MINING DILUTION AND MINERAL LOSSES

AN UNDERGROUND OPERATOR´S PERSPECTIVE

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Mining Dilution and Mineral Losses
An Underground Operator´s Perspective

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ABSTRACT

For the underground operator, dilution is often synonymous with over-break, which mining operations struggle to control. However, there are many additional factors impacting dilution which may surpass the importance of over-break, and these also need to be considered when assessing a project. Among these, ore contour variability is an important component of both dilution and mineral losses which is often overlooked. Mineral losses are often considered to be less important because it is considered that they will only have a small impact on net present value. This is not necessarily the case and in fact mineral losses may be much higher than indicated in mining studies due to aggregate factors and may have an important impact on shorter term economics.

This article is a companion to a separate article titled “Improving Accuracy of Mining Studies. An Underground Operator´s Perspective”.

KEYWORDS

Dilution, Mineral losses, Mining losses, Mine Evaluation, Mine Economics, Ore recovery, Mining Recovery, Underground Mining, Selectivity, Underground Mining Studies, Underground Mine design

INTRODUCTION

Three mining factors; dilution, operating costs and cut-off grade are used in current discourse as key performance indicators (KPIs) to compare mining operations and may be used to judge whether or not a mine is being run efficiently. These numbers can directly affect investor confidence, so there is a strong motive to keep the numbers aligned with what other operations are reporting and pressure on mine operators to report accordingly. If preproduction estimates for operating costs are optimistic, then cut-off grade will be lower, and the reserve tonnage higher. If only over-break is reported, it will be a lesser number than total dilution and will fall in line with what other mines report.

The consequence of providing overly optimistic estimates has ripple effects on government, community and investor relations and on the credibility of our industry. (Whillans 2016 [i])

Much of the published literature reviewed while preparing this article dealt almost exclusively with over-break; the Mathews Stability Graph and Equivalent Linear Over-break Slough (ELOS). These are well developed useful tools that and have undergone extensive challenges and verification and are not covered in this article. It is emphasized that over-break is but a component of dilution and frequently may not be the major source of total dilution.

REPORTING AND REPRESENTATION OF DILUTION. EXAMPLES AND CASE HISTORIES

Each of the following examples have appeared more than once in our work with operating mines.

Example 1: Relationship Between Over-break and Planned Dilution

When stope failures are being experienced repeatedly and production is delayed by handling of oversize and ore losses are being experienced, at some point there will be a temptation on the part of the stope designer to drill beyond the ore contact into the waste, thereby expanding the stope design with the intention of reducing oversize and speeding up the mining cycle. Figure 1 below illustrates that the overall dilution is the same but the proportion of planned to over-break changes.

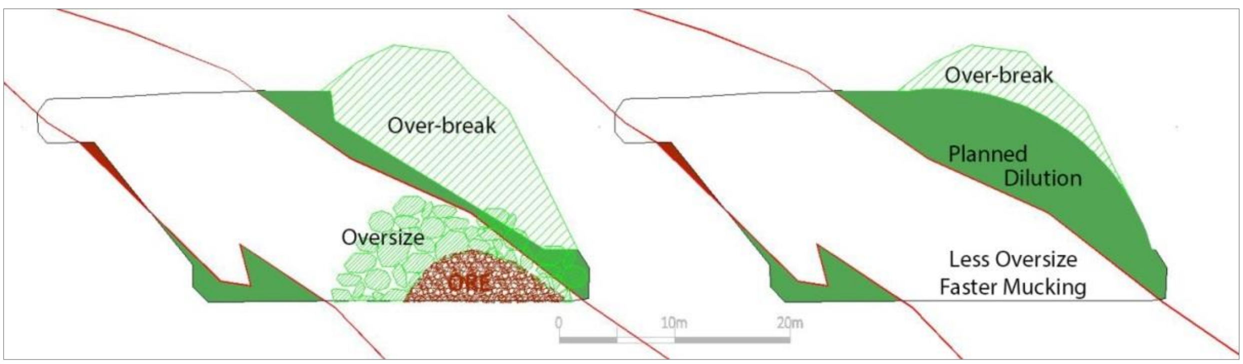


Figure 1: Relationship Over-break vs. Planned Dilution

Example 2: Dilution Often Included in the Resource Model

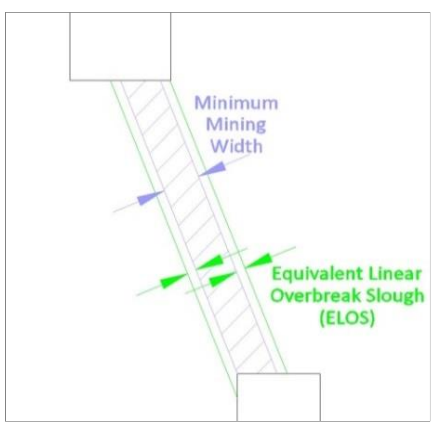


Figure 2: Minimum Mining Width and ELOS

CIM Best Practice Guidelines include minimum mining width among the engineering assumptions necessary for a mineral reserve but these assumptions in practice, are often included within mineral resources and thus may be not be reported as a source of dilution. Minimum mining widths may vary between 0.8m for narrow vein and 6.0m for larger equipment and have a direct impact on the reporting of over-break (ELOS) as shown in Figure 2. If the minimum mining width is increased the amount of over-break reported can be less.

Example 3: Manipulation of Density

A resource geologist working at a base metal mine was accountable for ensuring the grade predicted by technical services was the grade that was delivered to the mill, however the engineers at site would not attribute any value higher than 15% to dilution. The geologist responded by applying the same density to waste and ore in the block model thereby adding dilution at the modelling phase that he could not convince the mine engineers to add at the design phase.

Example 4: Internal Dilution within the ore Envelope

A block model should include internal dilution even if the drill hole spacing is insufficient to get a detailed picture of what that dilution might look like, (as illustrated in Figure 14 in the section dealing with ore contact variability below). This internal dilution is often not be reported but can be very useful for evaluating if a different mining method might be more appropriate.

Example 5: Misleading Reports of Dilution

Years ago, while employed at an operating mine, we received a series of questions about mining parameters from the Canadian Institute of Mining. The question about dilution was the most contentious. At that time at we were experiencing over-break in the order of 28%. It was quickly decided that a number as high as that could not be released, “we´ll look like we don´t know what we´re doing”. So a much lower number was sent back to the CIM and our mine fit in nicely with others that were reporting 10 to 15% dilution.

Example 6: Misleading Reports of Dilution and Tonnes

We have worked with a number of narrow vein mines with multiple sources of mill feed where the grade of chip samples taken perpendicular to the vein at the stope back were used to calculate mill feed grade as shown in Figure 3. A dilution factor, often in the range of 15% was added and the resulting grade was applied to the volume mined even when the measured stope width indicated dilution exceeded 100%. 15% dilution appeared in the reports and in monthly ore reconciliation calculations and other sources of mill feed were penalized to compensate for misreporting.

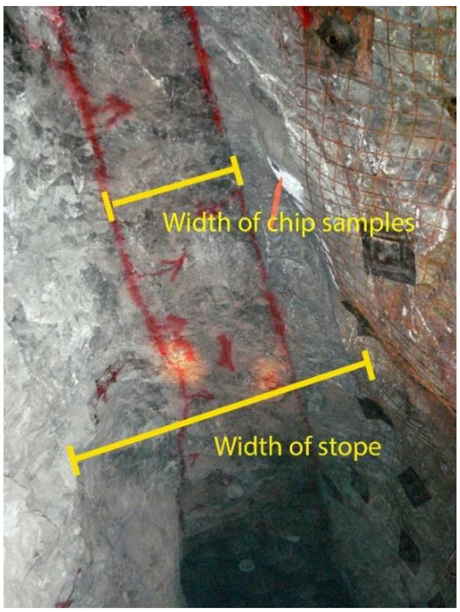


Figure 3 Narrow Vein Dilution

Some of the above examples show an effort on the part of mine operators to appear to be keeping in line with expectations which may be based on mining texts or studies with incomplete information. Unfortunately, mining texts are based on data provided by operating mines which themselves may be incomplete as per example 5 above. This represents a serious difficulty in obtaining reliable benchmarked numbers that can be used for studies of mines have not yet started to produce.

SKETCHES FOR MINERAL LOSS AND DILUTION

The importance of using sketches to investigate all sources of dilution is emphasized as a best practice because dilution comes from many sources, all of which need to be checked for their influence on mill feed grade.

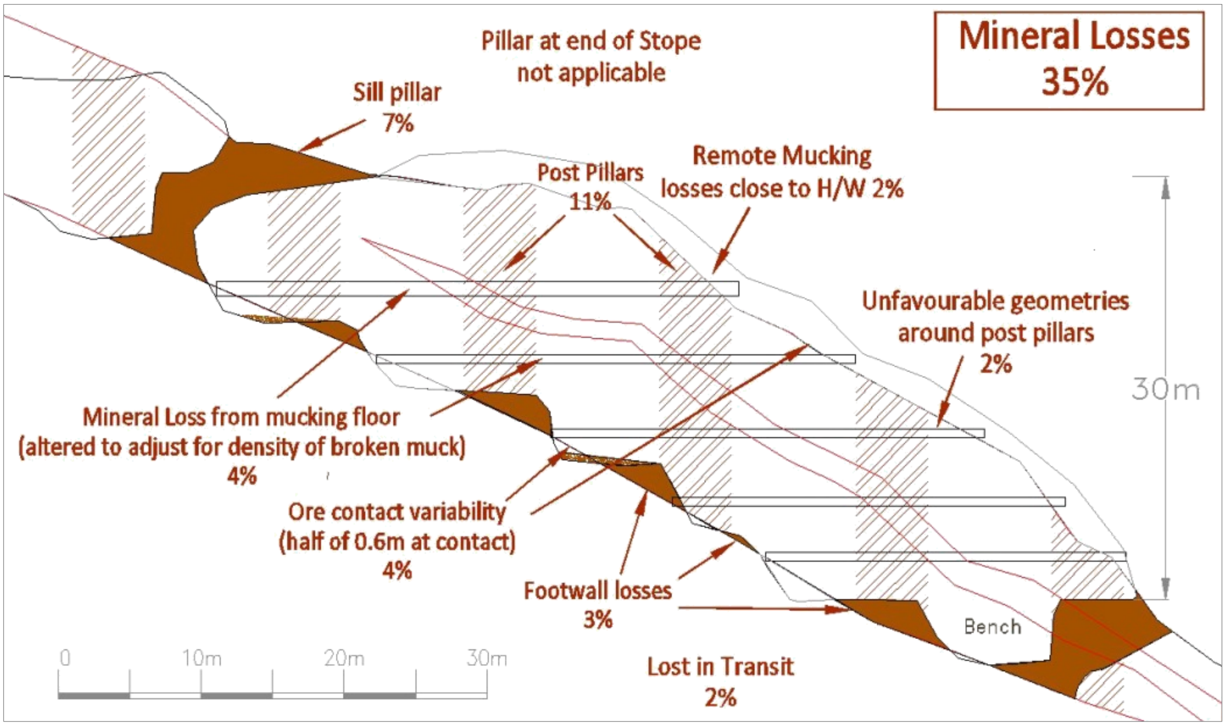


Figure 4 : Evaluation of Mineral Losses

Figure 4 is an evaluation of mineral losses for a specific mining condition. The value for mineral loss is higher than can be found in reference texts, but in fact some of the numbers are aggressive. The sill pillar is narrow and the unfavourable geometries around the post pillars would have to be looked at. The estimate of mineral loss and dilution from the mucking floor is perhaps the most contentious.

There is an increasing tendency to use the software solution of dilution “skins” expanding the ore envelope to calculate the grade of the dilution as shown in Figure 5. Dilution is not uniform as Figure 5.might suggest, it has to be understood, and the best way to achieve this is by providing sketches and through interaction and discussion. We have also found that the amount of dilution towers in importance over the grade of the dilution in almost every project we have worked on, reaffirming the importance of sketches.

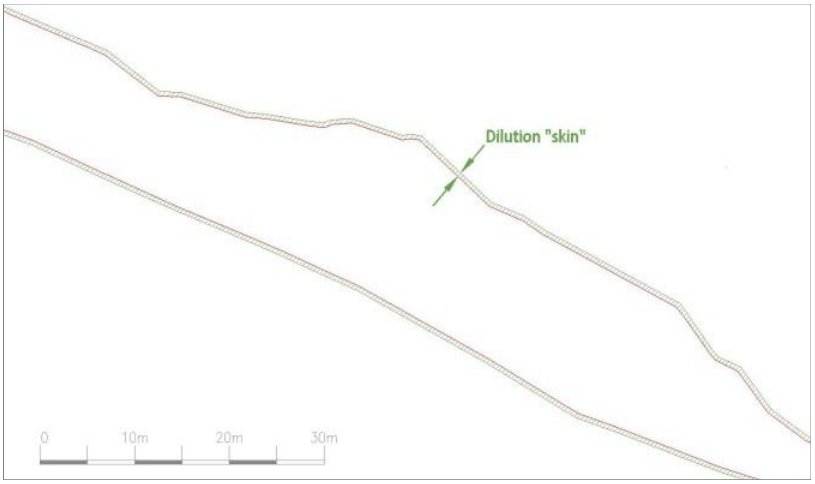


Figure 5 Dilution "Skin"

Figure 6 indicates that over-break, even if it is added to hangingwall arch and development notching is still much less than the total value of dilution.

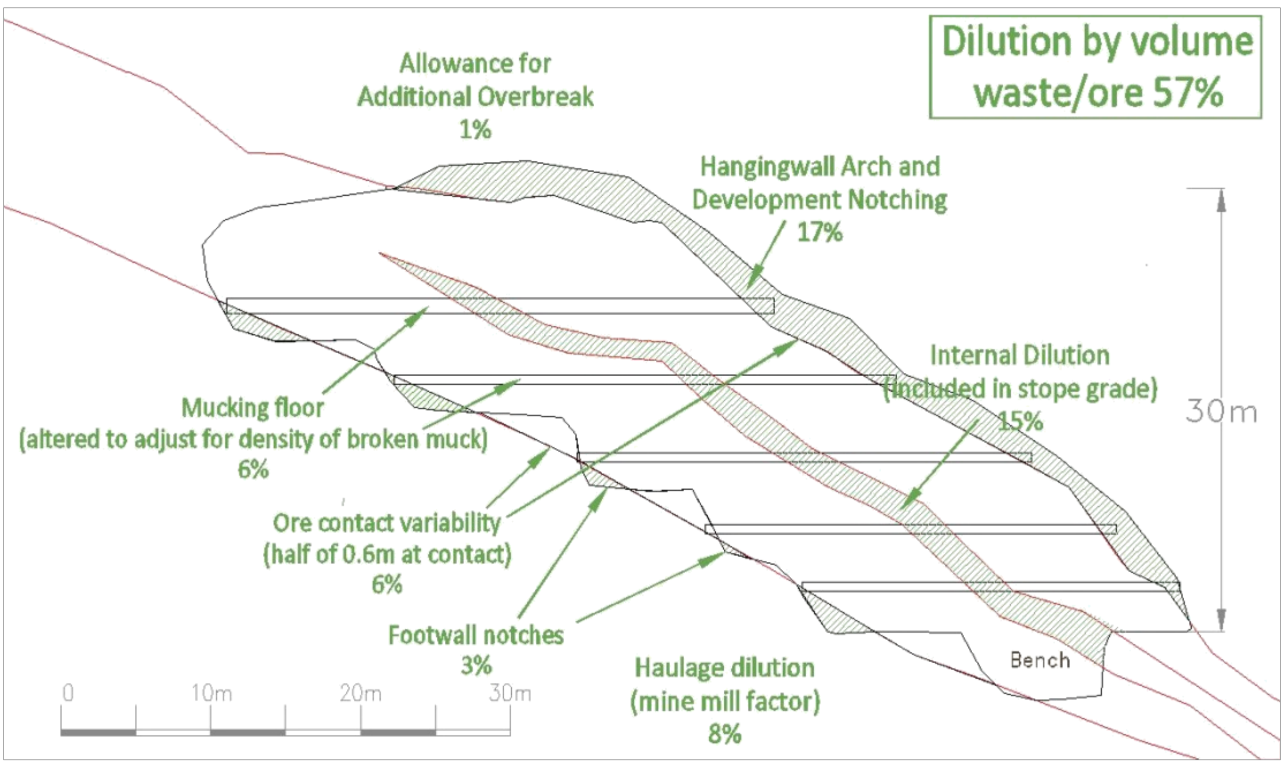


Figure 6 Assessment of Dilution

REFERENCE TEXTS

The numbers we have seen in the previous illustrations are not the numbers that appear in reference texts as per the example that follows:

Table 1 Rock Dilution and Ore Losses [ii]

	Rock Dilution (%)					Ore Losses (%)			
Mining Method	Ingler	Wright	O´Hara	BeFo	S.A.	Ingler	Wright	BeFo	S.A.
Stoping	5-30	5-10	10-30	15	32	5-15	3-5	16	14
Room and Pillar	0-10	-	10-30	5-12	-	5-30	-	28	-
Cut and Fill	5-10	15-30	5-25	12-16	-	5-10	5-7	6-15	-
Shrinkage	-	10-15	10-30	-	-	-	5-7	-	-
Sublevel Caving	10-30	10-15	-	25	-	10-30	12-15	18	-
Block Caving	10-30	15-20	-	-	-	0-30	15-20	-	-

The average of the numbers in Table 1 indicate values which are much lower than our experience indicates, and when referring to dilution it is probable that only over-break is expressed. As mentioned above, over-break can appear lower by increasing planned dilution or in the case of narrower orebodies, by increasing the minimum mining width. Values for dilution in Table 1 appear without units, waste/ore (w/o) or waste/ore+waste (w/o+w) or separation of data based on density. Figure 7 How Dilution is ReportedFigure 7 illustrates how density impacts the reporting of dilution. In tonnage-weighted reporting, the apparent dilution will be much less for a base metals mine where the density of the ore may be over 80% higher than the surrounding rock, than for a gold mine where the density of ore tends to match the density of the surrounding rock.

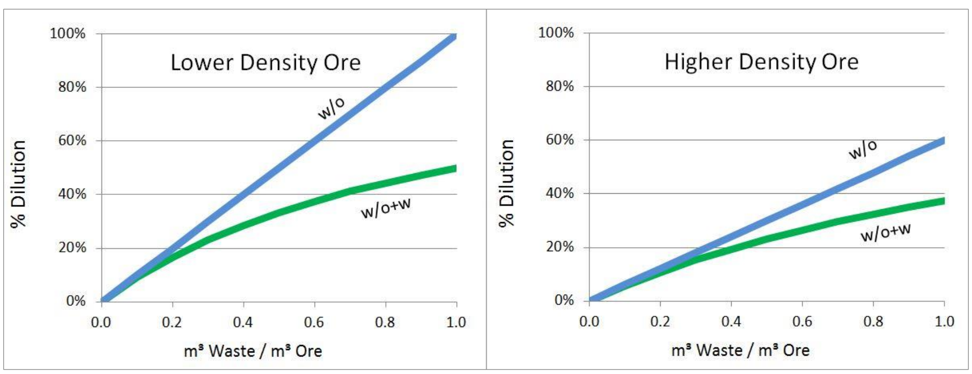


Figure 7 How Dilution is Reported

At higher rates of dilution such as experienced in narrow vein mines, there can be a big difference in units between reporting w/o and w/o+w. It is recommended that the industry standard for underground mining should be volume based, m³waste/m³ore then it should become easier to compare between mines. ELOS is volume-based but deals only with over-break.

AGGREGATE FACTORS FOR MINERAL LOSSES

In the context of this document, Mineral Loss includes any mineral that is part of a mineral resource or reserve, that is above cut-off grade and that for any reason is not mined. It is used in preference to "mining loss" because it is inclusive of losses experienced through upgrading the resource through inferred to indicated to measured and might include metallurgical loss (although metallurgical losses are not dealt with in this article.)

Many mining studies will simply peg mining loss between 5% and 15% whereas in our experience, if all factors are considered, the losses will often be much greater and will affect shorter term economics by having to increase ramp and access development by as much as 30% (in some cases, more) to compensate for ore losses.

The following aggregate factors when combined, indicate higher values for mineral losses than often appear in mining studies:

Quality of Evaluation.

Contemporary perception among some in our industry is that mineral losses are not that important and have only minimal impact on project net present value (NPV). This is only true if mineral losses are very low. We have not yet worked at a mine where mineral losses were as low as 10%.

More Ore Will be Discovered.

Years ago, while employed at an operating mine, I was fretting over not recovering some of the ore in a corner of the stope. It was explained to me that *"we actually don´t worry too much about mineral losses, the geologists will find more ore to replace whatever we don´t mine."* In fact, there is a significant cost and significant inherent risk in finding more ore.

Mine Reserve Cut-Off Grade Too Low.

As mentioned above, the cut-off grade which is used to calculate mineral reserves has an impact on shareholder confidence, so there is a motive to show a greater tonnage of reserve and hint that it can be mined at a lower cost. Underground mines may carry a cut-off grade for reserves that is lower than what can actually be mined at break even. Over time, as the better grade stopes are mined out, the marginal grade remains and many years may pass by before the cut-off grade is finally adjusted and the lower grade material removed from reserves resulting in a shortening of mine life.

High Grading and Fiscal Imprudence

High grading used to be considered a serious offence 30 years ago and people used to lose their jobs because of it. Now we all do it! It helps the Net Present Value (NPV) of the project.

The problem is actually not with high-grading but with fiscal imprudence. Are the profits from high grading fully reinvested in the mine or are they spent on something else? Fiscal imprudence is part of how countries, provinces, municipalities and we, as individuals function. Mining companies can do it as well.

Modeling, Design, Decision and Execution errors

Human errors occur at every stage of a mining operation and include errors in geological modelling and stope design as well as errors in decision making at every level and errors of execution of the work underground. When mines are under pressure to produce as a result of an overly optimistic mine plan errors combine and aggregate.

Conditions like those shown in Figure 8 may not appear in reports but impact mine life and by doing so, increase the relative cost of mine development. Secondary 2 on the right side of Figure 8 was a pillar between two primaries. The sterilized mineral amounted to some 100,000 tonnes.

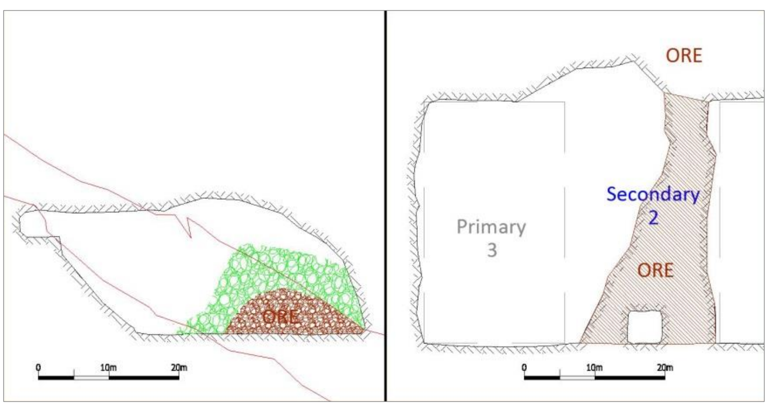


Figure 8: Examples of Low Reported Dilution but Significant Mineral Losses

Efforts to Combat Dilution

Attempts to reduce dilution may have a direct impact on mineral losses. This is especially the case with narrow vein orebodies when we attempt to reduce the width that is mined but in fact may end up losing ore as illustrated in Figure 19 in the section dealing with ore contact variability that follows.

When mining on top of waste fill or backfill, there will be mixing of ore and waste on the mucking floor. Mucking less and leaving ore on the floor mixed with waste will reduce dilution but impact mineral losses.

Resource Upgrade

Inferred resources may be included in a Preliminary Economic Assessment (PEA) but when inferred resources are upgraded to indicated and measured there is commonly a loss of resource tonnage brought about by better defining the mineralized zone as illustrated in the following section dealing with ore contact variability. The loss of resource tonnage through upgrade will vary according to local conditions and may fall between 30% and may be as high as 70%. If it is known there is a likelihood there could be a tonnage drop associated with the resource upgrade, then it should be considered in the PEA. In fact the statement that *"there is no guarantee that a mineral resource will become a mineral reserve"* is misleading because it leaves out information important enough to invalidate the accuracy of some PEAs. In a similar way, mineral losses associated with upgrading from indicated to measured should also be considered for higher level studies.

ORE CONTACT VARIABILITY

Ore contact variability is hardly mentioned in literature and deserves close attention. Examples follow.

Example 1: Ore Contact Variability and Resource Upgrade

Figure 9 through Figure 11 show what can happen when an inferred resource is upgraded through additional drilling and development. These diagrams illustrate the effect on resource tonnes and increasing complexity of the ore outline as more is known about the orebody. This impacts both mineral loss and dilution.

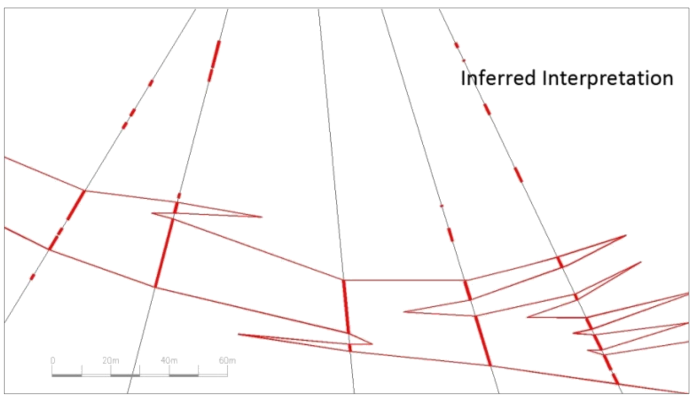


Figure 9: Inferred Interpretation

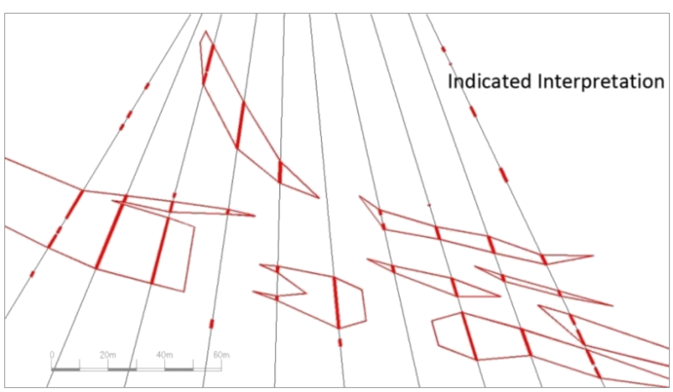


Figure 10: Upgrade to Indicated

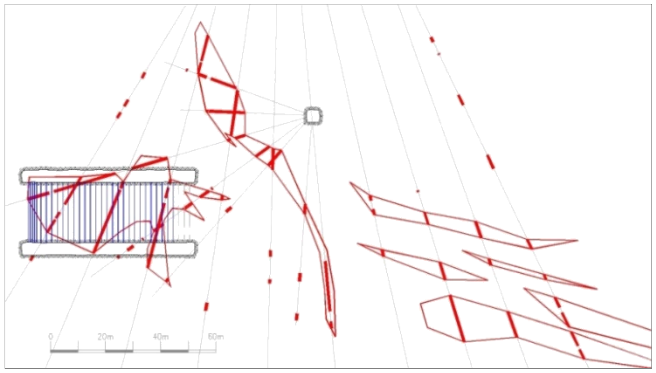


Figure 11 Upgrade to Measured and Proven

Figure 12 shows internal dilution and mineral losses as part of the stope design.

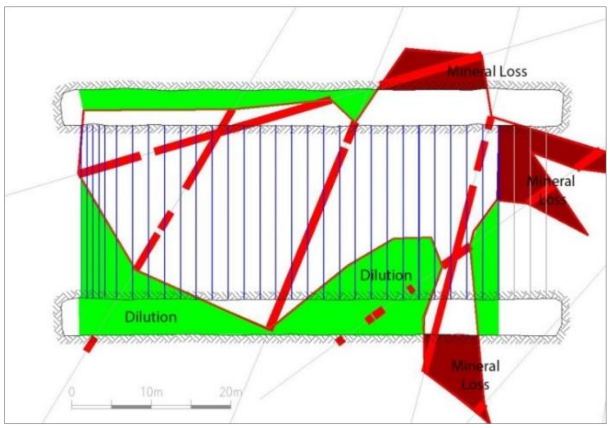


Figure 12: Dilution and Mineral Losses in Stope Design

The above diagrams indicate that the complexity of the ore contact outline increases as more information is gained about the mineralized zone. There is a point to which it is practical to collect ever more detailed information. So the ore contact that might be visible during stope development may hint at greater complexities as shown in Figure 13 and Figure 14 below.

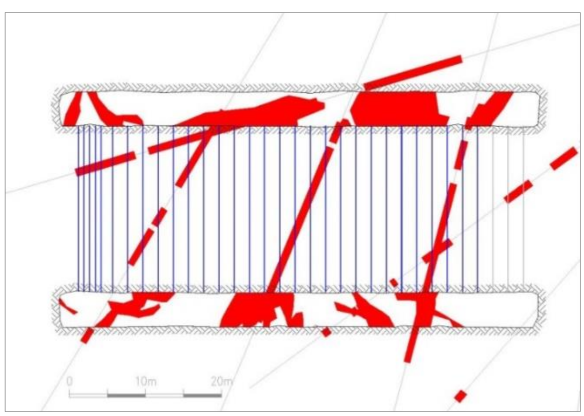


Figure 13: Ore visible in the development headings may hint at more complexities

Instead, it is assumed that the dilution within the ore outline as modelled should be represented in the block modeling. The dilution included within the block model should be reported as it may point to a need to alter mining method or designs for some areas.

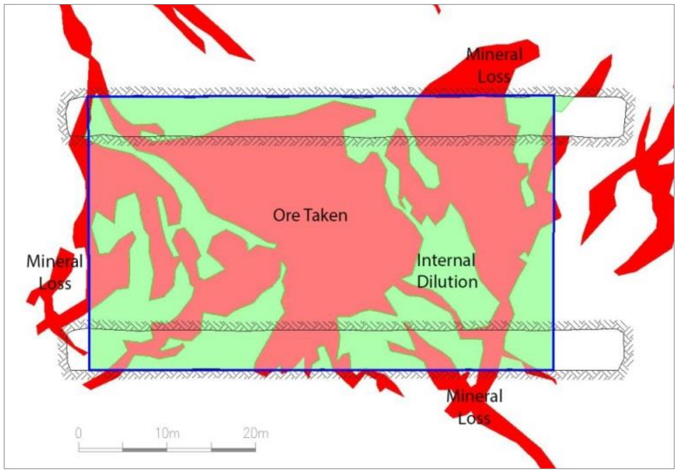


Figure 14 Stope design showing hypothetical ore outline

Example 2: Ore Contact Variability Narrow Vein Longhole

Figure 15 shows detailed information used to determine stope boundaries for narrow vein longhole mining that resulted in the selection of a mining outline top and bottom and a wireframe created between the sublevels.

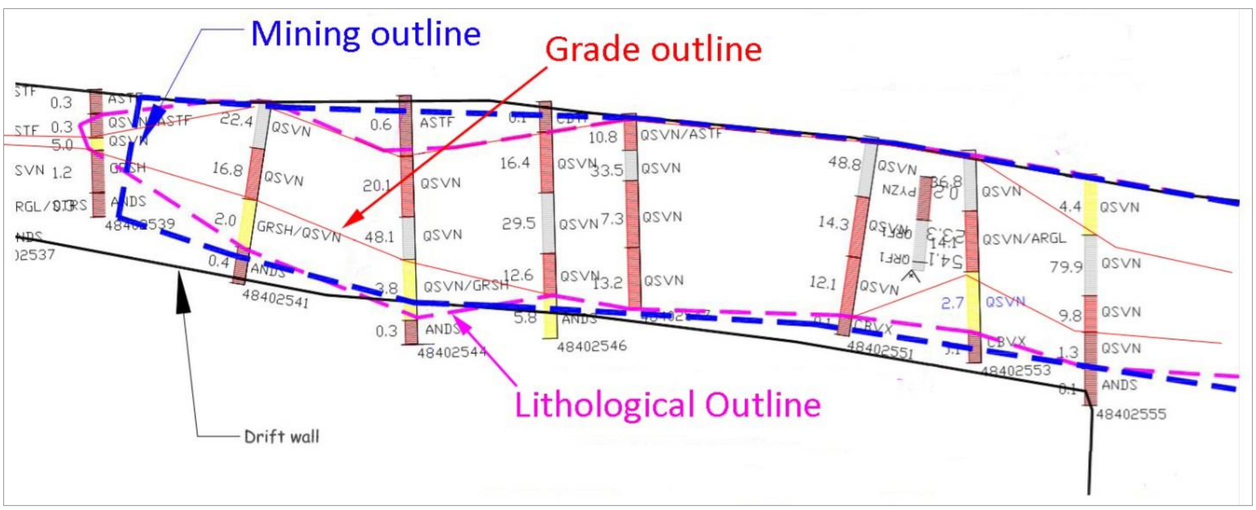


Figure 15: Determination of Mining Outline

Figure 16 shows the wireframe and with some chagrin I have to say this is my work from years ago and that there was absolutely no consideration for ore contact variability in the vertical sense. When stope production started at this mine, geologists were initially polite and respectful in asking if we could recover the ore in the open stope left on the hangingwall or footwall. Over time they became much more assertive. [iii]

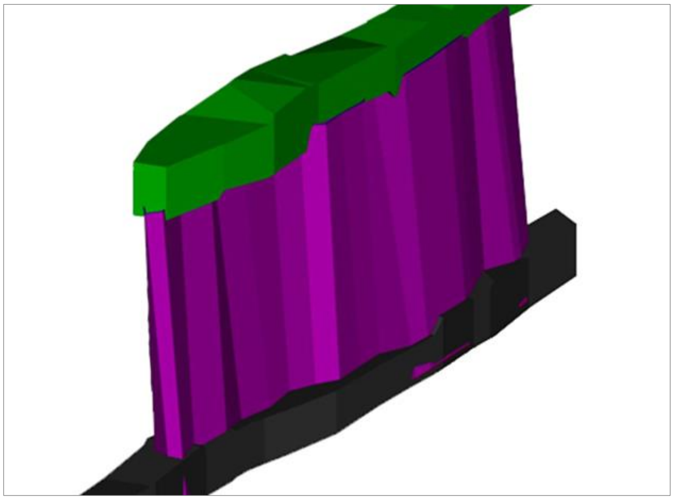


Figure 16: Resulting Wireframe

Example 3: Ore Contact Variability and Planning Sublevel Intervals

Figure 17 is an example from an operating mine and further illustrates the importance of considering ore contact variability. It shows wireframing between sublevels based on the back mapping. (We like straight lines in mining)

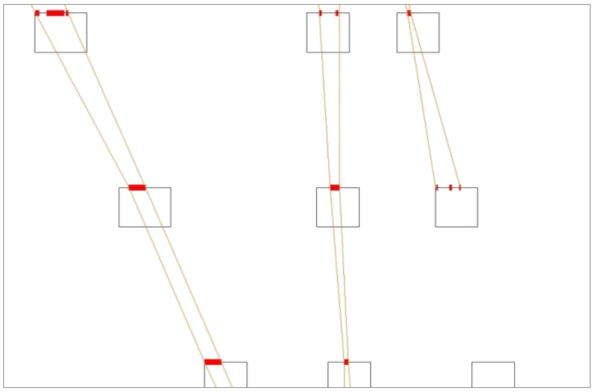


Figure 17: Interpolation between Sublevels

Drift mapping of the ore will show ore contact variability in the horizontal sense as shown in Figure 18

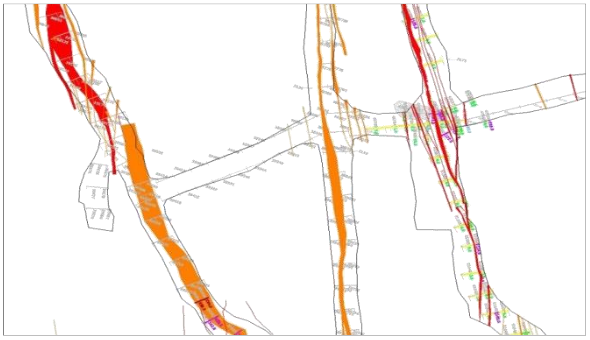


Figure 18. Mapping of ore outlines

If this mapping information is applied to sections as shown in Figure 19 it will provide an indication of ore continuity in the vertical sense and can be used to set a practical sublevel interval.

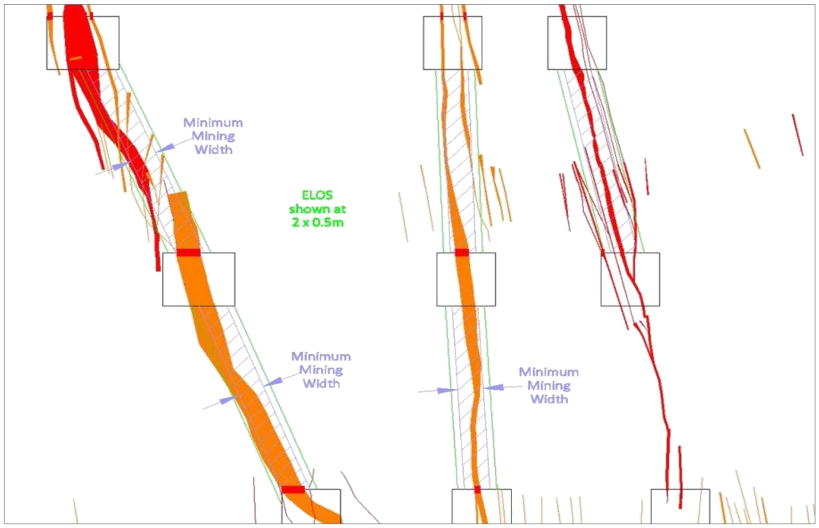


Figure 19: What the ore might look like

Figure 19 illustrates that dilution might be a way of ensuring that the ore is mined, especially for the vein on the left side of the image, but if overbreak happens on the hangingwall and not the footwall, ore loss is significant. There are a number of narrow vein mines that could have improved conventional selective mining techniques but instead switched to longhole mining in the past 10 years in conditions similar and with greater or contact variability than shown in Figure 19.

FACTORS AFFECTING DILUTION AND MINERAL LOSSES

Over-break may also be referred to as wall slough, Equivalent Linear Overbreak Slough (ELOS), external dilution, secondary dilution, unplanned dilution. In the context of this document, over-break falls into production areas as un-blasted rock and often as boulders which are difficult to handle. It is usually sub-grade or waste material but can also be ore (see Figure 8 and Figure 19). Therefore over-break is usually but not necessarily dilution.

If blasted mineral is abandoned because it has been buried by waste boulders then there may be little dilution but significant mineral losses. If the decision is made to remove the waste boulders to recover the blasted mineral beneath, mineral loss can be minimized but there may be significant dilution.

Just a few mining areas experiencing over-break may have a big impact on the mining operation. Considering technical advances in rock mechanics, over-break should no longer be treated as something that happens as a result of unexpected circumstances. The term unplanned dilution suggests a situation that hasn´t been considered and suggests faulty planning.

Table 2: Partial checklist of factors to quantify when compiling dilution and mineral loss estimates

	Affects Dilution	Affects Mineral Losses
Areas where a more detailed cost benefit analysis indicates changes in profit/loss		✓
Backfill dilution	✓	✓
Cut-off grade changes during life of mine due to fiscal situation of mining company, changes in metal prices or directives from head office.		✓
Cut-off grade of the reserve not representative of what might be mined		✓
Decisions made during geological modelling and stope design and quality of work	✓	✓
Decisions of mine supervision and miners and quality of work	✓	✓
Efforts to reduce dilution	✓	✓
Impact of flatly - dipping structures	✓	✓
Islands of waste in the mineral	✓	✓

	Affects Dilution	Affects Mineral Losses
Mine call factor which is not limited to errors in haulage delivery, ore that is not delivered to the mill or waste that appears in the mill and we don´t know why, alternating use of truck loadouts, mucking bays and ore passes for waste and ore and the number of times muck is re-handled.	✓	✓
Mineral buried under waste oversize when a stope fails	✓	✓
Mineral that is left in the corners while mucking a stope		✓
Mineral that is not mined due to variation in metal prices or changes of cut-off grade		✓
Minimum mining width	✓	✓
Mucking over backfill or waste	✓	✓
Notching above and below sublevels	✓	
Over-break	✓	(✓)
Pillars in ore to reduce span, protect infrastructure or prevent dilution from backfill		✓
Presence of water	✓	✓
Production schedule and whether it can be achieved	✓	✓
Profits from high grading not reinvested in mine		✓
Rock quality and stress	✓	✓
Sill pillars and crown pillars in mineral	✓	✓
Size of mining machinery, whether it is appropriate	✓	✓
Stand-up time	✓	✓
The necessity of providing a stable arched back	✓	
To what degree it is advisable to mine by lithology over grade	✓	✓
Upgrading of resource inferred - indicated - measured		✓
Variability of grade	✓	✓
Variability of the contact	✓	✓
Visibility of the contact	✓	✓

MINING DILUTION AND MINERAL LOSSES. CONCLUSIONS

- Some countries take it to heart that the mineral resource is the property of the nation and mining companies have to make a specific commitment to recovering it. In Canada, there is no accountability regarding mineral loss and it does not receive the attention it deserves. *“The orebody belongs to the people of Canada. We are given a license to mine it. It is in our best interests to make the best use of the resource that we can.”* (Bakker, F 2016) [iv]

- Many mining studies report low numbers for dilution and mineral loss that are based on texts that in turn use information from operating mines. The information from operating mines may be compromised because of concerns of how the operation might be perceived by investors and the need to stay in line with what other mines are reporting.

- Full feasibility studies are now being done without underground exposure. Considering ore contact variability has a tendency to increase as the resource is upgraded, it raises the question whether the increase in ore contact variability may be enough to invalidate the accuracy of some feasibility studies.

- Mineral losses experienced through upgrading of the resource inferred-indicated-measured should be considered in mining studies. The factor is large enough that it may invalidate some PEAs.

- If an assessment has been done well, all categories of dilution and mineral loss will have been considered. The different components should be categorized and clearly stated.

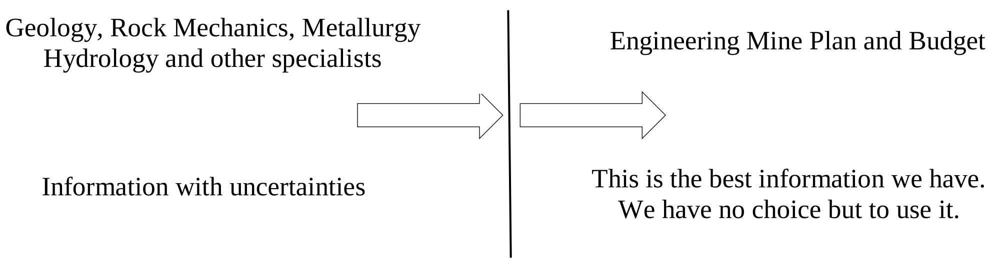
- The often ignored geometric variability of the ore contact requires special consideration.

- Sketches are need to improve transparency in the reporting of dilution and mineral losses.

- Where straight lines have been drawn between sublevels, quantify the effect of ore contact variability by applying ore contact variability in plan view to section views.
- As there is inter-dependency between minimum mining width and ELOS and between planned dilution and over-break, both need to be stated side by side.
- There is inconsistency in the reporting of dilution, it is recommended as a first step to report by volume m³ waste/m³ ore to make it easier to compare between mines with different ore densities.
- CIM best practice guidelines do not require underground exposure for full feasibility studies yet exposing the ore underground will often have a major impact on the understanding of the variability of the ore contact as well as the properties of minor faults that surpass accuracy requirements of a feasibility study. This needs to be re-evaluated by the CIM.
- Include the ore outline in all sketches and sections.
- If it is not known where the ore is, dilution is an unknown.

DEALING WITH UNCERTAINTIES

I remember pointing to a spot on a mine section (careful not to touch it because of fierce objections about my past scribblings) and asking the geologist. Is there ore here? The answer was “probably” I moved my finger a little and the geologist responded “probably not so much”.



Geological, metallurgical and geotechnical data can be expressed with a certain probabilistic outcomes. Mine engineers are tasked with using this information loaded with varying uncertainties and coming up with a defined mine plan and budget. The probabilistic outcomes may be absent in the budget statement because it´s hard to motivate an entire workforce by telling them we expect you to remove a defined tonnage and grade from an area but we are only partly certain of what conditions will be like:

At times, this leads to detailed stope designs done for inferred resources as shown in the example below which may be misleading and give the impression of detail where in fact knowledge is lacking.

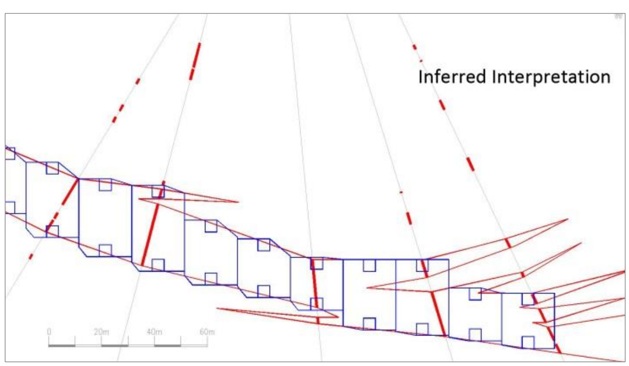


Figure 20: Detailed stope designs for inferred resources are misleading

The statements above are a reflection of the growing specialization in our industry and the lack of generalists which is covered in the upcoming section.

DILUTION AND… WHERE IS THE ORE ?

In the published literature reviewed in preparing this article, there was occasionally an admission from authors that if more were known about the quality of drilling and blasting it might affect some of their conclusions. An example of this gap between specialists and mine operations is illustrated below and is just one of many possible examples.

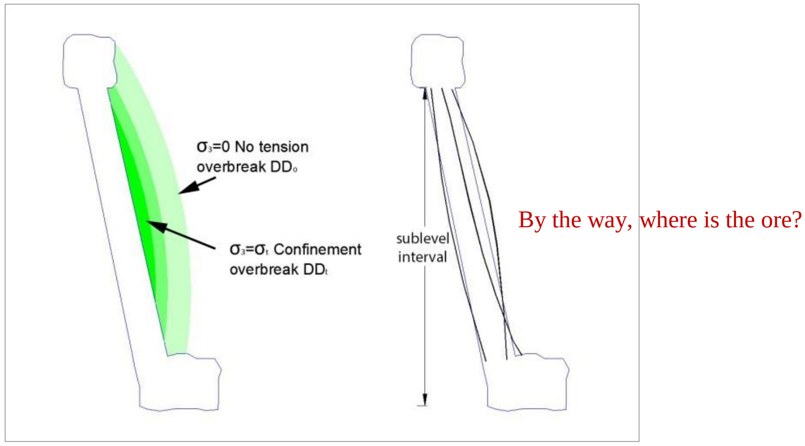


Figure 21 Specialist vs. Operational Approach

From a specialist´s viewpoint there could be justification in adjusting stope boundaries based on numerical modelling as shown on the left of Figure 21. However, a mine operator might note that the sublevel interval is approaching 30m, that the drill hole deviation has become excessive (drill hole spaghetti) and in an attempt to improve blast fragmentation, the drill hole diameter has been increased thereby increasing blast damage and …. in all of this analysis, where is the ore? Any really, is there enough information in the 30m sublevel interval to know how the ore contact oscillates?

There is validity in both the academic and the operational approaches and it is also clear that our advances in applied technology will accelerate if the two approaches can be combined.

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REFERENCES

[i] Whillans, P 2016 Underground Mining. The Difference between Optimal and Real CIM MEMO Sudbury 2016-10
[ii] Elbrond, J Economic effects of ore losses and rock dilution CIM 1994-03-01
[iii] Prinsloo, P Bulyanhulu 2001
[iv] Finley Bakker P.Geo personal correspondence