QUANTIFYING THE EFFECT OF LOCALIZED DEPRESSURIZATION ON A DEEP UNDERGROUND OREBODY AT THE MCARTHUR RIVER MINE THROUGH CROSS HOLE HYDRAULIC TESTING AND GROUNDWATER MODELING

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ABSTRACT

The McArthur River mine in northern Saskatchewan is the largest single producer of uranium in the world. Most of the ore is extracted by raisebore mining methods at depths of 530 to 600 m below ground surface where pore pressures in the fractured host sandstone and gneiss are on the order of 5 MPa. Currently, ground freezing is used to isolate the ore from ground-water sources. Localized depressurising of the freezing drifts is being considered to increase their ground-stability.

Cross-hole flow and shut-in tests in eight NQ-size coreholes were conducted in the basement rock that is adjacent to a fault contact with the overlying 500 m thick sandstone unit. The hydrogeologic parameters of basement rock in the vicinity of a freezing drift were obtained. A 15% to 25% reduction of pore pressure over a 25 m distance was observed within a three hour test period.

A detailed three-dimensional ground-water flow model was constructed to replicate the pore pressure measured in the coreholes. The pore pressure distribution simulated from the model provides the hydrogeologic input for geotechnical engineers to evaluate ground-stability and assess whether additional active depressurising should be conducted.

INTRODUCTION

The McArthur River mine, located in the southeastern part of the Athabasca Basin in northern Saskatchewan, Canada (Figure 1), is the largest single producer of uranium in the world. Most of the ore is extracted by raisebore mining methods at depths of 530 to 600 m below ground surface where pore pressures in the adjacent fractured sandstone are in the range of 5 MPa. Currently, ground freezing is used to isolate the ore from this high pressure ground-water. However, this methodology only enables ore to be extracted from the lower portion of the Zone 4 ore body (Figure 2) without additional freezing and utilizing the boxhole boring method. The potential of ground failure due to the high water pressure and low rock strength currently presents a challenge to extraction of a significant portion of the ore in the upper part of the Zone 4 ore body (Figure 2).

Figure 1– Location of McArthur River mine

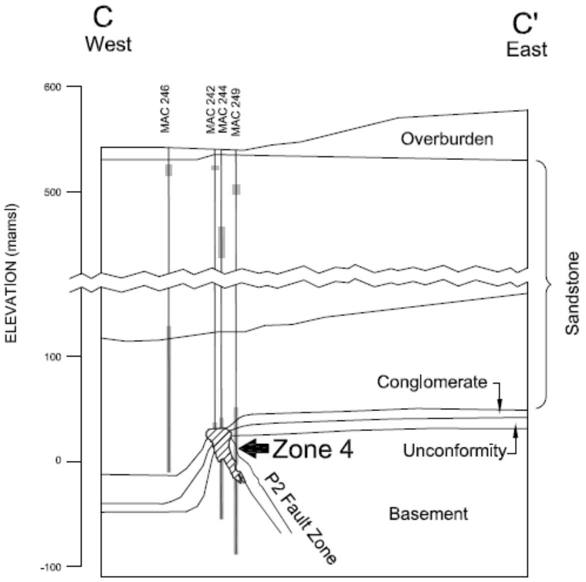
Pre-mining depressurising of the entire ore body was initially considered as a method to decrease the risk associated with mining near the 5 MPa water pressure and increasing the amount of ore that can be extracted by the mining operation. The challenge is to depressurise the high-grade ore bodies -- which are of relatively small lateral extent -- without propagating a significant amount of drawdown to the surface where impacts on surface-water resources and associated aquatic habitat would be significant environmental issues. Another important issue predicted by the model was the volume of water that would need to be continuously discharged to achieve large scale depressurisation. In this environment, the volume of discharge was considered to be problematic (Liu et al, 2008). As an alternative to the mine-scale depressurisation, localized depressurising of the freezing drifts is being considered to increase their ground-stability.

A preliminary program was designed and implemented to evaluate the effectiveness of local depressurisation of freezing drift. Cross-hole flow and shut-in tests were conducted in eight holes drill from the basement rock. A detailed groundwater flow model was conducted to simulate the reduction of pore pressure around the drifts as the result of the local depressurisation.

FIELD AND NUMERICAL INVESTIGATION

Basic Hydrogeology

The upper bedrock at the McArthur River mine site consists of 480 to 560 m of sandstones of the Athabasca Group which unconformably overlie crystalline Archean and Aphebian basement rocks. The mineralisation being exploited at the mine is associated with a major thrust fault known as the P2 fault (Figure 2) where the majority of the mineralisation occurs along the southeast-dipping thrust at the contact between the Athabasca sandstones and underlying basement rocks in a series of discontinuous ore bodies (Figure 3).



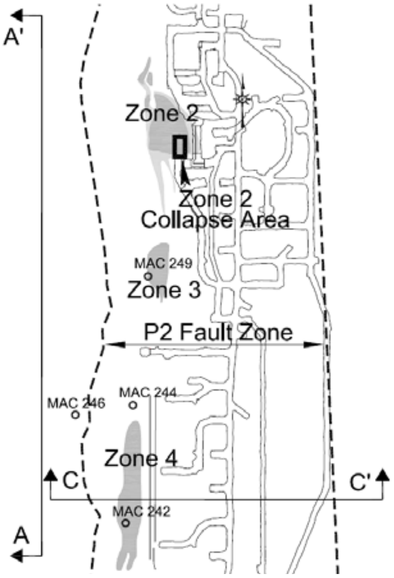


Figure 2 – Cross section of stratigraphy and ore body

Figure 3 – Base map of mine area

There are six major hydrostratigraphic units at the McArthur River mine including, from the stratigraphically highest to the lowest: post-glacial overburden, sandstone, fanglomerate with a basal paleo-weathered zone, an unconformity, the mineralized zone, and the basement rock. The measured horizontal hydraulic conductivity (K_h) values, as well as the geometric mean value, from packer testing conducted prior to shaft sinking are shown on Figure 4. These data show that the K_h of the sandstone unit is at least one order of magnitude greater than the basement rock.

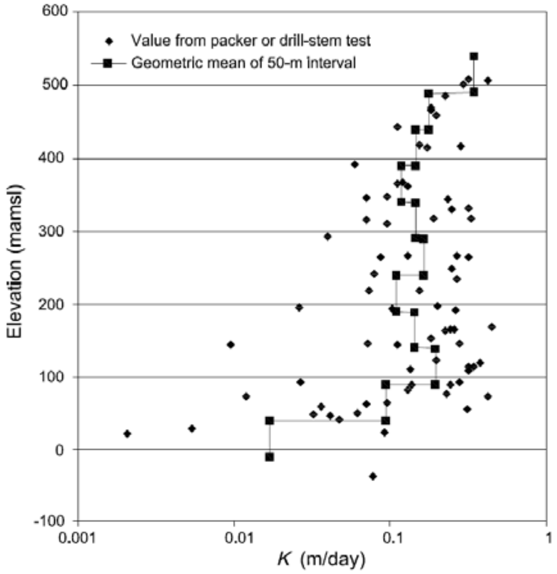


Figure 4 – Hydraulic conductivity vs. depth in sandstone

Field Testing

10 coreholes were drilled from the face of the 7860N freeze drift. Figure 5 shows the plan view of these test locations.

Figure 5 – Base map of McArthur River mine

Figure 6 shows the collar locations of the 10 coreholes, the projected corehole trajectories, and the distances from the drift face to the end of each core holes (the "y" distance along azimuth 270o. Of the 10 coreholes, seven pass below the planned 7300 E drift and three pass above it (Figure 7). All the coreholes are NQ-size and have HQ-size surface casing grouted into the basement rock for about 6 m. All coreholes were connected to a drain manifold and installed with ball valves and hoses for flow and pressure measurement. A small diameter nylon tube was connected to each corehole valve on the drain manifold and to one of the inlet fittings on the pressure measuring panel. Valves within this panel allowed sequential measurement of pressures in each corehole by a high precision digital pressure gauge.

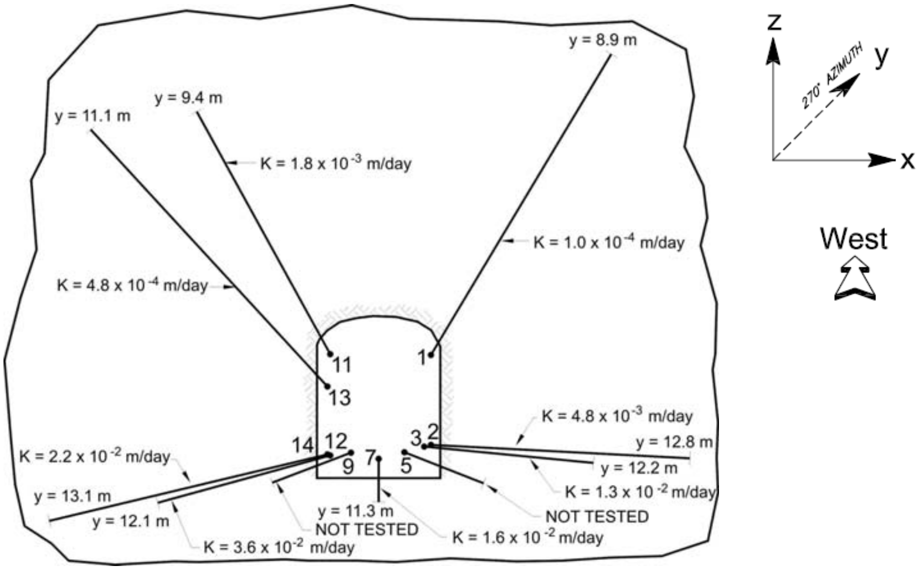


Figure 6 – Corehole locations and hydraulic conductivity values from flow and shut-in tests from face of 7860N freeze drift

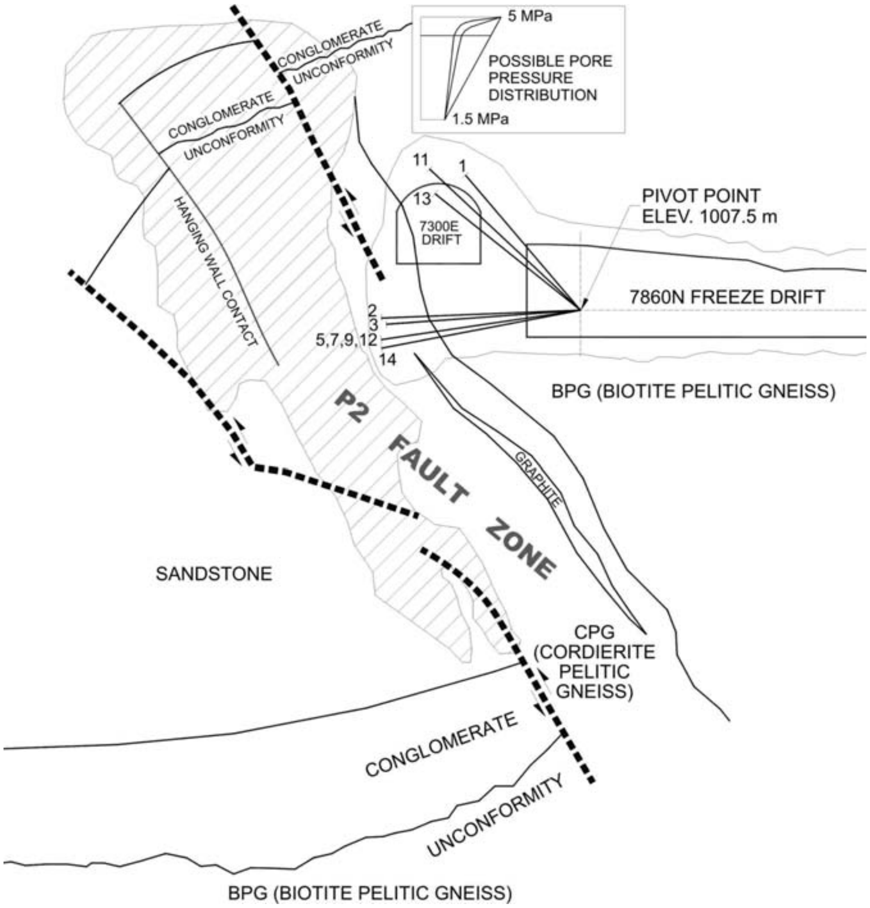


Figure 7 – Pore pressure distribution in cross section looking north, 7860Nl

Both flow and shut-in tests were conducted on each corehole for duration of about 200 to 380 minutes. The hydraulic conductivity (K) values from the flow tests were calculated using the Jacob-Lohman method and the shut-in tests were evaluated using the Cooper-Jacob method [1]. The derived K values from the testing are summarized on Figure 6

Detailed Groundwater Flow Model Simulations

Model Description

Based on the results from the field testing, detailed three dimensional groundwater flow model was built to (1) represent the hydrogeologic conditions and mine workings in the vicinity of the drift, (2) replicate the hydraulic head response to the flow test of selected corehole, and (3) predict the pore pressure distribution with the current configuration of coreholes as input to geotechnical analysis.

Figures 8 and 9 show the model domain in plan view and cross section, respectively. Note that elevations are referred to in mine levels which are true elevations in mamsl plau 1,000 m. The area of the model domain is about 120 m x 120 m. Its top is at 50 mamsl (the nominal 1050 mine level) and its bottom is at -50 mamsl (950 mine level). The model domain was discretised with 33,620 nodes, 60,800 elements, and 20 layers. To represent the geometry of the drifts, coreholes, and hydrogeology in the test area, a grid size of as small as 2 m in both the horizontal and vertical directions has been used in the model. The hydraulic properties assigned to each hydrogeologic unit are summarised on Figure 9.

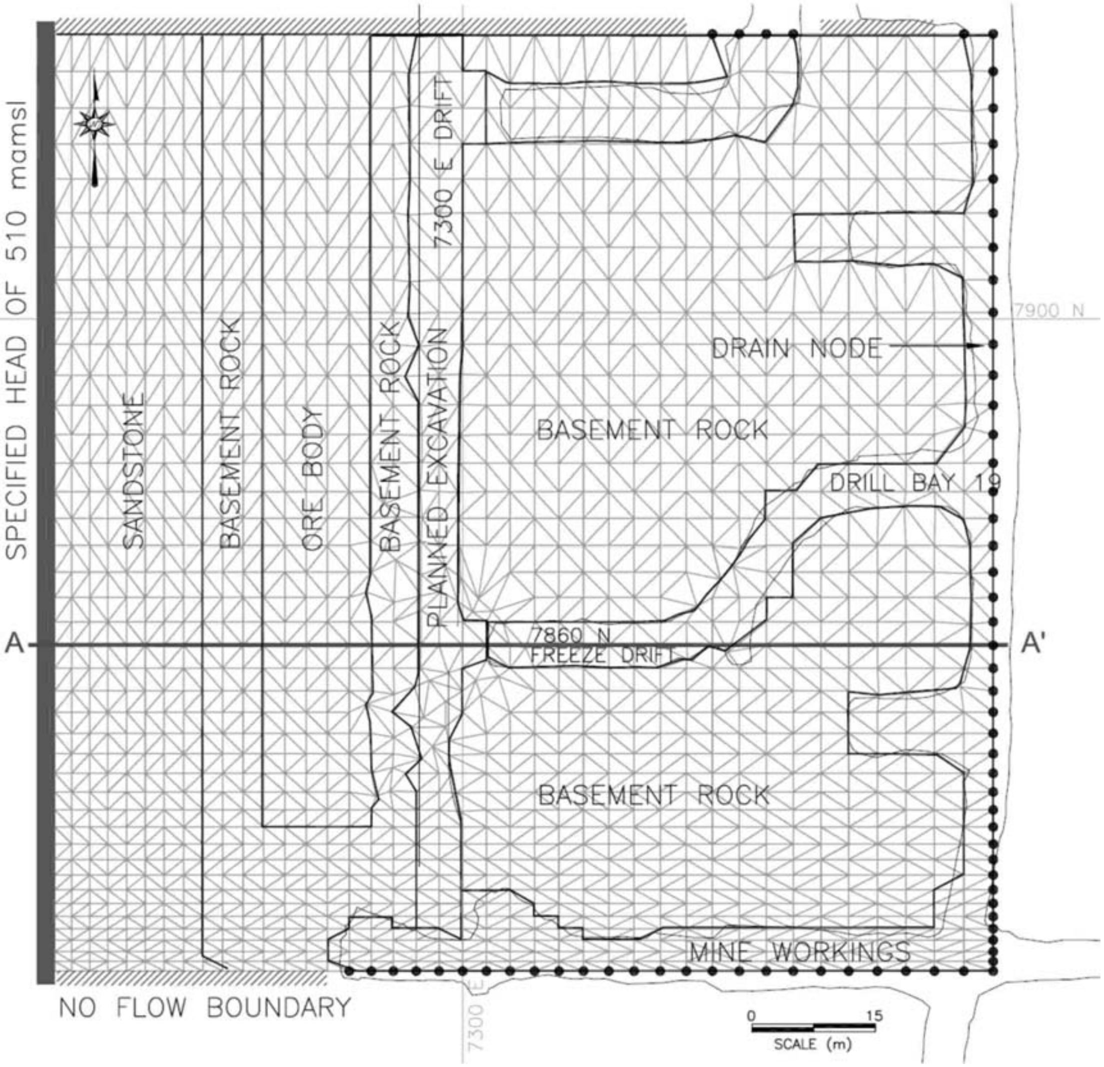


Figure 8 – Map view of model domain, geology represented, and hydraulic boundary conditions at nominal 1006 mine level

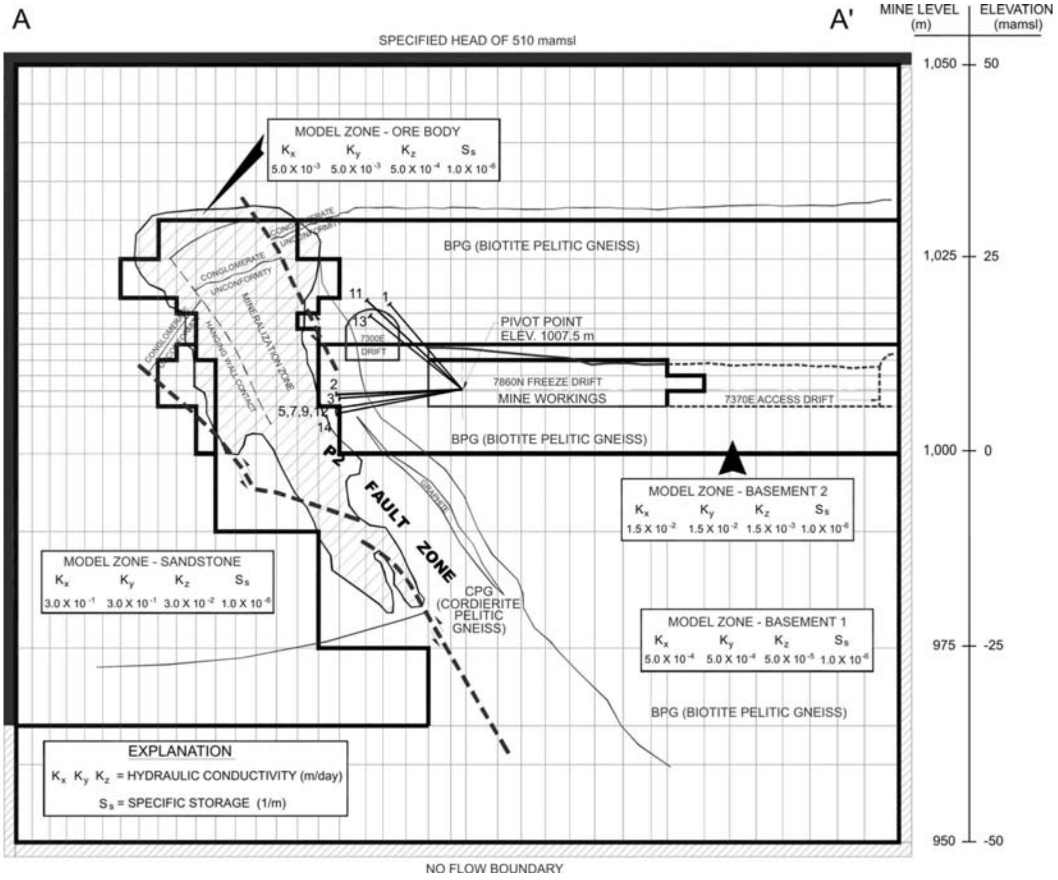


Figure 9 – Model domain, geology represented, and hydraulic boundary conditions along Cross-Section A-A'

The hydraulic boundary conditions assigned were:

1) A specified head of 510 mamsl at the top of the sandstone layer; this assumes that the relatively small amount of free drainage from the coreholes will have no significant effect on groundwater conditions in the sandstone, a major “aquifer”;

2) A similar specified head of 510 mamsl in the sandstone on the west boundary of the model;

3) Drain nodes with a head equal to elevation (i.e., $h = z$) for all nodes representing existing mine workings; and

4) No-flow conditions to all lateral model boundaries in the basement rock with the exception of the drain nodes assigned to the mine workings.

For a hydrogeologic control volume with the size of this model, most of the ground-water flow would be controlled by fractures. However, to adequately represent such fractures, a well-defined discrete fracture network (DFN) would be required. This preliminary model assumes that each rock unit can be reasonably represented as an equivalent (albeit anisotropic) porous media.

Model Simulations

Three stages of model simulations were conducted. At the first stage, the existing groundwater conditions were simulated. During the field testing programme, the fluid pressures in all coreholes were gradually observed to decrease with time, demonstrating the effect of depressurising simply due to mine development in the test area. Although this “background” depressurising did not have any significant effect on the results of the short-term flow and shut-in tests, it is important for the flow model to incorporate such a depressurising effect to establish the initial conditions prior to simulating the flow and shut-in tests.

At the second stage, the model was used to simulate the flow and shut-in tests in Corehole #2. Of all the coreholes tested, Corehole #2 had the highest discharge rate of 17.2 m^3/day. By first reproducing this discharge rate from all of the drain nodes that represent Corehole #2 in the model, the model calculated the hydraulic heads in the surrounding rock. Figure 10 shows the areal extent of the reduction in hydraulic head at the 1006 mine level at the end of the flow test. As indicated on Figure 10, a head reduction of about 5% to 30% was predicted. Due to the representation of discrete fracture flow with an equivalent porous media, the model tends to under-predict the head reduction in the coreholes that are more distal from Corehole #2. As shown on Figure 11, the model also predicts that the head reduction is laterally elongate (a function of the horizontal to vertical anisotropy incorporated into the model) and does not propagate as much to the area associated with the upward coreholes. This condition was observed during the test and was the basis for incorporating the anisotropy. Both Figures 10 and 11 demonstrate that the model reasonably replicates the results from the flow test.

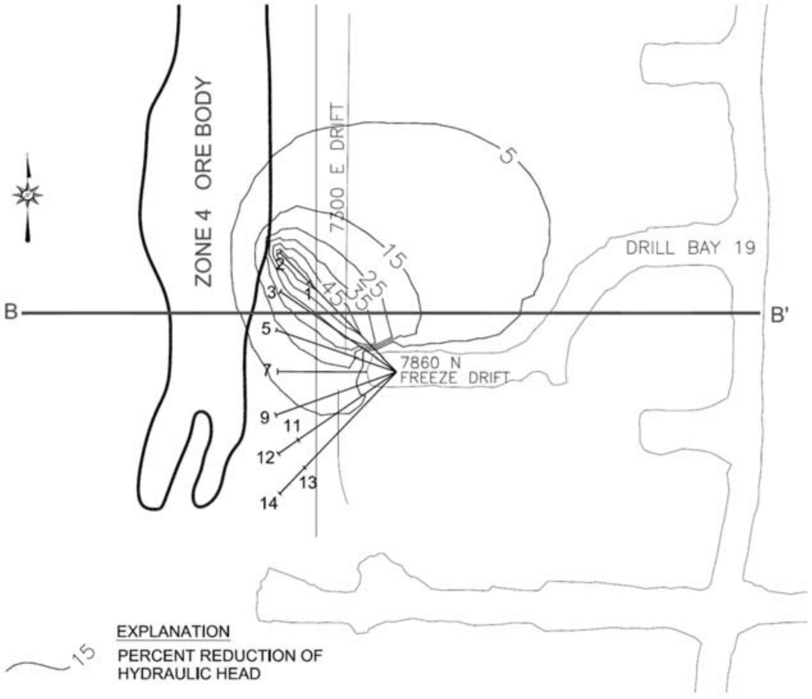


Figure 10 – Simulated percent reduction of hydraulic heads at nominal 1006 mine level at end of flow test in Corehole #2

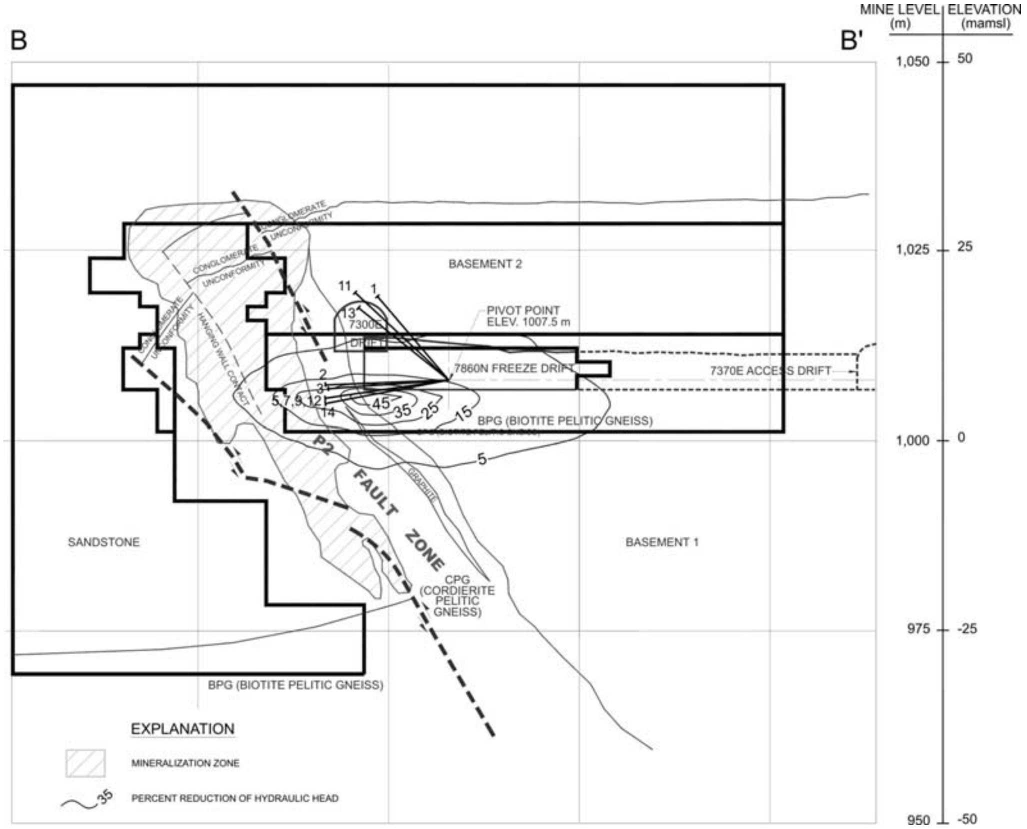


Figure 11 – Simulated percent reduction of hydraulic head in Cross-Section B-B' at end of flow test at Corehole #2

At the third stage, a predictive simulation was then conducted to predict the distribution of the pore pressures that would occur under long-term draining by the existing coreholes. The simulated discharge rate for each corehole was based on the value obtained during the flow and shut-in tests (HCItasca 2008). The numerical simulation indicates that essentially steady-state conditions are reached in less than two hours. Figure 12 shows that the areal extent over which there could be a 15% reduction in hydraulic head at the 1006 mine level is about 30 m x 60 m.

The predicted pore pressure distribution at the 1006 mine level and along cross-section A-A' is shown on Figures 13 and 14, respectively. These pressures were simply calculated from the model-calculated hydraulic heads and the elevations of various points from:

$$P = (h - z)/102 \tag{1}$$

where

P = pressure (MPa),
h = hydraulic head (mamsl), and
z = elevation (mamsl).

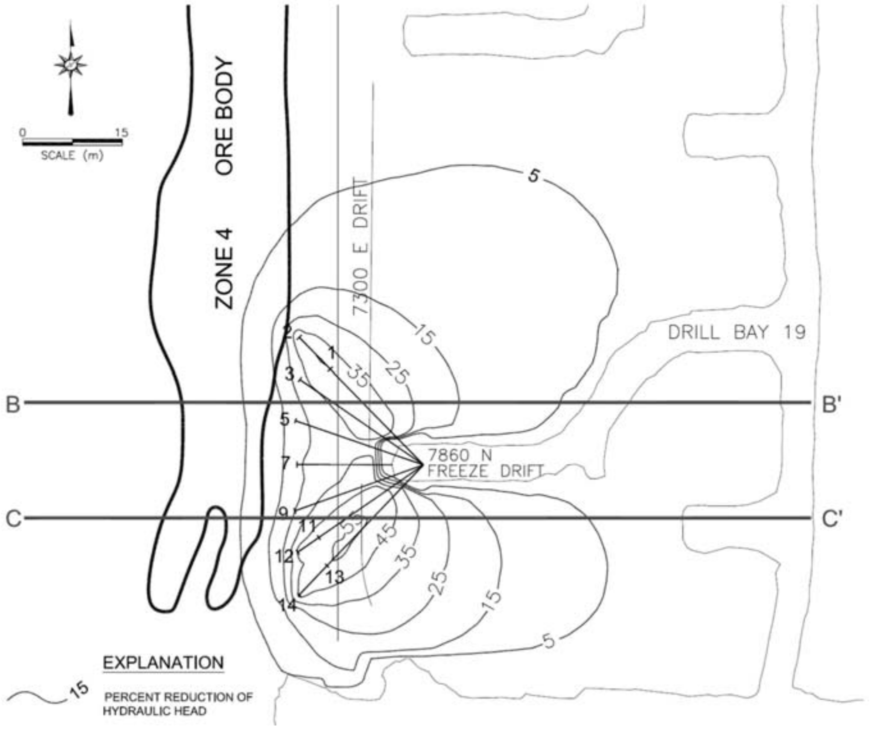


Figure 12 – Simulated percent reduction of hydraulic head at nominal 1006 mine level if existing coreholes are allowed to freely drain

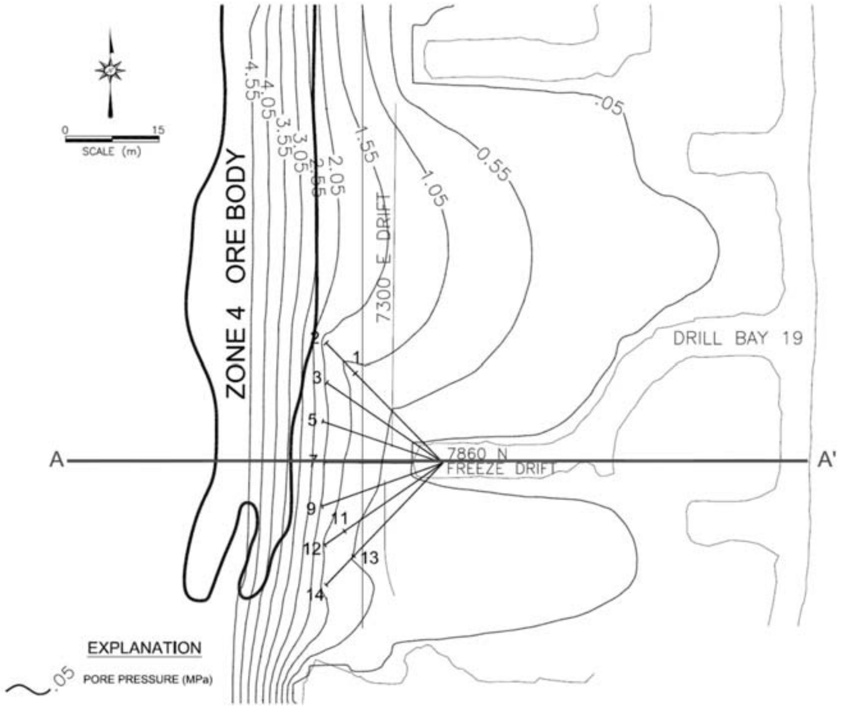


Figure 13 – Simulated pore pressure at nominal 1006 mine level if existing coreholes are allowed to freely drain

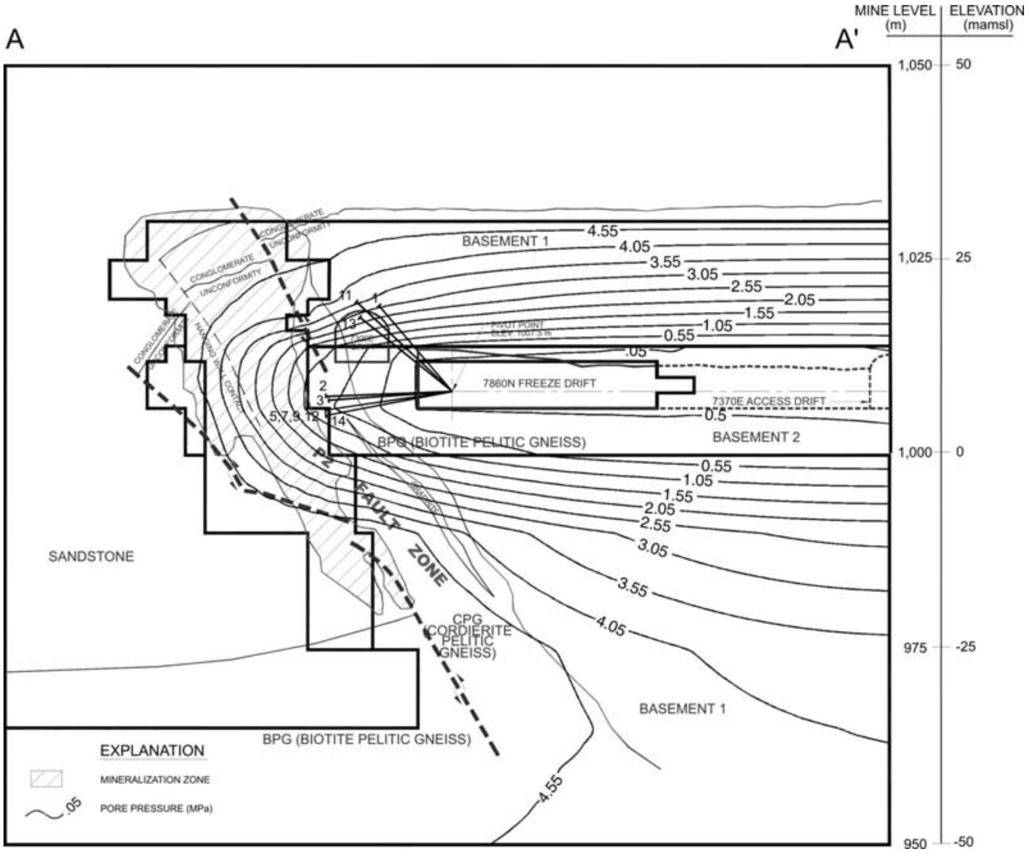


Figure 14 – Simulated pore pressure in Cross-Section A-A' if existing coreholes are allowed to drain freely

The predicted pore pressures range from less than 1 MPa in the area of the coreholes to 4.5 MPa in the sandstone unit. This predicted pore pressure distribution can be used by geotechnical engineers to evaluate ground stability when the freeze drifts are excavated and to assess the potential future need for depressurisation.

DISCUSSIONS AND CONCLUSIONS

The results from the flow and shut-in tests and the ground-water flow modelling simulations demonstrate that it is feasible to depressurise locally the basement rock in the vicinity of Drift 7300E. The detailed three dimensional model is a necessary tool to provide the pore pressure distributions that are required for addressing the ground stability by geomechanical analyses. Future investigation should include the optimal design of drainholes (location, depth, and configuration) through the iterative model simulations using both numerical groundwater flow and geomechanical modelling to achieve the targeted depressurisation goal.

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2. Azrag, E.A., Ugorets, V.I., and Atkinson, L.C., Use of a Finite-Element Code to Model Complex Mine Water Problems: Proceedings of Symposium on Mine Water and Environmental Impacts, vol. 1, International Mine Water Association, Johannesburg, September, 1998, 31-42.