PINCOCK Perspectives

Delivering Smarter Solutions

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PAH NEWS PIX

- **MECHEL STEEL LISTS SHARES IN U.S.**
- **ICSG EXPECTS COPPER MINING GROWTH**
- **GOLD DISCUSSED AT EUROMONEY CONFERENCE**

CALENDAR

- ***Mines & Money London 2004***
  November 30 – December 2, 2004
  London West Hotel and Convention Centre
  London, United Kingdom
  email: jane.burman@mining-journal.com
- ***SME 2004 Arizona Conference***
  December 5 – 6, 2004
  Doubletree Hotel at Reid Park
  Tucson, Arizona
  email: sme@smenet.org
- ***Northwest Mining Association's 110th Annual Meeting***
  December 6–10, 2004
  Red Lion Hotel at the Park
  Spokane, Washington
  email: pheywood@nwma.org
- ***Mineral Exploration Roundup 2005 – Discovering Our Future***
  January 24–27, 2005
  Westin Bayshore Resort & Marina
  Vancouver, B.C., Canada
  email: roundup@chamborofmines.bc.ca

Dilution and Ore Recovery

This month's topic for Pincock Perspectives was suggested by Ms. Evangelina Apparicio, Mine Planning Engineer, Companhia Vale do Rio Doce - CVRD

Dilution is one of many challenges confronting the professionals in mining, and is perhaps one of the oldest. It is a quiet thief, requiring the expenditure of money to mine or process material that has little or no value to the operation, and can convert valuable rock into waste. Dilution is defined most simply as waste material that is taken in the process of ore extraction, but there are multiple assumptions laying within this definition. It assumes that the operator knows with fair precision the location, shape and grade of a given ore block, and that the equipment operators are capable of mining at a similar resolution.

Historically, dilution and ore loss were little more than factors associated with the estimating methods of the time (polygonal, x-sectional, etc.). Now, with computers to help complicate matters, numerical methods are needed to describe and hopefully predict both losses and dilution.

There are four broad categories of dilution that the miner encounters. The first is the "mine call" dilution, which is simply a correction factor applied to the mine-estimated production grade to arrive at the mill-reported feed grade. The second is contact dilution or "external dilution," which is low-grade material taken unintentionally during mining. The third is internal dilution, which is waste material so ingrained within the ore that physical separation is impractical. The fourth form is "Murphy dilution," which is caused by mining errors.

Some would argue that there is a fifth form imposed by sampling errors, incurred at any number of stages throughout the mining process whenever a sample is taken. The author does not consider this to be a dilution problem, although it is certainly a consideration when trying to diagnose dilution sources. Sampling theory is a topic for another "Perspectives."

Mine Call Dilution

Some could argue that mine call dilution is not really dilution, but is actually a correction factor used to adjust for a combination of problems arising from other three forms of dilution, with sampling errors tossed in for good measure. This is probably accurate, as correction factors do little to describe the source of a dilution problem, and may actually mask deeper problems. Mine-call dilution has the redeeming virtue that it is an obvious measure that comes from reconciliation, and it is a clear indicator that something is rotten in Denmark.

If the discrepancy between the mine and mill is small, or if the operation is woefully understaffed (a more typical problem these days), then other priorities may override dilution in management's mind. From PAH's experience though, dilution can be a significant drain on cash flow in an industry where margins are often razor-thin, and should be analyzed and eliminated where possible.

Contact Dilution (External Dilution)

Contact dilution is determined by resolution; specifically, the ability to accurately define and then mine along the limits of an ore zone, such that the mining equipment available can successfully extract the material at those limits. In some cases, contacts between ore and waste are clear, but geometrically difficult, such as a 45 degree contact dipping into a high-wall, or a particularly vicious curve in the boundaries of a stope. In these cases, the mining limit should be set based upon the trade-off between ore value and waste cost.

Assuming that you could define an ore zone to within two inches, the ability of a P&H-4100 or BE-495 to mine that small an increment is questionable at best. Conversely, you can theoretically mine to the resolution of a teaspoon, but the deposit that would support mining at that accuracy is extremely rare (with all due respect to those valiant souls employing resuing methods).

■ ***MECHEL STEEL LISTS SHARES IN U.S.***

On October 29, 2004, Mechel Steel Group became the first Russian-owned company with mineral reserves to file with the U.S. Securities and Exchange Commission (SEC). Mechel produces steel products and is a miner of coal, iron ore and nickel, and is ranked the fifth largest steel producer in Russia. The company's American Depositary Shares (ADS) began trading on the New York Stock Exchange at US$20.85 per ADS. Mechel raised US$291 million from the initial public offering, making it the second largest by a Russian company.

Mechel has an option to place additional shares and boost its liquidity, as it has approval from shareholders and Russia's market watchdog to have up to 40 percent of its stock trading abroad. Company officials would not comment on whether Mechel is considering such a move. Analysts say Mechel's decision would largely depend on the outcome of a long-delayed tender for a 17.8 percent stake in steel giant Magnitogorsk Iron and Steel Works (MMK) expected later this year. Mechel owns 17 percent of MMK and is expected to bid. It is now one of seven Russian companies, mainly telecoms, currently trading on the NYSE. In support of Mechel's Initial Public Offering (IPO) filings with the SEC, PAH prepared reserve statements and mine valuations for all of Mechel's mining properties. PAH is currently working with Mechel to develop a procedure for implementing computerized geologic modeling and mine planning at all of Mechel's mines, so that future reserve statements are done using Industry Standard practices.

■ ***ICSG EXPECTS COPPER MINING GROWTH***

The International Copper Study Group (ICSG) predicts annual world copper mining capacity will grow 4.4 percent a year between 2004 and 2008. This represents a 2.9 million ton expansion in mine capacity over the period, 920,000 tons higher than predicted by the ICSG in July. The ICSG has also revised its prediction concerning the cumulative growth of smelter capacity, stating it will be 410,000 tons more than the estimate given in July. The total increase of smelter capacity between 2004 and 2008 is now forecast to be 1.2 million tons, an annual growth rate of 1.9 percent.

Clearly, there is a trade-off between lowering dilution and increasing operating costs.

Dipping beds in an open pit mine present their own challenges. Low to moderate gradients can be incorporated into the mining method by proper equipment selection. Higher inclinations may require either special blasting and benching, or acceptance of somewhat higher dilution. Again, basic engineering analysis resolves the problem.

Planning should adapt to the structure as well. While in theory a good shovel operator can mine to almost any angle, experience teaches us that it is almost always better to mine along a structure than across. Similarly, it is usually better to blast ore zones separately from waste zones.

In some cases, there is little control over dilution. Block caving is typically the least expensive mining method available to the underground operators. However, selectivity is not a strength of the method. While proper draw practices can reduce the dilution problem, there is always some inherent dilution that must be accepted. In these cases, the dilution should be predicted based upon location, then added into the model, either directly or at the scheduling stage.

In summary, management of contact dilution requires the following tasks:

- ♦ Define the contact
- ♦ Select the right equipment
- ♦ Mine with the contact
- ♦ Model the effects of unavoidable dilution

Internal Dilution

As noted earlier, internal dilution deals with waste material that is ingrained within the deposit. Contact definition assumes that you know the location of the contact between ore and waste. Internal dilution deals with the uncertainty of defining the contact. Contact dilution is primarily an operational and grade control issue for the mine operators, engineers, and geologists while internal dilution must be resolved by geologists and geostatisticians at the modeling stage (mining engineers are capable of this function as well, but only under proper supervision and with suitable medication).

Internal dilution is governed by four main components:

- ♦ Geology and Mineralogy
- ♦ Data Density
- ♦ Estimation Method
- ♦ Cutoff Grade and Grade Control

Geology and Mineralogy

Geology/mineralogy ultimately drives internal dilution. Consider a "disseminated" copper porphyry. The mineralization of interest is typically fine-grained with local but relatively small occurrences of rich mineralization. At small scales, the variation in grade over a few tens of centimeters may be extreme and unpredictable. But as the scale increases, the aggregate effects become more predictable. Geostatisticians might argue that if you wanted to drill 10mm holes on a fine pattern, you could predict the small-scale behavior, but on that path lies madness. Let's keep it real.

There is an implicit assumption that large-scale geology is understood and accounted for in the contact dilution. The problem is often that the division between "large-scale" and "small-scale" is not always clear. The solution to this issue lies in data density. At the early stages of an operation, data is typically wide-spaced exploration holes, and resolution of even relatively large structures may not be possible. As a project moves into production, data density typically improves (either through additional definition drilling or blast hole drilling), as does the geological mapping.

Ultimately, the geology and mineralogy must provide understanding of the nature of the internal grade variation within the mineralized areas. If there are large variations in grade over relatively small distances, then the ability to predict ore/waste contacts will be poor and the ability to employ selective mining will suffer.

Data Density

Once the geology is understood (if not predicted), the issue of density of data becomes important. Simply put, a highly variable deposit will require more drilling than a well-behaved, disseminated deposit. It is therefore imperative that some understanding of the relationship between variability and distance be established. For this we have the variogram.

The data collected in a drilling program often starts with some widely-spaced pattern that is intended to show the extent of a deposit. While a good exploration geologist will have a general idea of the continuity based upon deposit type, definition of short-range grades is not the objective. Once a deposit has shown that more expenditures are warranted, then consideration should be given to a closespaced fence of holes, both along and across the structure. This information should provide enough data to support a variogram, which will show the degree of variability as a function of distance. Granted that not all deposits can produce a good variogram, but that information is valuable as well in predicting dilution. However, the variogram should produce a reasonable range (or distance of maximum influence) a nugget effect, and a sill (note that we cannot get into the geostatistics in this article).

At this point, we are back to a resolution issue. From statistics we know that up to a point, more data makes a better estimate. The closer that the drilling data is spaced, the higher resolution will be possible. This is why PAH reports will often describe a "good global estimate," which means that we are confident that the ore is there, it just may not be exactly where we expect it to be. This is not surprising, as a 50-meter drilling pattern cannot reasonably resolve 15 or 20-meter structures if the deposit is highly variable.

Given that dilution definition requires that we are able to define an ore-waste contact, this clearly poses problems. If the drilling data is widely spaced, it is likely that local estimation errors will be high, which may be interpreted as dilution.

Estimation Method

As noted earlier, dilution back in the pre-computer days amounted to little more than a correction factor used to adjust manually-drawn reserves for inevitable differences between the mine and mill. The manual methods were generally a variant of either polygonal reserves or the related outline and average method. Both methods tend to overestimate grade and underestimate tonnes, largely due to the effect of drawing a hard line around what is likely a gradual change. Neither method is particularly good at de-clustering data, and both methods are prone to problems with the volume-variance impacts (we typically sample deposits on 1 or 2 meter cores of a few centimeters diameter, but we mine effectively thousands of core-equivalents with each truck load). The problem is further exacerbated by cutoff grade impacts, which polygonal methods typically do not model well.

With rare exception, the polygonal methods are more prone to dilution problems than are the statistical methods or inverse distance, which tend to smooth grades. In addition, manually-drawn polygons typically fare worse than computer-generated polygons, since the computerized methods are invariably better at looking in three dimensions, with or without variable search ellipses, than is a normal human geologist (assuming such a thing exists).

The statistical methods offer a number of advantages, in that they tend to create gradual grade changes, which are more plausible than the hard limits created by polygons. There are two broad categories here, the inverse-distance to a power and the omnipresent geostatistical methods. Both methods are widely employed and both will generally result in a more realistic grade distribution than would polygonal methods. Not surprisingly, dilution problems are usually less severe in properties where these methods are employed, and in many cases, no additional dilution is needed.

Cutoff Grade and Grade Control

Selection of cutoff grade can be a contributor to dilution. When a cutoff grade is applied to a deposit, the engineer assumes that the grade contacts are definable at any given grade. This is somewhat dangerous, as for many deposits, the variability is not just a function of direction and distance, but also of grade. Precious-metal deposits are good examples of this effect. For example, if a cutoff grade of 5 grams per tonne is applied to a deposit, it may be that the statistics are unpredictable at that cutoff grade, although the deposit may be well-behaved at a 1 gram per tonne cutoff.

A good test of this effect is the use of an indicator variogram at various cutoff grades. It is not uncommon to have a nice range and low nugget effect at a low grade, but at a 5 or 10 gram per tonne level, the variograms are virtually pure nugget, and selective mining will be difficult if not impossible (although many open-pit operators would love to have the problem). Dilution in these cases will be high, and may not be controllable with any grade control method. Purists may argue that this is no longer a dilution problem, but is instead an estimation problem, but the distinction is likely to be lost on most mine operators. Simply put, if you can't define it, you can't mine it.

The good news here is that normally data density is much higher at the grade control level. Blast-holes or definition drilling is usually available to refine the estimate. Grade control is effectively a fine-tuning of the reserve estimation process and it's job is to make a reality of the assumptions used for the long-range planning… the exploration model assumes that the deposit is mineable at some scale, but the grade control makes it happen. Grade control processes produce reams of data including blast-hole data that can be used to derive improved variograms over the initial

- ***GOLD DISCUSSED AT EUROMONEY CONFERENCE***

The gold mining industry was a hot topic as several major and new mining companies representing a wide geographical spread gathered at the Euromoney Conference in London. It is believed that Russia and central Asia will lead the gold sector within ten years, with plenty of opportunities in the region for both acquisitions and discoveries. One potential drawback could be the amount of time taken to achieve successful negotiations. While Russia and central Asia have future potential, Uzbekistan, Kyrgyzstan and Kazakhstan are currently viewed as the second largest gold regions in the world and in the lowest cost quartile. Much is also expected from China, which is at the same stage of development now as the Kyrgyz Republic was in 1994.

Minerals Corner—

Pirssonite
$Na_2 ,Ca(CO_3)_2$ - $2H_2O$, Hydrated Sodium Calcium Carbonate

Pirssonite is one of several carbonate minerals which forms in non-marine evaporite deposits. Evaporite minerals are geologically important because they are related to the environmental conditions that existed at the time of their deposition, namely arid. Pirssonite is best distinguished by its crystal habit, which has a tabular diamond-shaped crystal form. This mineral is colorless, yellowish or white and has a vitreous luster. Pirssonite was named in 1896 after Louis Valentine Pirsson, an American professor of geology. It can be found at Searles Lake, San Bernardino County, Deep Spring Lake, Inyo County and Borax Lake, Lake County, California, USA; and Mont-Saint-Hilaire, Quebec, Canada. Pirssonite can be easily recrystallized in laboratories in order to confirm specific characteristics of formation. It can also lose its water molecules and should be stored in a sealed container.

analyses. Problems with dilution are often rooted in a failure to adjust the grade control parameters. Simple changes, such as refinements to the blast-hole model estimation parameters can often remedy some dilution problems.

Certainly, an erratic or high-nugget variogram is a good indicator that grade control will be a problem, and as a result, mining will be complicated or frustrating. Again, the mining equipment must be consistent with the deposit. If structures average 3 meters, a 5 meter wide bucket is going to be creating dilution for all but the most skilled operators. Block caving methods are not going to work well for deposits with tight structural controls… in other words, the lessons from Basic Mining classes still apply.

Murphy Dilution

Assuming that we know and understand the technical basis for dilution, there is still the problem of Murphy Dilution. For those not familiar with colloquial English, Murphy is a reference to Murphy's Law, which states that "Anything that can go wrong, will go wrong." Other witty individuals note that it will also go wrong at the worst possible time, and in the worst way. The reference to Murphy may be colloquial, but every miner encountered by the author around the world knows about this Law. Mining seems to have more than its share of experience here.

Murphy Dilution is often a major cause of dilution problems. In one precious metals operation, the reconciliation was indicating that ore grade was much lower than expected. The geologist went out to the mine one night and watched multiple loads of ore get short-hauled to the dump, while upper-level waste loads were hauled to the mill (yes, it was a contract miner). In another case, the grade reporting out of a base metal block cave was experiencing poor tonnages and grades from many drawpoints. The problem was traced to supervisors pulling only high-grade drawpoints, thereby creating cross-dilution from depleted adjacent drawpoints. In another case, an over-enthusiastic blasting foreman was going for improved fragmentation, and ended up severely blending ore and waste.

Clearly, there are many ways to introduce Murphy dilution. However, the common theme here is people: Murphy dilution is primarily human in origin. In most cases, it is a lack of attention on the part of supervisors or management, or a lack of emphasis on the importance of grade. As a result it is both the easiest form of dilution to identify and, because it deals with people, it can be one of the hardest to remedy.

Ore Loss

The opposite side of dilution is ore loss (or mining recovery). Ore loss is self-explanatory to miners, though there are subtleties here as well. Material that is expected from the model that does not appear in production is an ore loss. As with dilution, it is an old aspect of the mining business, and it assumes a knowledge of the geology. To further complicate matters, there is a relationship between dilution and ore losses…. the operator can recover more ore tonnage, but usually at the expense of higher dilution. Conversely, reducing dilution through more selective mining often results in higher ore losses. Fortunately, the remedies for ore losses are similar to those for dilution.

Dilution Control

Given that dilution can be caused by a multitude of different sources, it is not surprising that the remedies are equally diverse.

- Recognition – This is the most important stage of dilution control. Many operators are unaware that a problem may even exist. The solution here is regular reconciliation, not just between the resource model and mine, but with the mine and mill and mill to sales. Consistent material differences between the resource model and mill are a major warning flag. (*Refer to Pincock Perspectives 49 and 50 on Reconciliation, under ww.pincock.com/news*)
- If a problem is identified, locate the source of the problem. If the exploration model and grade control models agree, then mining practices are a probable source. If there is a difference between the exploration model and grade control, look for trouble in sample preparation on both ends.
- Operationally, make sure that the supervisors and operators understand the ore body and work with the geologists, and ensure that the equipment is appropriate to the deposit.
- Analyse – be somewhat paranoid about modeling practices. Periodically use statistical tests to validate both the exploration model and grade control models. Understand the short-range characteristics of the deposit, and incorporate controls accordingly.
- Sample – Sampling protocol is a very common problem. Understand the mineralogy of both the ore minerals <u>and the waste</u>. The number of places where particle size segregation occurs in sample preparation is staggering, and can easily introduce bias into the most basic data used for mine operations: the sample.
- Supervise, Supervise, Supervise – the best technical staff in the world cannot cure mis-directed trucks. Dispatching systems are an excellent technical solution to this problem. Supervisors should always be aware of mining limits and rigidly enforce them.
- Educate. Many managers and supervisors have no idea of the cost of dilution. Consider the cost of a 240 tonne truck dumping waste into mill feed. At $3.00 per tonne, that equates to $720 dollars in direct losses for one truck, not including the opportunity cost associated with lost ore production. Conversely a load of 0.5% copper sent to the dump represents a loss of $3,100 in revenues at present prices.
- Commitment – as noted earlier, many managers and supervisors fail to understand the sources and controls on dilution. Not surprisingly, if management does not consider dilution to be a problem, the emphasis at the supervisory level is likely to be cursory at best. Management recognition and commitment are crucial.
- Reward – set dilution goals or grade targets into the bonus system for both hourly and salaried employees.

This month's article was provided by Gerald D. (Dave) Crawford, P.E., Principal Mining Engineer, dave.crawford@pincock.com

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