Original Article

Groundwater and surface water control at Highland Valley copper mine (HVC) (in rock and soil both)

Sean Daly[1] ©

Abstract

This paper is about dewatering of the two large open pit porphyry copper-molybdenum mines of Highland Valley Copper in BC, Canada. These two pits occur within the well differentiated Guichon Creek Batholith with phases progressively more acidic and coarser grained towards the center and intersected by intense fracturing within the ore bodies and also concentric alteration haloes. Also, they are both cut by the steeply dipping Lornex fault which is an average 155 m wide faulting zone with frequent sympathetic faults adjacent to it. As the two pits have mined down at depth, they have exposed bedrock especially with frequent toppling-type faults and shears which have exhibited varying degrees of toppling and ravelling of the pit walls. Also, on the east wall of the Valley Copper pit, there is up to about 350m of glacio-fluvial overburden, originally with artesian flows in two or three aquifers. The toppling is exacerbated by the hydrostatic pressure of the groundwater in the pit walls. Both pits have significant groundwater and run-off in the spring. In order to be able to continue mining down to depths of about 600 to about 750 meters it has been necessary to de-water the walls and divert the surface run-offs to prevent infiltration into the toppling faults. So two water diversion projects were necessary at the crest of the highwalls and were completed to drain both by gravity and pumping the spring run-off water away from the two pits. Also, a major well drilling project is ongoing in the glacio-fluvial overburden aquifers to dewater them with upwards of 4500 US gpm flows. In addition, an annual series of horizontal drainholes were drilled and are ongoing approximately every three benches to dewater and depressurize the bedrock. Minor bedrock wells in the crest of the Lornex Pit also contribute to the dewatering. All the dewatering has allowed the two pits to mine down to close to design depths without significant disruption.

Key words: Highland Valley; Guichon batholith; open pit; Lornex fault; artesian water; dewatering

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1 Introduction

Mine ownership, production rate and milling

Highland Valley Copper is a large integrated porphyry copper and molybdenum operation, now mining from three open pits, from north to south, Valley Copper, Lornex and Highmont. In the future, there may be more mining around the old Jersey and Iona pits.

Ownership of Valley Copper used to be by Cominco, Lornex by Lornex Mining Corporation, Highmont of Highmont Operating Company and the Jersey and Iona of Bethlehem Copper Corp. Now they are all amalgamated under Highland Valley Copper, owned by Teck Corp. In 1986, Lornex Mining Corp. and Cominco amalgamated into the Highland Valley Copper partnership, uniting the Lornex mill with the large Valley Copper orebody[1].

At first, the ore was milled at Bethlehem as well as Lornex, then the Bethlehem mill was shut down and all the ore went to the Lornex mill. The present production rate is 300,000 tonnes per day, of which about 155,000 is ore and the rest waste. Another set of flotation cells has been added to the mill to improve recovery. Mining began in the Highland Valley in 1963 with the opening of the Bethlehem Mine. The present mine produces copper and molybdenum primarily and with very minor gold and silver by-products. The mills are semi-autogenous which means that while there are grinding balls, mostly the harder ore grinds the softer and the grade control geologists must estimate the grinding rate of the ore for blending purposes in the mill, i.e. combining both hard and soft ore where possible.

The purpose of this paper is to identify and evaluate various methods of both surface and underground water control in a large open pit mining complex and it covers pit perimeter ditches and pipelines, horizontal drainhole drilling for groundwater in bedrock in the pit walls, and well dewatering mainly in glacio-fluvial overburden but also minor in bedrock at the two large open pits; Lornex and Valley Copper.

2 Regional and local geology

These orebodies are part of an approximately 3.5 billion tonne reserve mined plus unexploited ore yet and including the small pits at Bethlehem Mine, the Valley Copper pit, the Lornex pit, the Highmont pit and the untouched JA zone. They all occur within the well differentiated Guichon Creek Batholith which has four main phases which are more felsic and coarser grained towards the center of the Batholith[2]. Both the Lornex and Valley Copper orebodies are cut and truncated by the major approximately 40 km long N-S striking Lornex Fault and there are some other significant faults too. Regionally, Highland Valley copper mine is part of the Intermontane Belt of BC along with for example New Afton and the Copper Mt mines.

3 Importance of groundwater and surface water control and dewatering

The 300,000 tonne/day and the previous approximately 250,000 tonnes/day mining rates and therefore the increased economic pressure to reduce water infiltration and hydrostatic water pressure on the toppling faults has resulted in some major programs of surface water diversion and ongoing annual horizontal drainhole drilling. The high mining rate means more instability so that dewatering or diverting water has improved slope stability over the years and the prodigious amounts of water pumped from the glacio-fluvial aquifers has mostly fed the mills as a very useful by-product of the dewatering. An illustration of the effect of mining rate on instability was the economically forced closure of mining on the Lornex west wall in 1982 resulting` in a very stable slope for the approximate year of shut-down and as soon as the next bench was mined out there the slope movements increased significantly.

4 Discussion

4.1 Water diversion

A fine example of what I call “Nature’s Plumbing” was the diversion I had made at the crest of the Valley Copper Pit. It was springtime; about peak flow for the streams ie the surface run-off. Water started coming out at the base of the till cliff at the crest of the west wall. The underground stream caused sloughing in the till which came close to the blasthole drill on the wide operating berm below. So I traced the water or searched for its source, following several deeply incised dry stream beds up the natural slope until I found the culprit-two streams debouching onto the porous oxidized rock and then disappearing underground. So I surmised, rightly, that the water ended up in the underflow of the dry stream channels which conducted it to where it daylighted in the till face and caused the slide. So I asked to have the water diverted from where the two streams disappeared and so it was moved off to a stream far away where it did no harm and then there were no more till slides. As a corollary of this, just because a stream is dry on surface does not mean there is not flow a little deeper, but still in the gravelly layer in this case on top of the impermeable till.

In the Lornex Pit, we diverted the run-off water all the way around the west and southwest walls, well away from the major toppling zones on these two walls (Figs. 1 and 2)[3].

Figure 1. Lornex NW Wall toppling zone, with obsequent scarps on major toppling faults

Figure 2. Valley Copper open pit with minor obsequent scarps from toppling in central part of the photo

Through a series of ditches, pipelines and pumping from the Teit Ck and Beaver Pond sumps we were able to keep most of the surface run-off out of the bedrock where it had been exerting hydrostatic pressure on the toppling faults and exacerbating the attendant slope movement (Fig. 3)[3]. Also this excess water was then sent to the mill to help with the water usage there so was not wasted.

Figure 3. Water diversion at a mine in Ireland with lined channel (left). At HVC we lined one of our ditches with impermeable till or used pipelines where we crossed exposed bedrock with toppling potential structures (right)

4.2 Overburden well drilling

Another much larger source of water for the mill was the wells drilled by Drillwell Enterprises (a very good company and very friendly to work with) in the Highland Valley glacio-fluvial overburden which reached depths of up to 350 meters (Fig. 4)[4]. The other purpose of these wells was to allow mining to continue below the overburden on the east wall of the Valley Copper pit so that it wouldn't be swamped with groundwater[5]. A total of about 4500 US gallons per minute was being pumped from two or three good aquifers in this glacio-fluvial sequence. The stratigraphy of this sequence is shown in Fig. 5. The two most important aquifers were the Main Aquifer and the Basal Aquifer. When the Basal Aquifer was penetrated by Drillwell in the first hole, the water shot up 40 feet above the drill the pressure was so great! We knew this because there were 40 ft of drill rods on the drill rig above ground and it was shooting out of the top of these! The Drillwell drillers made very good logs of the geological units and I could improve on them but very little.

Figure 4. Drillwell drill at work (after Drillwell Enterprises photo)[4]

For about one year I worked with these Drillwell crews, logging their overburden samples and projecting where they would intersect the next units in their drilling so they could prepare for them (Fig. 4)[3]. I found their logs of the cuttings were very good and could be improved upon very little. Also, I would have the aquifers sands and gravels sieved to determine the mesh size of the screens to be installed in them. The crews were very helpful and it was a pleasure to work with them.
Highland Valley glacio-fluvial overburden stratigraphy (Fig. 5, from the top to bottom):

Aquifers and glacial tills

- Upper aquifer
- Three till units
- Main aquifer
- Alluvial fans

Lacustrine Sediments

- Unit 10A silts
- Unit 10B clays
- Unit 10C silt, silty sand, and sand

Basal Aquifer

- Sand and gravel

Figure 5. Orange main aquifer overlain by three grey tills with a dewatering well in the foreground

One very interesting phenomenon in this pumping from the three aquifers was how quantity changed into quality (Fig. 5). First, for several years the pumping was just de-pressurizing the water in the aquifers, but then as this quantity increased (of the water being removed) then dewatering began. This is somewhat akin to boiling water. First you add heat and increase it gradually, and eventually it undergoes a change of state from liquid to gas ie water vapor. Something similar is haulage by trucks of an ever-deeper pit so that as it gets deeper the haulage costs increase to the point where it becomes too expensive to haul all that way up a steep ramp so then this is resolved by extending a conveyor down into the pit near the pit bottom and thus reducing the haulage distance and costs.

4.3 Drainhole drilling

Also, as well as groundwater in overburden, there is groundwater in the bedrock ie in the granitic rock at Highland Valley Copper. This rock gets its permeability from the network of joints and faults that occur there especially the steeply dipping ones, due to tectonic processes and cooling of the magma that gave rise to the granitic rock[4]. So, we knew that we had significant groundwater firstly in the Lornex Pit because in mining out each bench on the west wall, we would find significant water flowing out of the fractures. So we employed some renowned geotechnical experts, including Chuck Brawner and Alberto Nieto and Peter Stacey and after sizing up the wall and talking to us they decided to recommend us drilling a series of horizontal drainholes every three benches vertically to remove and depressurize the water in the bedrock.

Thus did commence our annual series of HDHs (horizontal drainholes, (Figs. 6 and 7)[5] starting with Tonto Drilling out of Kamloops. They took their drill mast down off their rig and layed it on its side to drill our holes and in that way could drill up to 300 meters which was a good length to penetrate to the groundwater zones. So there would be a rhythmic seasonal process whereby first the snow would start melting and the surface run-off would occur (before our water diversion mentioned above), then the piezometers would show an increase in water levels/pressures[6], then the slope would start to move significantly, then our HDH flows would pick up and then the slope movements would reduce[6]. So we were successful in both the west walls of the Lornex and later the Valley Copper walls in being able to mine down to the bottom of the walls without excessive toppling. That was at least until about 1995 (from 1981 to 1995) when the Lornex west wall failed ie showers of rock came down off the obsequent scarps in the toppling fault zones about every 20 minutes but that was also when we developed the water diversion plans. An obsequent scarp is developed on toppling faults so that the rock mass on the wall side drops down relative to the rock on the pit side, then ravelling occurs. Ravelling is when rock sloughs on a slope.

NB the following comments on both horizontal drainhole drilling and vertical well drilling, both in bedrock for effective dewatering come from the paper by V. Straskabra entitled “Some technical aspects of open pit dewatering”. These comments have been significantly paraphrased and with frequent comments by Sean Daly from his intensive experience at Highland Valley Copper that may or may not corroborate the points in this paper.

Installation of horizontal drains in an aquifer that could cause instability of a slope in an open pit mine is a very efficient means of dewatering. The main advantage is a considerably minimal installation cost, no energy consumption for water discharge and low cost of drilling[5]. The principal drawback in the use of horizontal drains is the fact that it can be economically installed only after the completion of the mining out of pit benches rather than prior to excavation. But on the other hand, if in the northern hemisphere the horizontal drains are installed in the winter, then they will be ready for the spring run-off when their emplacement is key to achieving successful drawdrown. Horizontal drains can be emplaced in many kinds of aquifers and are highly efficient in confined aquifers with high pore pressures. They are also the prime means of dewatering bedrock aquifers with a well-structured vertical or steeply dipping fracture system which is the case at both the Lornex and Valley Copper pits at Highland Valley Copper Mine. Typically, horizontal drains have 1 1/2 to 2 inch PVC slotted pipe emplaced inside the drill rods ie lining the hole to alleviate caving in the hole. In most cases, for slope stability maintenance, drains 75 to 150 metres deep are sufficient. Hydraulic and economic efficiency significantly decrease with drains longer than 120 to 150 metres; therefore, longer drains should be installed only in particular cases such as to access a piezometer to monitor the drawdown. The size of slots in the PVC pipe should be selected according to the drained material. From practical experience, the most wide slot size which would permit removal of a reasonable amount of sand particles should be utilized, in particular in cases where chemical incrustation in the pipe may happen but chemical incrustation is probably more common in vertical wells. The drains can be installed from the bottom of the pit or from a bench, but preferably from the lowest part of the aquifer to be drained. In most cases at HVC (Highland Valley Copper) we drilled from benches usually about every three benches as we mined down. The drains should be installed at a gentle upslope angle (1-5 degree) for the following reasons: minimal hydraulic losses, water does not freeze at the drain exit so easily, compensation of drill rod deflection as per following discussion. During the drilling of horizontal drains the hole can deviate downwards significantly by the weight of drill pipes, or upwards. From the author's personal experience, the drain can be bent drastically up by the use of excessive pressure during drilling by a driller who is compensated by the foot. During one installation of a 180 metre deep drain at a three degree upward angle in coal waste materials, the drill pipe and bit bent to a 90 degree angle and exited the ground surface about 75 metres above the elevation of the drillhole collar[5]. Similar situations can explain why many drains emplaced without the supervision of an experienced engineer or geologist are withdrawing much less water than estimated as the geologist or engineer can adjust the drill dip to the structural geology conditions.

Actually it is not just the pressure or the weight of the rods that makes a drainhole deflect up or down but that in combination with the dip of the structure one is drilling into. If the structure especially a fault is dipping away from the drill, the drill bit will re-collar progressively at a lower elevation if the drill angle is at a relatively small angle to the fault, whereas if the structure is dipping towards the drill at a relatively small angle to the drill hole the bit can deflect upwards. So knowing these situations, one can increase or decrease the initial dip as required by the dominant structure being drilled into. Straskraba quoted in this same paper says that for a drain at an open pit coal mine it is feasible to accomplish drawdown of about 65 to 85 percent of the saturated thickness of the water bearing formation.

Figure 6. BAT Construction drainhole drill at HVC.

Figure 7. Completed horizontal drainhole with water flow

4.4 Wells in bedrock

On a much smaller scale were a few wells we drilled in bedrock at the pit crest in the Lornex Pit. One well in particular was drilled into the porphyry dyke which I knew from mapping was a good aquifer. So we obtained after its pump test a three US gpm sustainable flow which sounds rather low but over a period of one year it pumped from about 700,000 to 1 million gallons out of this rock. This then removed a major water source for the Lornex SE toppling zone and helped to stabilize this wall. Other experience demonstrates that cost effective dewatering by pumping the water from vertical wells is feasible when the hydraulic conductivity of the drained strata is at least about 10 feet/day for unconfined aquifers and at least about 1.0 to 1.6 feet/day for confined aquifers. From frequent mapping it was found that there was recurring artesian flow from the quartz porphyry dyke in the Lornex Pit, of about ½ US gpm so our successful well in this rock unit verified this keen observation. Attempts to employ vertical wells to dewater an aquifer in rock with mainly secondary permeability displaying vertical fractures usually result in failure. However, our successful well in the south highwall of the Lornex Pit was most likely in an area with steep fractures similar to most of this pit so was still successful in this case. Also, an aside from this article, from my understanding of secondary permeability of that which is enhanced by toppling movement, drilling it can significantly increase water flows because the rock mass is loosened up by slope movement.

The scope of dewatering wells differs from water supply wells since the well yield is not as important as the drawdown[5]. The spacing of dewatering wells subsequently differs from that of water supply wells. The optimum distance amongst dewatering wells is calculated from the results of aquifer tests usually done during the hydrogeologic investigation (especially pumping tests-S.Daly comment). The second well should be placed within the steep part of the cone of dewatering developed by pumping the first well. As a rule, the useful radius of dewatering of a well is usually equal to one-third of the radius of influence of the pumped well. For most vertical dewatering wells, the water supply well technology is employed. For the well completion, five- to six-inch PVC casing with slots or PVC screen and suitable gravel pack in drained materials are generally used.

The cost to drill, install and properly develop a dewatering well to a depth of about 183 metres is in the range of $15 to 18 per foot, with the cost of supervision, which amounts to an extra approximately $2 per foot. These costs are more than likely significantly more than this now as this comes from an old paper.

4.5 Cone of dewatering

One other factor of groundwater other than promoting slope instability is its cone of dewatering[7]. When I mapped underground at the El Mochito Mine in Honduras, some of the tunnels were streaming with water along the fractures and faults. Then when another new tunnel was driven below this one, this one would dry up because it was within the cone of dewatering. The cone of dewatering then is in the case of a shaft or vertical well, a cone shape within which the groundwater has been drawn down and everything within the cone is dry. For a tunnel, it would be a valley-shape, and the same for a horizontal drainhole. The ancient miners knew about this principal too, back in the 1500s in the Erzgebirge Mts. When they started a shaft and the water was pouring in, they would sink another shaft beside it (perhaps shorter) and the water would pour into it, thus drying up the first shaft and allowing them to work in dry conditions- so they are the ones who first discovered this principle, and as described in Georgius Agricola’s De Re Metallica. There was so much water at the El Mochito underground mine that if the pumps went down for two minutes the mine started to flood so that is why they had a large auxiliary generator on the surface.

4.6 Combination of various dewatering methods

In many dewatering projects, two or more previously discussed dewatering techniques have been utilized. In this way, the advantages of various dewatering methods may be combined. For example, with initial dewatering by means of vertical wells before mining activities start, safe and effective excavation can be promoted. In a later phase of mining, a series of horizontal drains may be emplaced on the final pit walls to remove the need for energy consuming well pumping. In every case the mine dewatering design must be founded on a firm understanding of site hydrogeology and on an overall cost study.

5 Conclusions

Both surface and groundwater control at a producing open pit mine in the temperate zone at least, is essential to the ability to mine down the open pit to the design pit bottom. This is because groundwater exerts both uplift and hydrostatic pressure on such unstable structures as wedge failures and toppling failures, for example on large open pit mines like the Highland Valley Copper mining complex. So dewatering, in the form of surface water diversion, horizontal drainholes and wells is key to reducing this water pressure and to ensure unimpeded mining throughout the depth extent of the designed pit or pits. Thanks to a combination of these measures, mining has been successful down to design pit bottom in both the Lornex and Valley Copper pits.

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Author contributions Sean Daly contributed his intensive experience with water diversion projects in both glacio-fluvial overburden and bedrock well drilling and data interpretation and drainhole drilling in bedrock in both the Lornex and Valley Copper major open pit.

Data availability statement The data interpretation of this study is available from the author upon reasonable request.

Declaration the author declares that he has no conflict of interest.

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