Depressurising an underground ore body at the McArthur River mine in northern Saskatchewan, Canada

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Abstract

Pre-mining depressurising of a deep ore body at the McArthur River mine in northern Saskatchewan was considered to decrease the risk associated with mining near 5 MPa water pressure and increasing the amount of ore that can be extracted. Based on a limited amount of field data, a three-dimensional finite element ground-water flow model was developed to predict the amount of water that would have to be pumped from surface wells or extracted with underground drainholes to meet this goal and the associated magnitude and extent of drawdown that would propagate to the surface over the life of the operation and its impact on surface-water resources. In addition, the results from the preliminary model were used to design a prototype depressurising well and a 30-day pumping test. Because of the predicted large volume of water that would have to be discharged, another still on-going investigation has been conducted to assess the effectiveness of localized depressurisation in improving mine tunnel stability in conjunction with ground freezing and cementaceous grouting.

Key Words: McArthur River mine, Athabasca Basin, uranium, depressurising, ground-water flow model

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*

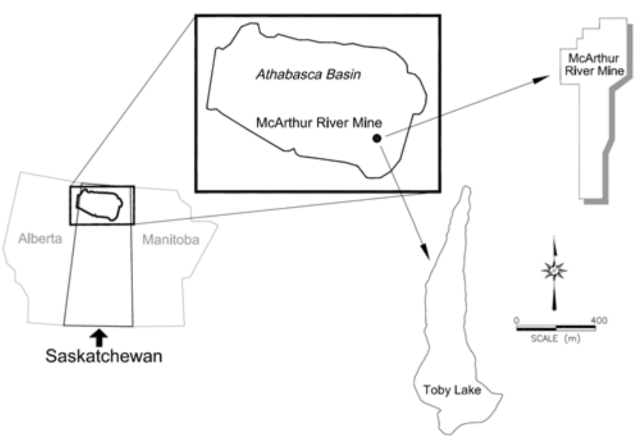
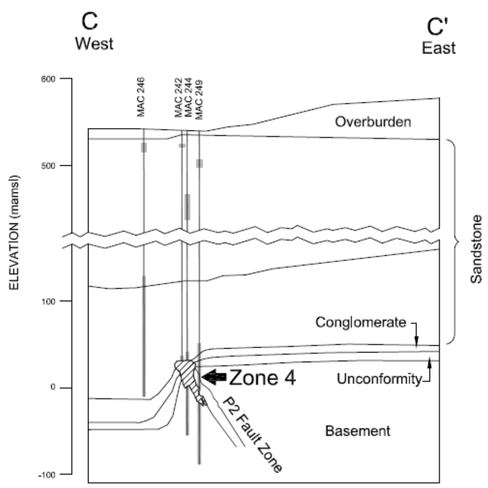


Figure 2 *Cross section of stratigraphy and ore body*



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.

A preliminary study, which included analysis of existing hydrogeologic and inflow data and development of a three-dimensional ground-water flow model was conducted to evaluate the technical and economic feasibility of depressurising the ore body.

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 3 *Base map of mine area*

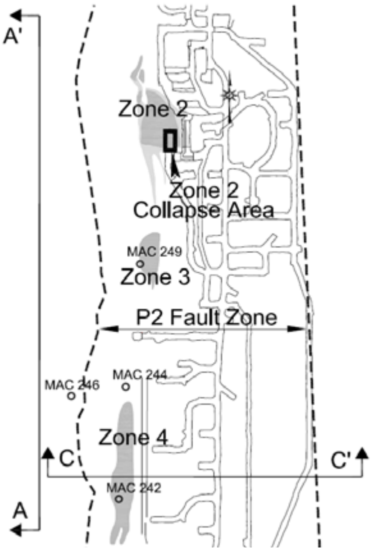
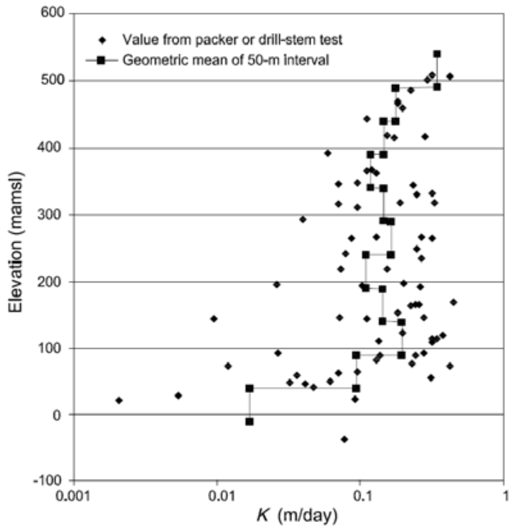


Figure 4 *Hydraulic conductivity vs. depth in sandstone*



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.

Previous Inflow to Underground Mine Workings

The McArthur River mine is considered to be a relatively dry mine because all the workings are within the basement rock. The inflow to the entire mine workings under normal working conditions is about 200 m^3/hr. However, on 6 April 2003, a major unexpected inflow occurred in a ramp advancing toward the nose of the Zone 2 ore body (Figure 3) when a failure in the roof of the ramp "chimneyed" up into the overlying sandstone. The initial ground-water inflow rate was in excess of 1,000 m^3/hr but decreased and remained steady at about 800 m^3/hr. Eventually a monolithic bulkhead was built and the inflow was mitigated.

Figure 5 *Drawdown due to April 2003 inflow event*

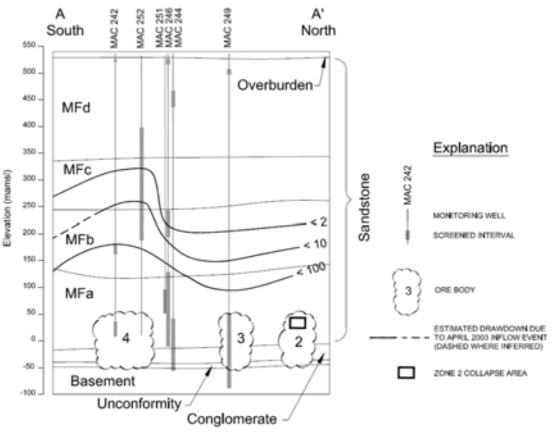
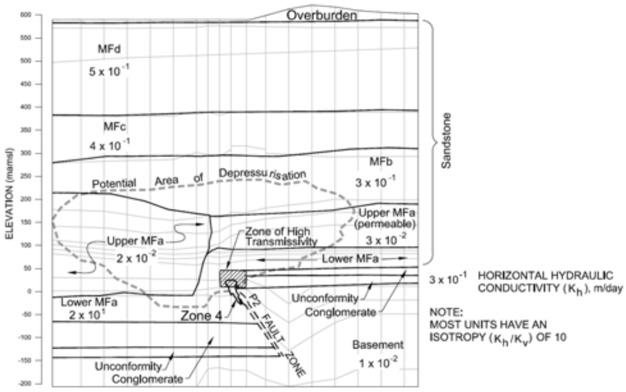


Figure 6 *Conceptual hydrogeologic model of mine area showing finite-element grid*



As unfortunate as it was, this inflow event provided some very useful information with which to base decisions regarding possible future active depressurising. Figure 5 shows that the drawdown (in m) in the overlying sandstone due to the inflow event was limited to the lower portion of the sandstone based on water level data from multi-level piezometers. The vertical extent of the 2-m drawdown contour was about 250 m above the collapse area.

The conditions shown on Figure 5, together with analyses of the temporal response of water levels in all monitoring wells at the site, indicate that:

1) there is a high transmissivity zone in the upper portion of the ore body that acts as a conduit for enhanced lateral movement of ground water -- at least in the north-south longitudinal direction (Figure 3) -- in the lower sandstone unit; and

2) the effect on surface-water resources due to depressurising would probably be relatively very small.

Conceptual Hydrogeologic Model

Based on analysis and evaluation of water "hits" in fan exploration drillholes into the Zone 4 ore body, the response of the various hydrogeologic units to the April 2003 inflow event, and the distribution of K_h values as shown on Figure 3, a conceptual hydrogeologic model for the McArthur River mine was developed (Figure 6). The so-called high transmissivity zone was assumed to exist only at the nose of the various ore bodies and to extend along their entire strike. If active depressurising were to be implemented with either wells drilled from the surface and screened only through the lower sandstone or drainholes installed underground, flow would be induced both laterally in the deep sandstone, especially along the high transmissivity zone, and vertically through the overlying sandstones. The magnitude and sustainability of the well/drainhole discharges and the magnitude and extent of depressurisation will depend on the vertical and horizontal hydraulic conductivities of the various hydrogeologic zones represented in the model.

Preliminary Ground-Water Flow Modelling

Based on the conceptual hydrogeologic model, a ground-water flow model was developed using the three-dimensional finite-element ground-water flow code, *MINEDW* (Azrag et al., 1999). The domain of the model encompasses approximately 140 km^2 and incorporates 15 different hydrogeologic units. The model also simulates all major lakes, selected streams, unlined portions of the shafts, and the main underground workings.

Both steady-state and transient calibrations of the ground-water model were conducted. The measured ground-water levels in 1992 were replicated in the steady-state calibration. Subsequently, two transient calibrations were conducted, first to inflow from the shafts and mine workings and then to the inflow rates and water levels following the April 2003 inflow event.

Finally, predictive simulations were made with the calibrated model to evaluate the potential effect of proposed active depressurising and its possible environmental impacts.

Findings

The primary findings from the preliminary predictive numerical simulations include:

1) the pumping rate from depressurising wells in the nose of the Zone 4 ore body would be about 2,000 m^3/hr (although not specifically simulated, underground drainholes would produce a similar amount of water);

2) depressurising of the Zone 4 ore body by as much as 3 to 4 MPa could probably be achieved with two depressurising wells;

3) the extent of the 1-m isopleth of drawdown that would develop in the overburden as a result of the active depressurising would range from a maximum of about 6 km to the south to 2 km to the east;

4) the ground-water discharge to Toby Lake (Figure 1) could be reduced by active depressurising by about 250 m^3/hr; and

5) active depressurising could reduce the residual inflow into the underground mine workings by about 60 m^3/hr.

On-Going and Future Work

Because of the predicted large volume of water that would have to be discharged from large-scale active depressurisation, an on-going investigation is being conducted to evaluate the effect of alternative localized depressurisation on the stability of mine excavations using underground drainholes. To further evaluate the feasibility of depressurising the McArthur River mine, a prototype depressurising well and more multi-level monitoring wells would need to be installed and a pumping test conducted for about 30 days. The cost of wells (or underground drainholes) and pumping systems will then be evaluated together with a complete environmental assessment to determine if the active depressurising is economically and environmentally acceptable and which method -- using surface wells or the currently used underground drainholes around the mine tunnel -- is the more technically- and cost-effective.

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Reference

Azrag, E.A., Ugorets, V.I., and Atkinson, L.C., (1998) 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, p. 31-42.