HOW TO MINE THIN VEINS BY SELECTIVE MINING

Executive Summary

It was commonly believed that mining thin veins was uneconomic on account of excessive dilution and the cost. A method of selective mining is gaining acceptance and is successfully used by many companies. The author has returned a number of operations to profitability by the adoption of selective mining.

The method involves careful mining of ore by cleaning off the waste and then mining the ore by excavator. While the machine is in ore it is assigned to the control of the geology department. Beforehand, the ore is defined by RC drilling and face mapping that results in a grade control model that allows for irregular ore-waste boundaries.

Blast-hole sampling and Bill of Quantity mining contracts are unsuited to selective mining; and if a contractor is used, then it tends to be done under expensive ‘charge-out’ rates. An owner-operator fleet is the best option, which is one reason why it is being adopted by many mining companies.

Not all the waste can be removed by selective mining, and disruptive technology is around the corner and will increasingly start to replace selective mining practices within the next decade or so.

Introduction

It is generally understood that mining thin ore veins produces excessive ore dilution and is uneconomic. Many mines have been unable to mine veins effectively because of poor mining methods: one gold mine in Mexico was ‘strip mining’ a bench by taking a 4 to 5 metre cut along the face, sending waste as well as ore to the plant. The veins at around 4 grams/tonne (g/t) were reporting a head grade of 0.4 g/t.

Fig. 1 – Strip mining

This is an extreme example of at least 150% dilution, and although dilution is more normally 20 to 40%, it can be reduced to around 5% by good mining practice. Each gram equivalent of gold saved by reducing dilution can raise as much as 0.4M USD on 8,000 tonnes/day throughput (see the Conclusion).

Causes of dilution

Anoush Ebrahimi\(^1\) of SRK states that a combination of orebody physical parameters, grade distribution, mining conditions and operational issues are the causes of dilution.

I would add that dilution is more specifically related to the following:

1. Geology of the ore body

\(^1\) The Importance of Dilution Factor for Open Pit Mining Projects; Anoush Ebrahimi, SRK Consulting; 2013
2. Mining methodology
3. Types of contractor mining
4. Inappropriate grade control

Geology of the ore body

Ebrahimi refers to internal dilution, pockets of waste or low grade within a deposit that cannot be separated out by mining or grade control. Each pocket can vary considerably and could be extensive in some forms of ‘stockworks’, those with sets of small veins interspersed by waste, that would be impossible for the excavator bucket to mine out, or too costly for grade control to differentiate each vein. In these cases, technology has come to the rescue in the form of ore sorters, which are discussed later.

External dilution or contact dilution refers to the waste outside of the orebody that can potentially be extracted by excavator, backhoe or dozer. However, it is impossible to separate all waste and ore, especially if there is throw after blasting, and a small amount of waste will be loaded as ore. In my view the best that can be achieved is 5% dilution.

**Mining methodology**

**Blast-hole sampling**

A conventional form of grade control is by sampling blast holes, which can result in massive dilution.

Example: we use a standard square pattern of 4.5 metres both burden and spacing. The five-metre high bench is mined in two flitches, and the composite sample is 2.5 metres. Each mining block is then 4.5 x 4.5 x 2.5 metres.

The bench below is drilled and sampled as in Fig. 3. The boundaries of each block are shown, and the grade of each determined by the composite sample. The holes are marked A to D.

**Fig. 3 – Grade control sampling of blast holes**

- Hole A is totally a waste hole so mining blocks 1 and 5 report as waste.
- Hole B is in ore for the top flitch and waste for the lower flitch. Block 2 reports as high grade while 6 reports as waste, despite the presence of the vein.
- Hole C reports as waste for block 3 and low grade for block 7.
- Hole D misses the vein in the top flitch and cuts the vein entirely in the lower flitch.

**Fig. 4 – Grade control mining blocks**
The consequences are:

1. Around half of the ore is consigned to the waste dump
2. The ore sent to the plant will have a mining grade far higher than the plant head grade and will not reconcile

Mines that use blast hole sampling on vein deposits will be expected to have difficulties in reconciling mined and head grades.

**Throw**

Another cause of excessive dilution is throw from blasting. This has to be monitored and measured and the displacement incorporated into the grade control model.

**Bench cleaning**

Many operators have the habit of leaving a small part of the broken material along the next face to be drilled and shot, especially when the mining contractor is on a Bill of Quantity contract. This waste along the toe of the next ore shot is likely to be dug along with the ore.

**Contractor mining**

Mining contractors are typically on a BCM or tonnage contract which behoves them to move material as much and as quickly as possible. It applies to ore as well as waste, especially if the mill is hungry or oversized.

Vein mining requires great care. The ore dig has to be controlled by the geological staff. Once the material is blasted and the throw calculated, the ore boundaries are marked on the ground or displayed on a tablet in the excavator’s cabin and with the geologist. The bucket is positioned along the ore-waste boundary by the geologist who also depends on visual contact.

The method is slow and liable to frustrate a contractor on a Bill of Quantity contract. The response of the client may also be to tolerate the inclusion of waste in order to keep the crusher full. It is a false economy unless the dilution can be reduced to a few percent.

In past contracts I have had ‘hourly hire’ or ‘charge out’ rates quoted whereby we can hire the equipment and mine at a slower rate; however, the rates tend to be prohibitive. As a result, companies faced with selective mining tend to use owner-operator fleets especially for the long term or life of mine.

**Grade control**

Conventional grade methods do not work well with selective mining.

In one mine I visited, the control was done by utilising mining blocks based on blast hole sampling. The grade of the blocks was retrospectively adjusted to the mill head grade, so the reconciliations reported to senior management were ‘spot on’. However, the reconciliations bore little relation to the resource model, causing conflict between the resource and mine geologists.

In another mine, faced with the same problem, the mine geologists abandoned grade control and used the resource model, despite the drill centres being on 30 metre
intervals. It was originally applauded by senior management as it saved a huge amount of money.

**Solutions to selective mining**

Solutions are based on:

1. Recognising and defining the ore-body by grade control
2. Employing the right mining method
3. Ore sorters

**The ore body**

Vein deposits tend to be structurally controlled, hence a detailed knowledge of the structural geology is required.

In an African mine the deposit was interpreted as a series of semi-horizontal sills interspersed with barren rock. It was mined cheaply by bulk mining with face shovels and blast-hole sampling. However, the reconciliations were always poor, the head grades low, and never matched the expectations raised by the resource model. In fact, the tendency on occasions was to abandon grade control and use the resource model.

Nonetheless, almost unnoticed a resource geologist had mapped the structures by face mapping. When compared against the resource model her structural map was a much better fit than the grade control block model.

The ore body was remodelled as a series of irregular sized veins dipping around 45 degrees. Once the owner-operated fleet was adapted to selective mining – two of the shovels were converted to excavators – head grade rose and mine-mill reconciliations improved. Blast hole sampling was abandoned along vein boundaries and replaced by RC² grade control.

Grade control modelling of veins uses irregular sized blocks to model the vein boundaries, in a process called solid modelling. It uses sub-blocks, which are progressively smaller and smaller blocks until it can represent an irregular ore-waste boundary. As a result, grade control ore body models are far more complex than the resource models and require better graphics. When I last modelled irregular blocks some years ago, we used gaming machines on account of their graphics handling and speed.

The irregular boundaries are determined by angled RC holes on irregular spacings, following the boundaries, and face mapping is often used to assist interpretation. One advantage of an RC rig is that it can determine ore deposits for at least three benches (5m bench height) down giving the geologists time to configure the model in advance.

**Fig.5 - RC drilling defining the ore body – section**

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² Reverse circulation drilling
Mining Method

After the ore blast is fired, the throw is measured by use of plastic rods or radio balls previously inserted into the shot, or some other method, and it is used to adjust the grade control model. The adjusted model is divided into flitches, commonly two, on a 5 or 6-metre high bench. Each bench has a mark-up of the ore, whether electronic or paper (dig plan), which is given to the excavator operator, the foreman, the surveyor, and the face geologist or technician.

There may be three mark-ups for each level, depending on the heave. It may be necessary to mine off the heave as a separate flitch.

Sometimes the mark-up may be painted on to the physical surface, although this is less common now that tablets are installed in the excavator cabin.

The excavator sits on top of the bench loading the trucks below. The face geologist stays with the excavator directing the positioning of the bucket. It is aligned with the ore mark-
up, that is, the ore boundaries, and the waste from the hanging wall side mined off first. Then the vein is mined.

The ore blast remains under geological control and only after the last ore is finished is the face given back to the foreman or the contractor.

The method is labour intensive, and its cost remains unpopular with many operations. If, say, two ore faces are to be mined per shift to keep up with the process plant's needs, then two 12-hour shifts will require the following:

- 4 grade control technicians
- 1 face mapper + assistant
- 1 mine geologist

Additionally, the operation will need a person to update the model on a daily basis, plus samplers, an RC rig crew and a chief geologist.

Ore sorters

Ore sorting machines pre-concentrate the ore at the start of processing by using x-ray transmission of laser sensor technology, or both. Ore recovery of 90% and removal in the range of 30 to 60% has been reported by manufacturers\(^3\). Ore sorters are a good example of disruption technology and it is likely that they will improve over the next decade or so and render selective mining unnecessary, but at present there are still limits to recovery to between given size ranges\(^4\) and it is recommended being used together with selective mining where the waste pods are too small to be separated out effectively.

**Conclusion**

Vein mining is possible and has become far more widely recognised. However, it is expensive and requires additional people and an excellent information flow from the laboratory to the grade control model, to the mining crew and to the process plant, and back through to the laboratory. Expensive modelling and information systems are used to control the flow and optimise the process, and it requires well-staffed and a strong geology department who can control the operation while the mining fleet is mining ore.

Nonetheless the benefits are substantial. At a gold price of 1,800 USD/oz each gram of gold gained is worth 52 USD (90% recovery) and at 8,000 tonnes per day the additional revenue is worth over 0.4M USD per day should comfortably pay for additional grade control costs, should they prove their worth.

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