HYDROGEOLOGIC INVESTIGATIONS IN THE CANADIAN NORTH

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ABSTRACT

Hydrogeologic investigations for mines in northern Canada confront challenges unique to the climate, geography, and geology of the region. Short field seasons under frigid conditions require data collection and monitoring methods that are not used in more benign environments. Soft, saturated ground conditions require use of lightweight diamond-core drilling rigs and improvised methods for hydraulic testing and well construction. Groundwater sampling from beneath permafrost can be done with packer-isolated airlift pumping because of short setup times (avoiding freezing) and simplicity. Long-term monitoring of sub-permafrost groundwater levels and composition requires innovative designs for wells. Methods to determine hydraulic conductivities must be flexible enough to measure values over several orders of magnitude in materials ranging from thick till and marine clays with very low hydraulic conductivities to exfoliated (from post-glacial unloading) bedrock whose horizontal hydraulic conductivity can be 2 to 3 orders of magnitude greater than the underlying rock.

RÉSUMÉ

Les investigations hydrogéologiques effectuées dans les mines du nord canadien font face à des défis uniques reliés au climat, à la géographie et à la géologie de la région. De courtes saisons de travail sur le terrain dans des conditions frigides nécessitent une collecte de données et des méthodes de surveillance qui ne sont pas utilisées dans des environnements plus normaux. Des conditions de terrain meubles et saturées nécessitent l'emploi de foreuses au diamant légères et de méthodes improvisées pour les essais hydrologiques et la construction de puits. L'échantillonnage de la nappe phréatique qui se trouve au-dessous du permafrost peut s'effectuer avec des systèmes de pressurisation pneumatique isolée grâce à leur installation rapide – évitant le gel – et leur simplicité. La surveillance à long terme des niveaux et des compositions d'une nappe phréatique sous le permafrost demande des conceptions de puits innovatrices. Il est essentiel que les méthodes utilisées pour déterminer les conductivités hydrauliques soient assez flexibles pour pouvoir effectuer des mesures sur une plage de plusieurs ordres de grandeur, aussi bien dans du till épais et des argiles marins de faible conductivité hydraulique, que dans des dépots rocheux post-glaciaires où la conductivité hydraulique horizontale peut être de 2 à 3 ordres de grandeur supérieure à celle de la roche sous-jacente.

1. INTRODUCTION

Hydrogeologic and water quality investigations are required at mine sites in northern Canada -- as elsewhere in the world -- to evaluate the requirements for and design of dewatering systems, to predict and design mitigation plans for the impacts of mining upon the hydrologic environment, and to develop water supplies for both process and potable water. The climate, geography, and geology -- including permafrost -- of northern Canada, however, present unique challenges to collecting representative hydrogeologic and water chemistry data and establishing and maintaining monitoring systems. Limitations of the available drilling methods and equipment also require innovations in hydraulic testing, completion of monitoring wells, and obtaining representative groundwater samples.

2. ACCESS, CLIMATE, AND DRILLING

The combination of limited access and environmental sensitivity in northern Canada require using light weight diamond core drilling equipment to conduct hydrogeologic investigations rather than the preferable, but heavier, reverse air rotary equipment used elsewhere. Early stage mineral exploration projects are supported almost entirely by core rigs, often helicopter supported. Even later stage exploration or feasibility level projects, sometimes accessible by ice roads or heavy air transport, continue to rely on core rigs, primarily because they do not require thick ice or gravel pads to be constructed at each drill site. It is not uncommon, therefore, for northern Canadian exploration and mine-development projects to have only core rigs on site until the very latest stages of pre-development. Consequently, most -- if not all -- of the hydrogeologic investigation of a potential mine must be adapted to the available core rigs.

The major disadvantage of core rigs in hydraulic testing is the lack of large-volume, high-pressure air compressors that are routinely part of rotary drill rigs. Hydraulic testing with the core rig, therefore, is limited to packer-injection testing and airlift tests at much lower discharge rates (to be described below). These smaller scale hydraulic tests yield hydraulic information representative of proportionally small areas of influence in the hydrogeologic units being tested.

Not surprisingly, packer-injection testing can be severely hampered by extreme cold conditions. Using normal setup procedures, the fittings, airlines, and other parts can freeze up, especially if already wet, almost immediately when the packer assembly is raised up the mast to be lowered into the corehole. It is not unusual, when the temperature drops to below -30ºC, to have to wrap the packer assembly with an insulating blanket for the one minute trip up and down an unprotected mast.

Core drilling is less desirable relative to rotary-air drilling in collecting representative groundwater samples because of the need to inject “exotic” fluids (i.e., non-formation water) to cool the bit. Depending on the depth to water (either the water table or potentiometric levels at depth), and the resulting differential head imposed by the column of drilling fluid, invasion into the formation of the exotic fluid can be significant; and purging of the fluid before representative groundwater samples can be obtained can take hours or, in many cases, days.

The best method of purging and sampling a corehole while diamond drilling is by airlift pumping using an auxiliary air compressor. It should be noted that small submersible pumps can be used, but they are not recommended in cold temperatures because the pump can be rendered useless in just a few minutes of exposure to the elements. The main advantage of airlift sampling is that there are no moving parts … and, more importantly, no freezing parts. Packer-isolated airlift pumping, as will be described below, yields the most reliable samples and is the only practical method that we know of to sample, while drilling, a chemically stratified groundwater system.

Where large rotary rigs cannot gain access, core rigs must again be used to install permanent monitoring wells. This can lead to difficulties if the wells are to be used for long-term groundwater sampling as well as water-level monitoring. HQ-size coreholes can accommodate as many as two nominal 1-inch flush-joint piezometer tubes (and, in our experience, to depths of as great as 350 m), but HQ coreholes cannot be used for deep (> 50 m) installation of a nominal 2-inch pipe because there is no room for a tremie pipe. Consequently, special groundwater sampling techniques must be devised for multi-level, small diameter piezometers.

In harsh climates, airlift pumping is again the most practical method if sampling remote, standpipe monitoring wells, especially small diameter piezometers. Other methods, including jack pumps (even with pneumatic or electrical actuators), Waterra® pumps (either hand pumped or with a motor), and hand-operated bailers tend to quickly freeze up. Figure 1 shows a simple device, built from common PVC fittings at a remote site, which can be used as a “pumping” wellhead to collect an airlift sample from a nominal 1-inch piezometer. A light-weight gasoline-powered air compressor, 20 to 50 m of nominal 3/8-inch polyethylene tubing (to be used as the airline), and a roll of duct tape are all else that are needed to collect the sample. The technique is so simple that pumping can begin within a few minutes of opening a well; after that, the latent heat of the groundwater discharge prevents the upper standpipe and wellhead apparatus from freezing. Airlift discharge rates of as much as 25 L/min can be obtained with such a set up, though 1 to 4 L/min is more typical.

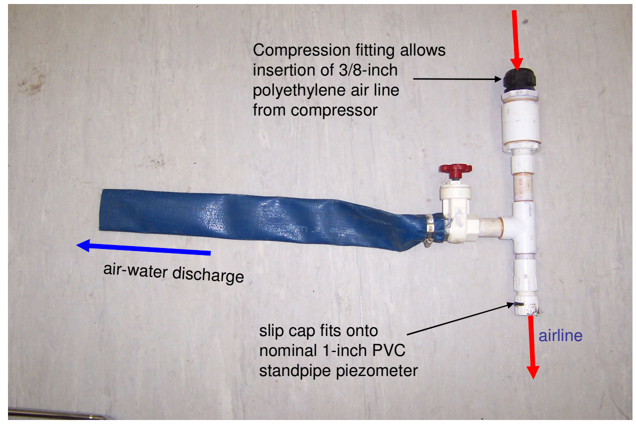

Figure 1. Simple device for airlift pumping groundwater samples from small diameter piezometers

3. PERMAFROST

Permafrost is a natural barrier to groundwater flow and can benefit a mining operation by limiting lateral inflow to mines and by isolating the deep groundwater aquifers from surface recharge. However, many large mines will eventually excavate to depths below the permafrost where groundwater inflow will occur. In northern Canada, the greatest challenge to a hydrogeologist in areas underlain by permafrost is to test the hydraulic conductivity and collect representative water samples from the bedrock below the permafrost without freezing in the equipment.

Packer-injection testing has been used as a “quick” method to test for permafrost (i.e., the permafrost will have essentially zero water take at any pressure achievable by the pump of the drill rig). Conversely, however, the method is a poor one for testing hydraulic conductivity in rock beneath the permafrost. Water in the corehole annulus and in the drilling rods can relatively quickly freeze in the permafrost zone, trapping the packer equipment down the hole. Consequently, packer-injection testing should be done beneath permafrost only while circulating brines, which obviously complicates the subsequent collection of representative ground water samples.

Airlift-recovery testing is a better way to test hydraulic conductivity beneath permafrost. Airlifting can be done in an open corehole (if it is done quickly, or, again, with brines, to prevent freezing), but it is more commonly done through the core rods partly retracted to expose the bottom portion of the corehole for testing. This through-the-bit testing can be done either with or without a packer assembly to isolate the zone of interest, but use of a packer to isolate the interval to be airlifted is strongly advised.

Figure 2 shows the basic setup for a packer-isolated airlift recovery test (and/or sample collection). In addition to the packer assembly, a simple wellhead (Figure 3) and an air compressor are needed. Optimum compressed air conditions for airlift testing in an HQ-size corehole are about 200 to 250 cfm at a pressure of about 90 psi. The injected air "pumps" the water out of the formation via the open mandrel between the packers.

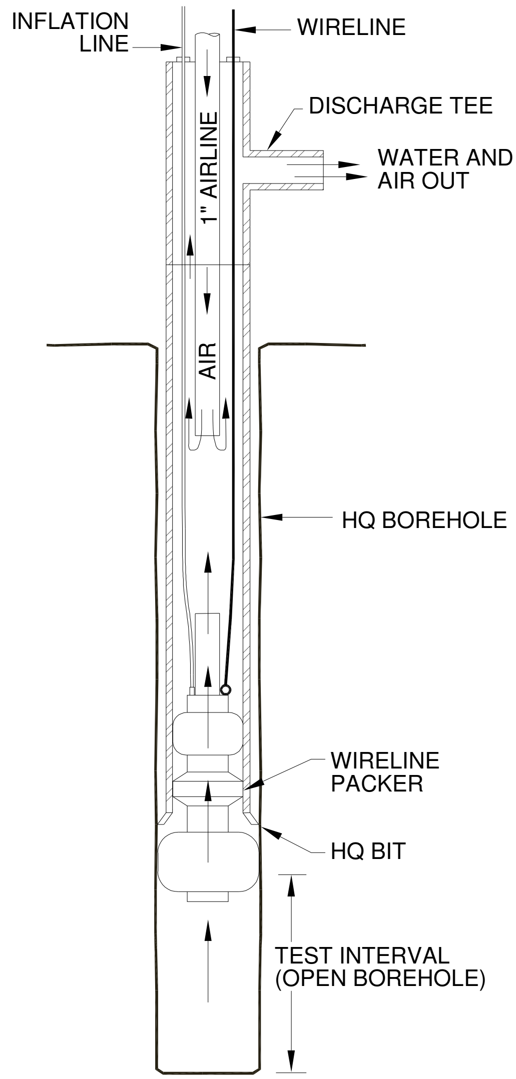

Figure 2. Setup for airlifting corehole with wireline packer assembly

Groundwater discharge rates depend on the hydraulic conductivity of the formation (actually the transmissivity of the test interval), the sizes of the core rods and airline, and the submergence of the airline (i.e., the ratio of the height of the pumping water level above the end of the airline to the length of the airline. Baski (1994) provides approximate rates in the range of 2 to 200 L/min to be expected for given pipe/airline sizes and submergences.

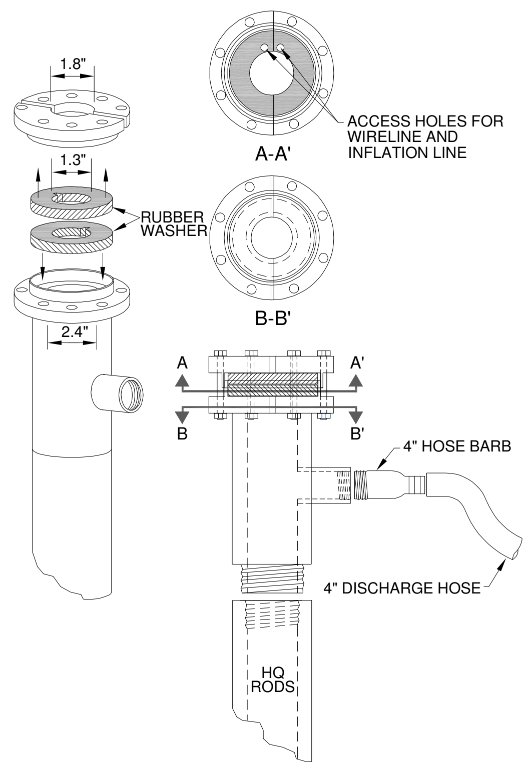

Figure 3. HQ wellhead assembly for packer-isolated airlift testing and sampling

The packer airlift method has an immediate advantage over packer injection testing in permafrost zones in that the process of airlifting moves the relatively warm groundwater up the drill rods, preventing (or at least delaying) the freezing-in of the apparatus during extended tests.

Airlifting works best where the transmissivity exceeds about 0.5 m^2/day, but it can also be done in zones of lower transmissivity using a smaller diameter eductor pipe and a 3/8-inch airline (Figure 4). This small eductor method is usually used if a groundwater sample is required from low permeability rocks, especially at great depth. This method reduces wellbore storage effects for a better interpretation of recovery data, and the sampling requires far less purging of the smaller casing volume than the wireline packer-isolated airlift method. In addition to the packer apparatus, this small diameter airlifting requires a simple wellhead (which can usually be fabricated on site) and an air compressor that only has to be able to deliver about 20 to 30 cfm at about 90 psi. Depending on the transmissivity of the test interval, airlift discharge rates of 0.2 to 2 L/min can be expected. At these rates, the discharge does not transfer a lot of heat, so that the method can result in freezing-in of equipment if testing is being done below permafrost.

Permanent monitoring beneath permafrost is particularly difficult; and the traditional method of filling standpipes with low-freezing-point liquids is generally not effective over any significant length of time. Although water levels can be monitored beneath a column of oil or antifreeze, water samples will freeze in the sampling tube if brought up through the liquid column which is itself at a temperature below 0ºC.

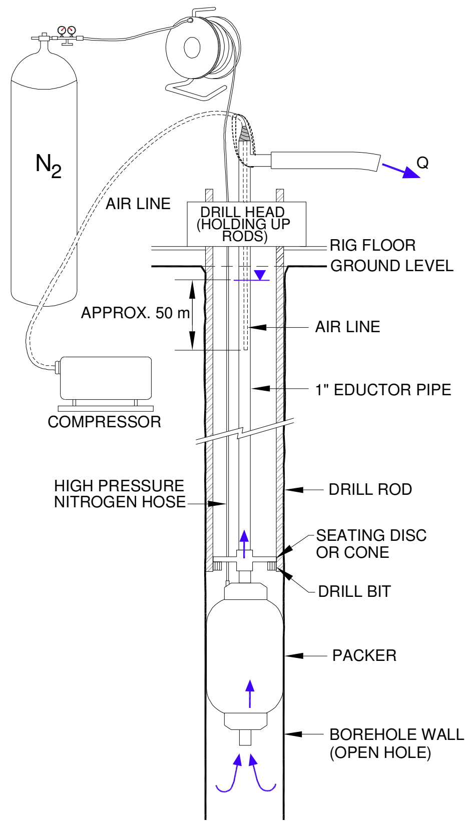

Figure 4. Small-eductor method for airlift testing low permeability materials

Westbay® systems (described in Emerson et al., 2006) can be used in areas underlain by permafrost, and they can be sampled any time of the year. However, the Westbay system commonly relies upon antifreeze throughout the column and upon potentially fallible seals to keep antifreeze from mixing and diluting with the formation water.

A relatively new technology for installing and maintaining monitoring wells below permafrost is based on the Thermos™ bottle principal and relies on evacuating, with compressed air or gas, the annulus between the well casing and sampling tube (Sutphin et al., 2006). However, it is a relatively complicated system which includes precision-milled head and foot valves, and heat tape to warm the sampling tube before opening the sample port.

4. POST-GLACIAL GEOLOGY

Surficial sediments deposited behind the retreating glaciers range from marine clay deposits as in the Hudson Bay Lowlands (Mahoney and Howell, 2006) to outwash sands, esker gravels, and till. The very low hydraulic conductivity of the marine clays and some tills resists timely drainage and can pose severe slope stability problems. These same materials, however, can again be important barriers between surface water and mine dewatering systems, limiting the amount of water that needs to be pumped and protecting surface water resources from the effects of dewatering. Consequently, vertical (K_v) as well as horizontal hydraulic conductivities (K_h) values of such materials must be carefully measured.

Packer-injection testing has been used to define hydraulic conductivities in some stiff tills and clays. However, there is a lower hydraulic conductivity value -- arguably about 3 x 10^{-5} m/day (Royle et al., 2006) -- below which test results are suspect. At very low hydraulic conductivities, the high injection pressures needed to induce a measurable “take” of water can also hydrofracture the formation or cause leakage around even a well-set packer. In either case, the test results will suggest, if not carefully discarded, an inaccurately high value of hydraulic conductivity.

Glacial processes also affect groundwater flow in bedrock fractures. Exfoliation caused by post-glacial unloading results locally in zones of relatively open, flat-lying fractures in the uppermost bedrock which can extend many tens of meters below surface. The hydraulic conductivity of exfoliation zones that occur within permafrost, of course, cannot be -- and generally, do not have to be -- characterised. However, the exfoliation zones beneath lakes and in other taliks can strongly affect inter-lake groundwater flow and potential groundwater flow into mining excavations. As a consequence of exfoliation, hydraulic conductivities can change over several orders of magnitude across short vertical distances (HCI, 2005). A drilling and testing program, therefore, must be set up to contend with materials of both very high and very low hydraulic conductivity.

The logistics of typical injection testing (e.g., the pump size, water availability, the size of the drop pipe, etc.) limit the upper range of hydraulic conductivity in a given test interval that can be measured using this method. Very generally, a transmissivity (again the average hydraulic conductivity times the length of the test interval) of about 3 x 10^{-1} m^2/day is the upper practical limit for packer injection testing using equipment commonly available on a typical HQ-size core drilling program. Conversely, airlift-recovery testing in a typical HQ-size corehole tends to have a lower limit of transmissivity of about 1 x 10^{-2} m^2/day, below which testing is impractical. At very low transmissivities, it is simply too difficult to accurately measure the airlift-discharge volume.

Although packer-isolated airlifting might be impractical for testing zones of very low hydraulic conductivity, one of the unique advantages of the technique, regardless of the climate or accessibility of the project, is that it can be used on small-scale multi-well tests across targeted structures or strata. Figure 5 shows the setup of a simple test conducted to measure the K_v of a thin claystone unit. The packer-isolated bottom of an HQ corehole in an underlying permeable unit was airlifted at a rate of about 6 L/s for 3 hrs, after which recovery data from the pumped unit and from the nearby monitoring wells were analyzed with a simple, radial groundwater flow model using *MODFLOW*. The hydraulic properties (i.e., K_v, specific storage) of the aquitard were derived by model calibration (HCI, 2006).

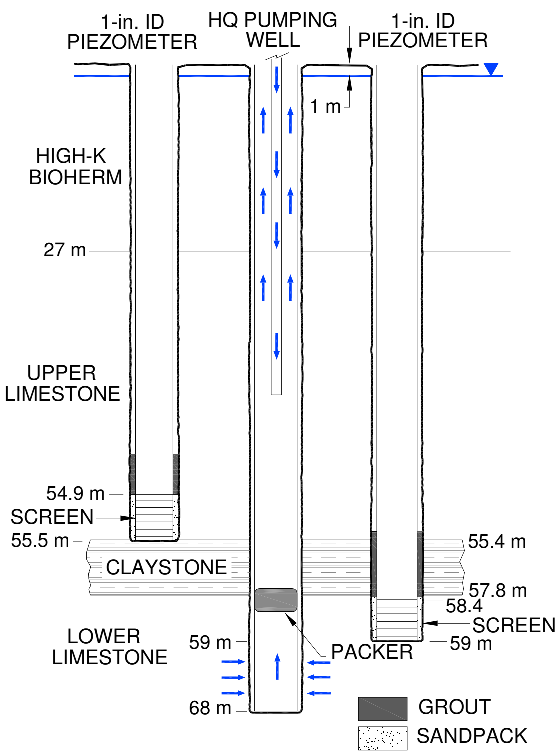

Figure 5. Testing K_v across a thin aquitard by airlift pumping in a packer-isolated HQ corehole

Long-term monitoring in materials of very low hydraulic conductivity is problematic in any environment. Where groundwater samples are not needed, the simplest method may be to eliminate the wells altogether by permanently installing transducers in sealed boreholes. McKenna (1995) describes the method of placing a transducer (preferably a vibrating-wire or other external-powered transducer) into a borehole and filling the borehole with a cement-bentonite grout. Long-term water levels can then be obtained from a control box and data logger on surface. This method is especially suited to low-permeability formations (e.g., marine clays, tills) because it eliminate the long response times during hydraulic tests. For sub-permafrost installations, even the grout can be done away with; a vibrating-wire transducer can be lowered into the corehole to below the level of the permafrost, and the signal cable simply allowed to freeze in place in the upper corehole.

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