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Drilling: The Most Cost Effective Technique for Mineral Resource Evaluation

Georgius Agricola in his famous mining tome *De Re Metallica*, first published in 1556, astutely observed: *"since by far the greater number of miners are unskilled rather than skilled in the art, it follows that mining is a profitable occupation to very few men, and a source of loss to many more."* Notwithstanding Agicola's admonition, the use of appropriate drilling methods serves to improve the potential for profitable occupation.

In Agricola's time, virtually all vertical penetrations of the earth's surface were done with hand-dug shafts for which the many safety and technical issues in constructing shafts are described in his book. However, drilling of vertical holes for resource evaluation is a technique that goes back to at least the Chinese in 1100 BC who used percussion drilling to obtain water. There have been many variations of the percussion tool, but the basic design has remained the same. The early percussion drills used strips of bamboo tied together with a heavy stone or metal weight on the tip. This tool was lifted and dropped by large teams of men, sometimes working for years, cutting holes up to three thousand feet deep, but normally much shallower. Water is man's most important mineral resource, essential to his survival. Therefore, it is not surprising that his earliest methods of using technology and tools were in the pursuit of one of life's necessities.

The purposes of drilling bore-holes or wells are many and varied, but fall into four main categories:

- To determine the stratigraphic or rock sequence penetrated by the hole.
- To locate and evaluate minerals and hydrocarbons that may have economic value.
- Where feasible to extract and bring to the surface any such economically valuable substances, i.e., minerals, hydrocarbons or geothermal steam.
- To provide data for correlating between holes the lithologic sequences penetrated in order to facilitate the plotting of underground stratigraphy.

This paper examines the evaluation of mineral resources, exclusive of energy fuels, despite their importance to man's well being. Water, of preeminent importance, is a specialized discipline whose evaluation is a science and technology in its own right.

Extensive drilling is also done to evaluate construction foundations, dam support, slope stability, environmental baseline, and engineering studies. The author worked with a pioneering paleomagnetic team in the early 1960s, where diamond core was recovered and analyzed to determine the position of the earth's magnetic field during distinct periods in geologic time. It was interesting to recount one summer when our drilling determined the position of the magnetic North Pole 230 million years ago – a conclusion that elicited some humorous responses.

The four primary methods of modern drillers are: cable drilling, rotary drilling, diamond drilling and sonic drilling.

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1. *Cable drilling* uses the percussion method mentioned above. In drilling, the tools are alternately lifted and dropped, the rock being cut by the repeated blows of the bit. Some water is always kept in the hole, whether naturally occurring or added from the top. The rock cuttings are removed in a bailer, which is lowered at intervals sufficiently frequent to keep the bottom of the hole clean of debris. These cuttings are dumped into a "slush pit" near the collar of the hole and serve as samples of the rocks drilled. The drilling advance is a function of the hardness of the rock.

2. *Rotary drilling* is accomplished by the rotation of a rock bit, firmly attached to the lower end of a string of pipe, known as a "drill stem". The drill stem itself is rotated by a turn-table at the mouth of the hole. The stem is lengthened by the addition of new "joints" of pipe whenever the increasing depth of the hole demands. During drilling, a thin mud is kept constantly flowing downward inside the drill stem, exiting through the perforations in the drill bit. The mud then flows upward between the drill stem and the walls of the hole (or innermost casing) and is discharged at the top or collar of the hole. The mud serves the duel purpose of cooling the bit and supporting the walls of the uncased portion of the hole through the hydrostatic pressure exerted by it. In drilling dry formations, where no water is anticipated, air may be substituted for mud.

Reverse Circulation Drilling (RC) is a variant of rotary drilling. In rotary drilling, the viscosity and up-hole velocity of the drilling fluid are the controlling factors in removing cuttings effectively; and if they are not removed, drilling cannot continue. In RC drilling the flow of the drilling fluid is reversed compared to rotary drilling. Water-based drilling fluid, often containing polymer additives, is pumped down the annular space between the drill pipe and borehole wall to the bottom of the hole. Rock cuttings "entrained" in the fluid reenter the drill pipe through ports in the drill bit where they are then carried to the surface and collected in a rotary cyclone from which samples are collected. RC drilling is the least expensive method for drilling large-diameter holes in unconsolidated formation. When geologic conditions are favorable, increasing the diameter of the borehole does not appreciably increase the cost of the well.

The ***dual-wall reverse circulation*** rotary method has been used for many years to obtain accurate geologic samples from known depths. It is much favored in precious metals exploration in the Western United States because of its ability to minimize downhole contamination of the drill cuttings. Unlike conventional RC, the drilling fluid does not run down the outside of the drill pipe, but instead the flow is contained between the two walls of the dual-wall pipe and only contacts the walls of the borehole near the bit. Air or water is forced down the annulus to lift the cuttings to the surface through the inner pipe. Surface casing is not needed when the dual-wall system is used. The advantages of the dual-wall system include:

- Continuous representative formation and mineralization samples can be obtained
- Fast penetration rates are possible in coarse alluvial deposit or broken rock
- Problems of lost circulation are either eliminated or reduced dramatically
- Washout zones are reduced or eliminated

3. Diamond Drilling is another process in which the drill stem and bit are rotated. The bit is a hollow cylinder of soft steel composite whose lower edge is embedded with small industrial diamonds that project from the outer and inner edges of the cylinder. Until the mid 1970s, most diamonds were natural and manually set into the bit. These, although still used on large diameter bits in the oil industry, have been mostly replaced by artificial diamonds in bits of greater uniformity and consistent quality. The bit is screwed to a "core-shoe" which is then screwed to the lower end of a "core barrel," and the core barrel in turn, is screwed on to a string of hollow steel rods which reach to the top of the hole. During drilling, the string of rods and the tools attached to it are rotated. The rods are clamped to a hydraulic feed which enables the driller to control the downward pressure applied to the bit. A stream of clear water or thin mud is kept flowing inside the rods and core barrel and up between the rods and the walls of the hole or casing, thereby cooling the tools. The diamonds embedded in the crown of the bit cut the rock into a cylindrical solid core of rock which remains in the hollow core barrel. When the rock core extends to the top of the barrel, the rods must be extracted from the hole and the core removed.

For improved drilling productivity and speed, it is common practice to use a "wire-line core barrel." This tool is so designed that the inner tube of the core barrel is removable, without the necessity of removing the rods and the diamond bit from the hole. Typically, the driller drops an "overshot" tool on a wireline cable inside the drill rods until it catches a latching mechanism on top of the core barrel. The latching releases the core barrel from its fastening inside the rod and the core barrel is then winched to the surface and the rock core removed. Once the wire-line barrel is removed by the driller, an empty second core barrel is allowed to free fall to the bottom (or is pumped for up-holes) where it locks into place inside the bottom rod containing the diamond bit. "Wire-line core barrels" may save considerable time because they eliminate the time needed to "break down" and "make up" the drill stem for each core as in conventional core drilling. The significant advantage to core is that the pieces of core are preserved in the order in which they were obtained and furnish an excellent record of the rocks penetrated by the hole. Measurement of the amount of core recovered for each interval drilled is critical to determine the representivity of the sample. Samples with less than 80 percent core recovery are not acceptable in the mining industry for calculation of resource estimates. In general, resource and reserve auditors expect that at least 20 percent of the drill hole information in a deposit will be derived from diamond drill core.

4. Sonic Drilling uses the vertical vibrations of the drill stem and sample to advance downward by slicing through unconsolidated materials. The drill head is a hydraulically activated unit that imparts high frequency sinusoidal wave vibrations, ranging from 50 to 180 Hz, into a drill string to effectuate a cutting action at the bit face. The Sonic drilling method yields excellent soil and unconsolidated core recoveries in formations that may be difficult or impossible with other methods. The rate of penetration varies with the type of formation, but the Sonic drill easily drills alluvium, sand, clays, permafrost, and caliche. As metal prices rise, the need to effectively sample tailings ponds, abandoned waste piles and related mining sites for new economic parameters makes the use of Sonic drills an important evaluation tool. Sonic samples are continuous, highly representative and relatively undisturbed core samples extruded in the drilling process into clear plastic sleeves which minimize the loss of material and allow field screening devices to provide soil or rock chemistry immediately after drilling.

Which Drilling Method to Use?

Some mineral discoveries result from a stroke of luck, or by serendipity. Others have been located only after perseverance and painstaking work by a team of explorationists over many years. Exploration proceeds in a series of calculated progressive steps involving the review of existing records, geologic maps, mining history, aerial photographs, satellite imagery, geochemical and geophysical surveys; but eventually the vertical, but unseen third dimension, must be tested. The typical exploration approach is an initial exploration drilling program followed by a targeted drilling program to evaluate any interesting results of the exploration drilling. The goals of both programs are to economically and skillfully test a property, or test the potential for an economically exploitable resource, such as an ore body. Once such a target has been "discovered," the next stage is the evaluation and resource definition drilling stage; whose emphasis is on providing high quality drill core or samples of rock cuttings.

The type of drilling best suited to mineral exploration or more detailed evaluation is determined by the requirements for sampling and information collection. The sampling requirement may be for: chips from mud or air circulation; auger or vacuum samples; core and sludge; or special core types such as oriented core used in geotechnical/slope stability analysis.

The type and size of the drill rig to be used will depend not only on the hole size and depth, but also on the nature of the drilling site and its location. For example a heli-portable diamond core rig at 1200 pounds is much more transportable than a 20-ton reverse circulation drill on wheels. Location factors include remote or difficult access, surface or underground, and drill angles for machine setup, since many rigs only drill vertical holes.

The type of drilling, rig type, and the most suitable drilling tools are all dependent on the deposit type and the rock formations to be penetrated. These may include: uniform conditions throughout the length of the hole (rare); foliated or bedded rock; broken and unpredictable ground; high clay content; presence of swelling or sticking clays; etc.

Cost factors are usually the ultimate criterion. The drilling must be cost effective; producing benefits at least equal to costs. Other equally compelling factors may be the available drilling technology and driller skills. With much of the current exploration taking place in foreign countries, a specific type of drill rig, which cannot be brought through customs, is not a viable option.

Exploration managers may decide that they will get a better volume of samples and assays by using less expensive chip sampling or dual pipe sampling than the considerably more expensive diamond core drilling. Their job is to balance less reliable methods against cost and time. Pincock Allen & Holt recommends a minimum of 20 percent coverage of diamond core in the total drilling coverage for complex metallic deposits. One effective means of achieving lower drilling costs in vertically zoned deposits, where an upper zone is barren of mineralization; is to use two different drilling methods. Such a program would drill through the uppermost layer with the least expensive method, set casing in this upper portion and then drill the mineralized zone with diamond core to obtain maximum geologic information and optimum material for analytical purposes. The coal industry has been using this approach for decades, since core samples are required for coal quality determination.

The Australian Drilling Industry Training Committee Limited's textbook "Drilling" describes different drilling results in other subordinate types of drilling used in exploration and mining:

Cable tool: In unconsolidated and weathered formation, cable tool drilling can produce "pieces" of formation. These "pieces make better samples than the disintegrated particles usually returned by fluid circulation methods. To achieve accuracy of sampling, casing must be driven close behind the bit.

Rotary water/mud: When the bit is operated to produce large chips, rotary methods provided good samples from most formations. Mud may be necessary to stop chips disintegrating. Often the exact source of the sample is doubtful.

Reverse water/mud: The reverse circulation system ensures that the cuttings are delivered to the surface rapidly and without contamination.

Rotary air (RAB): The more efficient bottom-hole clearing and the rapid up-hole velocity of air circulation provide samples superior to those from a liquid circulation system.

Reverse air (tri-cone or blade): Using dual-tube techniques, reverse air circulation provides large chips and small pieces of core from consolidated formations.

Rotary hammer: pressured air circulation will drive a down-hole hammer and produce superior chips even from very hard formations. A dual-tube system, achieved using either a center sample (RC) hammer or a cross-over connection above a conventional hammer, provides the benefit of rapid return of quality samples. This is the most commonly used method in the Western USA for metal deposit evaluation.

Auger drilling, jet drilling, hollow rod drilling (direct push) and casing wash techniques all provide formation samples, but will only sample unconsolidated, weathered or soft formations.

In summary, mining and exploration management have a wide variety of drilling methods from which to choose; however, in light of the much more stringent regulatory framework in which we work, some methods are more reliable and accurate for the determination of metal and mineral content than others; these are the primary methods for evaluating mineral deposits upon which sound economic decisions are ultimately based.

This month's article was provided by Barton G. Stone, C.P.G., Chief Geologist bart.stone@pincock.com

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