NWT & NUNAVUT CHAMBER OF MINES

Diamond Drilling in Permafrost / Arctic Conditions - Best Practises

Contents

Preamble 1
Drill Hole Set-Up Techniques 2
Drill Sampling Methodologies 2
Polymers 5
Drill Hole Abandonment 6
Fuel Management 7
Cuttings Management 7
Training, Certification and Workplace Safety 8
Acknowledgements 8

Preamble

The goal of NWT and Nunavut's resource exploration industry is to complete diamond drilling programs as quickly and cost effectively as possible – for production efficiency, safety, and protection of the environment. There are huge costs around diamond drilling in the North but very little understanding of the technical aspects. This begs for technological innovation and an examination of expertise in the area.

The "Alternative Diamond Drilling in Permafrost/Arctic Conditions" workshop was hosted by the NWT & Nunavut Chamber of Mines in Toronto on February 19 - 21, 2013. This innovative program focused on issues and challenges to drilling for resources in the Arctic. The workshop brought together experts in the diamond drilling industry with direct experience operating in the North. The goal was to discuss the latest innovations around operating in Arctic conditions, and possibly derive new ideas for piloting and/or testing these technologies.

Key themes for the workshop included: Production Innovation; Drill Site Management (Environmental Stewardship) and; Arctic/Remote Site Safety. The roundtable discussion resulted in a recommended action plan highlighting how to move arctic drilling research and innovation forward. Among the outcomes was the formation of a working group to identify and compile a list of arctic drilling best practices, the categories and contents of which are below.

Drill Hole Set-Up Techniques

Locations of drill holes will be based on criteria defined by the company. Typically drilling is classified as exploration, extension, infill or definition. Locations of a drill holes will be determined by the company and will be based on a GPS coordinate system or a local grid. Once a suitable collar location has been chosen, that location will be marked by a picket. Two or more pickets will be placed in front of the collar picket in the direction the hole will be drilled. The drill will be lined up with these front sight pickets. Photo's before drilling and after drilling will be taken and archived.

Once coring has commenced the collar azimuth will be checked to verify the azimuth after casing. Typically drillers will be asked to survey a hole at predetermined spot intervals to track the trace of the hole. There are numerous types of surveying equipment however most involve lowering a piece of equipment down the hole to a survey depth. Measurements of the azimuth, dip and other factors are recorded by the equipment. Two popular survey tools are EZ Shot and EZ Trac.

On holes where a higher degree of accuracy is required, other techniques like the Maxibore and Gyro systems provide a near continuous reading of the trace (approximately every 3m). Drilling will continue to a predetermined depth at which time a Geologist will review the hole and decide if the target has been achieved. During or after drilling, the location of the collar and water pump will be surveyed by either chain to a local grid or GPS. Once all drilling on a specific set-up has been completed, that site will be cleaned of all debris and materials. Casing will be removed and or the hole capped or plugged.

Drill Sampling Methodologies

Reverse Circulation Drill Samples

Reverse Circulation methods consist of a rock chip sample created by a down hole air hammer. This method is usually faster and more economical then Diamond core sample, but can sometimes be less reliable as far as value and identification of geologic relationships and lithology goes.

In Arctic permafrost conditions, Reverse Circulation drilling should be conducted in dry conditions because if water is introduced into the permafrost condition, this will cause freezing problems. However when water is encountered, the drilling method can be converted to diamond core drilling to insure hole completion.

Reverse Circulation drill samples are collected immediately at the drill-hole site. Dry drill sample cuttings are collected in a cyclone over an interval determined according to the type of system that is being explored. From there it is passed through some type of splitter to sequentially reduce the sample size. The ratio will be determined by the geologist in charge of the individual project. A common practice is to use one-eighth of the sample interval. This presents approximately 9-10 kg. It is then placed into a pre-labelled plastic bag, sealed with a plastic zip tie, and identified with a unique sample numbering system.

The bagged samples are then transported to the nearest company camp, where they are stored in a secure area pending shipment to a certified laboratory sample prep facility.

The remaining seven-eighths of the sample are then stored in a large, labelled plastic bag at the drill site for future reference. The reference samples from mineralized intervals are transported to the nearest camp, by personnel. A small representative sample of the rock cuttings from each interval is placed into a plastic sample tray for subsequent geological logging of the hole by a geologist.

Reverse Circulation is usually a preferred method for first pass exploration and/or at the prospecting stage of a project, as well as for ore control once a mine is operative, and on some occasions, as a pre-collar for diamond core holes.

Diamond Drilling Samples

The diamond core drilling method is produced by using a core barrel headed with a hollow diamond drill bit. These systems come in different sizes commonly known has HQ hole diameter (3.5” or 96 mm): with a core diameter of (2.5” or 63.5 mm); NQ hole (3” or 75.7 mm) and; NQ core (1 7/8” or 47.6 mm). Other sizes are PQ (approximately 4.8”) and BQ (approximately 2.36”). The size will normally be determined by the type of rock, sampling protocols (base metals vs. precious metals vs. diamonds) and the final depth of the hole, with core width diminishing over certain depths and lithologies. This method will produce a more reliable and cohesive sample as far as mineral values, geological relationships and lithology over Reverse Circulation.

This method is more expensive and sometimes will cause more disturbances to the environment through longer drilling times and the necessity to introduce fluids for cooling and lubrication. In Arctic permafrost drilling conditions, this method requires a drilling fluid that is either heated and/or salt enhanced. Where the former can cause permafrost melting, the latter can result in damage to the immediate delicate flora, and perhaps more widely spread damage through inadvertent run-off.

Diamond drill core is collected at the drill site. It is then place in special core box trays. From there, it is transported to a core logging facility where the samples collected are logged. Logging involves a geological description, physical rock property measurements (e.g. structure, density, magnetic susceptibility) and RQD (Rock Quality Designation). Also, the core is now normally be photographed for further record, if needed. More recently, this is accompanied by photographing the hole itself with a televiewer in order to better determine the orientation of rock fabrics, shears, faults and fractures.

After geologically logging the core, the samples are typically sampled over a predetermined interval, usually depending on the logging results and requirements. The core is commonly cut with a diamond saw with half the sample retained in the core boxes for future reference and the other half placed into a pre-labelled plastic bag, sealed with a plastic zip tie, and identified with a unique sample number. The bagged samples are then stored in a secure area pending shipment to a certified laboratory sample prep facility.

The Diamond Core drilling method is preferred when programed holes are at a greater depth, or at the definition Drilling stage, where water is present, and/or when other specific requirements are necessary.

Use of Hole Surveys

Irrespective of whether reverse circulation or diamond drilling is the chosen method, information as to geology, structure or the nearby presence of mineralization can be defined not only by examining the nature of the rocks brought up as drill core, but also by taking measurements along the length of the drill hole using hole surveys or downhole sensors.

There are two types of hole surveys. The first type is called a *downhole orientation sensor*, and is deployed within the drill stem. More sophisticated orientation sensors can not only continuously measure changes in the orientation of the hole, but also changes in hole direction. These data are critical for the drillers to determine whether they will intersect a desired depth and target rock formation, and for the geologist to determine the true orientation of various geologic features intercepted by the drill hole.

The second type of survey is deployed after the drill stem is retracted from the drill hole, usually when the hole is completed (but not always). Sensors consist of a receiver/detector that is encased within a probe (Figure X). The instrument is lowered down the drill hole on a cable that can transmit data collected by the sensor to a surface recording instrument and then a laptop computer for electronic storage and analysis. Some cables are also used to transmit power to the sensor, depending on whether the system is “passive” or “active”. Other necessary equipment include a depth counter and a winch.

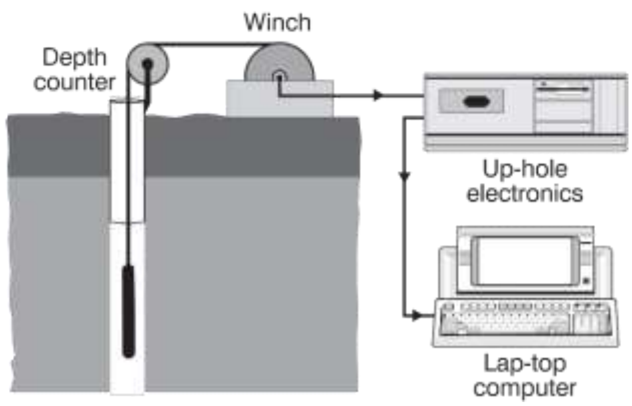

Figure 1 Schematic of a downhole sensor system (taken from Killeen, 1997)

The series of continuous measurements taken by the sensor is known as “logging”. The types of data logging include physical properties such as magnetic susceptibility, radiation and gravity fluctuations. Calipers may be extended from the probe to trace the surface of the drill holes to detect fracture patterns or to measure rock hardness. Probes can also include televiewers that take continuous pictures of the drill hole walls to define changes in rock type, fabric or structure. “Active” logging systems involve inducing a current into the surrounding rock and measuring fluctuations in how the electrical current travels through the rock. These electromagnetic and magnetic sensors can be used as an array within a group of drill holes to develop a three dimensional map of the results. Seismic signals can also be recorded by shocking the surrounding rocks through either a nearby small explosive charge or hammering on a metal plate or rock surface.

Downhole logging is usually carried out by a specialty contractor hired by the exploration or mining company that has contracted the drilling. There has to be close communication between the drill team and the down hole logging team in order to determine whether the holes are “clean”, or whether the drill hole walls are fractured and friable, and may hinder the passage and retrieval of a down hole probe. These probes can be worth up to tens of thousands of dollars, and can be very difficult to retrieve if they become jammed.

Reference: *Killeen, P.G., 1997, Borehole Geophysics: Exploring the Third Dimension; in Proceedings of the 10th Annual Symposium on the Application of Geophysics to Engineering and Environmental Problems, Reno, Nevada, 23-26 March 1997.*

Polymers

To maintain a properly conditioned drill hole, drilling fluids are added to drill water and injected down the hole. Additives, such as polymers, assist in lubrication, wall cake suspension, and other functions needed for different drilling conditions. Hole conditioning is an important component to a successfully drilled borehole, especially in challenging and adverse subsurface conditions. It is preferable to utilize environmentally friendly drill fluids to minimize impact to the environment in the inadvertent or planned release of drilling fluids.

Drill additives used while working in permafrost conditions present a new challenge when it includes calcium and/or hot water. With the addition of calcium to the drill water and/or raising the temperature, the chemical properties of certain drilling fluid additives can be altered, thereby making them less efficient in their application. Establishing knowledge on how these drill fluids are altered by the reaction of temperature and chemical changes to the mixture will increase efficiency and maximize their use. Drill fluids in challenging subsurface drilling conditions can present large costs to a drill program. Ensuring a proper understanding of chemical reactions with the assistance of the distributor's knowledge is essential to the efficient use of additives.

Flocculent

Flocculent agents are used to assist in removing drill cuttings from the drill water supply in the event that recirculation and containment of fluids/spoils are required. Using the principles of surface area contact, vibration, gravity, and flocculent an efficient recirculation system is created. The use of proper drill fluid additives can be more efficient and reduce environmental impacts as well as cost.

Calcium Chloride

When subsurface permafrost conditions exist, there may be a requirement for the use of calcium chloride ($CaCl_2$) depending on various factors such as depth and temperatures of the actual zone. The chemical properties of $CaCl_2$ lowers the freezing point of drill fluids to allow them to remain in liquid form while drilling in freezing subsurface conditions. The calcium is typically supplied in bags in crystal form, and is added to the drill supply water to lower its freezing point. The concentration of the Calcium is closely monitored to ensure the minimum and maximum requirements are not missed or exceeded. A properly managed salt concentration will assist in reducing salt consumption; minimizes freezing in and possible solidification if too much is used. The use of refract meters will help monitor and maintain the proper mixture.

Efforts should be made to minimize the use of this product and look for alternative products. When it is determined that $CaCl_2$ is necessary to ensure the completion of drill holes, it needs to be properly managed to protect workers and the environment due to its caustic properties. Proper PPE is used to protect workers from the irritant effects of the chemical such as salt burns. A similar reaction occurs if the solution if released to a vegetated environment whereby it has the same effect of salt burn and has the potential to damage the environment if not managed properly.

Drill Hole Abandonment

Permitting Regulations

Removal and Sealing of Drill casing: the permittee shall remove or cut off and seal off all drill casings at ground level immediately upon completion of operations at each borehole.

The permittee shall, when flowing water from bore holes is encountered, plug the borehole in such a manner as to permanently prevent any further outflow of water.

The reclamation of drill holes must include the removal of any drill casing materials and the capping of holes with a permanent seal (as per the Nunavut Water Board licence).

Abandoned drillholes need to be sealed properly to prevent:

- Pollution of ground water by the entry of poor quality water and other foreign substances down the drillhole;
- Intermingling of waters from different aquifers;
- Possible water from flowing uncontrolled out of the drillhole;
- Irradiation of surface and groundwater .from downhole intercepts of uranium mineralization which has concentration levels greater than 1% over a length of >1.0 metre and with a metre per cent concentration >5 %;
- Lake water from entering the drill hole, which may later cause severe flooding of any succeeding underground workings developed below the lake.

Abandonment Methodologies

Grout Plugs
These are mechanical style plugs that are set at predetermined positions down the drill hole. Various styles of grout plugs can be used depending on requirements i.e. grouting to overcome pressurized zones, plugging various areas in the drill hole or plugging entire length of the drill hole.

A grout / cement mixture is used on top of plug or pumped through a plug to cement below a plug.

Mixtures are predetermined on diameter size and depth of the drill hole to be plugged.

The cost of freight and storage on site must be taken into consideration, as freight to remote sites is costly. If grout / cement bags are not stored properly than their contents may become spoiled and unusable.

Bentonite Grout Plugs
Bentonite grout comes in both powder and pellets material and has a faster setting time than cement. It is easier to use, however there is a possibility that shrinkage may occur.

Saline water at higher concentrations may cause the bentonite grout to flocculate and reduce its viscosity.

Bentonite is easy to store and transport to site. The product can be supplied in plastic bags or pails (preferred containment may be plastic bags as they have less impact on the environment).

Freeze Over
When drilling in permafrost areas, abandon drill hole and allow water remaining in drill hole to freeze thus plugging the drill hole. Drill holes must have water return for this technique to work. This would create a natural and very efficient hole abandonment. This is not reliable for drilling under any lake as there is virtually no permafrost is present.

While the use of Grout Plugs and Bentonite Grout Plugs are common practise where permafrost does not exist, Freeze Over is the recommended hole abandonment method in permafrost conditions.

In the event casing is left in the ground, to prevent water flow, either in or out of the hole, steel or aluminum caps can be screwed onto the casing. Cement or bentonite grout should be placed around the annulus of the casing and ground to further prevent inflow or outflow of water. It must be recognized that cement will not set below freezing conditions.

Fuel Management

The costs associated with transporting and use of fuel to/on remote properties in the Arctic is a considerable expense which needs to be properly managed and maintained to ensure program longevity and budgets.

Fuel consumption is at its highest during winter drilling seasons due to required heat to enable drill crews to work in sub-zero freezing temperatures. Proper design of drilling enclosures which capture and contain as much radiant and direct fired heat as possible, will reduce fuel consumption by using thermostats which cycle heaters only on an as needed basis.

Technical advances of electrical style heaters and glycol based heat exchanger systems may also provide a more economical way to provide heat in colder conditions and move away from forced air units. During summer drilling seasons when there is no snow cover on land or ice on lake to capitalize on skid mount drilling operations, helicopters must be used to move equipment between drill sites. Designing drill equipment to maximize the helicopter lift capability with each pick will increase the efficiency of the helicopter and reduce fuel consumption. Proper management and scheduling for drill parts, servicing and support will also assist in reducing fuel consumption.

Double walled containments for fuel storage bins and drip trays will protect the environment from potential spills. Proper training on fuel supply systems and safety trip mechanisms will also prevent inadvertent release to the environment.

Cuttings Management

Where required, cutting management systems are to be employed to reduce environmental impact, maximize drilling fluids and salt use and increase efficiency in water consumption in areas where water may not be limited due to accessibility.

Recirculation systems are especially important when calcium is needed during drilling operations to reduce impact to the environment. Using the principles of volume, gravity, surface contact, vibration and additives, drill cuttings can be filtered out to reuse the drill water and capture environmentally damaging fluids, which can then be transported to a designated, contained area.

Movement of drill returns to designated areas can be accomplished with the assistance of containment bins and grain sacks. Efficient recirculation systems should properly filter drill cuttings only and not transfer large quantities of drill mud or water to containment equipment. This will reduce environmental footprints, and decrease costs associated with moving the cuttings to these areas (i.e. hours on equipment and helicopter time).

Training, Certification and Workplace Safety

Individuals must receive proper training in drill operations to ensure safe and efficient procedures at the drill site. Applicants must complete a "Diamond Drillers Helper Training Program" delivered in a northern context by a recognized Canadian college or affiliate. In addition to receiving certification as a "Diamond Driller's Assistant", applicants must also complete the following before beginning work onsite:

- First Aid/Wilderness First Aid (CPR)
- WHMIS

Once the applicant has received this basic training, the hiring company has one year to complete the required other modules (surface, underground or specialty). These modules must be done on the job, by a person who is a qualified Trainer. Once the applicant has received his training to the satisfaction of the Company appointed Signing Authority, the Signing Authority signs and submits the original training applications and training reports to the local apprenticeship authority.

Acknowledgements

The compilation of "Best Practises" for diamond drilling in permafrost/arctic conditions was provided by the NWT & Nunavut Chamber of Mines, Newmont (Hope Bay) Mining Ltd., Sabina Gold & Silver Corp., the Canadian Mining Innovation Council, Geotech Drilling, Team Drilling, Boart Longyear, and the Government of Nunavut unless otherwise noted. Partners for the project include the National Research Council Industrial Research Assistance Program, the Nunavut Mining Symposium Society, and Nunavut Tunngavik Inc. The NWT & Nunavut Chamber of Mines is grateful to everyone who has contributed to the preparation of this publication.