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Selection and Application of Cutoff Grades in Underground Mine Planning—Practical Application

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ABSTRACT

This paper discusses the determination of cutoff grade (COG), including all revenue and cost factors and how to apply the COG in the world of engineering studies and mine planning for underground mines. It provides the engineer with important considerations and practical methods to establish COG and methods of using the COG in the work of mine planning, including the application of Mineable Stope Optimizer (MSO) software which is available on several 3D mine planning packages.

INTRODUCTION

Why this Paper is Required

The authors, in the course of their work, have seen wide variations of how COGs are developed and applied while evaluating and planning underground mines. We recognize that one set of practices will not satisfy all situations but do believe that methodology can be more clearly defined than we have experienced. This paper is not intended to revise the strategic work of Lane, Rendu, and others, but to look at the issue at a more granular level, after the global and strategic issues are addressed. Some may consider this paper a refresher on basic mine cost engineering and economics.

Definition of Cutoff Grade

From *SME Mining Engineering Handbook*: "Cutoff grade is traditionally defined as the grade that is normally used to discriminate between ore and waste within a given ore body. This definition can be extended to differentiate various ore types for different metallurgical processing options."

Ultimately, the COG is determined by economics (i.e., the economic value [revenue] of the contained material must exceed a certain threshold).

Another way of considering COG is that it defines the boundary between ore and waste, or is the minimum grade used to plan mining operations.

From the perspective of the mine planner, there may be more than one COG that must be considered in his/her work.

- **Break-Even COG (Incremental)** – the minimum grade that recovers all direct mining, process, and site costs. It includes in-stope (ore) development, but does not include level or access development, or any capital recovery. The break-even COG is used to refine stope shapes and mineable outlines but should not be used to determine mineable shape.
- **Planning or Design COG**—the minimum grade that recovers all operating costs (direct mining, required stope specific access development, processing, and site costs). Normally, a stope should not be included if it will not meet this grade. This should be the minimum COG used in reporting mineral reserves. The planning COG is the starting point for determining mineable shapes.

Cutoff Grade Reporting Terminology

- **Direct Grade**—traditionally, COGs have been reported in assay units of the prime commodity (g/t [opt] Au, %Cu, etc.). Occasionally, the COG may be reported as the assay value of a specific class of the target element, such as acid soluble copper.
- **Equivalent Grade**—in polymetallic deposits, equivalent units are often used (e.g., gold as g/t gold equivalent or AuEq) where the equivalent value is determined by the combined economic value of the primary and other elements. Equivalent value calculations are usually based on average grades, metal prices, process recoveries and other relevant conversion factors. Equivalent grade can be assigned to each block in the planning block model (discussed later). This method suffers from the fact that it assumes constant ratios between commodity prices, process recovery, commodity prices, and payabilities.
- **Revenue Value**—our preferred method is to report COG based on revenue, commonly referred to as net smelter return (NSR) or returned metal value (RMV), although that term does not adequately describe the actual economic value of the ore. Instead of the term cut-off grade, we prefer the term cut-off value (COV) because it better describes the economic value used for planning.

STARTING POINT—RESOURCES MODEL

Regardless of the commodity, mining method, processing method, or any other factor; mineral resource estimation, mine planning, and declaration of mineral reserves depends on having a reliable resource model. Typically, these are prepared by the resource geologist and include considerations of the mining method, general economics of the commodity, and reasonable prospects of economic extraction. This paper assumes that a block model has been prepared with suitable block dimensions, orientation, and data fields.

MINE PLANNING MODEL

For mine planning purposes, we recommend that the mine planners work with the resource geologist to modify the resource model to eliminate fields that are not required and add those that are required (for example: processing recovery rates, NSR) for the planning exercise and create a purpose built planning model. This may reduce the size of the model and minimize the potential for mistakes. As an example, resource models often contain multiple grade calculations to serve as internal checks of the models, such as the example in Table 1 for gold grades.

Table 1. Gold Grades (g/t)

Au OK	Au NN	Au ID2	Au ID3
6.39	5.99	6.27	6.48

In this example, the planning model should only include the field to be used for planning purposes and revenue calculations to reduce the chance of inadvertently applying the wrong field. The resource modeler must be included in the creation of the planning model and approve the resource fields. The engineers should add any specific fields that they may need for planning purposes.

Overall Project Considerations

The planning model cannot be prepared in isolation. The level of detail in the planning model will depend on the maturity of the project. An early-stage evaluation model (e.g., initial assessment) will not have the same amount of detail that the model for an operating mine will have.

In preparing the planning model, the engineer must be careful to include all factors required for mine planning as well as other factors required to support overall project evaluation and reporting. These might include consideration of the following factors.

- Geotechnical
- Geometallurgical
- Hydrological
- Environmental/ESG considerations
- Property ownership
- Jurisdictional boundaries
- Royalties/Streaming agreements

The planning model input and reporting fields should be reviewed by all who provide input data and will use the output to ensure that the model will return usable results before it is approved for use. It is easier to modify the model before the plans are complete than to revise the plans because the model has changed.

REVENUE SIDE OF THE EQUATION

The definition of "revenue" depends somewhat on the purpose to which it will be used. For any specific project, it is important that the definition be formalized, and all battery limits, restrictions, inclusions, and exclusions be clearly defined. We will define "revenue" as "revenue at the gate" (Rev-g) (i.e., what the value of the material is when the salable product departs the property). Rev-g is shown in Table 2.

Rev-g is the income from the customer, less all expenses and burdens associated with delivering the material to the customer, and less all direct fees and charges. Some of these

Table 2. Revenue at the Gate

Payable:
NSR or other payable from customer
Less:
Penalties
Inland freight
Stevedore or handling costs
Cleaning & disposal costs
Sea freight
Handling & freight at destination
Insurance
Sampling/assay/umpire
Fees/charges
Royalties/severance taxes
Import/export duties
Other charges or burdens
Revenue at Gate (Rev-g)

items, such as royalties and taxes, may be treated differently in financial and economic models, however, they are burdens that should be included in the revenue and COV calculations.

Calculated Rev-g should be included in the planning model and used for planning purposes.

COST SIDE OF THE EQUATION

The cost side of the equation is not straightforward. There are a number of variables that must be considered, some of which are dependent on owner accounting practices.

Costs considered in determining COV have been traditionally restricted to operating costs, with capital costs not being considered.

The boundary between capital and operating costs is often defined by accounting / financial / taxation considerations that are beyond the scope of this paper. To determine COV, the distinction between capital and operating costs should not be considered. What should be considered is whether those costs are directly related to the production activity (waste development on level), or are broadly mine-related (i.e., capital expenditure for a hoisting shaft).

DILUTION / RECOVERY

Dilution and stope recovery must be accounted for in determining the COV.

- Dilution:
  - Internal dilution, also called planned dilution, is low-grade or waste material that is within the planned stope or mineable shape and is included in the stope reserve.
  - External dilution is material outside the planned mineable shape that is not planned but must be accounted for in the COV calculation.
  - Calculation of dilution percentage and grade is outside the scope of this paper.
- Recovery:
  - Recovery number quantifies how much material (ore + dilution) is recovered from the stope, recognizing that some material is not recovered.
  - Recovery percentage varies with mining method and numerous other factors and is outside the scope of this paper.

FINANCIAL BURDENS

Several financial burdens are usually not considered "operating costs" but must be considered in calculating COV. These items are listed below and often neglected in COG calculations.

- Royalty payments,
- Taxes,
- Penalties,
- Minimum profit
  - Owner / management requirements
  - We are opposed to "recreational" or "practice" mining.

EXAMPLE

For our example, we will assume that the mining method is transverse sublevel open stoping (SLOS), with backfill. The details will vary with other mining methods, but the principals are the same. Figure 1 illustrates the key features of this method and which portions of mine development are considered under which cost category.

Example with Manual Calculation

Table 3 shows information on an example stope using transverse SLOS, with backfill.

Table 3. Example Stope

Stope:	20,000 tonnes (neat)
(25 × 15 × 20 m)	Rev-g = $200/tonne
Waste development	footwall lateral: 15 m Stope crosscut: 15 m
Stope recovery	93%
Dilution	10%
Dilution grade	Rev-g = $0.00/tonne
Process recovery	90%
Revenue payable	95%

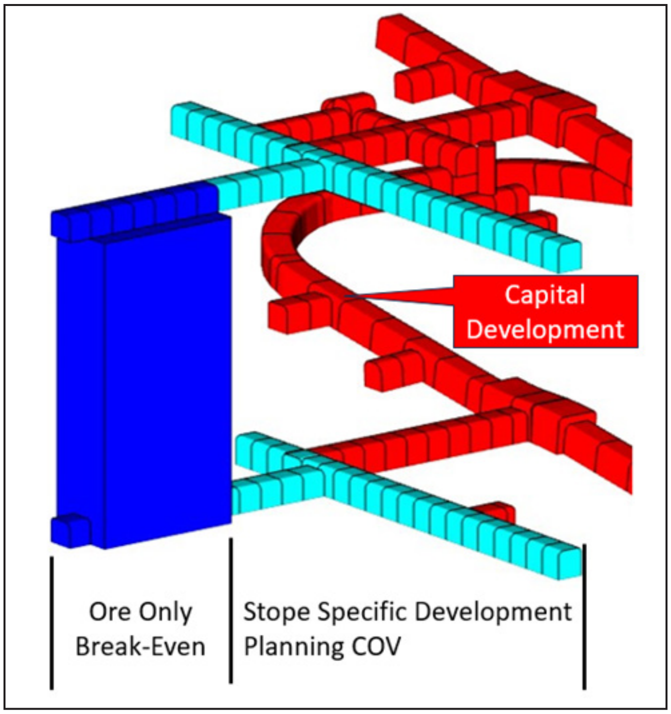

Figure 1. Transverse Sublevel Open Stoping

Stope Revenue

The revenue calculations shown in Table 4 illustrate how the stope revenue is calculated. The "payable" factor (95.0%) is a composite factor used for convenience that incorporates all items included in the "Rev-g" discussion shown in Table 2. The value itself is a composite from several recent projects with which the authors are familiar.

This clearly shows the change in contained value that occurs between the initial stope design and the revenue received after all operational factors and off-site expenses are accounted for.

STOPE COSTS AND CUTOFF GRADE VALUATION

The cost side of the equations for our example stope is presented in Table 5. It shows the costs applied for the break-even and planning costs presented above.

COV at the Mill head grade is the same as the Total cost per tonne, in our example: $103.00 & $126.90. Since the mill head grade is always lower than the in situ stope reserve, a correction must be made to allow for unplanned stope dilution and recovery.

To make this correction, we calculate the Stope Grade Factor from Table 4 as follows.

$$\text{Stope Grade Factor} = \frac{\dfrac{\text{Rev-g Stope Reserve}}{\text{Rev-g Mill Head}}}{\dfrac{\$200}{\$181.82}} = 1.100$$

Table 5. Cost Side for Example Stope

	Cut-off Value Calculations	
	Break Even	**Planning**
Operating	**$/t**	**$/t**
Mining	50.00	50.00
Backfill	15.00	15.00
Mine overhead	10.00	10.00
Process + tails	18.00	18.00
Site general and administrative	10.00	10.00
Sustaining capital	**$/t**	**$/t**
Waste development - footwall lateral	—	6.00
Waste development - stope cross-cut	—	6.00
Mobile equipment - replace and rebuild	—	2.50
Other	—	—
Subtotal cost per tonne ($/t)	**103.00**	**117.50**
Margin (%)	0	8.0
Total cost per tonne	**$ 103.00**	**$ 126.90**
COV - Mill Head (Rev-g $/tonne)	**$ 103.00**	**$ 126.90**
Stope Grade Factor	×1.100	×1.100
COV - Stope Neat Line (Rev-g $/tonne)	**$113.30**	**$139.59**

Table 4. Stope Revenue Calculation

	Stope Reserve	Dilution	Stope Inventory	Stope Recovery	Mill Head	Shipped Metal	Payable (Rev-g)
		10.0%		93.0%		90.0%	95.0%
Tonnes	20,000	2,000	22,000	20,460	20,460		
Rev-g value	$200.00	$ -	$181.82	$181.82	$181.82		
Contained value ($ ×1,000)	$4,000	$ -	$4,000	$3,720	$3,720	$3,348	
							$3,180.6

The Stope Grade Factor is applied to the total cost per tonne (in this example $103 & $126.90) to determine the COV to be applied to the Neat Line stope ($113.30 and $139.59).

The break even COV does not reflect all costs associated with mining the stope. It does not include any cost to develop access to the stope, costs for equipment replacement, or any margin. This is truly "recreational mining" and provides no advantage to the owner except to keep the mill fed and the lights on.

The planning COV includes all operating and stope specific sustaining capital costs, an allowance for other costs, and a minimum margin for the owner. For mine planning and estimating (study) purposes, we recommend that the "Planning COV" be the starting point.

At the beginning of the planning cycle, the planning model should be interrogated (tabulation and 3D image) at each of these COV's to allow the planners to have an understanding of grade distribution, geometry of the economic and marginal portions of the deposit and identify zones of potential low grade and waste pillars that could influence mine design.

As planning progresses, it may become desirable to include material of lower grade than the planning COV for a variety of reasons, but the starting point should always be to cover all costs and show a reasonable margin for the owner.

Optimization of the mine plan may indicate that a higher, or variable COV will yield a more attractive net present value or internal rate of return, but the base case should always be the planning COV.

MINEABLE STOPE OPTIMIZER (MSO) SOFTWARE

Current practice in most applications is to use MSO software, in conjunction with 3D mine planning software to develop stope designs and production plans. Effective use of the MSO, as with any software, requires that the user understand its limitations, provides valid input data, and critically analyzes the results.

Simplistically, MSO will use input values for stope variables including:

- COV of the neat line stope ($139.59 in the example above).
- Stope dimensions.
- Minimum mining width.
- Stope orientation.
- Dilution parameters.
- Other detailed design parameters.

The MSO will interrogate the planning model, using the input values, and generate finished stope solids that satisfy the user-specified attributes, and report mineable tonnes, grade, and other items that can be used in production planning and scheduling.

The MSO report is for neat line stope tonnes, which include internal dilution, but not external, or unplanned dilution. Stope dilution and recovery factors must be applied to obtain the final production forecast.

For the purposes of mine plan and production scenario optimization, MSO allows the user to quickly consider a range of COVs to support evaluation of alternate production and scheduling scenarios.

CONCLUSION

Selection of the correct COV is critical to the ultimate success of a mining project. During the life of a mining project, economic and operational factors often change, necessitating the revision of the COV used in planning for future work.

It is critical that the engineer consider all appropriate costs and operational factors when recommending the COV for a proposed or existing mining project.

The methods presented in this paper are straightforward and allow the engineer to quickly and effectively determine appropriate COV for the project.

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Sulfide Tailings as Potential Secondary Sources of Critical Minerals: Tellurium

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ABSTRACT

Sulfide tailings from past and present mining activities are important hosts of critical elements and precious metals. This review paper presented a literature survey on the recovery practices of some critical minerals containing Te from sulfide tailings with a special focus on the physical beneficiation and hydrometallurgical separation methods. Finally, a conceptual framework and possible processing flowsheets were proposed. The findings of this review will be useful for the researchers in the field of geochemistry, mineral processing, and metallurgy to evaluate the separation processes for reprocessing of mine tailings for the recovery of critical minerals.

INTRODUCTION

Tellurium (Te), with a concentration as low as 1–5 ppb in the Earth's crust, is even more scarce than Au, Ag, Pt, and REEs [1]. Except for a standalone Te deposit in China, [2], Te is typically found in association with other minerals like pyrite, chalcopyrite, galena, and sphalerite and usually recovered as a byproduct of copper ore processing. Given the increasing global demand for Te, its limited reserves, and relatively low recovery, it has been classified as a critical element in several countries [3–5]. Most of the Te production occurs in China (61%), Japan (11%), Sweden (9%), Russia (8%), and Canada (8%) [6,7]. Determining global Te production precisely is challenging due to the incomplete reporting by companies and countries, but the world's current production for refined Te is estimated to be 500 to 550 tons per year [7–9].

Because of their outstanding thermal, optical, and electrical characteristics, Te and Te-containing compounds find broad applications across diverse industries. Over the past decade, there has been a substantial global increase in the production of cadmium telluride (CdTe) thin-film solar cells, rising from negligible levels in the mid-2000s to surpassing 6 gigawatts in 2020 alone, according to the Fraunhofer Institute for Solar Energy Systems (2022) [10]. This increase in CdTe production led to a corresponding rise in Te demand, making up approximately 40% of global Te usage and standing as its most substantial application [11–13]. Te is also employed in various other industry sectors including thermoelectric production (constituting 30% of global Te production), metallurgical alloys (15%), color ceramics and glass fibers (10%), and heat-resistant rubber (5%) [14,15].

The escalating worldwide demand for Te in recent years has led to increased focus on recovering tellurium from ores, tailings, and metallurgical by-products [16,17]. According to Ojebuoboh's research [18], about 90% of Te in ores is typically lost to tailings during the concentration processes of copper-containing sulfide minerals at mining