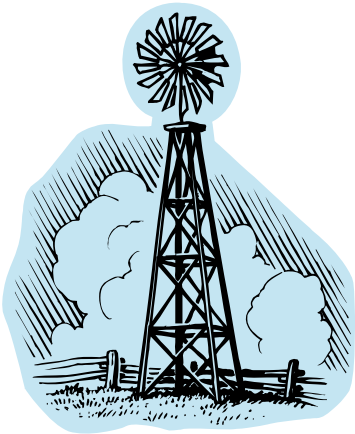
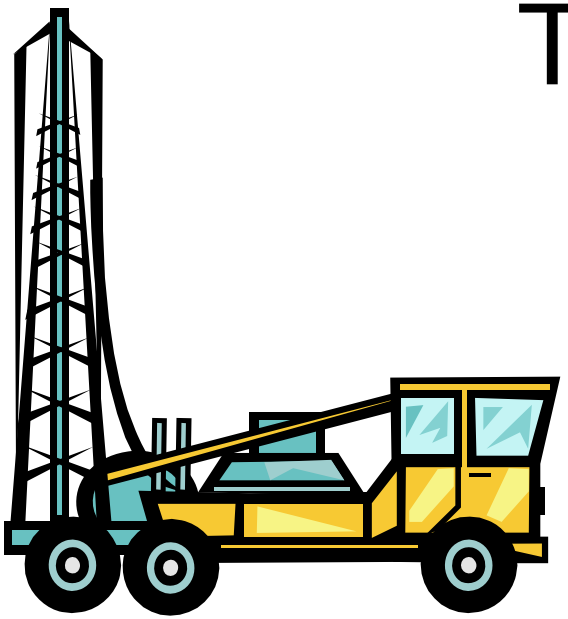
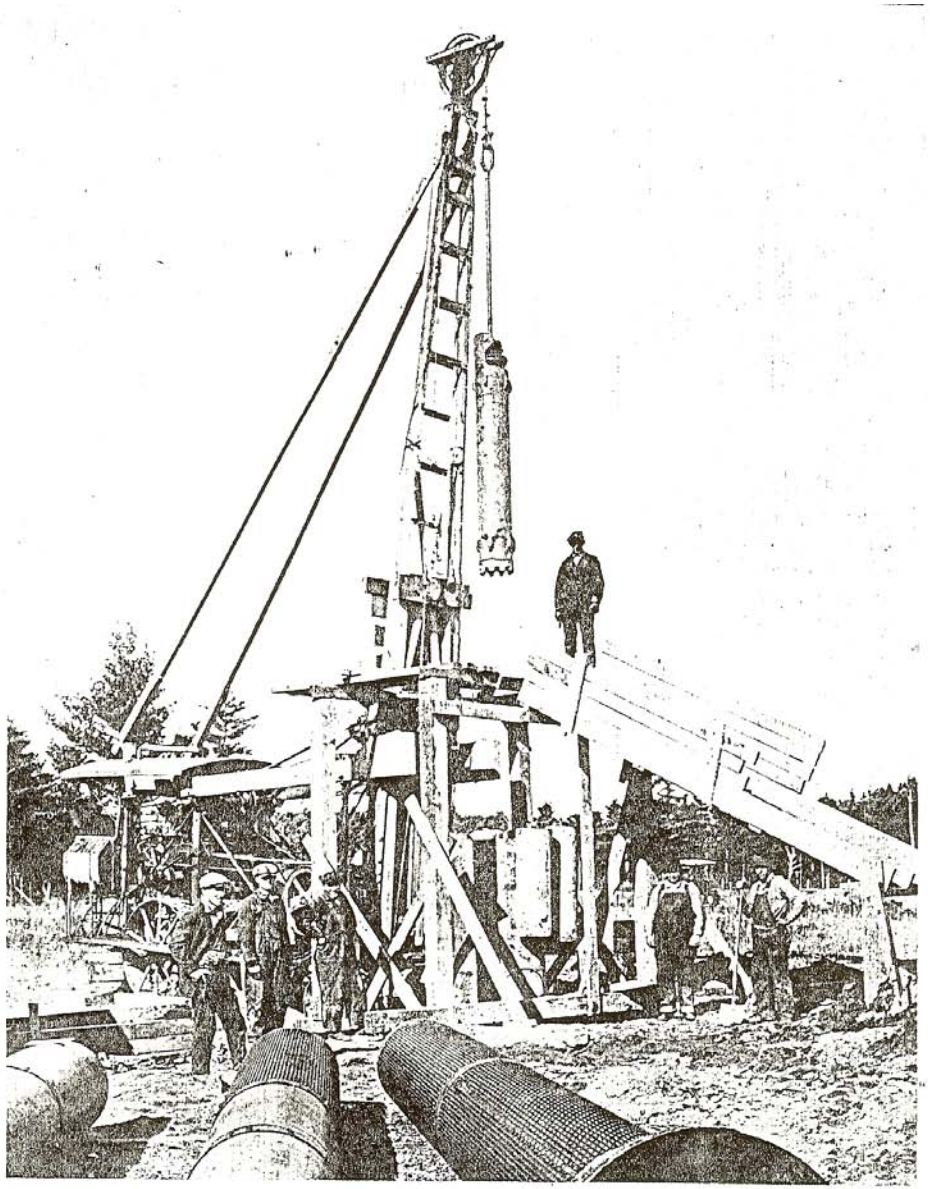


Advances in Well Drilling Technology



Early Well Drilling

- The earliest known drilling method was Chinese bamboo tools. (Spring pole salt-drill).
- One of the first European wells drilled was in 1832 and was a French Artesian well.
- Cable tool drilling was standard drilling technology from the late 1800’s to the mid 1950’s.
- The mid 1950’s brought the new technology mud rotary drilling.
- Not long after the mid 1960’s was the advent of air rotary drilling.
- The 1980’s brought us duel rotary and sonic & coil tube technology.



Sinking well of large diameter in sand. H. J. Fischer, Marathon, Wisconsin

This unusual well was drilled by H. J. and S. R. Fischer. It is 42 inches in diameter, 86 feet deep and required 137 hours to complete. It was drilled through formations of clay and boulders, gravel, sand gravel and boulders. Note the large vacuum sand-pump in the derrick.

Solid Drill with Hemp Rope

Circa 1930

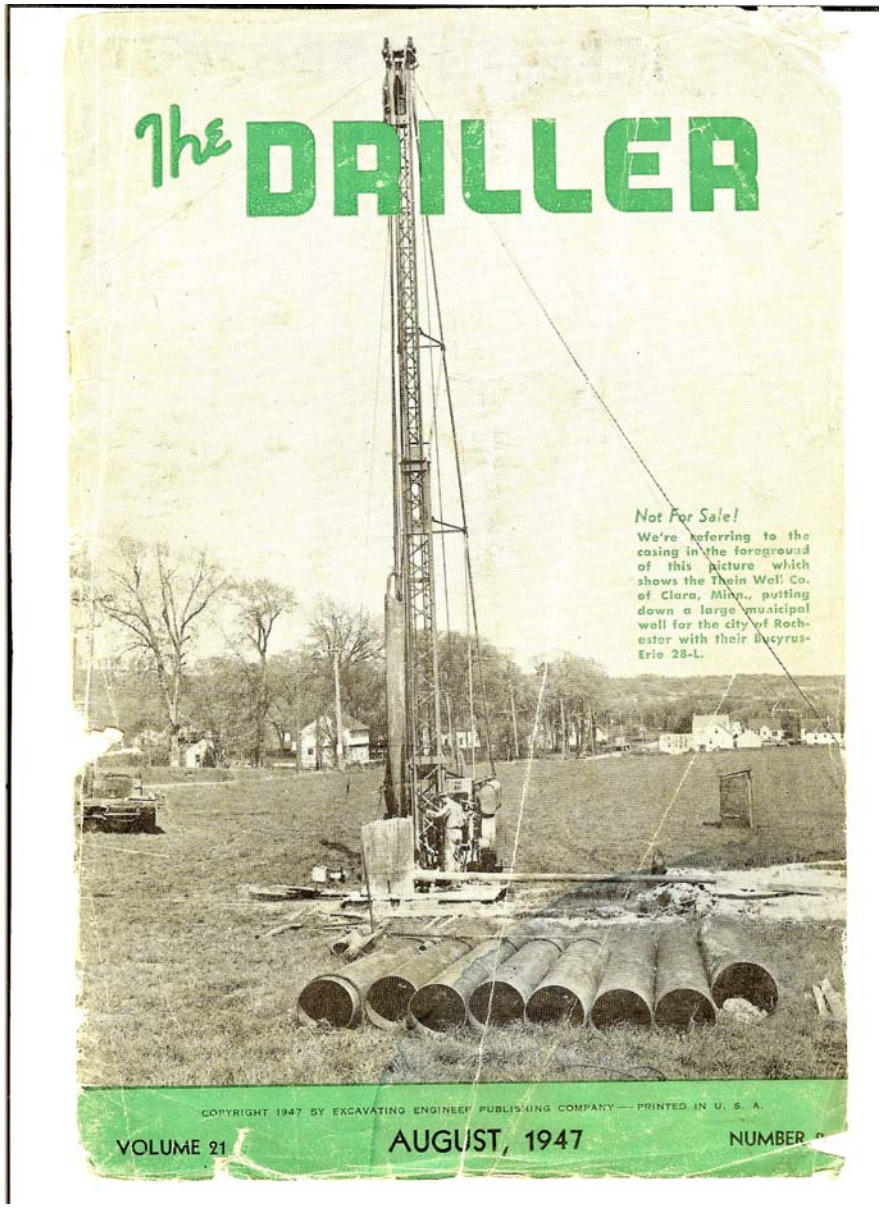
Truck Mounted Unit

Circa 1920

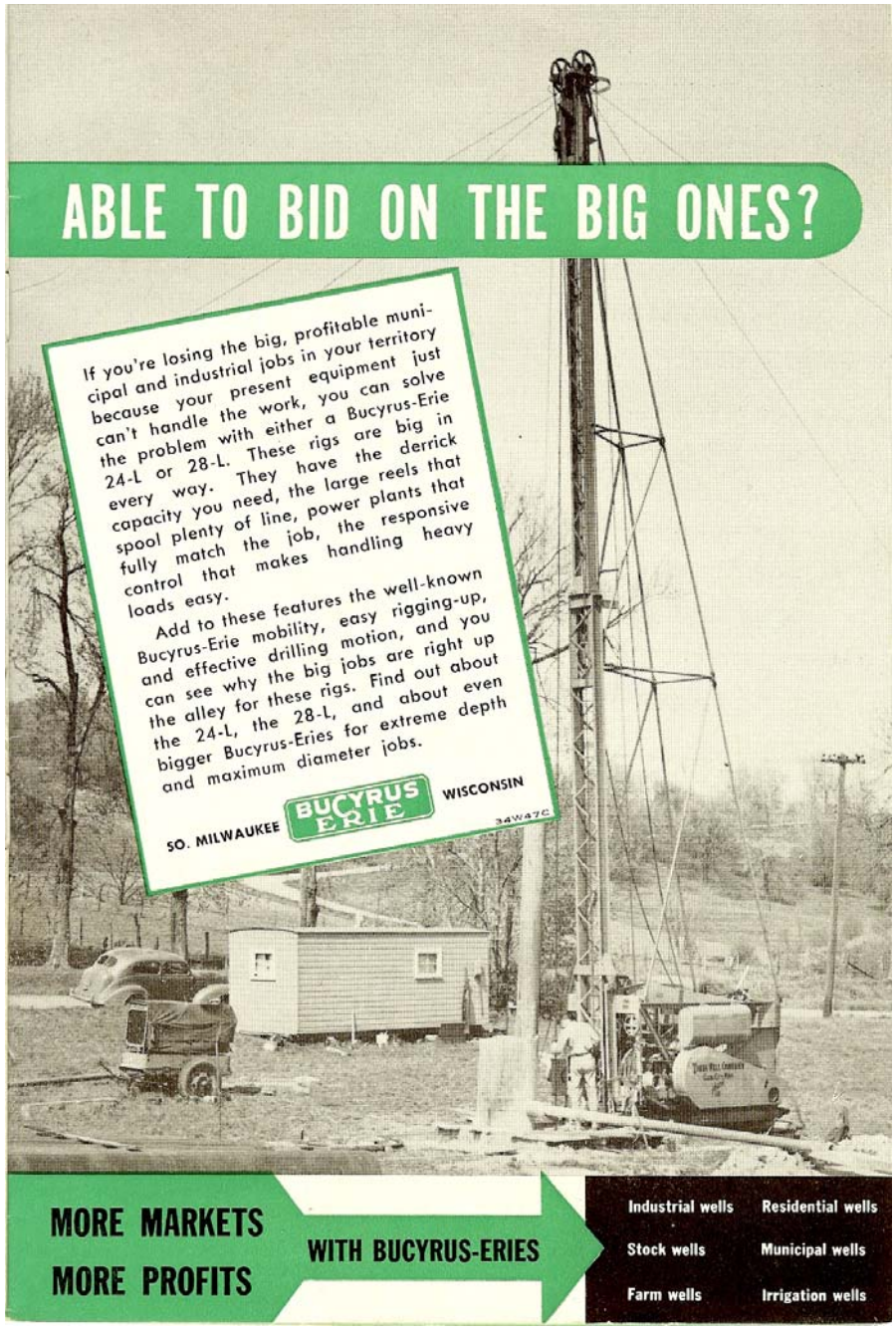
Truck Mounted Drilling

Circa 1930

The 1940's saw the advancement of larger diameter cable drilling

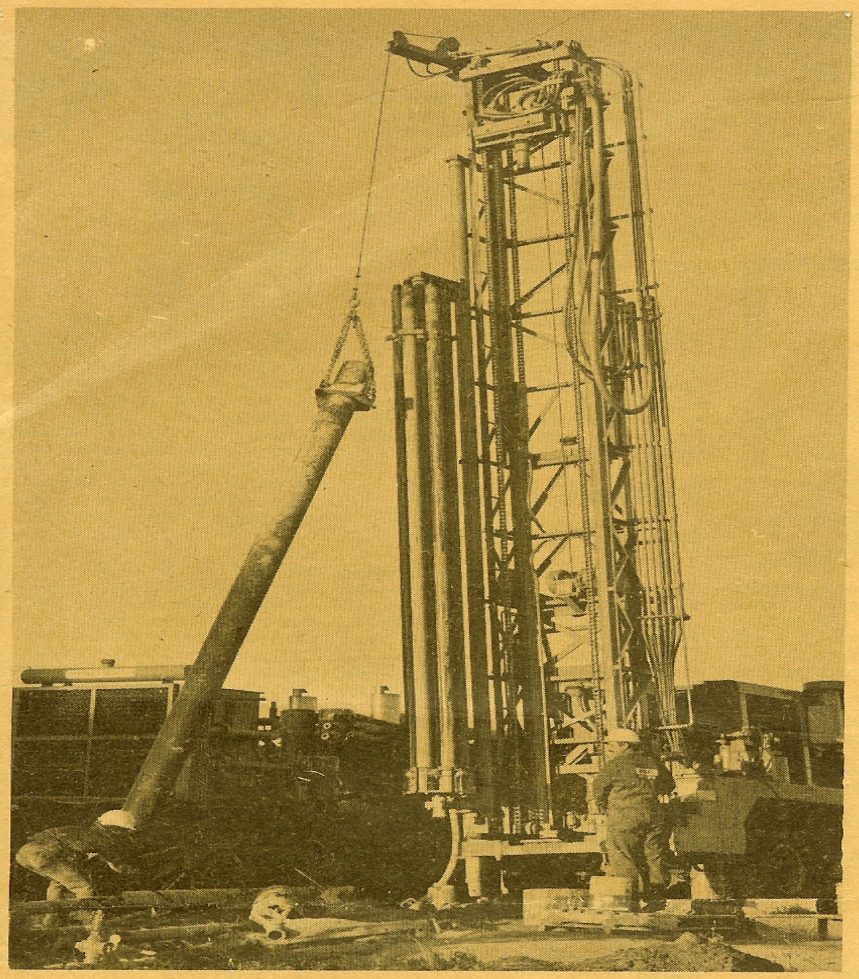


This 1940's drilling rig was capable of drilling to 2,000 feet.



Similar to the 1940's was this drill rig in the 1950's.

Year around operations

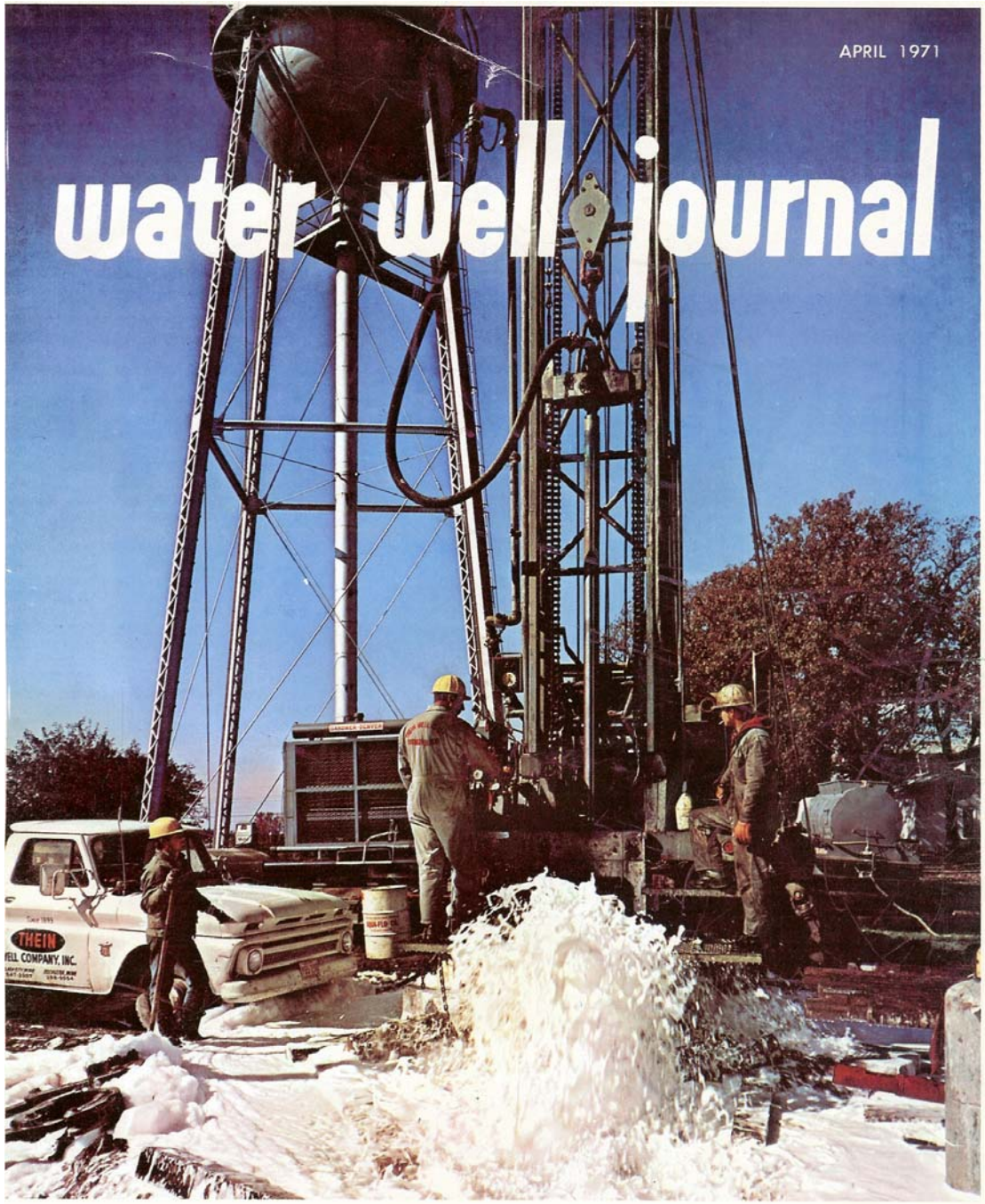


Work got started last week on the new well in Garretson which will supplement the town's two other wells and double the water supply. The Thein Well Co. is doing the work. Engineers are Schmitz-Kalda and Associates.

Garretson will soon have twice as much available water

The 1960's brought us

Air Drilling



High Pressure Air being used in the 1970's

Typical Water Well Site

1,400 foot Well in West Bend, IA

Circa 1980

Typical Residential Site
Circa 1980

Typical Municipal Site

Modern Drill Operation

Well Completion with 2,000 gpm
Dundas, MN

Reverse Package
University of MN

Dual Rotary

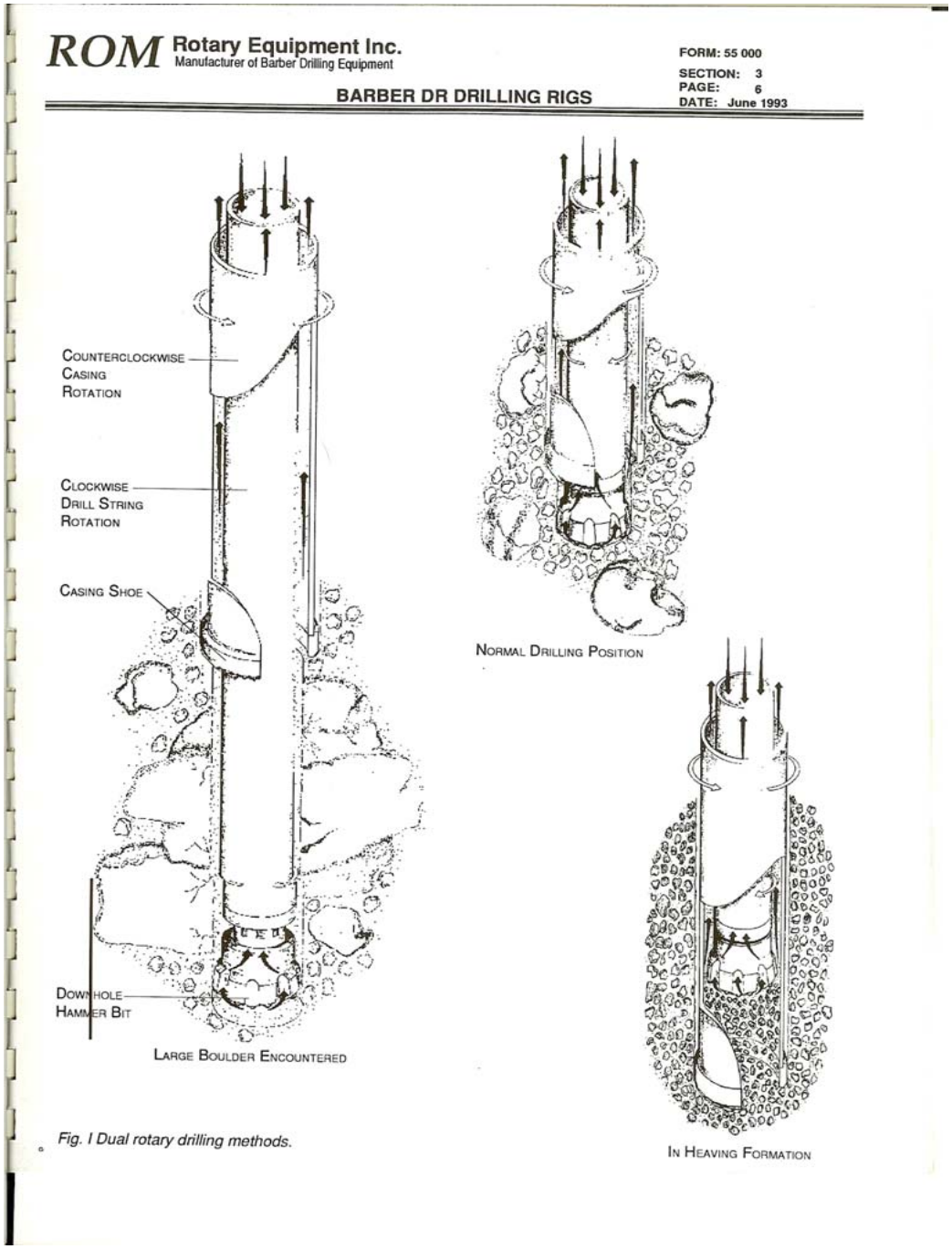
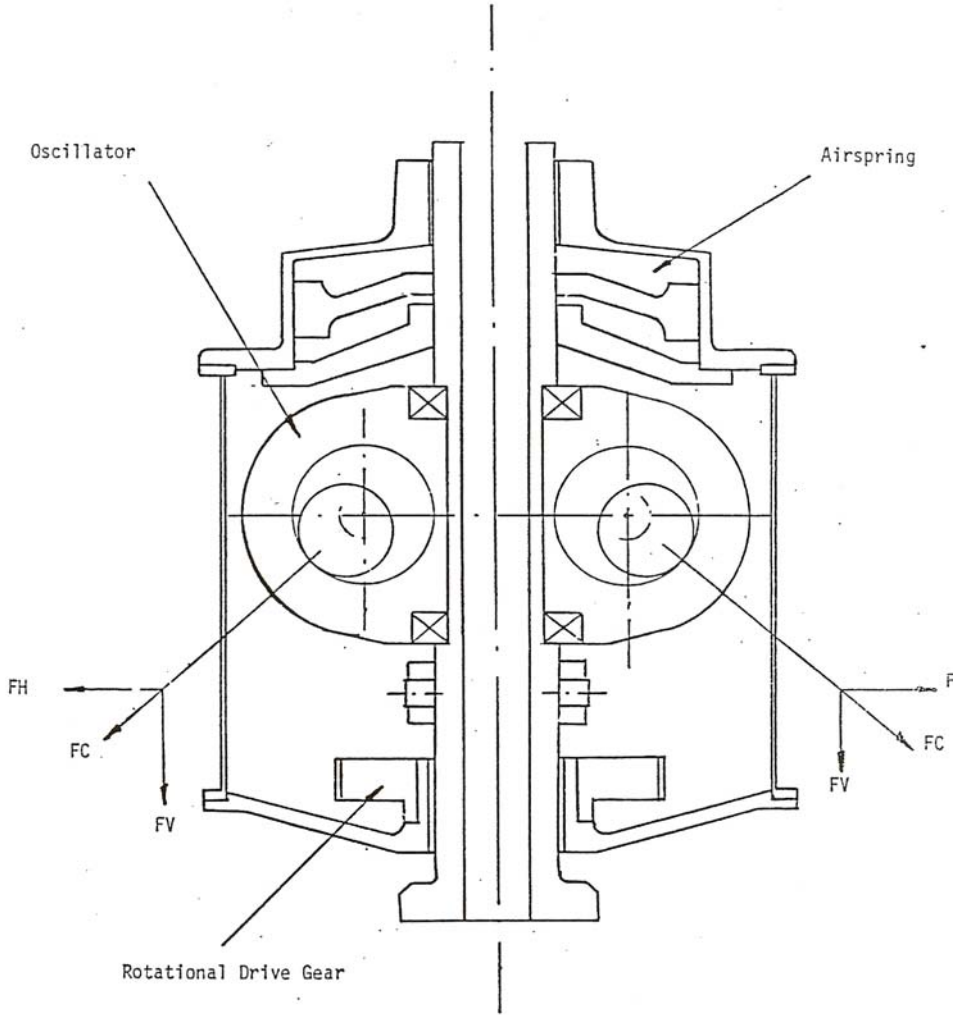


Fig. I Dual rotary drilling methods.

Concept of Dual Rotary Casing & Bore Simultaneously

Sonic Drill Technology

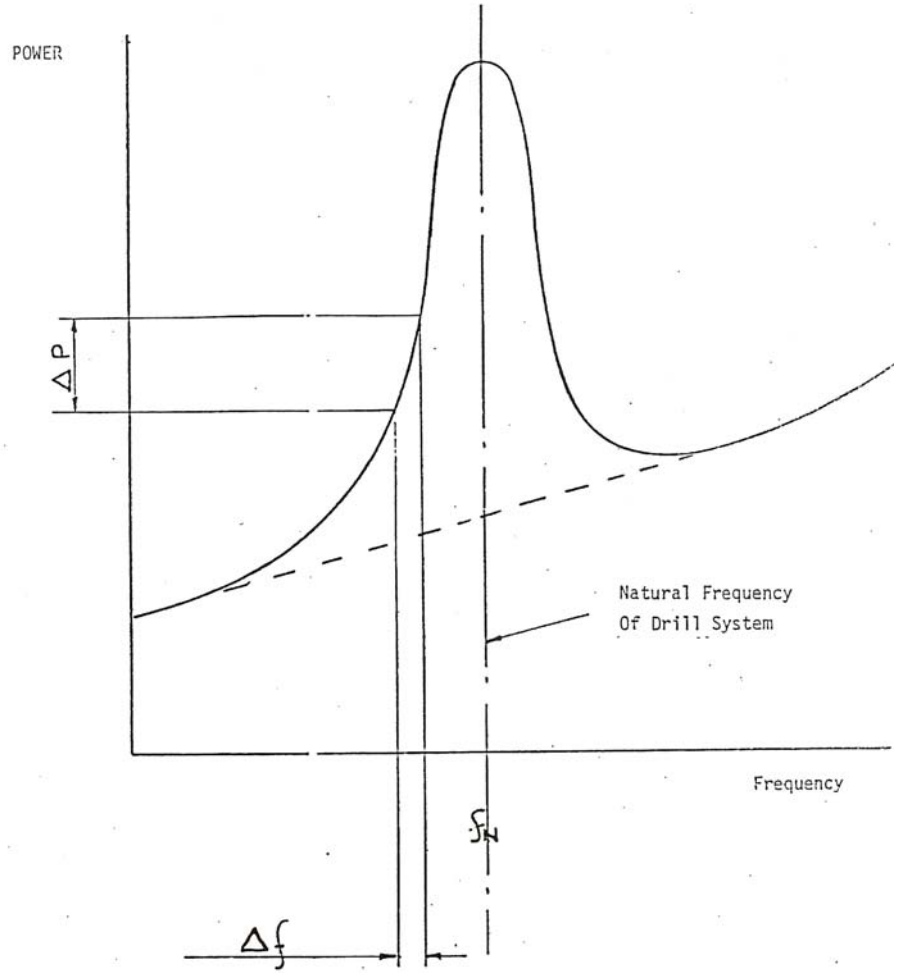
Modern Sonic Rig



RESONANT DRILL LAYOUT

Fig. 2

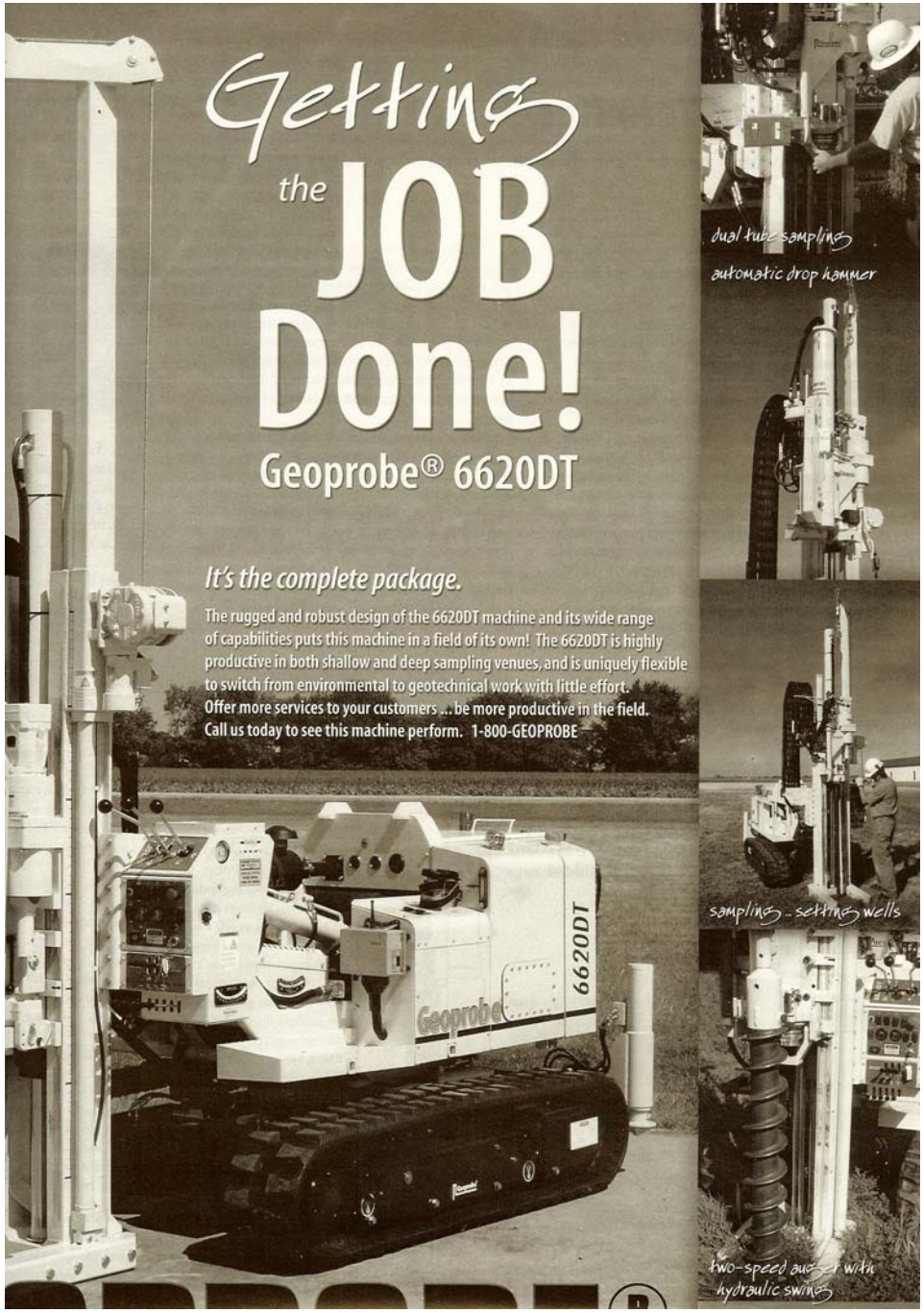
Resonant Drill Layout



TYPICAL POWER FREQUENCY
CHARACTERISTIC CURVE FOR THE DRILL

Fig. 1

Resonant Frequency



Typical Direct Push Rig

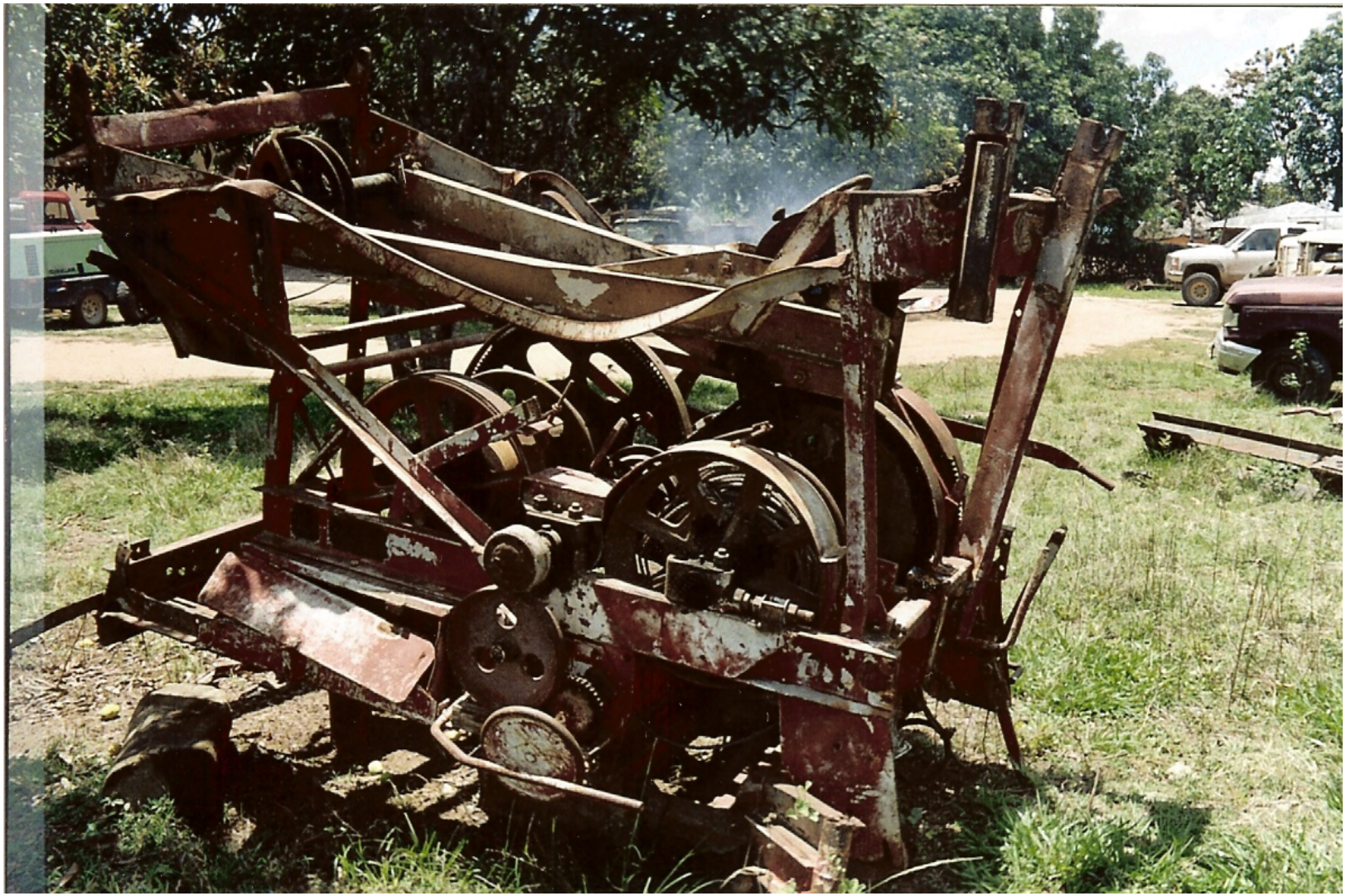
Limited Access Probe

Typical Probe Unit

Auger Drill

Auger Drill

Coil Tube – for Geothermal Application



Destroyed Cable Tool Rig
After Flash Flood
Haiti

Replaced with Modern Rotary Drill
Haiti

Drill Types

- There are a variety of drill mechanisms which can be used to sink a borehole into the ground.

- Each has its advantages and disadvantages, in terms of
  - the depth to which it can drill
  - the type of sample returned
  - the costs involved
  - penetration rates achieved

- There are two basic types of drills
  - drills which produce rock chips
  - and drills which produce core samples

Auger Drilling

- Auger drilling is done with a helical screw which is driven into the ground with rotation; the earth is lifted up the borehole by the blade of the screw.

- Hollow stem Auger drilling is used for environmental drilling, geotechnical drilling, soil engineering and geochemistry reconnaissance work in exploration for mineral deposits.

- Solid flight augers/bucket augers are used in construction drilling. In some cases, mine shafts are dug with auger drills. Small augers can be mounted on the back of a utility truck, with large augers used for sinking piles for bridge foundations.

- Auger drilling is restricted to generally soft unconsolidated material or weak weathered rock. It is cheap and fast.

Air Core Drilling

- Air core drilling and related methods use hardened steel or tungsten blades to bore a hole into unconsolidated ground. The drill bit has three blades arranged around the bit head, which cut the unconsolidated ground.

- The rods are hollow and contain an inner tube which sits inside the hollow outer rod barrel. The drill cuttings are removed by injection of compressed air into the hole via the annular area between the inner tube and the drill rod.

- The cuttings are then blown back to surface up the inner tube where they pass through the sample separating system and are collected if needed.

- Drilling continues with the addition of rods to the top of the drill string. Air core drilling can occasionally produce small chunks of cored rock.

- This method of drilling is used to drill the weathered regolith, as the drill rig and steel or tungsten blades cannot penetrate fresh rock. Where possible, air core drilling is preferred over RAB drilling as it provides a more representative sample.

- Air core drilling can achieve depths approaching 300 meters in good conditions. As the cuttings are removed inside the rods and are less prone to contamination compared to conventional drilling where the cuttings pass to the surface via outside return between the outside of the drill rob and the walls of the hole. This method is more costly and slower than RAB.

Cable Tool Drilling

- Cable tool rigs are a traditional way of drilling water wells internationally and in the United States. The majority of large diameter water supply wells, especially deep wells completed in bedrock aquifers, were completed using this drilling method. Although this drilling method has largely been supplanted in recent years by other, faster drilling techniques, it is still the most practicable drilling method for large diameter, deep bedrock wells, and in widespread use for small rural water supply wells.

- Also sometimes called "spudders", these rigs raise and drop a drill string to finely pulverize the subsurface materials. The drill string is comprised of the upper drill rods, a set of "jars" (inter-locking "sliders" that help transmit additional energy to the drill bit and assist in removing the bit if it is stuck) and a drill bit. During the drilling process, the drill string is periodically removed from the borehole and a bailer is lowered to collect the drill cuttings (rock fragments, soil, etc.).

- The bailer is a bucket-like tool with a trapdoor in the base. If the borehole is dry, water is added so that the drill cuttings will flow into the bailer. When lifted, the bailer closes and the cuttings are then raised and removed. Since the drill string must be raised and lowered to advance the boring, casing (larger diameter outer piping) is typically used to hold back upper soil materials and stabilize the borehole.

- Cable tool rigs are simpler and cheaper than similarly sized rotary rigs, although loud and very slow to operate. The world record Cable Tool Well was drilled in New York to a depth of almost 12,000 feet.

- The common Bucyrus Erie 22 can drill down to about 1,100 feet. Since cable tool drilling does not use air to eject the drilling chips like a rotary, instead using a cable strung bailer, technically there is no limitation on depth.

Reverse Circulation (RC) Drilling

- RC drilling is similar to air core drilling, in that the drill cuttings are returned to surface inside the rods. The drilling mechanism is a pneumatic reciprocating piston known as a *hammer* driving a tungsten-steel drill bit. RC drilling utilizes much larger rigs and machinery and depths of up to 500 meters are routinely achieved. RC drilling ideally produces dry rock chips, as large air compressors dry the rock out ahead of the advancing drill bit. RC drilling is slower and costlier but achieves better penetration than RAB or air core drilling; it is cheaper than diamond coring and is thus preferred for most mineral exploration work.

- Reverse circulation is achieved by blowing air down the rods, the differential pressure creating air lift of the water and cuttings up the *inner tube* which is inside each rod. It reaches the *bell* at the top of the hole, then moves through a sample hose which is attached to the top of the *cyclone*. The drill cuttings travel around the inside of the cyclone until they fall through an opening at the bottom and are collected in a sample bag.

- The most commonly used RC drill bits are 5-8 inches (12.7–20.32 cm) in diameter and have round metal 'buttons' that protrude from the bit, which are required to drill through rock and shale. As the buttons wear down, drilling becomes slower and the rod string can potentially become bogged in the hole. This is a problem as trying to recover the rods may take hours and in some cases weeks. The rods and drill bits themselves are very expensive, often resulting in great cost to drilling companies when equipment is lost down the bore hole. Most companies will regularly 'sharpen' the buttons on their drill bits in order to prevent this, and to speed up progress. Usually, when something is lost (breaks off) in the hole, it is not the drill string, but rather from the bit, hammer, or stabilizer to the bottom of the drill string (bit). This is usually caused by a blunt bit getting stuck in fresh rock, over-stressed metal, or a fresh drill bit getting stuck in a part of the hole that is too small, due to having used a bit that has worn to smaller than the desired hole diameter.

- Although RC drilling is air-powered, water is also used, to reduce dust, keep the drill bit cool, and assist in pushing cuttings back upwards, but also when *collaring* a new hole. A mud called *liqui-pol* is mixed with water and pumped into the rod string, down the hole. This helps to bring up the sample to the surface by making the sand stick together. Occasionally, 'super-foam' (AKA 'quik-foam') is also used, to bring all the very fine cuttings to the surface, and to clean the hole. When the drill reaches hard rock, a *collar* is put down the hole around the rods which is normally PVC piping. Occasionally the collar may be made from metal casing. Collaring a hole is needed to stop the walls from caving in and bogging the rod string at the top of the hole. Collars may be up to 60 meters deep, depending on the ground, although if drilling through hard rock a collar may not be necessary.

- Reverse circulation rig setups usually consist of a support vehicle, an auxiliary vehicle, as well as the rig itself. The support vehicle, normally a truck, holds diesel and water tanks for resupplying the rig. It also holds other supplies needed for maintenance on the rig. The auxiliary is a vehicle, carrying an auxiliary engine and a booster engine. These engines are connected to the rig by high pressure air hoses. Although RC rigs have their own booster and compressor to generate air pressure, extra power is needed which usually isn't supplied by the rig due to lack of space for these large engines. Instead, the engines are mounted on the auxiliary vehicle. Compressors on an RC rig have an output of around 1000 cfm at 500 psi (500 L·s-1 at 3.4 MPa). Alternatively, stand-alone air compressors which have an output of 900-1150cfm at 300-350 psi each are used in sets of 2, 3, or 4, which are all routed to the rig through a multi-valve manifold.

Diamond Core Drilling

- Diamond core drilling (Exploration diamond drilling) utilizes an annular diamond-impregnated drill bit attached to the end of hollow drill rods to cut a cylindrical core of solid rock. The diamonds used are fine to micro fine industrial grade diamonds. They are set within a matrix of varying hardness, from brass to high-grade steel. Matrix hardness, diamond size and dosing can be varied according to the rock which must be cut. Holes within the bit allow water to be delivered to the cutting face. This provides three essential functions; lubrication, cooling, and removal of drill cuttings from the hole.

- Diamond drilling is much slower than reverse circulation (RC) drilling due to the hardness of the ground being drilled. Drilling of 1200 to 1800 meters is common and at these depths, ground is mainly hard rock. Diamond rigs need to drill slowly to lengthen the life of drill bits and rods, which are very expensive.

- Core Samples are retrieved via the use of a *lifter tube*, a hollow tube lowered inside the rod string by a winch cable until it stops inside the core barrel. As the core is drilled, the core lifter slides over the core as it is cut. An *overshot* attached to the end of the winch cable is lowered inside the rod string and locks on to the *backend*, located on the top end of the lifter tube. The winch is retracted, pulling the lifter tube to the surface. The core does not drop out the inside of the lifter tube when lifted because a "core lifter spring," located at the bottom of the tube allows the core to move inside the tube but not fall out.

- Once a rod is removed from the hole, the core sample is then removed from the rod and catalogued. The Driller's offsider screws the rod apart using tube clamps, then each part of the rod is taken and the core is shaken out into core trays. The core is washed, measured and broken into smaller pieces using a hammer to make it fit into the sample trays. Once catalogued, the core trays are retrieved by geologists who then analyze the core and determine if the drill site is a good location to expand future mining operations.

- Diamond rigs can also be part of a multi-combination rig. Multi-combination rigs are a dual setup rig capable of operating in either a reverse circulation (RC) and diamond drilling role (though not at the same time). This is a common scenario where exploration drilling is being performed in a very isolated location. The rig is first set up to drill as an RC rig and once the desired meters are drilled, the rig is set up for diamond drilling. This way the deeper meters of the hole can be drilled without moving the rig and waiting for a diamond rig to set up on the pad.

Direct Push Rigs

- Direct push technology includes several types of drilling rigs and drilling equipment which advances a drill string by pushing or hammering without rotating the drill string. This should perhaps not properly be called drilling, however the same basic results (i.e. a borehole) are achieved. Direct push rigs include both cone penetration testing (CPT) rigs and direct push sampling rigs such as a Geoprobe. Direct push rigs typically are limited to drilling in unconsolidated soil materials and very soft rock.

- CPT rigs advance specialized testing equipment (such as electronic cones), and soil samplers using large hydraulic rams. Most CPT rigs are heavily ballasted (20 metric tons is typical) as a counter force against the pushing force of the hydraulic rams which are often rated up to 20kn. Alternatively, small, light CPT rigs and offshore CPT rigs will use anchors such as screwed-in ground anchors to create the reactive force. In ideal conditions, CPT rigs can achieve production rates of up to 250-300 meters per day.

- Geoprobe rigs use hydraulic cylinders and a hydraulic hammer in advancing a hollow core sampler to gather soil and groundwater samples. The speed and depth of penetration is largely dependent on the soil type, the size of the sampler, and the weight and power the rig. Direct push techniques are generally limited to shallow soil sample recovery in unconsolidated soil materials. The advantage of direct push technology is that in the right soil type it can produce a large number of high quality samples quickly and cheaply, generally from 50 to 75 meters per day. Rather than hammering, direct push can also be combined with sonic (vibratory) methods to increase drill efficiency.

Hydraulic-Rotary Drilling

- Oil well drilling utilizes tri-cone roller, carbide embedded, fixed-cutter diamond, or diamond-impregnated drill bits to wear away at the cutting face. This is preferred because there is no need to return intact samples to surface for assay as the objective is to strike a formation containing oil or natural gas. Sizable machinery is used, enabling depths of several kilometers to be penetrated. Rotating hollow drill pipes carry down bentonite and barite infused drilling muds to lubricate, cool, and clean the drilling bit, control down hole pressures, stabilize the wall of the borehole and remove drill cuttings. The mud travels back to the surface around the outside of the drill pipe, called the annulus. Examining rock chips extracted from the mud is known as mud logging. Another form of well logging is electronic and is frequently employed to evaluate the existence of possible oil and gas deposits in the borehole. This can take place while the well is being drilled, using Measurement While Drilling tools, or after drilling, by lowering measurement tools into the newly-drilled hole.

- The rotary system of drilling was in general use in Texas in the early 1900's. It is a modification of one invented by Fauvelle in 1845, and used in the early years of the oil industry in some of the oil-producing countries in Europe. Originally pressurized water was used instead of mud, and was almost useless in hard rock before the diamond cutting bit. The main breakthrough for rotary drilling came in 1901, when Anthony Francis Lucas combined the use of a steam-driven rig and of mud instead of water in the Spindletop discovery well.

- The drilling and production of oil and gas pose a safety risk and a hazard to the environment from the ignition of the entrained gas causing dangerous fires and also from the risk of oil leakage polluting water, land and groundwater. For these reasons, redundant safety systems and highly trained personnel are required by law in all countries with significant production.

Sonic (Vibratory) Drilling

- A sonic drill head works by sending high frequency resonant vibrations down the drill string to the drill bit, while the operator controls these frequencies to suit the specific conditions of the soil/rock geology.

- Resonance magnifies the amplitude of the drill bit, which fluidizes the soil particles at the bit face, allowing for fast and easy penetration through most geological formations. An internal spring system isolates these vibrational forces from the rest of the drill rig.

Limits of the technology

- Drill technology has advanced steadily since the 19th century. However, there are several basic limiting factors which will determine the depth to which a bore hole can be sunk.

- All holes must maintain *outer diameter*; the diameter of the hole must remain wider than the diameter of the rods or the rods cannot turn in the hole and progress cannot continue. Friction caused by rotation will tend to reduce the outside diameter of the drill bit. This applies to all drilling methods, except that in diamond core drilling and oil well drilling the use of thinner rods and casing may permit the hole to continue. Casing is simply a hollow sheath which protects the hole against collapse during drilling, and is often made of metal or PVC. Often diamond holes will start off at a large diameter and when outside diameter is lost, thinner rods put down inside casing to continue, until finally the hole becomes too thin. Alternatively, the hole can be reamed.

- For percussion techniques, the main limitation is air pressure. Air must be delivered to the piston at sufficient pressure to activate the reciprocating action, and in turn drive the head into the rock with sufficient strength to fracture and pulverize it. With depth, volume is added to the in-rod string, requiring larger compressors to achieve operational pressures. Secondly, groundwater is ubiquitous, and increases in pressure with depth in the ground. The air inside the rod string must be pressurized enough to overcome this water pressure at the bit face. Then, the air must be able to carry the rock fragments to surface. This is why depths in excess of 500 m for reverse circulation drilling are rarely achieved, because the cost is prohibitive and approaches the threshold at which diamond core drilling is more economic.

- Diamond drilling can routinely achieve depths in excess of 1200 m. In cases where money is no issue, extreme depths have been achieved because there is no requirement to overcome water pressure. However, circulation must be maintained to return the drill cuttings to surface, and more importantly to maintain cooling and lubrication of the cutting surface.

- Without sufficient lubrication and cooling, the matrix of the drill bit will soften. While diamond is one of the hardest substances known to man at 10 on the Mohs hardness scale, it must remain firmly in the matrix to achieve cutting. Weight on bit, the force exerted on the cutting face of the bit by the drill rods in the hole above the bit, must also be monitored.

- One final phenomenon limiting drilling only became apparent during deep drilling of an attempted Mohole