circulating prevents effective settling.

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Technical Area: 4 Drilling Control

Item: 4-2 Mud Pump Operation

1: Objectives
To be able to explain and advise for how to operate mud pump for effective use.

2. Contents
- Mud Pump Operation

3. Teaching Methods
(1) Explain structure and components of mud pump using operation manual.
(2) Explain capacity (discharge rate and pressure) of mud pump using capacity curve.
(3) Explain precautions for mud pump operation using check-list

4. Materials
4-2M1 DDCA's Manual for Drilling Works

3.2 MUD PUMP OPERATION (TA CODE 4-2)

The discharge rate of mud pump is important for the removal of the drill cuttings. Usual cares shall be taken on the worn out of the parts of the mud pump, because it decreases the discharge rate. In case that the discharge rate decreases during drilling, drill string shall be raised up to the depth up to the safe depth (in the casing) to check the mud pump.

The pump pressure shall be kept recorded as it is an important parameters to identify the borehole conditions. The variation of the pump pressure indicates the following conditions:

<u>Increase of the pressure:</u>

- Encountering clayey formations
- Mud visicosity and/or density is elevated
- Bore wall collapse
- Drill cuttings remains in the hole
- Bit is covered by the clay
- According to the increase of depth

Decrease of the pressure:

- Breakdown of the mud pump
- Mud viscosity and/or density is decreased
- Lost circulation
- Encountering sandy formations

Please refer to Technical Item 2-4 for the further specifications and structure of the mud pump.

Technical Area: 4 Drilling Control
Item: 4-3 Casing for mud drilling

1: Objectives

To be able to explain and advise for specifications of surface and conductor casings and procedure to install and remove them.

2. Contents

- Surface casing
- Conductor casing
- Casing installation and removal

3. Teaching Methods

(1) Explain specification of steel pipes (inside and out diameters, thickness, unit weight, unit length) using specification list of steel pipes.

(2) Explain procedure of casing installation.

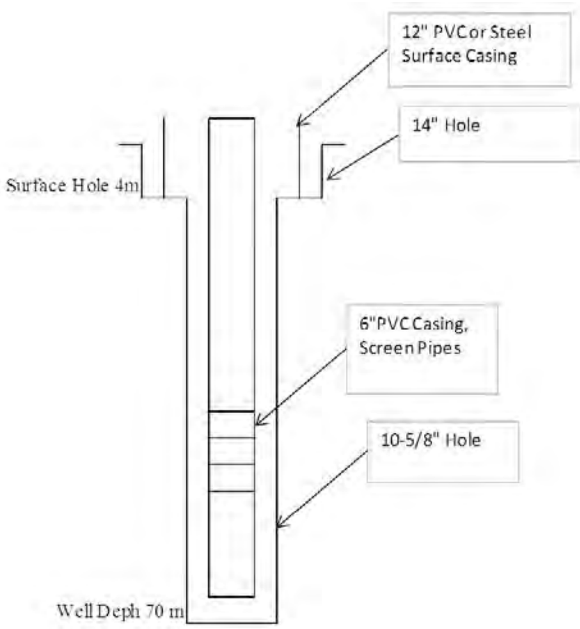
(3) Explain procedure of casing removal.

4. Materials

4-3M1 DDCA's Manual for Drilling Works

3.3 CASING FOR MUD DRILLING (TA CODE 4-3)

The boreholes in sedimentary formation are normally drilled by mud drilling methods in two stages, i.e. surface hole drilling and production hole drilling. Unlike DTH drilling, conductor casing is not installed unless collapsible and/or lost circulation formation exists which shall be protected by the conductor casing. ***Figure 20*** shows an example of the casing program for mud drilling borehole of which production casing and screen pipes are of 6".



The surface casing is required when:

- Surface water must be sealed off
- Unstable formations interfere with drilling, or
- Artesian flows are possible. in this case the surface casing must be cemented

The purpose of surface casing is to isolate freshwater zones so that they are not contaminated during drilling and completion. The surface casing is also necessary for the smooth work around the borehole during the drilling.

PVC casing and screen pipes are used for most of the boreholes in Tanzania. Please refer Technical Item 6-1 for the specifications of PVC casing and screens and Technical Item 6-3 for the installation procedures.

Technical Area: 4 Drilling Control

Item: 4-4 Drilling operation for mud drilling

1: Objectives
To be able to explain and advise for how to control various parameter of drilling and procedures of each work such as pipe connection, cleaning hole etc.

2. Contents
- Weight on bit
- Rotation speed
- Drill pipe connection
- Pipe retrieval
- Drilling log
- Reaming hole
- Cleaning hole

3. Teaching Methods
(1) Explain standard weight on bit to be loaded and rotation speed according to hole diameter and geological condition using manual.
(2) Explain procedure of drill pipe connection and pipe retrieval.
(3) Explain how to keep drilling log using record format.
(4) Explain necessity of reaming and cleaning of hole and precautions for the work, using manual
(5) Explain rig operation using operation manual and daily service check-sheet

4. Materials
4-4M1 DDCA's Manual for Drilling Works
4-4M2 Drilling Chap. 7 P274-284

3.4 DRILLING OPERATION FOR MUD DRILLING (TA CODE 4-4)

Figure 20 shows the process of the drilling works by mud drilling method. It includes many processes and drillers are required to acquire lots of knowledge and techniques. Technical Item 1 to 15 covers all the process and drillers can refer to each material to conduct the works.

DDCA has the report forms for the record of the drilling works. Drillers shall keep proper records of their works using these forms. ***Figure 21*** shows an example of well completion form and ***Figure 22*** is another example of well section drawing.

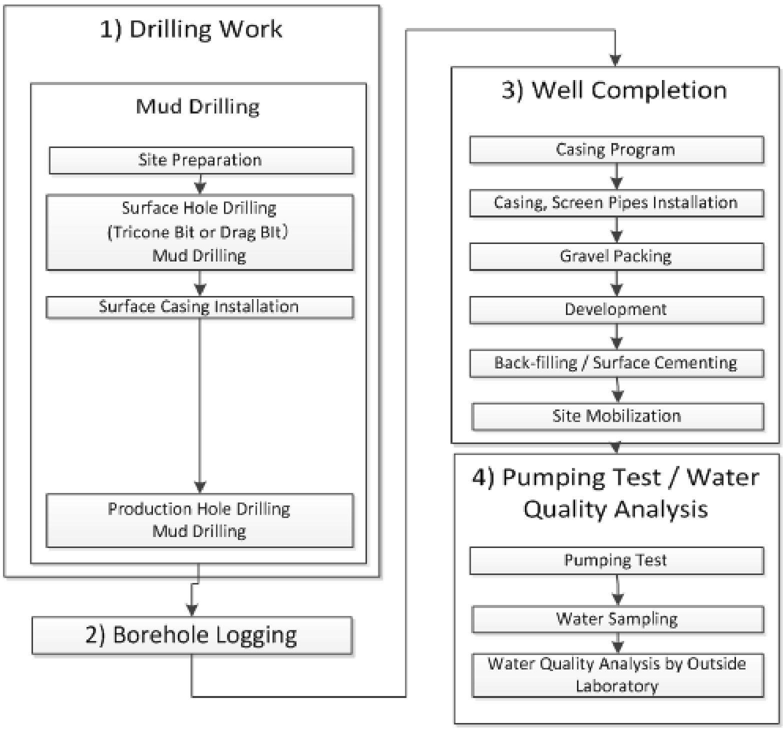


Figure 20 Work Flow of Mud Drilling

DRILLING AND DAM CONSTRUCTION AGENCY
WATER-WELL COMPLETION FORM

Borehole No: TBR 756/2008 **Drilled By (Rig No./Type):** 81
Locación/Área: MSIKITI WA IJUMAA **District:** TABORA TOWN **Region:** TABORA
Name of Applicant & Address: M/S. IGBAR
Date of Commencement: 02.12.2008 **Date of Completion:** 02.12.2008

1. STRATA:

From		To		General Description
m	cm	m	cm	
00	00	04	00	Sand top soil
04	00	06	00	Sandy clay
06	00	08	00	Fractured granite
08	00	12	00	Weathered granite
12	00	24	00	Granite
24	00	30	00	Fractured granite
30	00	34	00	Fractured and weathered granite
34	00	36	00	Granite
36	00	50	00	Fractured granite
50	00	56	00	Granite

2. WATER:
Struck at: 5,38,40 m
W.L. rose to: 02 m 57 cm
Yield tasted: 700 LPH
Water quality to taste: GOOD

3. DIAMETER DRILLED AND DEPTH:
8 **inch Ø to** 56 **m** 00 **cm**
...**inch Ø to**......**m**.......**cm**
...**inch Ø to**......**m**.......**cm**
Depth on completion: 53 m 96 cm

4. CASING/SCREEN LEFT IN HOLE:
Type: **Dia:** **Length:**
uPVC **Casing** 06 **inch** 36 **m** 56 **cm**
.........**Casing**.......**inch**......**m**.......**cm**
uPVC **Screen** 06 **inch** 17 **m** 40 **cm**
.........**Screen**.......**inch**......**m**.......**cm**
Casing above G.L: 00 m 50 cm
Top of Casing Secured: uPVC Cap
Bottom end of Casing protected with: uPVC Plug

5. FINISH OF SECTION UNCASED:
Hole uncased: 02 m 04 cm
Back-filled to: 53 m 96 cm
Filled with: Cuttings **Average size**.......
Other Method: Sanitary seal to 5m

6. GRAVEL SCREEN:
Gravel Type: Quartz **Gravel**
Average Size: 2 – 4 mm
Inserted from:53m 96 **to** 05 **m** 00 **cm**

7. DRILLING METHOD:
Air Rotary to: 06 **m** 00 **cm**
Mud Rotary to:.......**m**.......**cm**
Air Hammer to: 56 **m** 00 **cm**
Cable-Tool to:........**m**........**cm**

MR. TITO MTANDA
Driller in charge signature:
Satisfied this Well has been completed in a manlike manner & drilling regulations have been complied with."

....
MANAGING DIRECTOR:
For: Managing Director
Drilling and Dam Construction Agency
P.O. Box [illegible]
DAR ES SALAAM

Figure 21 DDCA's Well Completion Form

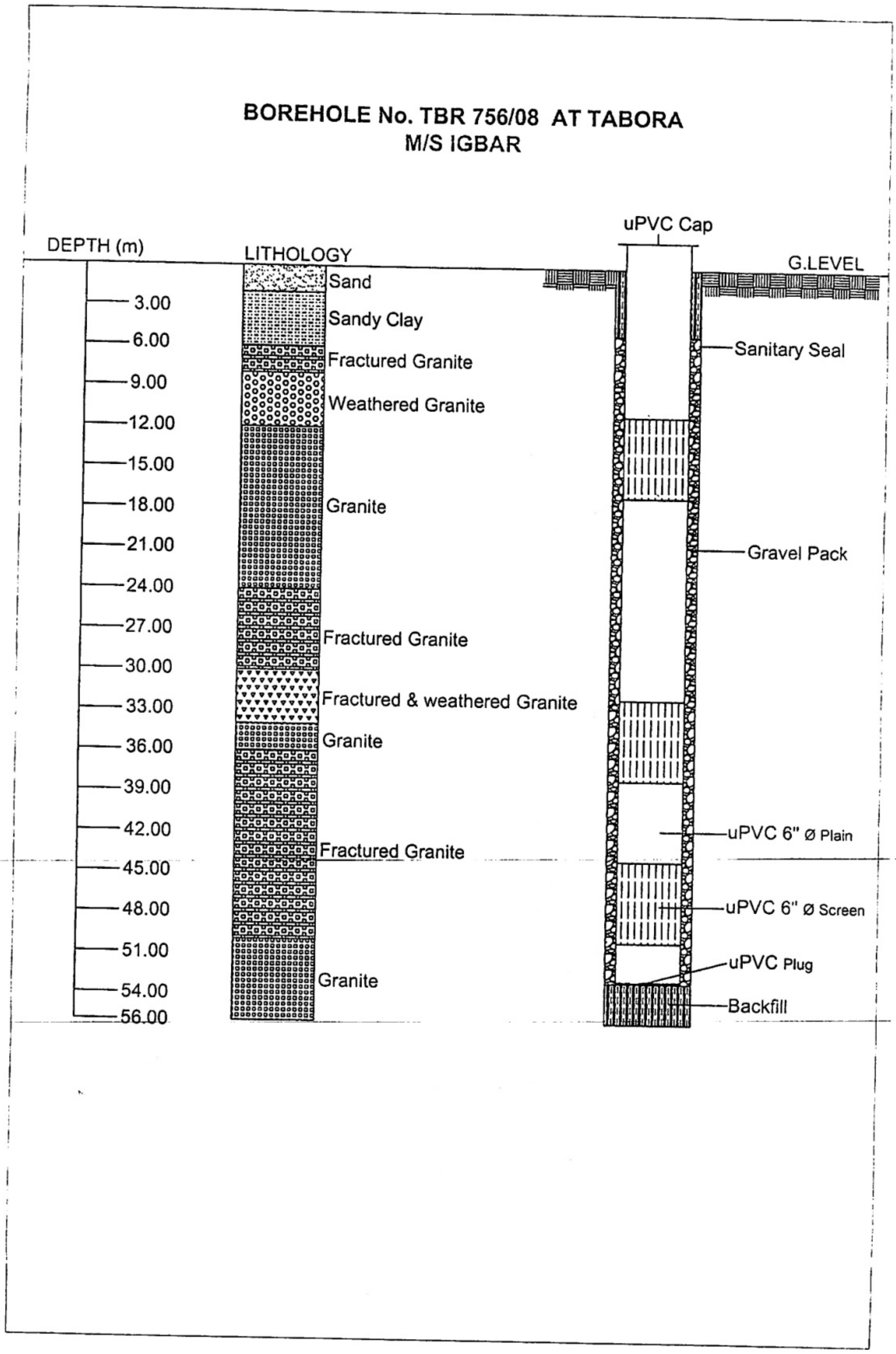


Figure 22 DDCA's Well Section Drawing Form

Section 6 Rotary drilling practice

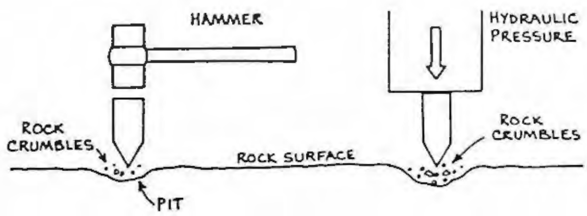
- Rotary drilling summarised
- Selection of a drill string
- Drill string hydraulics
- The bit program
- Penetration using roller bits
- Rotation speed
- Drilling fluids affect penetration
- Penetration using a D.H.H.

Rotary drilling summarized

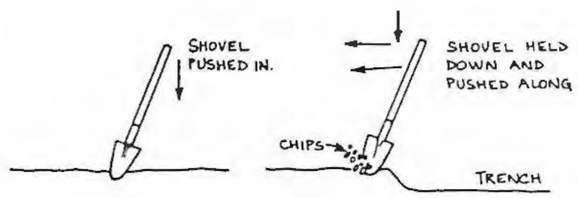
Rotary drilling involves both fracturing-crushing processes and shearing-tearing processes. We need some technical understanding if we are to adjust and refine these processes, but in essence, they are simply stated as follows.

Breaking hard rock: Put a punch on a rock surface and hit it with a hammer. The result? The impact makes the rock under the point crumble. It flies out in small chips.

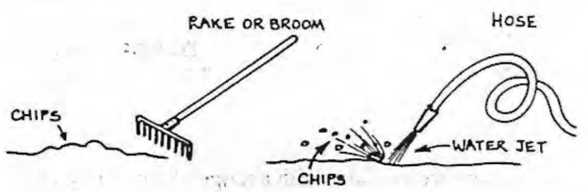
Push the point with a hydraulic press and the same thing happens. You finish up with a small pit on the rock surface.



Tearing soft materials: Push a shovel into soil. When you hold it down, drag it along. Result? Chips plow around the blade leaving a trench in the soil.



Clearing the chips: Chips lying on the surface will interfere with the continuing breaking or tearing: push or scrape them away or wash them away.



These are simple processes. We must examine how we make them happen at the bottom of a hole.

Selection of a drill string

We have seen that the drilling processes are, in essence, simple. We have also learned that the drill string is used to transfer energy and control from the driller's position to the bit.

We have seen that to do the job effectively the drill string must convey a wide range of forces over a wide range of speeds. We have dealt with the make-up of the rotary drill string in Chapter 3.

Drill collar size: Hoisting capacity in light and medium rigs may not be sufficient to handle as much weight as may be desired in the drill collars. But even if large weights cannot be selected, at least we can gain the benefit of the stabilizing effect of a large diameter **stabilizer bar.**

Collar or stabilizer diameter should be approximately 80% of the bit diameter.

For example:

Bit diameter	= 187 mm ($7^3/_8$ in.)
Collar diameter	= 80% of bit diam.
	= 150 mm (6 in.)

Roller-type stabilizers are common in hard rock. Hard-faced wiper types of various designs are used in softer material. These should all rotate freely with the drill string.

A suitable casing diameter should be selected to provide the desired clearance between the casing O.D. and the walls of the hole. This choice will be influenced by formation stability and the casing application; (e.g., whether the casing is temporary or permanent; whether it is to be grouted; or whether sufficient clearance must be provided to allow for a stabilizing fill or gravel pack).

Drill string hydraulics

Most double acting, positive displacement duplex pumps have the ability to achieve adequate hole clearing velocities, providing the annular area is not too large, i.e., the area between drill pipe and hole wall.

An area that is constantly overlooked however, is the pump's ability to overcome pressure (or friction) losses throughout the entire discharge system. Typical pressure losses are:

Pipe fittings	100 kPa (15 psi)
Stand pipe and hose	150 kPa (21 psi)
Swivel	50 kPa (8 psi)
Drill pipe (100 m)	750 kPa (110 psi)
Drill collar	150 kPa (21 psi)
Bit body	200 kPa (30 psi)
Up-hole annulus	100 kPa (15 psi)
Total pressure loss	1500 kPa (220 psi)

These losses are increased if rig piping, swivels, tool joints, subs and drill collars have small inside diameters or restrictions.

Bits inserted with high velocity jet nozzles create the largest pressure (or friction) losses in any circulation system. Therefore, care should be exercised when selecting jet nozzle sizes (if jets are even necessary), to ensure that the pump can maintain adequate pressure to overcome all losses in the system.

We have all tried the hose as a way of washing mud off a floor. We know that it only works when we use a jetting process, that is, when a high velocity flow is used. A jet velocity of 40 m/sec (130 ft/sec) is the lowest that is likely to be of much use in a bore hole. Oil field practice calls for velocities exceeding 100 m/sec (330 ft/sec).

A velocity of 40 m/sec (130 ft/sec) with a flow rate of 15 L/sec (240 USgpm), requires a pressure drop through the nozzle of 1000 kPa (150 psi). If pressures of this order are going to be available, the drill string must be selected so as to minimise pressure losses in other places. A drill string with satisfactory hydraulic characteristics, will allow for half the available pressure drop to be used at the bit. On the small rig, use:

- large bore hose and swivel.
- large bore tool joints.
- large bore drill collars/stabilizers.

The bit program

Geological data and drilling records provide information necessary for the driller to decide on a bit program.

1. Types of bits:

Selection is based on past drilling in similar formations and any particular characteristics of the formations at the drill site. In totally unknown formations, a bit might have to be pulled to check its condition and life.

2. Sizes of bits:

Bit sizes must allow for the desired hole size and the casing program. Changes in hole size will be necessary where the hole design includes:

- setting of surface casing.
- setting of other casing string to overcome down-hole problems.
- under-reamed intervals.

3. Quantities of bits:

An estimate of bit life in each drilling size and formation is made to allow adequate stocks of bits to be ordered.

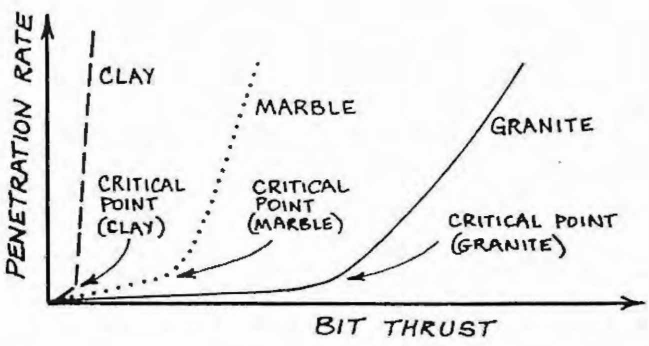
Blade and roller bits: These bits are designed to drill holes of the same diameter throughout their life. A small amount of wear on the gauge cutters during the last few metres of their life is compensated for by reaming the hole when a new bit is run. In abrasive formations or formations where the usable hole size is reduced by "ledges" in the hole, a **reamer** should be run behind the bit to keep the hole "on gauge".

Hammer bits: Percussion bits are worn by the constant rubbing of the cutting faces on abrasive formations. The wear on the gauge causes a steady loss of hole size. The hole steadily reduces in diameter as it gets deeper. The driller using hammer bits must carry a range of bits of differing sizes so that he can run a bit that will operate without binding in the hole.

Penetration using roller bits

The need for maximum penetration rates and bit performance in oilfield drilling has resulted in extensive research into penetration rates. Drillers in other sectors of the drilling industry should take advantage of the results of this work.

Weight of the bit: As we have seen, a driller will aim at providing 80% of the required weight using drill collars. The weight available from the collars (and from the drill pipe) is reduced by the **buoyancy** effect of the mud. A dense mud in the hole will reduce the weight available for driving the bit. Every formation requires a minimum bit force before it will drill. Some formations require much higher pressures than others. Clay, for example, needs only a very small bit pressure for drilling to start; marble needs more pressure and granite more again .



The points of importance to drillers are:

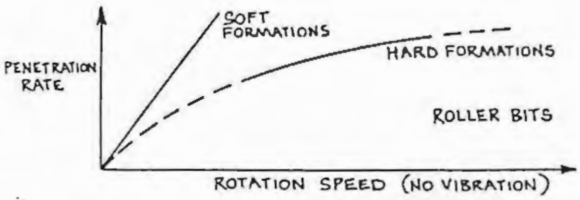
- Materials of high drillability require little pressure to make the bit cut.
- Although most materials will give some penetration with low pressures, the penetration is slow and is produced by wearing or abrading rather than a desirable cutting action.
- Once the critical point for a formation is reached, the penetration rate increases in a "linear" fashion. That is, if increasing the bit thrust by 1 tonne (1 ton) improves the penetration by 2 metres per hour, ($6^1/_2$ ft/hr), an increase of 2 tonnes will bring a penetration rate increase of 4 metres per hour (13 ft/hr).

Drilling operations

Cable tool, hammer and other percussive methods have their own variations on these physical factors.

Rotation speed

An increase in rotation speed will bring about an increase in penetration rate within certain limits.



In soft formations where chips are produced by cutting/tearing actions, the increase in penetration rate is nearly proportional to the change in rotation speed (provided that the chips are all being cleared as soon as they are produced).

The operation of rollers on hard rocks is complicated by "sliding" and "skipping" of the teeth as the rock breaks unevenly. Failure to get complete clearing of the cuttings becomes a larger problem at high speeds. The result is that there is little advantage in increasing the rotary speed above recommended levels.

Bit wear increases rapidly as rotation speed is increased, both for rollers and hammer bits. When using a roller bit at the recommended thrust loading, rotation at twice the speed:

- increases penetration rate 30%
- reduces bit life 50%

There is obviously a trade-off. Both thrust and rotation speed must be kept within the safe and economic limits for the rig and the drill string (including the bit).

Fatigue failures are increased by increases in thrust and rotation speed. These two factors combine with the size of the annulus (the clearance between the pipe and the hole) to control drill string vibration.

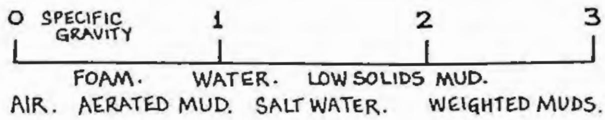
Smooth, vibration free drill operation produces hole most efficiently. Possible gains from high rotation speeds may have to be sacrificed to get smooth operation that reduces the risk of catastrophic problems such as unrepairable bit damage.

Drilling fluids affect penetration

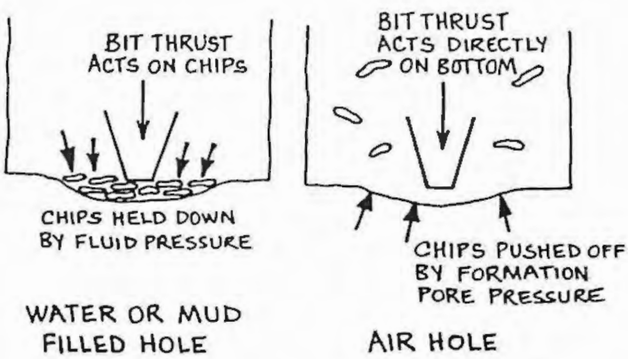
The movement of the fluid carries away the chips as they are produced. The nature of the fluid controls:

- the bottom hole pressure,
- the character of the flow (turbulent),
- the stability of some formations,
- the chip hold-down pressure,
- the formation of filter cake,
- bit wear and chip size,
- lubrication of the bit action,
- adhesion of chips to the bit.

The most important pressure relationship affecting drilling rate is the difference between the pressure in the hole and the pore pressure in the formation. The pressure in the hole is controlled by the fluid density. Fluid density may vary from near zero to 3.5 specific gravity (S.G).

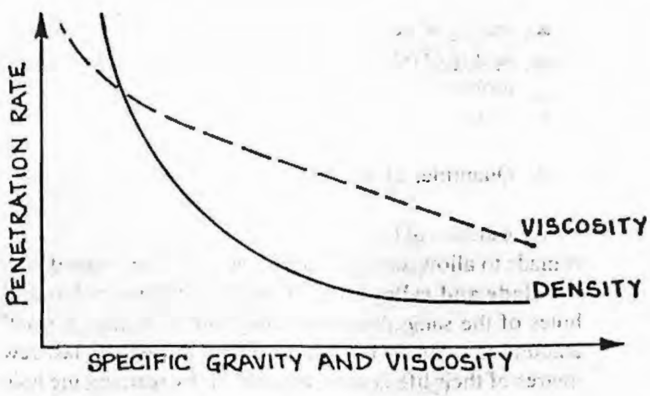


Pressure effects: Formation pore pressure is usually assumed to be in balance with a hole filled with water to the standing water level (S.W.L.). That means that a hole circulating water or mud is operating with a bottom hole pressure exceeding the pore pressure. An air or foam drilled hole has a pressure less than the pore pressure.



A bit operating in a hole having a bottom hole pressure lower than the formation pore pressure is more likely to make new chips as each tooth strikes. The higher formation pressure "pushes" the chips away as they are formed.

Viscosity effects: The graph shows that an increase in density acts quickly to slow penetration, but further increases have little affect. On the other hand, a small increase in viscosity causes some slowing of penetration. As the viscosity is further increased so the penetration goes on slowing.



Viscosity reduces the ability of the fluid to clear the cuttings quickly. Viscosity reduces the pressure available at the bit by increasing pressure losses in other parts of the circulation.

A low viscosity mud gives best penetration rates.

Filtrate rate effects: Chip separation was described in Chapter 5. A mud having a high water loss can allow better chip separation in permeable formations. A mud which quickly builds a **filter cake** can be expected to slow penetration.

Chemical effects: The salinity of the drilling fluid, its pH, and the presence of oil or detergents in the fluid will affect in varying degrees:

1. the hydration and stickiness of shales and clays (high salinity has less effect) and
2. the separation and preservation of chips.

Solids content effects: Fluids with more than 2% sand content cause

1. **lowered penetration rates and**
2. **high wear rates.**

Drilling fluids and their properties and effects are described in detail in Chapter 6.

Penetration using a down hole hammer

Down hole hammers (D.H.H.) draw the energy for penetration from the air supply. The rotary action plays an "indexing" role only. It merely rotates the bit so that the next blow falls on a different part of the bottom of the hole.

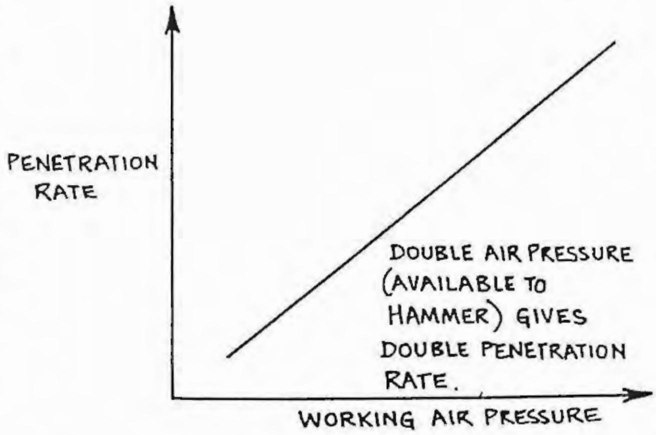
A D.H.H. is designed to provide the energy necessary to fracture hard rocks in a hole suited to the hammer. Larger diameter holes require tools with larger pistons so that the greater mass provides more energy.

The hammer is adjusted, using chokes or plugs in the air passages, to give the air flow through the hammer to clear the chips from the bit.

As the hammer operates in an air filled hole, the bottom hole pressure is always lower than the formation pore pressure.

Chips are "exploded" off the bottom, and highly efficient chip clearing is possible.

Air pressure is critical to the performance of the hammer. Restrictions in the drill string which could prevent full pressure being available at the hammer must be eliminated. **High pressure air** allows for higher energy and faster penetration. The piston is driven faster; it produces more energy per blow as well as more blows per minute. The higher flow rates that come with higher pressure improve chip clearing.



When using a down-hole hammer, it is normal for some energy to be transmitted back up the drill string in the form of vibration. When using a top drive rig, this vibration can result in costly damage to the rotary head components over time. The use of a cushion sub below the top drive head will absorb the shock loadings generated by the hammer, thus increasing bearing life. Some manufacturers also incorporate a floating mechanism into the sub. This device telescopes, allowing the top drive head to remain in one position while threads are made up or broken, effectively reducing the time for making or breaking joints and protecting the threads against damage and wear.

Section 7 Rotary drilling tasks

- Driller's action sequences
- Bit thrust and rotation speed
- Hints for rotary drillers
- Recognising "what's happening"
- Achieving best cutting action
- Operating a down hole hammer
- Operating hints for hammer drillers

Driller's action sequences

The driller's tasks in rotary operations are summarized in the following sections and tables, incorporating the previous discussion. Readers are encouraged to refer to the preceding sections and other relevant chapters.

Drilling operations

THE KELLY (FIRST ROD) DOWN

DRILLER'S ACTION | POINTS TO WATCH | CONSEQUENCES OF ACTION

- With the selected bit (for the hole collar drilling) held in a bit breaker, make up the bit to the kelly.

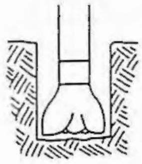
  (Directly on stabilizer bar on top drive machine).

  ➡ To hold the bit safely and to allow correct make up torque, use a bit breaker. Measure or calculate the torque used.

Bit secured ready for drilling to commence.

- Lower bit to within 1 cm of ground (or bottom of starting hole). Insert drive bushing (or guide bushing).

  ➡ Check operation of winches, clutches or hydraulic controls. Rotary drive or steady bushing fits correctly.

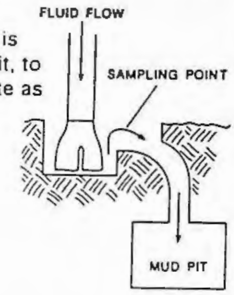


Rotary drive is in position and stabilized.

- Partially open the air supply, or operate pump slowly, to operate circulation.

  Observe flow and operation of chip collection provision.

  ➡ Check that flow through bit is correctly conveyed to the pit, to sample separator or to waste as required.



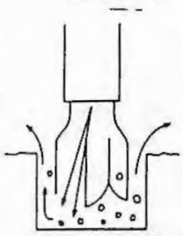
Driller knows that circulation is operating and he is able to collect and inspect samples.

- Engage rotary drive at slow revs.

  ➡ Check that rotary action is operating smoothly.

- Slowly lower bit (engage feed at slow rate). Observe bit starting to cut.

  ➡ Bit is rotating smoothly and chips are being cleared effectively.



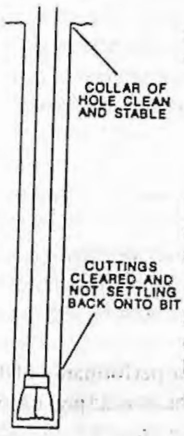
Rotary drive is ready to make hole.

- Increase weight on bit (feed rate) observing that smooth cutting continues.

  ➡ Reduce feed if bit shows signs of "grabbing" or "bouncing".

- Increase rotation speed to desirable speed for the bit in use

  ➡ Check that rotation remains smooth. Smooth operation is first requirement.



Smooth operation is established.

- Increase weight on bit (feed rate) up to rig's capacity.

  ➡ Check steady return of cuttings in keeping with rate of "making chips". Check for "loss" of circulation.

Desirable bit rotation speeds and feed pressures are established.

- When kelly (first rod) is right down, stop feed and rotation. Allow cuttings return to clear.

  ➡ Check that circulation does "clean up". i.e. that a clean stable hole has been achieved.

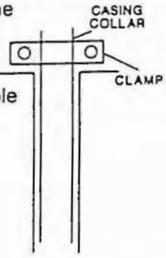
Making hole will be able to continue if a stable clean hole has been established.

THE KELLY (FIRST ROD) DOWN CONTINUED

DRILLER'S ACTION → **POINTS TO WATCH** → **CONSEQUENCE OF ACTION**

- When the hole is clear, pull back the bit: ➡ Check that the bit is free in the hole.
  - – to the table. (Rotary Rigs) ➡ Check the condition of the hole at the collar.
  - – to put the top joint ready for breaking. (Top Drive Rigs). ➡ Decide on changes in the circulating fluid.

  Cut off circulation.



(If a COLLAR CASING is to be set, the bit is removed from the hole and the casing set now).

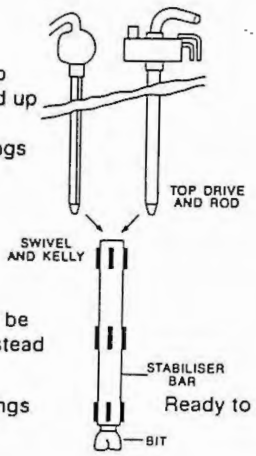
- Rotary table machines; break off the bit. Make up bit (or new bit) to bottom of drill collar/stabilizer. Run bit and drill collar into hole. ➡ Use bit breaker.

  Ensure that newly made up joints are correctly torqued up.

  Watch for cuttings or cavings bottom of hole.

- Top drive machines; break off rod and add new rod. Make up kelly/top rod to drill collar/stabilizer. ➡ If two stabilizer bars are to be run, add extra stabilizer instead of rod.

- Re-start circulation and lower bit to bottom. ➡ Observe whether any cuttings have settled.



Ready to continue making hole.

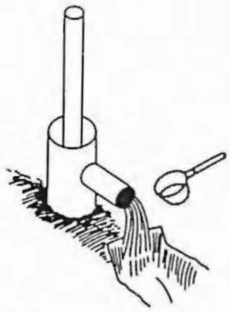
DRILLING WITH BLADE OR ROLLER BITS

DRILLER'S ACTION → **POINTS TO WATCH**

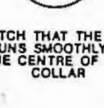
- When fluid is circulating, commence rotation and apply weight to bit (engage feed). ➡ Observe return cuttings, smoothness of return and torque required.
- Increase rotation and thrust to recommended levels (unless drill string or rig behaviour restricts thrust or speed). Match thrust and rotation to:
  - – formation
  - – rig capacity

  ➡ Blade bits require little thrust in soft formations and hold back rather than thrust may be necessary to avoid bogging in.

  Roller bits will skid and wear unless sufficient thrust is applied.
- Adjust thrust and rotation to suit variations in the formation and drill string behaviour. ➡ Watch for indicators of deviation, such as cyclic torque variation.
- Collect and identify returning cuttings. ➡ Monitor penetration rate and circulation loss to correlate with formation changes.



- COLLECT AND EXAMINE CUTTINGS
- RECORD DEPTHS WHEN CIRCULATION FLOW CHANGES IN VOLUME OR COLOUR



WATCH THAT THE PIPE RUNS SMOOTHLY IN THE CENTRE OF THE COLLAR

Drilling decisions will affect:

- SAFETY of crew and rig.
- DAMAGE to rig through vibration, shock or overloading.
- WEAR on bits, drill string and rig components.
- DAMAGE TO HOLE or FORMATIONS penetrated.
- BIT LIFE.
- DEVIATION and DOG LEGS in hole.
- SUITABILITY of CIRCULATION FLUID for down hole conditions.
- QUALITY OF SAMPLE recovered.

Drilling operations

Bit thrust and rotation speed

At the commencement of the hole, safe and smooth rotation and feed rates must be aimed for above any other consideration.

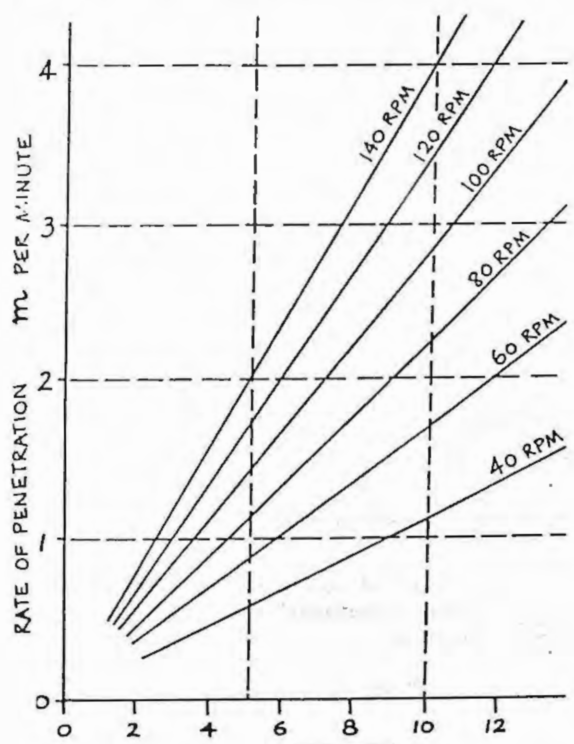
When the hole is safely collared and drilling is proceeding, smooth operation continues to be the prime aim, but while maintaining smooth operation, work to achieve the desirable thrust loadings and rotational speed to give correct chip making.

The chip size produced by a rotary bit is controlled by four factors:

1. nature of the formation.
2. the way that the bit makes the chip (crushing, cutting, tearing etc).
3. rotary speed.
4. penetration rate.

Larger chips mean better samples and less energy required to penetrate. Larger chips also make chip clearing more difficult.

BIT PENETRATION AND ROTARY SPEED



Blade bit chip making: Clearing the cuttings becomes the main problem when penetrating rapidly. Chapter 6 deals with this important subject.

Recommended thrust and speed: While guidelines can be given in the way of bit loading forces and rotational speeds, remember that these are only guidelines. The driller must make the decision in the light of:

1. the formation,
2. the drill string,
3. the interaction between these and the drilling rig.

In Section 6, we said that penetration rate improves as we increase thrust and rotation speed. But this holds true only while the bit operates correctly.

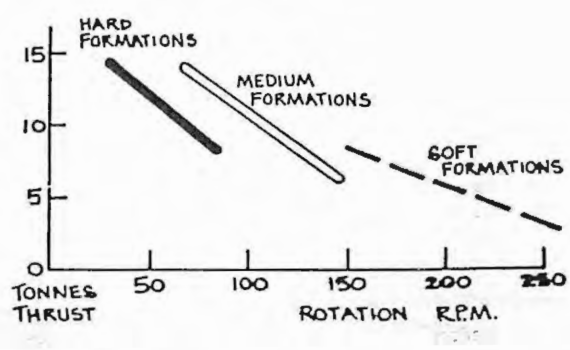
If the bit is overloaded or runs too fast, the bearings break down, the gauge cutters wear rapidly and the chip clearing operation bogs down. For all bits, there is a **maximum thrust** and **speed.** For most bits, there is a minimum thrust to make them penetrate correctly.

Hammer bits must be rotated slowly. Desirable range is 10-25 R.P.M.

Drillability tests have shown that the high drillability formations (those allowing high penetration rates) require less bit thrust and rotation speed than harder formations.

Bits, drill strings and the rig are more likely to be damaged when high thrust and rotation are attempted at the same time. Therefore, the general rule is that formations requiring higher thrust are drilled using lower rotation speeds. In abrasive formations, use very low rotation speeds. For 150-300 mm (6 - 12 in) diameter roller bits, use thrusts and speeds shown on the chart:

ROTARY ROLLER BITS



Drilling using air circulation

- Standard rotary drilling with air circulation, or hammer drilling, requires careful attention to cuttings return and the size and shape of the cuttings.
- Because of its low density and rapid chip clearing ability, air will give superior bit performance.
- A change from air to other fluids may be necessary to achieve hole stability or overcome water pressure or other pressure formations.

- A small water inflow into an air circulation hole can prevent chip clearing.
- Sometimes an **air blow** with the bit just off bottom may clear the hole.
- Hammer tools allow increased air flow when the tool is raised off bottom.
- If this is not successful **misting** should commence. Inject 5-10 litres of water per minute (1.3 - 2.6 US gpm) into the air line to convert the cutting mass to a slurry.

Misting, when air drilling, is used through roller bits or hammers.

Misting has these advantages:

- It eliminates dust, which is a health hazard and can damage equipment.
- It improves cooling of the bit or hammer tool.
- It clears the hole.

But it has a serious disadvantage.

- It accelerates **corrosion.**

After misting, always add oil and a corrosion inhibitor to the rod string and the bit or hammer.

- **Holes producing water** may require the use of **high pressure air** to maintain bottom clearing or hammer operation.
- Loss of pressure across the hammer due to the back pressure of the water column robs the hammer of the energy necessary to achieve desired penetration rates.

Hints for rotary drillers

1. Reduce nondrilling time: Drilling efficiency mainly depends on reducing nondrilling time. Better results are achieved, not so much by fast penetration as by making sure that the minimum of time is lost from the task of **making hole.**
2. Smoothness of operation saves a lot of "lost drilling time".
3. Most vibration and rough running originates down the hole and **wastes energy.** Therefore, have the bit properly stabilized by drill collars or stabilizer bars.
4. Against this is the need for good hole clearing and good circulation flow. Provide the largest annulus possible without bringing on hole deviation and vibration.
5. Reduce recoil and shock waves travelling from the bit (or down hole hammer) up through the string. This can be done by fitting surface type **shock absorbers** in the drill string immediately below the kelly or top drive.
6. Be ingenious and self-sufficient and save money and time. Many tools and parts in rotary drilling can be repaired or manufacturered by the driller.

- Stabilizer bars can be made up or adjusted in size to suit the formation.
- Hole openers for soft formations can be made up by welding replaceable wing blades to a heavy-bodied bit.
- The same for harder formations is done by welding roller cones on a drill collar or heavy sub.
- Blade bits, bit shoulders, wiper stabilisers, and other wear tools can be hard-faced with welding rods incorporating tungsten carbide chips.
- Rehabilitation of bits and recycling of tools are available at a fraction of new part cost.

Recognising "what's happening"

The rotary driller has much to watch over and many indicators to monitor if he is to be properly aware of "what's happening":

- Each indicator could be conveying a range of messages to the driller.
- A thorough understanding of "what's happening" must be gained if the driller is going to "achieve the best cutting action".

INDICATOR	HOW IT WORKS	WHAT IT COULD SHOW
• Circulation flow or flow change.	➡ Flow at collar. Pump/air pressure. Cutting return.	➡ Hole clearing. Hole stability. Formation permeability.
• Penetration rate and rate changes.	➡ Time for measured feed. Feed stops. Rods drop.	➡ Formation change. Bit wear. Hole problems.
• Torque or torque change.	➡ Instrument Reading. Noise in transmission. Engine noise. Pipe/rod "wind-up".	➡ Formation change. Bit wear or damage. Hole deviation. Hole collapse.
• Cutting return and size and shape of cuttings.	➡ Examination of sample collected at collar.	➡ Bit performance. Hole clearing. Bit condition. Formation change.
• Pump pressure or pressure change.	➡ Pressure gauge reading. Hose stiffening or relaxing. Leaking swivel. Pump engine noise.	➡ Drill pipe damage. Pipe or bit blockage. Caving or formation change. Pump malfunction. Mud rings or "balling".
• Rough running of pipe or vibration.	➡ Noise in rig gears. Movement of pipe. Vibration noise. Slowing (or even stopping) of rotation. Rattling of rotary drive.	➡ Fractured or loose boulder formation. Crooked hole. Dry hole Oversize hole. Loose joints in string. Damaged bit.
• Bit weight or bit weight changes.	➡ Weight indicator or feed pressure gauge. Rig jacking up. Torque increase/decrease. Penetration rate or rate change.	➡ Bit loading, unloading or overloading. Bit wear. Formation change. Cuttings not clearing.
• Hole deviation.	➡ Survey reading. Torque increase. Pipe hanging off centre.	➡ Wrong bottom hole assembly. Blunt bit. Incorrect bit thrust.

Achieving best cutting action (A.B.C.A.)

A driller who wants to achieve the best cutting action will watch closely over three things.

1. Smoothness

- Smoothness of rotation.
- Smoothness of engine and other drive noise.

2. Penetration

- Penetration at a consistent rate.
- Penetration at a satisfactory rate.

3. Circulation

- Steady circulation pressure.
- Constant flow and return of cuttings.

In his efforts to achieve these three primary characteristics of good chip making, the driller will;

- be vigilant as conditions change, and
- adopt an experimental approach.

The experimental approach: In drilling it is given that down hole conditions are;

(1) never known exactly.
(2) continually changing.

The only way that a driller can hope to pursue the objective of achieving best cutting action is to *continually* experiment to check that the factors which he controls, are operating at the best possible level.

These factors, listed opposite, must be checked out by examination and *judicious adjustment*, with checks on the effect of the change:

- Bit thrust.
- Rotary speed.
- Bit type and design.
- Bottom hole assembly.
- Frequency and timing of pulling bit.
- Fluid properties and flow rate.
- Hoisting and lowering speeds.
- Attitude and fitness of crew.

The last item is usually the most difficult of all. It is considered in detail in Chapter 13. It is worthwhile considering recommendations and hints in this section in all kinds of drilling operations.

Operating a down- hole hammer

To start drilling, turn on air and rotate slowly. Then feed down slowly until the piston starts operating. Add just enough pull-down pressure to start breaking rock. Make sure the bit does not drift when it first strikes the formation because this can damage the bit buttons.

Always check the operation of a D.D.H. tool before running it into a hole. Try it out first on a solid piece of timber at the surface.

As the tool approaches the bottom of the hole, proceed cautiously to avoid damaging the buttons. Always turn on air and start rotation before putting weight on the bit.

The presence of water in the hole when drilling is resumed will not prevent tool operation. Lowering the tool into the hole with the air turned on will force the water out of the hole.

Bit weight

When the bit first contacts the formation, apply minimal weight on the bit. After a few minutes, increase the thrust pressure to allow the tool to run smoothly.

The correct optimum weight should be monitored and maintained throughout the drilling operation. As the hole gets deeper and drill pipe is added, the thrust pressure must be reduced to compensate for the added weight of the drill pipe. Hydraulic pressure required to keep the optimum weight on the bit varies from rig to rig.

Back pressure

In order to maintain an annular flow of air, water and cuttings, a certain pressure is required. This is called back pressure or bottom-hole pressure, and the tool must exhaust into this pressure.

With high back pressure, the tool will run, but energy per blow of the piston and number of strokes of the piston are less that that developed at zero back pressure.

In order to overcome the back pressure problem, it is necessary to increase air pressure capacity at the inlet. This provides enough increase in inlet pressure to regain the efficiency lost to back pressure. The increase in inlet pressure must be substantially more than the back pressure. If possible, the pressure should be increased until an acceptable drilling rate is achieved. To increase the inlet pressure, more compressed air volume and/or air pressure is required at the surface. This can be done using a booster, which can double or even triple the pressure available from the compressor.

Rotation speed

Proper rotation speed is important for long bit life and optimum penetration. The recommended speed ranges from 12 to 40 rpm. A slower rotation is used in hard, abrasive formations. A faster rotation is acceptable when drilling in soft, nonabrasive formations.

Ideally, the bit should penetrate about 10 mm ($^3/_8$ in) per drill pipe revolution. "Rule of thumb" is penetration rate in metres-per-hour × 1.6 to obtain rpm or rpm about one-half of the penetration rate in feet-per-hour. (Adjust up or down several rpm to match formation.)

Lubrication

Correct lubrication during operation of the D.H.H. tool is extremely important. Inadequate lubrication can be a major cause of tool wear and failure. A positive displacement oil injection pump is recommended to ensure continual oil injection.

When using new drill pipe or pipe that has not previously been coated with oil, approximately 1/2 litre (1 pint) of oil should be poured down the drill pipe each time a new joint is added.

Rock-drill oil is the only lubricant recommended for a D.H.H. tool (for nonenvironmental jobs). It is especially formulated for compressed air-powered, percussion drilling equipment. The characteristics of this oil include high film strength, good adhesion, stable viscosity, a high flash point and the ability to emulsify with water. A grade of oil should be used that is proper for the climatic and operating conditions at the drilling site. Three grades are supplied by the major manufacturers: Grade 10 (light), Grade 30 (medium) and Grade 50 (heavy). The grade number refers to the approximate SAE viscosity number.

The use of mineral-based oils, such as Rock-drill, are usually not permitted on environmental jobs due to the contamination of the sample with oil exhausting from the D.H.H. In such cases vegetable oil-based lubricants, such as Shell X-100 Super M are used.

Operating hints for hammer drillers

A. Maintain good hold-down pressure on the tool and ensure that the hole is being cleaned.
B. For efficient drilling, it may be necessary to clean the hole occasionally by raising the tool 150 to 200 mm (6 to 8 inches) off the bottom to stop the piston from oscillating for about a minute. This allows maximum air to flow through the bit, forcing cuttings from the hole.
C. Small amounts of water may form mud rings and partially block the hole. This is prevented by injecting additional water into the air stream during

drilling. Approximately 8 to 15 litres (2 to 4 gallons), depending on hole size and tool model, of water per minute is sufficient. If the rig is not equipped with a water injection pump, lift the tool off the bottom about 300 mm(12 in), turn off the air, and pour water into the hole to form a slurry. With the tool raised, turn on the air for several minutes to clean the hole.

Water injection during drilling does not harm the tool and can be beneficial to tool performance in some applications. Water injection offers the following advantages:

- it reduces dust damage to the drilling equipment on the surface.
- it protects the health of drilling personnel.
- it reduces temperature of the air preventing close-fitting parts from seizing or galling.
- it helps clean the drilled hole when the formation is producing small amounts of water.
- it acts as a seal on worn parts.

Caution: Personnel should protect themselves from breathing or ingesting dust during drilling operations, particularly if the rig is not equipped for water injection. Remember to increase oil injection rate when using foam or high rates of water injection.

D. If the tool starts drilling extremely fast because of the nature of the formation, the rig's pull-down system may not be capable of maintaining the minimum weight required on the bit. The oscillating piston will strike the bit when it is not against the rock face. Every effort should be made to prevent or decrease this condition because operating the tool with too little weight on the bit is the leading cause of bit shank breakage.

E. If there is drop-off in the size and volume of cuttings or air pressure build-up while the tool is operating at a normal rate, raise the tool without turning off the rotation and work the tool up and down to ensure that the tool and pipe are free before continuing to drill.

F. Cracks in the formation may cause the tool to bind. If this happens, raise the tool, clear the hole with air, and work the tool and pipe up and down to ensure that they are free. Rotate slowly and feed the tool down slowly to resume drilling.

G. If the top of the hole craters, allowing cuttings and debris to fall into the hole, install a short length of casing in the hole, extending 150 to 200 mm (6 to 8 inches) above the surface, and pack rags, clay or dirt around it.

Caution: When rotation stops, the tool will continue to hammer unless it is raised from the bottom. The bit buttons will become buried in the same points of the formation. If rotation is resumed, the buttons may be damaged.

H. Very rough rotation can be caused by a dull bit or certain rock formations.

I. If the tool fails to function properly after all possible external causes have been checked, the problem may be worn or broken parts in the tool itself. Then it will be necessary to stop drilling, disassemble the tool, and inspect it closely according to the procedures provided within the manufacturer's instruction manual.

Section 8 Diamond drilling

- Diamond drilling and rotary drilling
- Diamond bits for friable and soft formations
- Face set bits for harder formations
- Bit selection
- Wear patterns, problems, and remedies
- Reamer shells – diamond care
- Specifying a diamond unit
- Diamond bit rotation and thrust
- The rod drive system
- Loading the bit
- Measuring bit thrust
- Bit rotation speeds
- The drill string – a high speed shaft
- Circulation in diamond drill holes
- Circulation pressure and flow
- Properties of the circulation fluid
- Directional control in diamond drilling

Diamond drilling and rotary drilling

In Chapter 3, we saw the features which separated slim hole coring or diamond drilling from the other rotary drilling techniques. The cutting action of a diamond bit is a subject of continuing debate. There is, however, no doubt that the cutting action is different in formations of differing drillability. And, to some extent, the driller can control the cutting action by selection of:

- diamond size and setting pattern.
- bit thrust and rotation speed.

Much of the material on "making hole" by rotary drilling, as set out in the previous sections of this chapter, has relevance to diamond drillers.

A driller concerned about achieving the best cutting action by careful control of the **chip making** action of a diamond bit also achieves better performance with a standard **diamond drill.** There are some advantages for the diamond driller:

1. The machine, in general, is lighter than the average rotary rig. Being lighter, it is more sensitive to changes in bit performance and the changes are more easily detected by the driller.
2. Hydraulic feed systems are most common. These allow clear and accurate instrumentation of bit thrust.

Technical Area: 4 Drilling Control

Item: 4-5 Bit control and repairing for mud drilling

1: Objectives
To be able to explain and advise for how to control and repair bits for effective use.

2. Contents
-Bit control
- Bit repairing

3. Teaching Methods
(1) Explain how to control bit numbers and check bit conditions using bit log form.
(2) Explain how to recondition roller bits and blade bits using manual.

4. Materials
4-5M1 DDCA's Manual for Drilling Works

3.5 BIT CONTROL AND REPARING FOR MUD DRILLING (TA CODE 4-5)

Rotary bits shall be correctly controlled and the proper repair and/or replacement is required. The excessive use of bits over their lifetime brings about the following problems:

- Under gauge of the hole which causes the wearing of bit and/or tool stucking.
- By the wearing of bearings of roller bits, cones falls into the hole.
- Buttons or pieces of tooth fall into the hole.

For the drag bits, periodical repairing on their blades and gauges by welding is needed.

Drillers are required to conduct proper bit record and repairing/replacement using the log sheet as shown in ***Table 31*** .

Table 31 Example of Bit Log Sheet

<table>
<tr><td colspan="6"><u>BIT LOG SHEET</u></td></tr>
<tr><td colspan="2">Type:</td><td colspan="3">Bit Size:</td><td>Part No.:</td></tr>
<tr><td colspan="6">Bit No.:</td></tr>
<tr><td colspan="6">Date of Issue:</td></tr>
<tr><td colspan="6">To Rig No.:</td></tr>
<tr><td colspan="3">Date of Return:</td><td colspan="3">From Rig No.</td></tr>
<tr><td>Date</td><td>Metrage Drilled w/Bit</td><td>Times Sharpened</td><td>Diameter or gauge after re-sharpened</td><td>Type of Formation Penetrated</td><td>Remark Service Record.</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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</table>

Technical Area: 4 Drilling Control

Item: 4-6 Air control for DTH drilling

1: Objectives
To be able to explain and advise for rolls of air and how to control pressure and delivery for effective DTH drilling.

2. Contents
- Air delivery and pressure
- Annular velocity
- Air control for DTH drilling

3. Teaching Methods
(1) Explain proper air delivery and pressure according to size of DTH and DTH bits using operation manual.
(2) Explain how to calculate annualar velocity and necessary velocity to remove cuttings.
(3) Explain how to regulate air according to drilling conditions using manual.

4. Materials
4-6M1 DDCA's Manual for Drilling Works

3.6 AIR CONTROL FOR DTH DRILLING (TA CODE 4-6)

It can be observed that drilling with Megadrills and Megabits do by far not reach the performance recommended by the manufacturer of the tools. Low penetration rate may result from problem of different nature of operation of Megadrills and bits such as:

- Air supply is not according to requirement resulting in not adequate air pressure in the Megadrill or air volume is not less than 1,200 m per minute or air pressure required for A 53-15 Megadrill not less than 9.0 to 10.3 bar.
- The drill bit is not sharpened properly
- The Megadrill is worn-out, clearance of piston and piston case sealing O- rings worn-out etc.
- Bits are very dully because of overrunning
- The necessary bit weight is not on the bit or there is too much load on the bit (for A 53-15 Megadrills 680 kg minimum weight and 1,600 kg maximum weight (is recommended).
- Rotation of bit is not according to the geological formation and to the expected penetration rate per revolution. Ideally the bit should penetrate 3/8"into the formation of the drill pipe. Generally acceptable revolution per minute are considered with 15rpm to 30rpm
- No use of water injection will create problems of “collaring” or bridging caused by scopage of small amounts of formation water into the hole. To be avoided by injecting 2 to 5 CPM of water into the air stream.
- The “back pressure” created by considerable formation water influx may reduce extremely the penetration rate. To overcome this problem form has to be used in quantities.

Drillers are required to understand the mechanism and function of the air-compressor and the DTH using the operation manual of the manufacturers. They have to consider the static water pressure, back-pressure, annular velocity necessary to remove the cuttings from the borehole and conduct proper operation of the air-compressor.

Technical Area: 4 Drilling Control

Item: 4-7 Air compressor operation

1: Objectives To be able to explain and advise for how to operate air compressor for effective use.
2. Contents - Air compressor operation
3. Teaching Methods (1) Explain precautions for air compressor operation using operation manual
4. Materials 4-7M1 DDCA's Manual for Drilling Works

3.7 AIR COMPRESSOR OPERATION (TA CODE 4-7)

The specifications and structure of the air-compressor are described in Technical Item 2-4. The air-compressor is the major and important equipment for the DTH drilling. Therefore, the drillers are required to acquire the knowledge of the functions, maintenance and operation of the air-compressor. Please refer to other section of this manual related to the DTH drilling, for further comprehension of the operation of the air-compressor.

Technical Area: 4 Drilling Control

Item: 4-8 Casing for DTH drilling

1: Objectives
To be able to explain and advise for specifications of surface and conductor casings and procedure to install and remove them.

2. Contents
- Surface casing
- Conductor casing
- Casing installation and removal

3. Teaching Methods
(1) Explain specification of steel pipes (inside and out diameters, thickness, unit weight, unit length) using specification list of steel pipes.
(2) Explain procedure of casing installation.
(3) Explain procedure of casing removal.

4. Materials
4-8M1 DDCA's Manual for Drilling Works

3.8 CASING FOR DTH DRILLING (TA CODE 4-8)

The boreholes in hard rock formation are normally drilled by DTH drilling methods in three stages, i.e. surface hole drilling, conductor hole drilling and production hole drilling. In general the shallow part in hard rock formation is unconsolidated overburden and is collapsible during air drilling. Therefore, down to 5 to 30 m, sometimes even to 60 m, this overburden shall be drilled by the mud drilling and the conductor casing shall be installed. ***Figure 23*** show an example of the casing program for DTH drilling borehole.

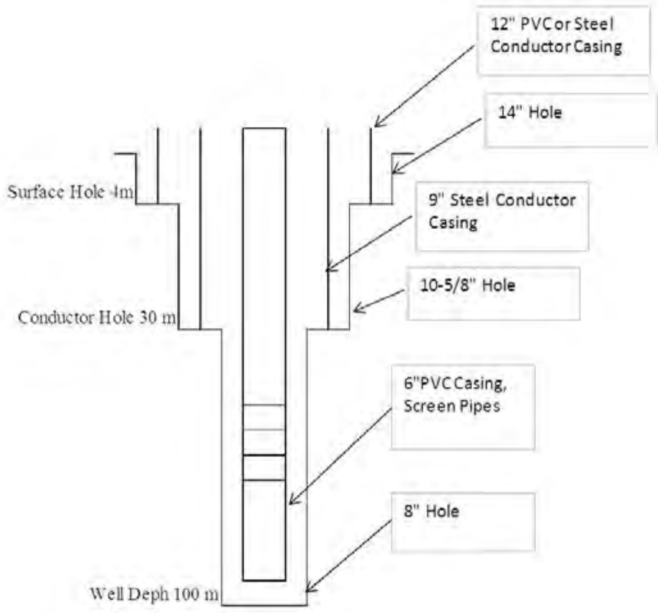


Figure 23 Example of the Casing Program for DTH Drilling

The surface casing is required when:

- Surface water must be sealed off
- Unstable formations interfere with drilling, or
- Artesian flows are possible. in this case the surface casing must be cemented

The purpose of surface casing is to isolate freshwater zones so that they are not contaminated during drilling and completion. The surface casing is also necessary for the smooth work around the borehole during the drilling.

PVC casing and screen pipes are used for most of the boreholes in Tanzania. Please refer Technical Item 6-1 for the specifications of PVC casing and screens and Technical Item 6-3 for the installation procedures.

The conductor casings are in general of steel and with flush joint. In many cases they are temporary and are to be removed after the completion of the drilling work. The preparation of the conductor casing with sufficient number on site is quite important to obtain the smooth progress of the drilling works by DTH. Please refer to Technical Item 2-5 for the specifications of steel casing pipes.

Technical Area: 4 Drilling Control

Item: 4-9 Drilling operation for DTH drilling

1: Objectives
To be able to explain and advise for how to control various parameter of drilling and procedures of each work such as pipe connection, cleaning hole etc.

2. Contents
- Weight on bit
- Rotation speed
- Drill pipe connection
- Pipe retrieval
- Drilling log
- Reaming hole
- Cleaning hole

3. Teaching Methods
(1) Explain standard weight on bit to be loaded and rotation speed according to hole diameter and geological condition using manual.
(2) Explain procedure of drill pipe connection and pipe retrieval.
(3) Explain how to keep drilling log using record format.
(4) Explain necessity of reaming and cleaning of hole and precautions for the work, using manual
(5) Explain rig operation using operation manual and daily service check-sheet

4. Materials
4-9M1 DDCA's Manual for Drilling Works
4-9M2 Drilling Chap. 7 P283-P285

3.9 DRILLING OPERATION FOR DTH DRILLING (TA CODE 4-9)

Figure 24 shows the process of the drilling works by mud drilling method. It includes many processes and drillers are required to acquire lots of knowledge and techniques. Technical Item 1 to 15 covers all the process and drillers can refer to each material to conduct the works.

DDCA has the report forms for the record of the drilling works. Drillers shall keep proper records of their works using these forms. These forms are commonly used between mud drilling wells and DTH drilling wells. Please refer to Technical Item 4-4 for the examples of well completion forms.

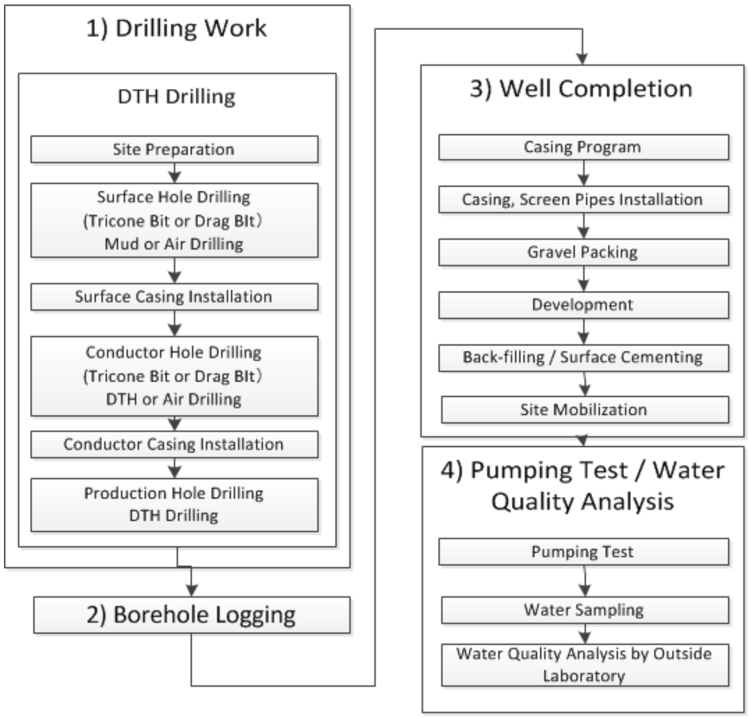


Figure 24 Work Flow of DTH Drilling

- Bit thrust.
- Rotary speed.
- Bit type and design.
- Bottom hole assembly.
- Frequency and timing of pulling bit.
- Fluid properties and flow rate.
- Hoisting and lowering speeds.
- Attitude and fitness of crew.

The last item is usually the most difficult of all. It is considered in detail in Chapter 13. It is worthwhile considering recommendations and hints in this section in all kinds of drilling operations.

Operating a down- hole hammer

To start drilling, turn on air and rotate slowly. Then feed down slowly until the piston starts operating. Add just enough pull-down pressure to start breaking rock. Make sure the bit does not drift when it first strikes the formation because this can damage the bit buttons.

Always check the operation of a D.D.H. tool before running it into a hole. Try it out first on a solid piece of timber at the surface.

As the tool approaches the bottom of the hole, proceed cautiously to avoid damaging the buttons. Always turn on air and start rotation before putting weight on the bit.

The presence of water in the hole when drilling is resumed will not prevent tool operation. Lowering the tool into the hole with the air turned on will force the water out of the hole.

Bit weight

When the bit first contacts the formation, apply minimal weight on the bit. After a few minutes, increase the thrust pressure to allow the tool to run smoothly.

The correct optimum weight should be monitored and maintained throughout the drilling operation. As the hole gets deeper and drill pipe is added, the thrust pressure must be reduced to compensate for the added weight of the drill pipe. Hydraulic pressure required to keep the optimum weight on the bit varies from rig to rig.

Back pressure

In order to maintain an annular flow of air, water and cuttings, a certain pressure is required. This is called back pressure or bottom-hole pressure, and the tool must exhaust into this pressure.

With high back pressure, the tool will run, but energy per blow of the piston and number of strokes of the piston are less that that developed at zero back pressure.

In order to overcome the back pressure problem, it is necessary to increase air pressure capacity at the inlet. This provides enough increase in inlet pressure to regain the efficiency lost to back pressure. The increase in inlet pressure must be substantially more than the back pressure. If possible, the pressure should be increased until an acceptable drilling rate is achieved. To increase the inlet pressure, more compressed air volume and/or air pressure is required at the surface. This can be done using a booster, which can double or even triple the pressure available from the compressor.

Rotation speed

Proper rotation speed is important for long bit life and optimum penetration. The recommended speed ranges from 12 to 40 rpm. A slower rotation is used in hard, abrasive formations. A faster rotation is acceptable when drilling in soft, nonabrasive formations.

Ideally, the bit should penetrate about 10 mm ($^3/_8$ in) per drill pipe revolution. "Rule of thumb" is penetration rate in metres-per-hour × 1.6 to obtain rpm or rpm about one-half of the penetration rate in feet-per-hour. (Adjust up or down several rpm to match formation.)

Lubrication

Correct lubrication during operation of the D.H.H. tool is extremely important. Inadequate lubrication can be a major cause of tool wear and failure. A positive displacement oil injection pump is recommended to ensure continual oil injection.

When using new drill pipe or pipe that has not previously been coated with oil, approximately 1/2 litre (1 pint) of oil should be poured down the drill pipe each time a new joint is added.

Rock-drill oil is the only lubricant recommended for a D.H.H. tool (for nonenvironmental jobs). It is especially formulated for compressed air-powered, percussion drilling equipment. The characteristics of this oil include high film strength, good adhesion, stable viscosity, a high flash point and the ability to emulsify with water. A grade of oil should be used that is proper for the climatic and operating conditions at the drilling site. Three grades are supplied by the major manufacturers: Grade 10 (light), Grade 30 (medium) and Grade 50 (heavy). The grade number refers to the approximate SAE viscosity number.

The use of mineral-based oils, such as Rock-drill, are usually not permitted on environmental jobs due to the contamination of the sample with oil exhausting from the D.H.H. In such cases vegetable oil-based lubricants, such as Shell X-100 Super M are used.

Operating hints for hammer drillers

A. Maintain good hold-down pressure on the tool and ensure that the hole is being cleaned.
B. For efficient drilling, it may be necessary to clean the hole occasionally by raising the tool 150 to 200 mm (6 to 8 inches) off the bottom to stop the piston from oscillating for about a minute. This allows maximum air to flow through the bit, forcing cuttings from the hole.
C. Small amounts of water may form mud rings and partially block the hole. This is prevented by injecting additional water into the air stream during

drilling. Approximately 8 to 15 litres (2 to 4 gallons), depending on hole size and tool model, of water per minute is sufficient. If the rig is not equipped with a water injection pump, lift the tool off the bottom about 300 mm(12 in), turn off the air, and pour water into the hole to form a slurry. With the tool raised, turn on the air for several minutes to clean the hole.

Water injection during drilling does not harm the tool and can be beneficial to tool performance in some applications. Water injection offers the following advantages:

- it reduces dust damage to the drilling equipment on the surface.
- it protects the health of drilling personnel.
- it reduces temperature of the air preventing close-fitting parts from seizing or galling.
- it helps clean the drilled hole when the formation is producing small amounts of water.
- it acts as a seal on worn parts.

Caution: Personnel should protect themselves from breathing or ingesting dust during drilling operations, particularly if the rig is not equipped for water injection. Remember to increase oil injection rate when using foam or high rates of water injection.

D. If the tool starts drilling extremely fast because of the nature of the formation, the rig's pull-down system may not be capable of maintaining the minimum weight required on the bit. The oscillating piston will strike the bit when it is not against the rock face. Every effort should be made to prevent or decrease this condition because operating the tool with too little weight on the bit is the leading cause of bit shank breakage.

E. If there is drop-off in the size and volume of cuttings or air pressure build-up while the tool is operating at a normal rate, raise the tool without turning off the rotation and work the tool up and down to ensure that the tool and pipe are free before continuing to drill.

F. Cracks in the formation may cause the tool to bind. If this happens, raise the tool, clear the hole with air, and work the tool and pipe up and down to ensure that they are free. Rotate slowly and feed the tool down slowly to resume drilling.

G. If the top of the hole craters, allowing cuttings and debris to fall into the hole, install a short length of casing in the hole, extending 150 to 200 mm (6 to 8 inches) above the surface, and pack rags, clay or dirt around it.

Caution: When rotation stops, the tool will continue to hammer unless it is raised from the bottom. The bit buttons will become buried in the same points of the formation. If rotation is resumed, the buttons may be damaged.

H. Very rough rotation can be caused by a dull bit or certain rock formations.

I. If the tool fails to function properly after all possible external causes have been checked, the problem may be worn or broken parts in the tool itself. Then it will be necessary to stop drilling, disassemble the tool, and inspect it closely according to the procedures provided within the manufacturer's instruction manual.

Section 8 Diamond drilling

- Diamond drilling and rotary drilling
- Diamond bits for friable and soft formations
- Face set bits for harder formations
- Bit selection
- Wear patterns, problems, and remedies
- Reamer shells – diamond care
- Specifying a diamond unit
- Diamond bit rotation and thrust
- The rod drive system
- Loading the bit
- Measuring bit thrust
- Bit rotation speeds
- The drill string – a high speed shaft
- Circulation in diamond drill holes
- Circulation pressure and flow
- Properties of the circulation fluid
- Directional control in diamond drilling

Diamond drilling and rotary drilling

In Chapter 3, we saw the features which separated slim hole coring or diamond drilling from the other rotary drilling techniques. The cutting action of a diamond bit is a subject of continuing debate. There is, however, no doubt that the cutting action is different in formations of differing drillability. And, to some extent, the driller can control the cutting action by selection of:

- diamond size and setting pattern.
- bit thrust and rotation speed.

Much of the material on "making hole" by rotary drilling, as set out in the previous sections of this chapter, has relevance to diamond drillers.

A driller concerned about achieving the best cutting action by careful control of the **chip making** action of a diamond bit also achieves better performance with a standard **diamond drill.** There are some advantages for the diamond driller:

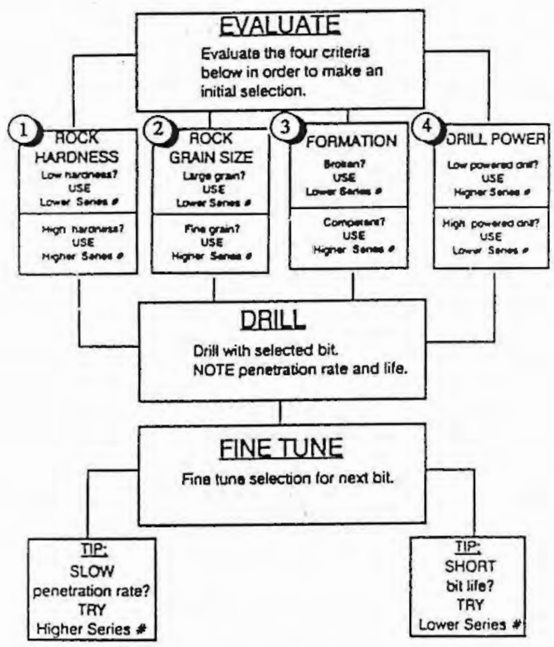
1. The machine, in general, is lighter than the average rotary rig. Being lighter, it is more sensitive to changes in bit performance and the changes are more easily detected by the driller.
2. Hydraulic feed systems are most common. These allow clear and accurate instrumentation of bit thrust.

4-9M2 - 2

3. Most diamond coring is performed in hard or at least consolidated rocks. The range of formation characteristics to be handled is not so great as with rotary methods (but hardly ever uniform).

However, good core recovery is one of the most difficult tasks set for a driller. To achieve it, he needs all of the above advantages. A place to start is proper bit selection. Bit selection, as in rotary drilling, is determined by the rock type. The following figure provides a good introduction to the thought process in diamond bit selection:

SELECTING IMPREGNATED BITS



Provided courtesy of Boart Longyear

Bit designations and rankings: One widely accepted bit ranking system matches bit "series" to the 1 to 10 Moh's degree of hardness ranking.

BIT SERIES	TYPICAL USES
Series 1	For extremly abrasive and broken, softer formations. Should only be used on very powerful drills with high torque, high thrust capability.
Series 2	For abrasive formations and/or most fractured formations. A durable, versatile, general purpose bit for use on all types of adequately powered drills. Higher bit loads than those recommended in the tables may be used without serious risk of excessive bit wear.
Series 4	For medium hard, abrasive, competent formations. Recommended for low powered drills only. Bit loads in excess of those recommended will seriously reduce bit life.
Series 6	For medium to hard, moderately abrasive and partly fractured formations. Less susceptible to overdrilling at high bit loads than is SERIES 4.
Series 8	For hard, competent and non-abrasive formations. This free cutting bit requires high rotational speeds and light bit loads for best performance.
Series 9	Very free cutting bit with very good life in hard competent and non-abrasive formations. Should be used at high rotational speeds and high bit loads. Cannot be stripped down the hole and, should close up, must be re-exposed by sand blasting. Popularly used in underground drilling operations in the smaller sizes.
Series 10	Recommended for ultra-hard, non-abrasive formations. Needs high rotational speeds and low thrusts. With experience this bit can be used to good effect in a variety of other non-abrasive formations.

Provided courtesy of Boart Longyear

Diamond bits for friable and soft formations

As we have seen, these formations are best drilled using cutting, tearing or plowing actions. To cut in this way, a surface set diamond bit (that is, one set with individual stones positioned on the face of the bit) will need large diamonds set to maximum exposure.

Each diamond then acts as a single point drag bit. The diamonds must be arranged to (1) allow good chip clearing from between the points and (2) provide sufficient points to adequately cut the full bottom hole surface. The matrix of the bit must resist abrasion by the coarse particles moving over the face of the bit.

The circulation "water-holes" and waterways must provide the flushing needed to move the chips produced.

Technical Area: 4 Drilling Control

Item: 4-10 Bit control and repairing for DTH drilling

1: Objectives
To be able to explain and advise for how to control and repair DTH bits for effective use.

2. Contents
- Bit control
- Bit repairing

3. Teaching Methods
(1) Explain how to control bit numbers and check bit conditions using bit log form.
(2) Explain how to recondition roller bits and blade bits using manual.

4. Materials
4-10 DDCA's Manual for Drilling Works

3.10 BIT CONTROL AND REPARING FOR DTH DRILLING (TA CODE 4-10)

DTH bits shall be correctly controlled and the proper repair and/or replacement is required. The excessive use of bits over their lifetime brings about the following problems:

- Under gauge of the hole which causes the wearing of bit and/or tool stucking.
- Buttons or pieces of tooth fall into the hole.
- Progress of drilling decreases when the buttons of bits are worn.

Periodical sharpening shall be conducted to keep the good drilling progress. Please refer to Technical Item 2-3 for the repairing of DTH Bit.

Together with Bit Log Sheet (Technical Item 3-5), DTH tool shall be controlled using the DTH log sheet as shown in

Table 32 Example of DTH Log Sheet

DTH LOG SHEET				
Model:				
No. of Tool				
Date of Issue:			To Rig No.:	
Date of Return:			From Rig No.:	
Date	Hours tool/Run	Metrage Drilled	Type of Formation Penetrated	Remarks, Cleaning Servicing Tool

Technical Area: 5 Borehole Logging

Item: 5-1 Borehole logging instruments

1: Objectives
To be able to explain and advise for principles, measuring items and operation procedures of borehole logging.

2. Contents
- Principle of borehole logging
- Resistivity, SP, gamma ray
- Operation of borehole logging

3. Teaching Methods
(1) Explain purpose of borehole logging using manual.
(2) Explain meaning of resistivity, SP and gamma ray using manual.
(3) Explain the operation of borehole logging instrument using manual.

4. Materials
5-1M1 DDCA's Manual for Drilling Works

4 BOREHOLE LOGGING (TA CODE 5)

4.1 BOEREHOLE LOGGING INSTRUMENTS (TA CODE 5-1)

4.1.1 GENERAL INFORMATION ABOUT BOREHOLE LOGGING

Many of the geophysical survey methods for groundwater exploration, which are carried out on the ground-surface, can also be used within a borehole in vertical direction.

- **Resistivity well logs – RES**

  Resistivity logging, usually called electric logging, provide a useful tool, and the information gained increases in general the effectiveness of the well design. A good log gives a detailed picture of the character and thickness of the various formations at the well site and an indication of the water quality by measuring the apparent resitivity of the subsurface material cross-sectioned in the borehole. Electric logging offers several important advantages, such as locating the top and bottom of each distinct layer, determining relative water quality, and differentiating fresh hard rock layers from fractured and weathered parts. A limiting factor in electric logging is that the method can only be done in boreholes that do not have casings and are filled with drilling fluid or water. The method is therefore best to be carried out in rotary mud circulation boreholes.

  Please note that in low-yield boreholes in hard rock formation, it is advised to carry out borehole logging the other morning after drilling was completed to allow the water level to rise for one night due to low recharge conditions.

- **Spontaneous Potential (SP) Logs**

  Self-potential or spontaneous potential logs are always run in conjunction with the electric logs. Spontaneous potentials are naturally occurring electrical potentials (voltages) that result from chemical and physical changes at the contact between different types of formation material. In a borehole, potentials also occur between the drilling fluid in the borehole and the fluid in the formation and also between the drilling fluid and the filter cake on the borehole wall.
  As in the case of drilling DTH in Swaziland, where fluid in the borehole is the same groundwater as in the formation, there cannot be a difference in the potential of both waters (fluids). In general SP logs make only sense in boreholes filled with drilling fluid (drilling mud).

  To measure SP at various depths, an electrode is lowered into an uncased borehole filled with drilling fluid as one electrical terminal. The terminal of the arrangement is connected as a ground terminal at the surface, which is often placed in the mud pit. The down-hole electrode is usually negative with respect to the surface electrode. Any current in the circuit, which results from electrochemical action between the drilling fluid and the formation or formation water, is conducted to the surface through the drilling fluid column. The milli-voltmeter connected between the electrodes, therefore, measures the drop (difference) in potential in the drilling fluid column between the down-hole electrode and the surface electrode.

  As the down-hole electrode is moved up and down in the borehole, the meter registers variations in spontaneous potentials of the different formations. A curve showing these potentials plotted against borehole depth provides what is called the SP log. Although the SP log may indicate the permeable zones, there is no definite relationship between the magnitude of the SP deflection and the permeability and porosity of the formation. Variations shown by the SP curve are interpreted along with variations in apparent resistivity shown by the resistivity curve. The two curves together constitute what is usually called the electric log.

  The SP log is plotted on the left-hand of the curve sheet, where it can be compared easily with the resistivity log on the right-hand side.

- **Natural Gamma Ray (GR) logs**

In gamma logging, measurements are made of naturally occurring radiation coming from the materials encountered in the borehole. The record of gamma radiation is used as a qualitative guide for correlation of formations and permeability of formations.

Gamma radiation is emitted from certain elements in geologic materials that are unstable and decay spontaneously into other more stable elements. Gamma rays are similar to X-rays in that having a great ability to penetrate other materials (for example even steel casings), but gamma rays have a shorter wave length.

Certain radioactive elements occur naturally in igneous rocks (granites, gabbros) and metamorphic rocks (slate, mica-schist, gneiss) and as depositional particles in sedimentary rocks. Clays and shale contain high concentration of radioactive isotopes, usually potassium. Sands and gravel on the other hand contain primarily silica, a stable substance, and therefore emit only very low levels of radiation.

So gamma ray curves of silica rich, light colored, acidic rocks, such as granites, gneiss and sandstones are showing deflections in the curve to the left.

Gamma ray logging has a fundamental advantage over electrical logging. It can be done either in cased wells or in open boreholes containing air, water, or drilling fluid. Therefore with gamma ray it is possible logging existing wells, where logs have been lost or were not carried out. The gamma probe is very simple, having a detecting element, which is measuring the pulses given off by the radioactive materials in the different formations. The radiation extensity is expressed as the average number of counts per second (cps).

The minerals normally found in sedimentary materials such as clay, silt, sand, or sandstones contain small amounts of radioactive potassium-40, and decay products of uranium and thorium. Potassium is an important constituent of clay minerals, mica, feldspar, and shale. Quartz sand contains no potassium or radioactive potassium-40. Quartz sand formations emit gamma-rays at extremely low levels. Normally the gamma logs show more cps at depths, corresponding to clay or shale layers and few cps at depths corresponding to sand or sandstone layers, if the sand is mostly consisting from quartz.

4.1.2 OPERATION OF BOREHOLE LOGGING

Components of the equipment of the Geologger 3030:

- Power winch 3895
- Geologger 3030 machine
- Combination Probe (GR, SP, RES)
- Sheave, sheave stand and supporting legs
- 2 Batteries 12 V
- 2 Surface electrodes
- Power supply cords
- Cable for Geologger 3030 to power winch
- Cable for Geologger 3030 to sheave

Connection of the equipment:

1. Join up the components of the probe (GR + SP/RES) then seal the joint with insulation tape

2. Connect slowly the winch connector to the probe turning slowly until there is a click sound, and then lock the link
3. Connect the battery to the power winch
4. Sheave stand is then put over the borehole and sometimes there might be a need for the sheave's stand additional / support legs in case, when the temporary casing is more than 30 cm above the ground
5. Then wind the cable from the winch, while the probe lies on the ground, to the sheave wheel and the direction of the wheel will be decided by the winding of the cable. The winding of the cable should be in a cross manner and sometimes, just wind it straight. Then use the lock to prevent any slippage. Lock the probe cable with the lock knob from the wheel to avoid any slippage of the cable from the wheel and getting damaged
6. Connect the cables from power winch and sheave to connector panel of Geologger
7. Connect the earth electrodes to the connector panel and then to the ground with the B-near (black) the borehole- and the N-30m (red) maximum away from the borehole and they should be connected to wet ground.
8. After all the connection from the connector panel has been completed and the setting of the sheave then the probe is put inside the borehole. Then connect the cable from the Geologger to another battery.

Operation of the equipment:

Set the probe into the borehole and knowing the casing top above ground level, you will know exactly the top of the spring of the probe would set level with ground level.

Set the power switch "ON" and the menu will be displayed at the LCD display. As the menu items are displayed, they will respond to function keys shown to the left of the menu, F1 to F4.

First step

For the display and the setting of date and time, observe the following procedures:

- Choose date and time by pressing F1
- Setting the date by pressing the key (*) star. This enables you to set the date, "YY MM DD", by putting in the figures from the keyboard.
- Set the time by pressing the hash key (#). This enables you to set the time, " HH MM SS", by putting in the figures from the keyboard. Then enter.

Second step:

- Choose system by pressing F4
- System check by pressing F1

This enables the machine to check that everything is functioning well and if it is in order. It will let you know in case, which part of the system is not ok.

Note: If there is an error, for example with the floppy disk drive, it will tell you where the error is, and all you have to do, is to check, if the floppy disk is inside and then slightly press or move it sideways. Then cancel and restart system check.

Third step:

- Choose measure by pressing F3
- Measure by pressing F1

Depth input will appear, and then change depth to zero and then press enter. Sign change due to the direction of probe movement from sheave by pressing F1, if necessary – then press enter.

- Then set the gamma range, which is normally 0. 2K cps by pressing F3 – then press enter
- The ampere range is automatically set.
- Input sampling interval is normally every 10 cm, but can be change to other measuring interval.
- On the display will appear >>Reset data & start. Just press enter.
- After measuring press the enter key.
- Enter ID No. of the borehole. Then enter.
- Print out click play back on F2
- Input of ID No. This helps to know the file, in which the recorded data are stored on the floppy disk. This is entered with three figures e. g. M2-10-2, ID No. is 001 when measuring down and 002 when measuring up. With more reference to the recorded data, there is a sheet that needs to be filled for ID No. and borehole No.
- Depth scale selection is normally 1/500, but select by pressing F4.
- Selection of gamma scale can be selected from the keyboard from 1 to 9.
- Selection of resistivity scale can be selected from the keyboard from 1 to 9.
- Selection of Spontaneous Potential (SP) scale can be selected from keyboard from 1 to 5.

Please note for the scale selection of the different methods, it is important to observe constantly the measuring keyboard, while driving the probe down. Then you know the scale in which the measured values, ohmmeter for RES, mV for SP and cps for GR, are lying and subsequently you choose the appropriate scale for the print out process. The pictures of ***Figure 25*** shows the above procedures.

1.Measuring of the water level before Logging

2. Preparation of the Loging Equipment

3. Outlining the principles of the borehole-logging methods

4. Explaining the installation of sheave stand on top of the borehole

5. Arrangement of the logging equipment

6. Explanation of how to connect the cables to the equipment

7. Explaining the probes

8. How to insulate the probes

9. Connecting the probe to the winch

10. Inserting the probe into borehole

11. Explaining operation and measurementwith Geologger

12. Carrying out the borehole logging

13. Trainee personnel running the borehole-logging

14. Explanation of logging interpretation and casing plan

Source: JICA's Water Supply Project in Swaziland

Figure 25 Work Procedure of Borehole Logging (Geologer 3030)

Technical Area: 5 Borehole Logging

Item: 5-2 Interpretation of borehole logging results

1: Objectives
To be able to explain and advise for how to determine screen position from borehole logging results.

2. Contents
- Interpretation of borehole logging results
- determination of screen position

3. Teaching Methods
(1) Explain how to identify water bearing layer from curves of resistivity, SP and gamma ray.
(2) Explain how to determin screen position.

4. Materials
5-2M1 DDCA's Manual for Drilling Works

4.2 INTERPRETATION OF BOREHOLE LOGGING RESULTS (TA CODE 5-2)

4.2.1 INTERPRETATION OF BOREHOLE LOGGING RESULTS

- **Interpretation of electric logs**

The electric log cannot be used to qualitatively identify the material encountered in the borehole, because the measured resitivity is a function of various different parameters, such as composition of the drilling mud or the fluid in the borehole, fluids in the formation, diameter of the borehole and the distance of the electrodes within the measuring probe. Depth related rock samples recovered during the drilling (drilling cuttings) are required for positive identification of specific geological formations. Dry formations are poor electrical conductors and show very high resistivities as well as fresh and dense igneous, metamorphic and volcanic rocks, such as granites, granodiorites, amphibolites, gneiss, dolerites, basalts and ryolites. Saturation of a formation reduces its resistivity. The reduction again is partly controlled by the porosity of the formation.

The type of material is only factor, which is influencing the resistivity. Water in the pore space is always mineralized differently due to the material of the formation and it's chemical composition. So various different factors are influencing the resistivity and experience is an important factor in the interpretation of electric logs. Knowledge of the general trends and the spectrum described above are also very important. In the hard rock formation of Swaziland high resistivities are usually indicating dense and dry hard rock types, whereas curves changing to lower resistivity values are indicating fractures and fissures and weathered formations, which can be filled with groundwater.

- **Interpretation of SP logs**

Interpreting SP logs is generally very difficult and it makes only sense to analyze logs which were carried out in an uncased borehole filled with drilling fluid and in a borehole having distinctive clay layers to provide a so called baseline (clay line). Please note here that SP logs published from oil-field works are completely different from SP logs run in water-wells. It is important to understand the differences between oil-well and water-well SP curves. In general groundwater associated with oil is salt water. The electrical conductivity of this water is extremely high in comparison with the conductivity of the water in the drilling fluid.

Groundwater suitable for drinking water purposes has low dissolved solids, on the other hand, and therefore has a much lower conductivity than oil-field brine. Its electrical conductivity may be about the same as, or even less than, the conductivity of water in the drilling fluid. Thus, the electrochemical reaction between the formation water and the drilling fluid is quite different, depending on whether the formation water is considerably more salty than the drilling fluid (oil-field condition), or whether the formation water has about the same salinity as the drilling fluid (water-well condition). When a permeable formation (aquifer) contains salt water and the drilling fluid is made with fresh water, the SP normally shows a relatively large deflection to the left in relation to the clay baseline. The SP deflection opposite the same formation containing fresh water, however, would be relatively small. Another way to describe the difference is to note that the formation with salt water shows a high negative potential in relation to clay layers, whereas the formation with fresh water shows only a slight negative potential. Some helpful observations in interpreting SP logs for formation with fresh water:

- It is often difficult to interpret a SP curve at shallow depth. SP deflections are more pronounced in moderately deeper to deeper wells because, as depth increases, the ground-water tends to become more highly mineralized.
- The first step in interpretation is to establish a clay baseline (shale baseline) on the log. If clay layers are not present, the SP log add little information to the interpretation. For many wells, the SP curve may be of little value, because variations in the curve may be

insignificant.

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- Note deflections to either the left (negative) side or the right (positive) side of the clay base-line. Formations having deflections to the left, generally indicate groundwater having higher chemical activity than formations having deflections to the right. These deflections indicate the positions and thickness of aquifers containing fresh water. Deflections in the SP curve may be insignificant unless the formation has at least a thickness of 1 – 1. 5 m.
- Conclusions drawn from the SP curve will generally correlate with data from the resistivity curve, although the SP curve will usually move in opposite direction.
- The clay baseline may shift gradually or abruptly at increasing depth for no apparent reason.
- SP curves should always be used in conjunction with resisitivity or other logs, because it may be particularly difficult to interpret the curves.

- **Interpretation of Gamma Ray (GR) logs**

In the hard rocks, we can say simply that silica rich, light colored, acidic rocks like granites, gneiss, contain less radioactive decaying minerals and showing less cps, than rocks with less silica content, but high in micas, dark colored, basic rocks, like diorites, gabbros, amphibolites, shales contain more radioactive decaying minerals, showing more cps.

A problem of interpretation is related to the borehole diameter. As we know, gamma ray can only be detected around the borehole wall into the formation with a distance of about 0. 3 m. Where caving clay or shales are encountered and a wash-out occurs, the gamma ray log will indicate low cps opposite of the enlarged section of the borehole. Thus the log will appear to indicate a sand- or granite formation. Borehole samples, the driller's log, and a caliper log can be used to minimize this difficulty in interpretation.

4.2.3 Determination of Screen Position

After having successfully carried out the borehole-logging operation, the casing plan has to be established. As described earlier, in certain low-yielding wells it might be suitable to carry out the logging the other day, allowing the low recharging water table to rise to the static level. The following information is necessary to establish a sound casing plan:

- Situation of the static water level after completion of drilling
- Depth of various or single water strikes
- Description of the drill cutting samples
- Penetration rate records
- Measurements of water quantities at various depths
- Information about the stability of the borehole wall
- Drillers general observation of fracture zones and water strikes

Generally, high yielding water wells with distinctive, groundwater producing fractures zones need only a limited quantity of screen length opposite of the fractures. Low yielding wells however, or wells with a certain number of micro fractures need a longer screen length to exploit groundwater as much as possible from every fracture present. In order to achieve a hydraulically good connection between the well and the aquifer(s), it is good practice to install one screen section only, for better inflow conditions of the groundwater into the well.

For a more safe installation of the well assembly into the well, it is common practice to drill some 1-3% deeper than the depth, at which it is intended to place the bottom cap of the casings. The following pipe-lengths are available to install within the project:

- Plain casing length of 5.72 m
- Plain casing length of 2.81 m
- Plain casing length of 0.93 m
- Plain screen length of 2.81 m

The depth calculation of the casings and screens to be installed into the borehole should start from the bottom to the top of the borehole, indicating as well the portion of casings, which is going to stand over the ground surface. Knowing from the records the height of the drilling table of the drilling rig above ground surface, it is possible to indicate exactly the casing depth.

Screens need to be placed opposite of groundwater bearing zones (aquifers) and not shallower than the first water strike, which was reported during drilling. The project is not allowing the installation of screens at a shallower depth than 20 m below ground surface.

Generally on top of the bottom cap (lowest part of the well) a so called sedimentation pipe or sump pipe has to be installed, being a plain casing pipe with 2.81 m length.

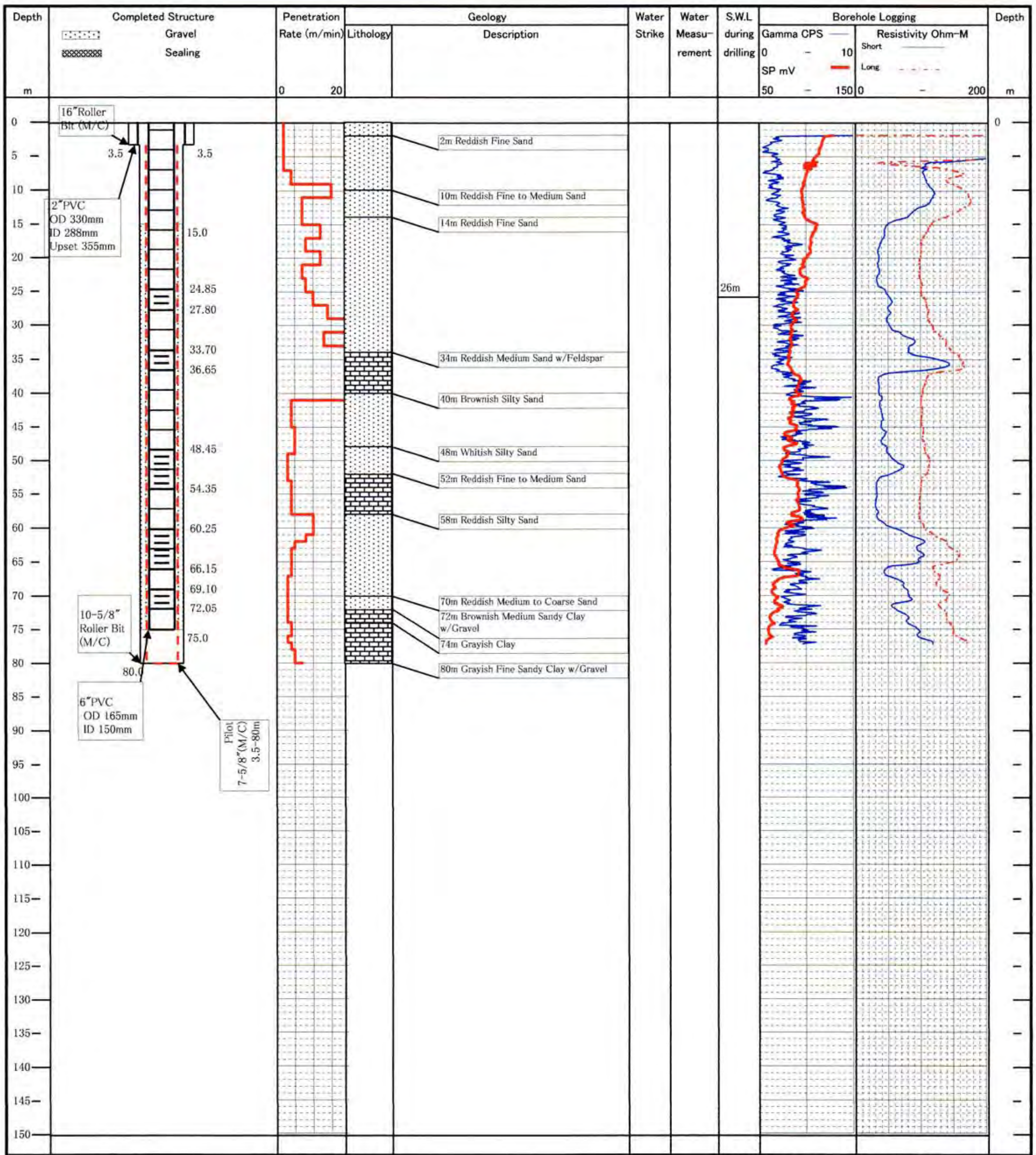
Centralizers have to be installed around casing and screens in the depth where gravel pack is intended to be placed, in order to keep the pipes centrically in the borehole and allowing the gravel pack to be placed evenly around the screen pipes.

Figure 26 shows the example of logging results and casing program for a borehole in sedimentary formation in Kisarawe region. ***Figure 27*** shows the one for a borehole in hard rock formation in Bagamoyo region. Principally, resistivity shows the high value at the position of the aquifer in sedimentary formation. On the contrary the resistivity of the aquifer in hard rock formation becomes higher than the formation with lower water contents.

Form No.: QC-4-6
QC Item: Drilling Work
Form Name: Drilling Report

GPS Coordinates:
Logitude (E) 38-38-21.96
Latitude (S) 07-21-38.76
Elevation (m): 314

		Date of Submission:	5-Nov-07
BH No.	KSW-1-BH3	Date of Commenceme	8-Oct-07
BH Order	DD-009	Date of Completion	1-Nov-07
Borehole No.	CO 562/2007	Contractor	DDCA
Vil No.	KSW-1		
Village	Chole		
Village/Street	Chole		
District/Municipality	KISARAWE	Rig	Pat 301 TP / Schran
Region	COAST	Driller	Elia Samuel / Melkiol
Scheme No.	KSW-1		
Scheme	Chole		



Remarks	Submitted By:	Inspected By:
The borehole did not produce any water. It was judged to be unsuccessful. The pumping test and the water quality analysis were not carried out.	Contractor	Consultant

Figure 26 Example of Logging Result and Casing Program (Sedimentary Formation)

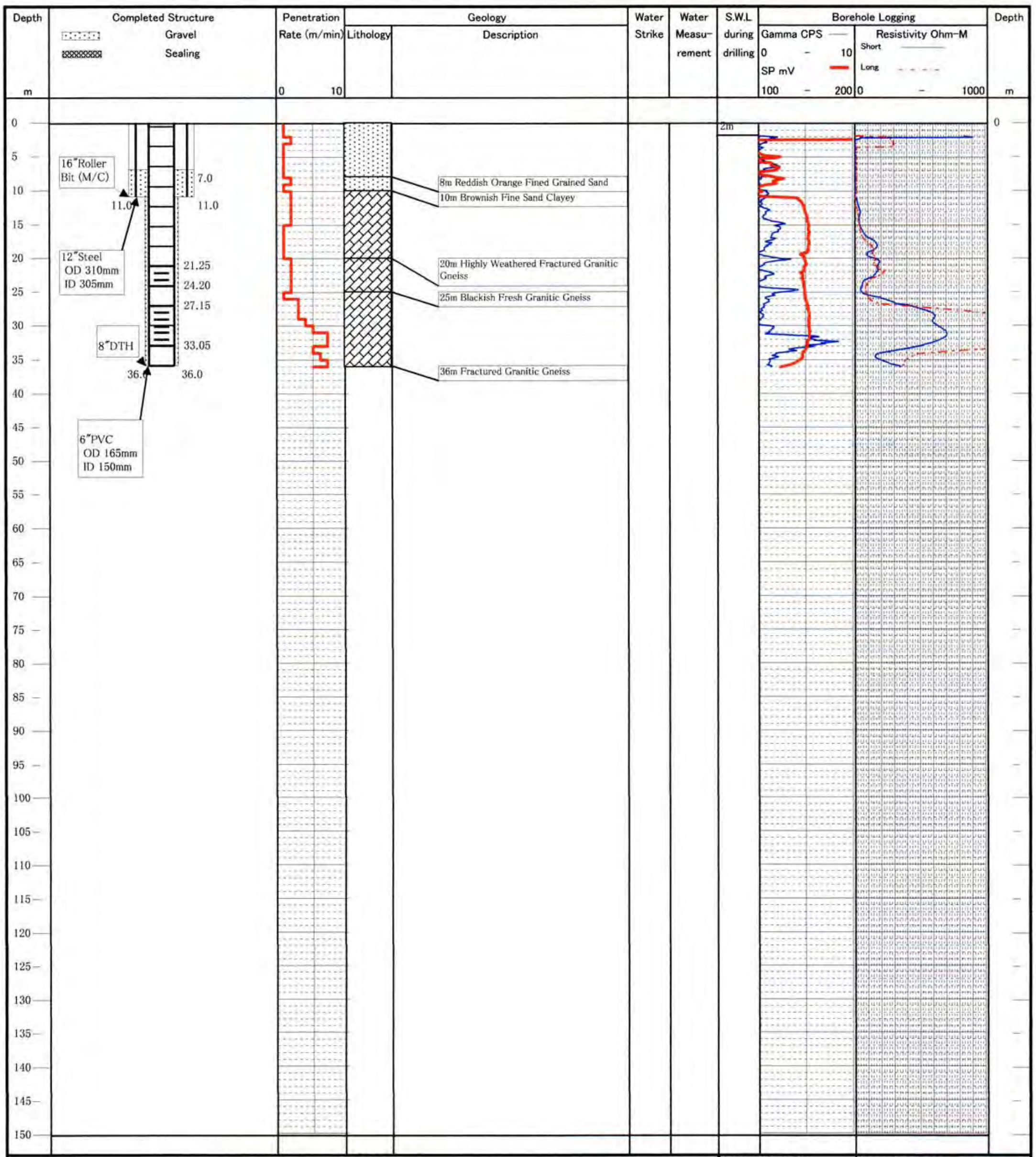
Form No.: QC-4-6
QC Item: Drilling Work
Form Name: Drilling Report

GPS Coordinates:

Logitude (E)	Latitude (S)
37-55-41.28	05-59-30.00

Elevation (m): 401

		Date of Submission:	5-Nov-07
BH No.	BGM-1-BH1	Date of Commenceme	21-Sep-07
BH Order	DD-008	Date of Completion	13-Oct-07
Borehole No.	CO 543/2007	Contractor	DDCA
Vil No.	BGM-1		
Village	Kibindu		
Village/Street	Kibindu		
District/Municipality	BAGAMOYO	Rig	Schramm 49 / Schra
Region	COAST	Driller	Steven Halinga / Kar
Scheme No.	BGM-1		
Scheme	Kibindu		



Remarks

The water was taken from the fractured gneiss deeper than 11m.
Surface steel casing remained in the borehole.
Borehole was judged to be successful.

Submitted By:	Inspected By:
Contractor	Consultant

Figure 27 Example of Logging Result and Casing Program (Hard Rock Formation)