The Distribution of Hydraulic Head and Conductivity Around Mine Drifts

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ABSTRACT

Hydraulic head and conductivity profiles were measured in three boreholes, 40 m in length, drilled from drifts located 300 m below the surface in the Niobec Mine, Chicoutimi, Québec. The hydraulic head profiles show a local maximum at about 10 m from the drift face, corresponding to a minimum in hydraulic conductivity. Numerical simulations of the stress field suggest that the stress perturbation is not the only cause of these anomalous hydraulic profiles. These excavation-induced hydraulic perturbations add uncertainties to the prediction of the rate of groundwater inflow.

INTRODUCTION

It is well known in rock mechanics that the presence of excavations causes a redistribution of the mechanical stress field in the surrounding rock mass [1]. Also, numerous laboratory experiments have indicated that the permeability of rock decreases with increasing confining stress, particularly in a rock with fracture porosity [2]. The effect of increasing normal stress in reducing the transmissivity of individual fractures is well documented [3,4]. Therefore, the perturbation of the stress field around an excavation is likely to induce a corresponding modification of the hydraulic properties of the rock mass close to the excavation [5,6]. This stress-permeability effect around excavations has rarely been measured in the field although it may significantly affect the accuracy of predictions of groundwater inflow into mines and other excavations.

We report on the results of field measurements of hydraulic head and conductivity conducted in three boreholes drilled from underground excavations at Niobec Mine near Chicoutimi, Québec. Numerical simulations of the stress field were also carried out to correlate the head and conductivity profiles with stress perturbations.

THE SITE

Niobec is a niobium mine located in a carbonatite intrusion in the Grenville Province of the Canadian Shield [7] (Fig. 1). The regional substratum is constituted of Precambrian crystalline rocks, mostly gneiss, granite and anorthosite. The carbonatite intrusion is almost completely covered by a remnant of subhorizontal limestone and shale of Paleozoic age. The intrusion constitutes a relatively homogeneous rock body, characterized by large-scale concentric lithological variations.

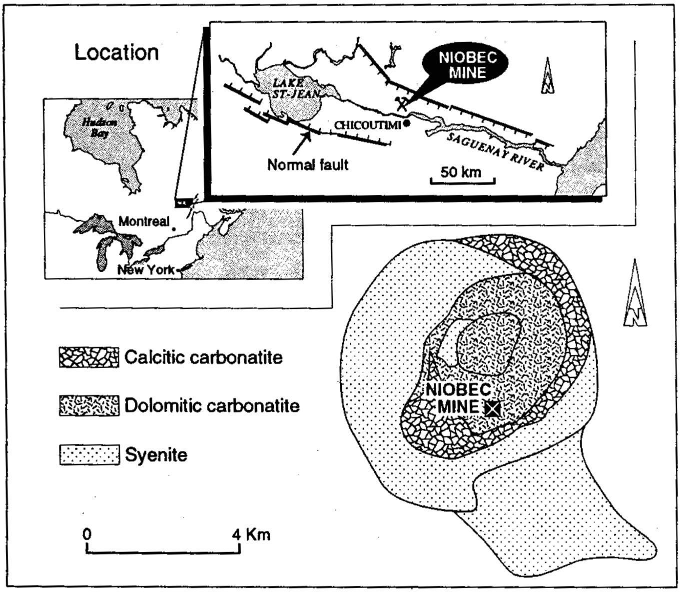

Figure 1. Location of Niobec Mine in a circular carbonatite complex, associated with the Saguenay Graben.

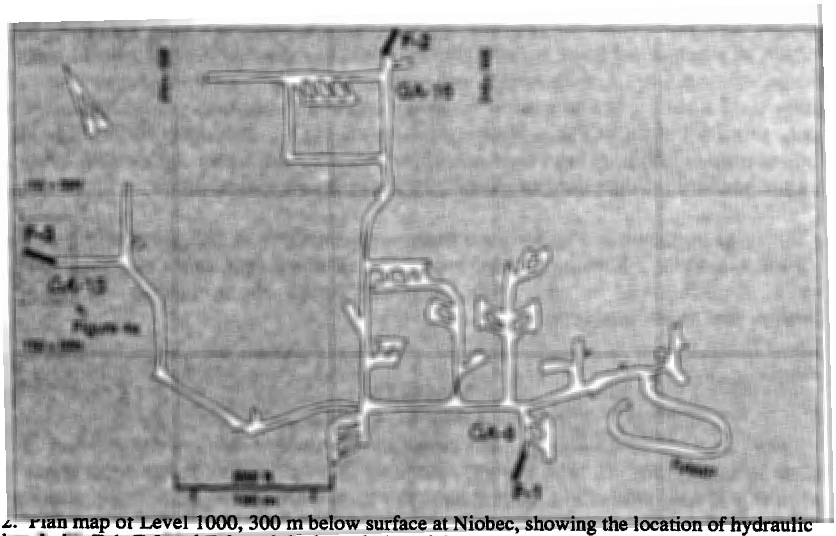

Figure 2. Plan map of Level 1000, 300 m below surface at Niobec, showing the location of hydraulic testing boreholes F-1, F-2 and F-3, and the boundaries of the stress simulation domain of Figure 4.

The deepest mine level is presently at 300 metres below surface (level 1000'). Three boreholes were drilled from this level (Fig. 2) for hydraulic testing, each one about 40 metres in length and plunging at about 50°. They were located at the periphery of the excavations, both to insure least perturbation of the mechanical stress and hydraulic pressure fields, and to minimise interference with mining operations.

HYDRAULIC MEASUREMENTS

Systematic hydraulic testing was carried out in the three boreholes, using a double-packer system isolating 1.5 m intervals. In each interval, the hydraulic pressure was measured after a stabilisation period required to dissipate the overpressure in the test interval produced by the inflation of the packers. Constant-head injection (or withdrawal) tests were then conducted to estimate the hydraulic conductivity of the adjoining rock mass [8]. The results are shown in Figure 3.

In general the pressure stabilisation period could not exceed 1.5 hours because of mining operations. This time constraint may have caused an overestimation of the *in situ* hydraulic head particularly in lower permeability intervals.

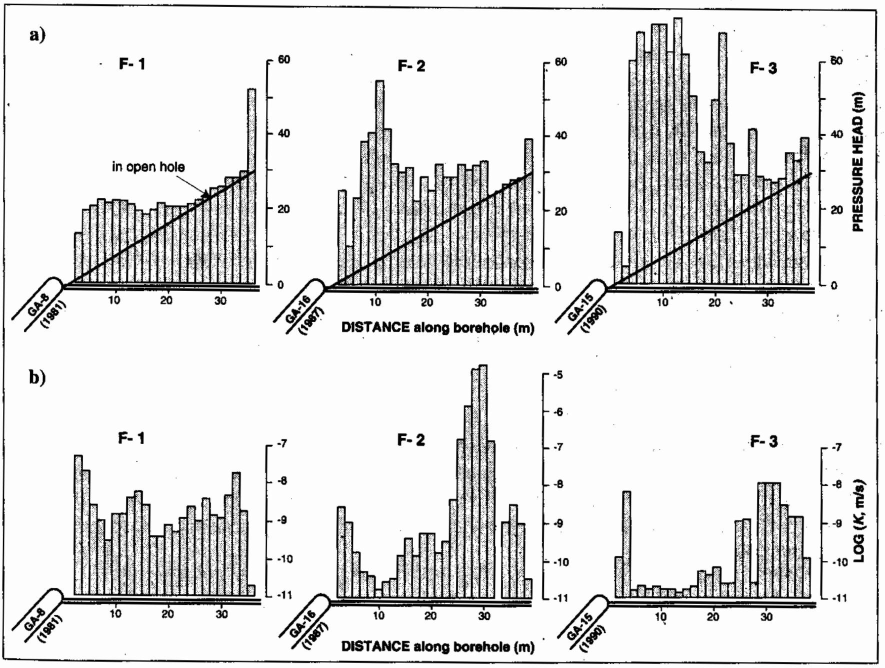

Figure 3. Profiles of a) pressure head and b) hydraulic conductivity in the three boreholes, measured in 1.5 m packer intervals. The drift face is shown, with its number and the year it was driven.

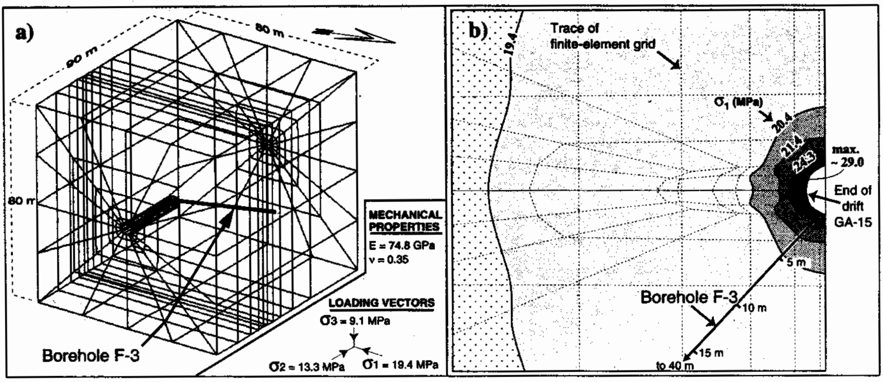

Figure 4. Numerical simulation of the stress field around drift GA-15: a) outline of the finite element grid on the outside boundaries of the simulated domain; b) contours of the magnitude of the maximum principal stress σ_1 in the vertical plane containing borehole F-3.

The pressure head profiles (Fig. 3a) show a maximum value at a distance of about 10 m from the drift face, and low values at about 30 m, in all three boreholes. At greater distances, in the absence of data it may be assumed that the head increases more or less regularly with the logarithm of distance. The high head values at 10 m partly correspond to actual high pressure zones, but these may also be due to a lower permeability of the rock mass and thus a slower dissipation of the overpressure from the packer inflation. The low head values at distances of about 30 m resulted in withdrawal test being impossible at an atmospheric counterpressure in some of the intervals, since the pressure head in the interval was about the same as that in the open hole at the same distance. In any case, the profiles indicate a zoning in the hydraulic properties of the rock mass with respect to the distance from the drift.

A similar zoning is also apparent on the hydraulic conductivity (*K*) profiles (Fig. 3b) particularly for boreholes F-2 and F-3, with low *K* values located at a distance of about 10 m from the drift face, in areas of high pressure head values. Note that the *K* value is below the measurement limit of our field equipment ($\sim 10^{-11}$ m/s) in some of the intervals at distances of 5 to 15 m in the borehole F-3.

Interestingly, the profiles in figure 3 a and b show a trend from one borehole to the other that parallels the age of the drifts from which the boreholes were drilled. Indeed, the maximum in pressure head and the minimum in *K* values at a distance of 10 m are both more accentuated in boreholes drilled from more recent drifts. This trend may be due to heterogeneities in the rock mass, but also to a time effect in the response of the hydraulic properties of the rock mass to perturbations related to the excavations.

STRESS FIELD SIMULATION

The stress perturbation due to the excavations is commonly assumed to be the main cause of alteration of hydraulic properties of the rock mass. Consequently, stress field simulations (Fig. 4) were carried out in order to investigate the possible effect of drifts and mining stopes on rock mass permeability [9]. The linear-elasticity stress-strain equations were solved in a homogeneous and isotropic medium using a three-dimensional finite-element code. The elastic properties of the material and the stress values at the boundaries are average values from laboratory and field measurements by Arjang [10].

The relevant conclusions of Gaudreault et al. (in press) are summarized in four points:

1. The stress perturbation due to large mining stopes appears to be negligible in the borehole areas.
2. The changes in rock permeability inferred on the basis of variations of the mean stress, or confining stress, are often opposite to changes that may be brought by sliding on fracture planes due to variations in differential stress.
3. The stress perturbation due to a drift does not extend much further than 5 m from the drift wall (Fig. 4b).
4. The stress perturbation is unlikely to be the only cause of the observed anomalous hydraulic head and conductivity profiles along the boreholes.

DISCUSSION

The data from Niobec Mine strongly suggest that the presence of excavations significantly affects the hydraulic properties of the rock mass. However, they also underline the generally poor understanding of the effects of the stress perturbation on rock mass permeability around excavations. Two factors particularly critical on the stress-flow relationship are the effect of shearing on the transmissivity of individual fractures, and the extent of the plastic deformation zone close to excavations, and its evolution with time.

Also, the stress-permeability coupling around excavation is superposed to other factors potentially affecting the permeability, such as blasting damages [11], and a variety of physico-chemical processes related to temperature change and to hydraulic depressurisation. These later processes include mineral dissolution-precipitation, and also groundwater degasing and the resulting two-phase flow regime [12]. All of these coupled processes are presumably acting on quite different time scales, making even more difficult the prediction of their effects.

Yet, the prevision of groundwater inflow into mines has considerable importance for economic, safety and environmental considerations, as described by the following examples.

An estimate of the flow rate to be pumped from a mine is required in the planning of the energy needed for a mine operation. The cost of electric energy is often more advantageous when the prediction of the needs are made with a better accuracy.

Zones of high hydraulic pressure may be induced by excavations. A better understanding of the mechanisms inducing high hydraulic pressure around excavations would help preventing groundwater inrushes, thus improving the safety of mining operations.

Waters pumped from mines generally have a higher content of dissolved substances than surface waters. Their emission on the surface often affects adversely the ecology of surface hydrologic systems. A prediction of the pumping flow rate from a mine at the design stage, combined with groundwater chemistry data, are required for an appropriate treatment of pumped waters before their release in the surface environment.

It is well known that the prediction of groundwater inflow is made difficult by the lithological and structural heterogeneities within a rock mass, and the resulting variability in hydraulic properties. It has been shown that the perturbation of rock stress, ambient temperature and hydraulic pressure, within the rock mass around mine workings, also add considerable uncertainties to this prediction.

CONCLUSION

Anomalous profiles of hydraulic head and conductivity have been observed in the rock mass around excavations at Niobec Mine. They are interpreted as the results of stress perturbations and a variety of physico-chemical processes related to the excavations and to mine dewatering. The resulting modifications of the groundwater flow regime make more difficult the prevision of water inflow into the mine workings.

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