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Hydrogeological challenges and strategies at McArthur River Operation

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ABSTRACT
High pressure, radon-bearing water has been identified as one of the most critical challenges in mining the high grade uranium deposit at the McArthur River Operation, Cameco Corporation. The ore deposits are located between 490 m and 640 m below the surface and surrounded by water bearing Athabasca sandstone, a graphitic fault zone, and highly altered ground. This paper introduces the inflow risk management program at McArthur River Operation which includes various hydrogeological challenges and the corresponding strategies applied, such as risk based probe and grout programs (geological, hydrogeological, and geotechnical), ground freezing programs, and comprehensive ground control programs. These programs have being developed, tested, and proven successful over years of mining practices. Working with this world-class deposit of high risk and low tolerance, the authors believe that these experiences might be beneficial to other mining operations with similar hydrogeological characteristics.
KEYWORDS: Inflow risk management; Geotechnical and development probe and grout programs; Ground freezing; Ground control

1. INTRODUCTION

The McArthur River Operation is an underground mine located in the eastern part of the Athabasca Basin of northern Saskatchewan, approximately 620 km north of Saskatoon, Canada.

As the world's largest high-grade uranium mine, it has proven and probable reserves of 336.5 million pounds U_3O_8 (Cameco's share – 234.9 million pounds) with an average ore grade of 10.94 % U_3O_8 at December 31, 2015. Cameco is the operator of the mine with 69.805% ownership in partnership with AREVA Resources Canada Inc. who owns the remaining 30.195%. Multiple mining methods have been developed and approved and are being employed at McArthur River: the first one is a unique non-entry Raisebore mining method; the second one is Boxhole mining; and the third is drill and blast stope mining, which has the potential to be one of the major mining methods in the future at McArthur River. The ore is grinded into slurry at underground, and then pumped to surface where it is loaded into special containers and shipped to Key Lake for milling. In 2015, the total ore production at McArthur River was 19,782,596 lbs (8,973,235 kg) of U_3O_8.

As an underground high-grade uranium mining operation, the protection of workers and the environment during the mining activities have been the top priorities in all phases of the design, development, and operation of the mine. The mining activity at this operation faces three major challenges:

- Hydrogeological: the ore is located in proximity to water enriched sandstone with high hydrostatic water pressures.
- Geotechnical: mine openings have to be developed in highly variable ground conditions ranging from excellent rock to wholly unconsolidated clays and gravels.
- Radiation protection: workers have to be protected from radon bearing water and mineralization with high-grade uranium.

This paper intends to introduce the hydrogeological challenges at this Operation, and present the corresponding strategies that have been successfully employed by the site to permit safe mine operations.

2. MINE GEOLOGY AND INFLOW MECHANISMS

The McArthur River uranium deposit is located in the southeastern portion of the Athabasca Basin, within the southwest part of the Churchill structural province of the Canadian Shield. The crystalline basement rocks underlying the deposit are members of the Aphebian Wollaston Domain meta-sedimentary sequence. These rocks are overlain by flat lying sandstones and conglomerates of the Helikian Athabasca Group. These sediments are over 500 m thick in the deposit area.

High-grade uranium mineralization has been delineated from surface drilling over a strike length of 1,700 m, occurring at or close to the unconformity,

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which separates the overlying, horizontally bedded sandstones of the Athabasca Group from the metamorphosed basement rocks, located between 500 m and 640 m below the surface. Underground exploration drilling programs have covered approximately 750 m of the 1,900 m strike length delineated from surface. Ore body widths are variable along strike but the most consistent, high grade mineralization occurs proximal to the main graphitic thrust fault around the "nose" of the up thrust basement rock. Less consistent and generally lower grade mineralization occurs down dip along this fault contact between basement rock and sandstone. Locally the basement rocks include pelitic gneisses and significant quartzite units. Alteration is characterized by intense silicification of the sandstone with less intense clay alteration compared with other Athabasca deposits. The mineralization at McArthur River is associated with a northeast trending, southeast dipping zone of reverse faulting, along which the unconformity is displaced vertically 60 m to 80 m, as shown in Figure 1.

Hydrogeologically, the brittle, flat lying sandstone has been highly fractured by the tectonic forces of the thrust fault and these fractures are water bearing. Drawdown testing has demonstrated that the fracture patterns, along with water bearing joints and bedding planes are directly connected to the surface groundwater table. This indicates an unlimited volume of high-pressure water is sourced within the sandstone, and significant flows could be produced if the water is intersected by the mine development.

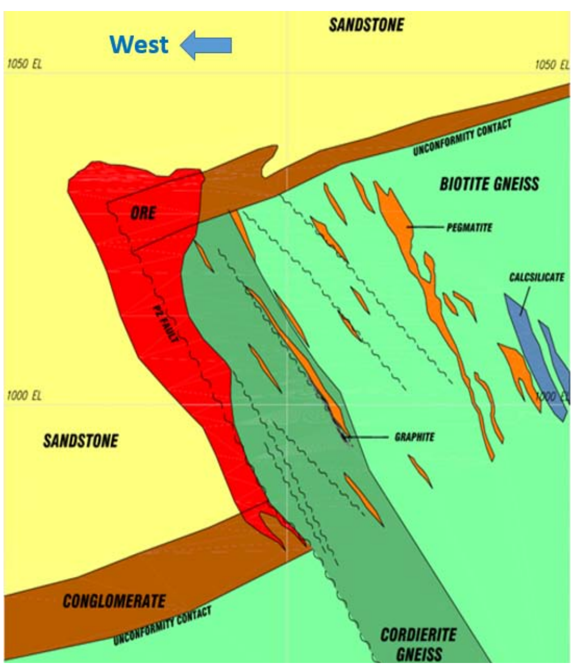

Figure 1: Typical Zone 4 geological section.

There are two major channels by which the water could enter the underground openings:

- Boreholes - grouted or ungrouted,
- Geological formation - directly or indirectly

Underground probe/exploration holes are drilled into all planned mining areas to collect hydrogeological and structural information prior to mining through it. These drill holes could intersect intervals, generally structural related, which contain a substantial amount of high-pressure water. Any loss of control might result in these holes being conduits for a significant inflow of water into the mine. To minimize this risk, rigorous collar security standards have been developed for all underground drilling.

There is a potential risk for encountering ungrouted or poorly grouted surface holes during underground excavation. Therefore additional precautions need to be taken in the vicinity of a surface hole during design and development phases. Any underground development within 8 m of a surface borehole is treated as high risk as per ENG-01-09.

Water inflows into the mine could also occur if a water bearing geological structure was encountered during development or if the mine development inadvertently breached the unconformity. In 2003, a breach of the unconformity in Bay 12 during development resulted in a peak inflow of 1,069 m^3/hr, and then stabilized at 700 m^3/hr.

In order to prevent high pressure and radon-bearing water from entering the mine, several different tactics have been developed and applied at the McArthur River Operation:

- Artificial ground freezing to form a frozen curtain between the water bearing sandstone and the ore body.
- Probe and grout drilling to evaluate hydrogeological and structural conditions prior to drift development and to reduce the water conductivity of the surrounding rocks with pressure grouting, if no freeze wall protection exists.
- Strategically locate the underground excavations away from known water sources whenever possible.

3. GROUND FREEZING

Artificial ground freezing is an excavation support method that involves the use of refrigeration to convert in-situ pore water into ice. Over the last several decades, many mining operations have successfully utilized artificial ground freezing for deep excavation support while shaft sinking. McArthur River successfully maintains a very large-scale ground freezing infrastructure. The resulting freeze walls act as barriers between the underground mine workings and the water bearing formations.

Freeze methods used consist of the following three categories:

3.1 *Freeze Wall Isolation*

Freeze wall isolation consists of creating one or more freeze walls to isolate an area from water bearing ground. In order to be effective, the freeze walls must be tied together and completely enclosed or anchored into non-water bearing and non-permeable ground. The lower portions of Zones 2 and 4 were isolated from the ground water by creating three freeze walls (north, west and south) and by using the geometry of the thrust fault to take advantage of the non-water bearing basement rock to seal the top, east and bottom of the zone (Refer to Figure 2). More recently, freeze wall protection for the upper portions of Zone 2 and Zone 4 have included a frozen cap, as shown in Figure 3. The freeze hole drilling for Zone 1 is currently in progress and is based on this design.

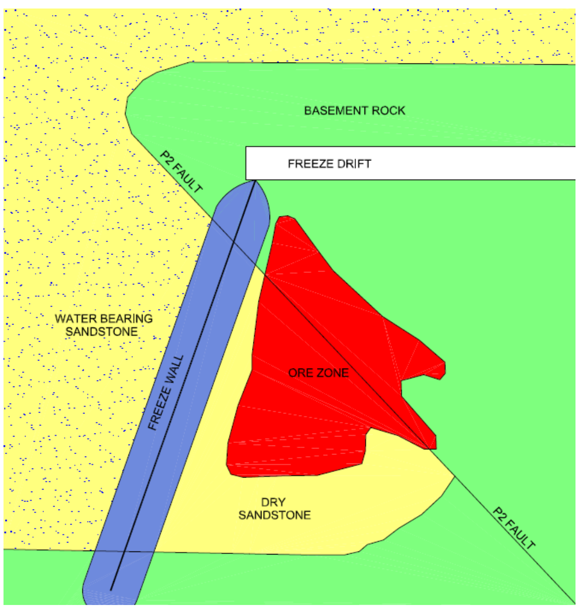

Figure 2: Typical freeze wall insulation situation with three freeze walls.

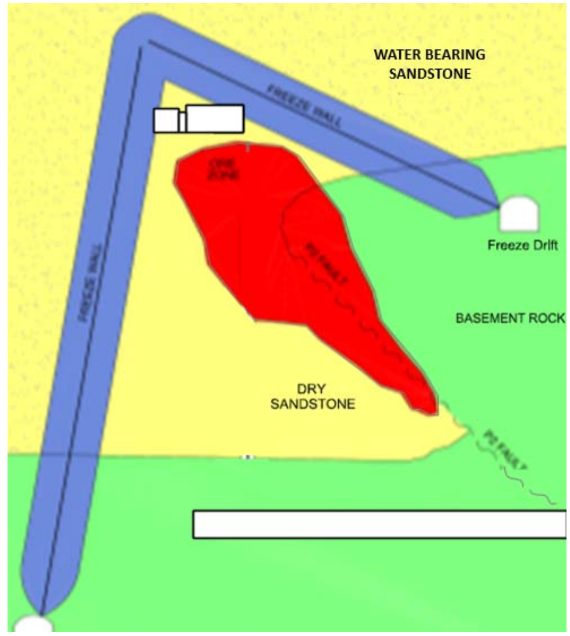

Figure 3: Typical freeze wall insulation situation with top freeze cap as well.

3.2 *Mass Freezing*

Mass freezing consists of freezing an entire area to isolate it from water bearing ground. To date, mass freezing has been used at McArthur River only for the Boxhole mining test at Zone 4 North. This might be considered as an option for the upper portions of Zone 2 and 4 mining area due to the presence of a massive clay zone right above the high grade ore (Refer to Figure 4).

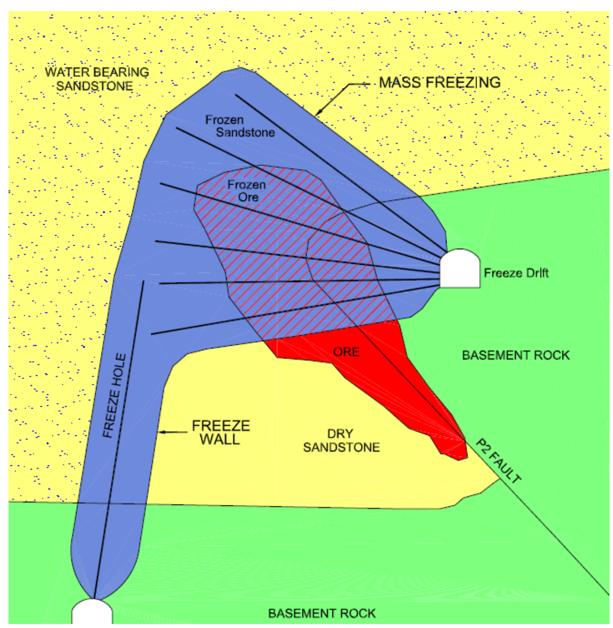

Figure 4: Massive freeze insulation.

3.3 *Freeze Shield Protection*

Freeze shield protection consists of creating freeze walls that are not completely enclosed in certain situations where potential water sources are strongly dominated from one direction. They do not provide full protection from water, but do help mitigate the risks associated with developing near water bearing ground. Freeze shields have been used for some 530 level development in the Zone 4 Central Lower mining area. (Refer to Figure 5).

Freeze holes spacing is determined by various factors such as geothermal properties, drilling accuracy, schedule requirements, and cost. Hole spacing has varied slightly, but is typically in the range of 2.5 to 4 m.

3.4 Freeze Drilling

A freeze hole drilling program is carried out according to an approved engineering design. Each hole typically begins with a 9 m long grouted standpipe, which is pressure tested to ensure that it is secure and that there is no leakage to the mine workings. The hole is drilled to depth and the outer freeze rods are grouted to the rock. A second set of freeze steel is grouted inside of the outer steel. A deviation survey is performed on the hole and the data is entered into the drill hole database. The location of the hole is compared to the adjacent freeze holes to ensure that the final spacing is within the design criteria. Infill holes are occasionally required to fill gaps. At regularly spaced intervals adjacent to a freeze wall, temperature monitoring holes are drilled. Thermocouplers are inserted and grouted at 5 to 10 m spaced intervals within each of these holes and the resulting temperature data is recorded into a central database. This information is used to monitor the temperatures and to provide data for 3D modelling of the freeze wall as it forms.

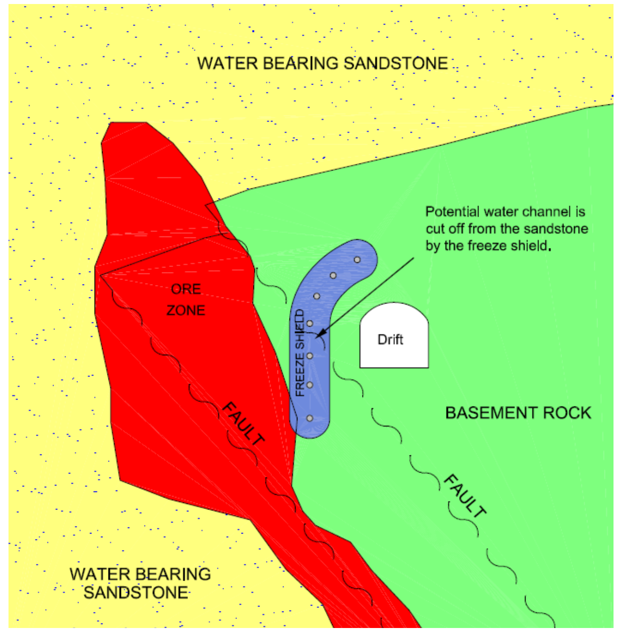

Figure 5: Freeze shield insulation situation.

3.5 Ground Freeze Commissioning

After the freeze holes are drilled off, the brine distribution system is installed and the brine is circulating, the freeze wall is left to develop for approximately six months. The freeze wall is considered to be in place when temperatures from the monitoring holes and results from the block modelling indicate that ground conditions meet the minimum criteria of -3°C or lower and a freeze structure thickness of at least 4 m. Within the confines of the freeze wall, the ground will contain unfrozen water that remains at full hydrostatic pressure. A series of strategically placed diamond drill holes, with full collar security, will target the unfrozen rock within the freeze wall. These holes will dewater and depressurize the area before any mine development or other production activities are carried out within the freeze structure. Water flows and pressures will be regularly measured to confirm that the isolated ground is not recharging from outside the freeze wall. The results will be subjected to a review and approval process before the freeze wall is officially commissioned.

3.6 Ground Freezing Maintenance

After a freeze structure is established sufficiently for mining operations to proceed, the wall will continue to grow. Ground temperatures are monitored throughout the life of the freeze structure. This helps the operation to monitor the freeze wall status, make decisions on brine circulation rates, verify or refine future freeze design criteria and assists in establishing the baseline for the overall freeze loading capacity requirements. If temperature readings indicate unusual or unknown changes, an investigation will be conducted to diagnose and resolve the problem in a timely manner.

4. PROBE AND GROUT PROGRAMS

All mine development will be assessed and assigned a risk level: low risk, medium risk, or high risk based on the available hydrogeological, geotechnical, and radiological information. Once the risk level for the proposed development area is assigned, a probe and grout design will be created based on the standards that have been established for each risk level. The probe and grout coverage will extend 10 m beyond the designed development end and at least 5 m on either side of the proposed development. An extra probe hole might be required to confirm the location of the unconformity. In the case of water concerns encountered during normal probe drilling for the upcoming development, extensive probe and grout might be needed to seal off the paths of water. A probe and grout program done with a jumbo might be considered for covering short distances within low risk development.

Figure 6 is a typical example of probe and grout patterns for high risk development.

Once a probe and grout program is completed, a formal review will be conducted to identify any risk (geological, hydrogeological, and geotechnical) and provide recommendations for the future development. Geological structures and hydrogeological information will be documented. Geotechnical information will be assessed through a Ground Hazard Model and Rock Mass Rating system. The heading will be formally released for development with proper controls in place for excavation and ground support.

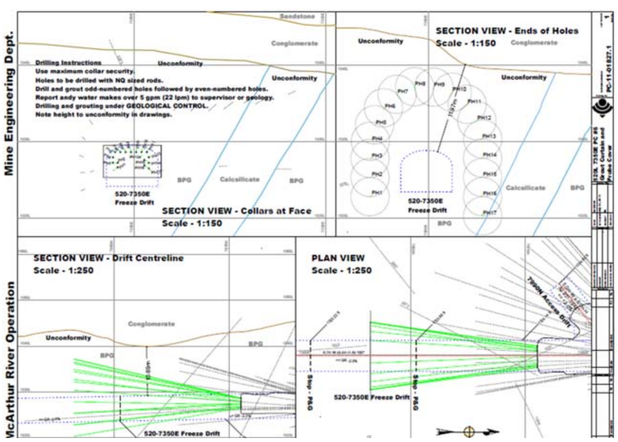

Figure 6: Typical probe and grout pattern for high risk development.

5. CONTINGENCY DEWATERING OF HIGH RISK DEVELOPMENT WITHOUT FREEZE PROTECTION

Any high risk development less than 15 m to the unconformity without ground freeze protection may have risk of unknown water interception. In order to mitigate this risk, contingency plans have to be in place to manage the risk, such as contingency dewatering infrastructure including water hitch, drainage holes, and sufficient dewatering pumping capacity.

6. CONCLUSIONS

The practices used for dealing with hydrogeological challenges at McArthur River Operation are:

- Probe and grout drilling programs prior to any development without freeze protection to collect detailed geological, hydrogeological, geotechnical, and radiological information. Results collected are formally reviewed and then the heading can be released for development with proper controls applied if required.
- Freeze walls have been used effectively to isolate production areas from water enriched formations, such as Zone 2, Zone 4 Lower, Zone 4 North upper, and Zone 4 Central upper.
- Freeze shield protection was used for the 530-7300E Raisebore drift to allow for the mining of Zone 4 Central Low portion.
- Dewatering and pressure relief drilling were used in Zone 2 Panel 5 and Zone 4 North Upper as part of the freeze wall commissioning process.
- Additional precautions are taken with underground development in the vicinity of known surface drill holes. If a new development without freeze wall protection from the water source is located within 8 m of any ungrouted surface hole, it will be considered as high risk development.
- Before any hydrological high risk development without freeze wall protection is allowed to take place, an emergency water handling plan must be in place, such as water hitches or drainage holes, etc. The corresponding mine dewatering capacity must also be sufficient.

7. ACKNOWLEDGEMENT

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