Assessing the reasonable prospects for eventual economic extraction of a caving project

W Bennett *Mining Plus, Australia*

A Fowler *Mining Plus, Australia*

Abstract

As the rigour required for mineral resource reporting increases, criteria for 'reasonable prospects for eventual economic extraction' (RPEEE) are becoming more common in the industry and are an explicit requirement in some reporting jurisdictions. These criteria require an assessment of the mineral's potential price, its processing characteristics and mining factors including the mineral's concentration and the deposit's geometry. For near-surface deposits, which are likely to be mined as open pits or high grade deep deposits to be mined using underground selective methods, this assessment is relatively straightforward. However, for mining massive deep deposits, it is more complex.

This paper discusses the complexities of defining RPEEE when an underground caving method is expected and describes an approach and a brief application case developed by the authors for assessing what material can be reported as a resource under these criteria. The paper should be of interest to geological professionals who are preparing resource statements, and financial and mining professionals who are evaluating the reserve and economic potential of those resources.

Keywords: *reasonable prospects for eventual economic extraction, RPEEE, caving*

1 What are reasonable prospects for eventual economic extraction?

The Joint Ore Reserves Committee (JORC) Code (JORC 2012) states that:

> "All reports of Mineral Resources must satisfy the requirement that there are reasonable prospects for eventual economic extraction (ie more likely than not), regardless of the classification of the resource.
>
> Portions of a deposit that do not have reasonable prospects for eventual economic extraction must not be included in a Mineral Resource. The basis for the reasonable prospects assumption is always a material matter, and must be explicitly disclosed and discussed by the Competent Person within the Public Report…"

The Canadian Institute for Mining, Metallurgy and Petroleum (CIM) "Estimation of Mineral Resources and Mineral Reserves Best Practice Guidelines" (CIM 2019), which is referenced in the Canadian National Instrument 43-101 (NI 43-101) goes into more detail and states that:

> "For Mineral Resources that are amenable to open pit mining methods, the "reasonable prospects for eventual economic extraction" should consider not only an economic limit (such as the cut-off grade or value), but technical requirements as well (such as the wall slope angles)… At a minimum, the constraints can be addressed by creation of constraining surfaces (pit shells).
>
> Mineral Resource statements for underground mining scenarios must satisfy the reasonable prospects for eventual economic extraction" by demonstration of the spatial continuity of the mineralization within a potentially mineable shape… At a minimum, these constraints can be addressed by creation of constraining volumes."

In the authors' experience, a company's typical optimisation objective when reporting a mineral resource estimate (MRE) is to maximise tonnes and/or contained metal. Neither head grade, net present value (NPV), internal rate of return (IRR) nor present value ratio (PVR) are typically considered, as these objectives will tend to decrease the total tonnage and/or contained metal that can be reported. Furthermore, in the authors' experience on projects where they have acted as 'competent' or 'qualified' persons, this optimisation objective has been acceptable to securities administrators for the reporting of mineral resources.

There is a distinction between mineralised material that is included in a geological model, material that has reasonable prospects for eventual economic extraction (RPEEE) and material that could be included in a mine plan. For example, there may be mineralised material in a geological model with a resource classification that has been suitably estimated based on the available drill data, but is too narrow and at too low a grade to add value to any mining operation. Similarly, there may be material that is of a high grade in a thick vein, but that has been excluded from a mine plan because under the mining strategy it is part of a rib pillar between stopes.

With this in mind, the RPEEE assessment should consider factors including the economic, technical, social, legal and environmental that will affect the extraction of the mineral. The assessment is not a full mining study, but relevant findings of any mining studies that have been completed should be included in the factors. Many of these factors can be represented by a three-dimensional solid or surface that can encompass or select the mineralised material in a geological model that has RPEEE. A key function of these constraining volumes or surfaces is to exclude material that is:

- Too deep to mine by an open pit mining method.

- Too low grade or discontinuous to mine by an underground selective stoping method.

- Of insufficient quantity or appropriate geometry to be mined by an underground bulk mining method such as caving.

The focus of this paper is then how to define and generate the constraining volumes that satisfy the RPEEE criteria to report a mineral resource that is potentially mineable by caving.

2   Pits, stopes and caves

For the purpose of this discussion, mining methods will be grouped into three types. The types have different characteristics which determine the most appropriate method for generating the constraining volumes:

- Surface open pit methods.

- Underground stoping (selective) methods.

- Underground caving methods.

In practice, a combination of mining methods is typically assessed in the authors' experience and the combination that maximises tonnage and/or contained metal is chosen for demonstrating RPEEE and stating the mineral resource.

2.1   Surface open pit methods

In open pit methods, the mining sequence is top down and subject to the constraints of maintaining geotechnically stable wall angles. These constraints allow a mathematically optimum pit shell (maximum economic envelope) to be generated, outside of which any combination of blocks will reduce the overall (undiscounted) value and therefore should not be included in an RPEEE assessment.

Gossan & Smith (2007) recommend using a Lerchs–Grossman (LG) pit shell generated on all of the measured, indicated and inferred confidence categories as the constraining surface for the RPEEE assessment.

Therefore, generally the revenue factor 1 pit will be chosen for the MRE statement as this is the largest pit shell that can be justified from the economic constraints.

Note that a mine plan may consider different mining strategies that will separate the mining into different pushbacks or stop at different final pit shell designs. However, the maximum economic envelope (RPEEE constraining volume) will be unchanged, as the remaining increment will still be economically positive (Figure 1).
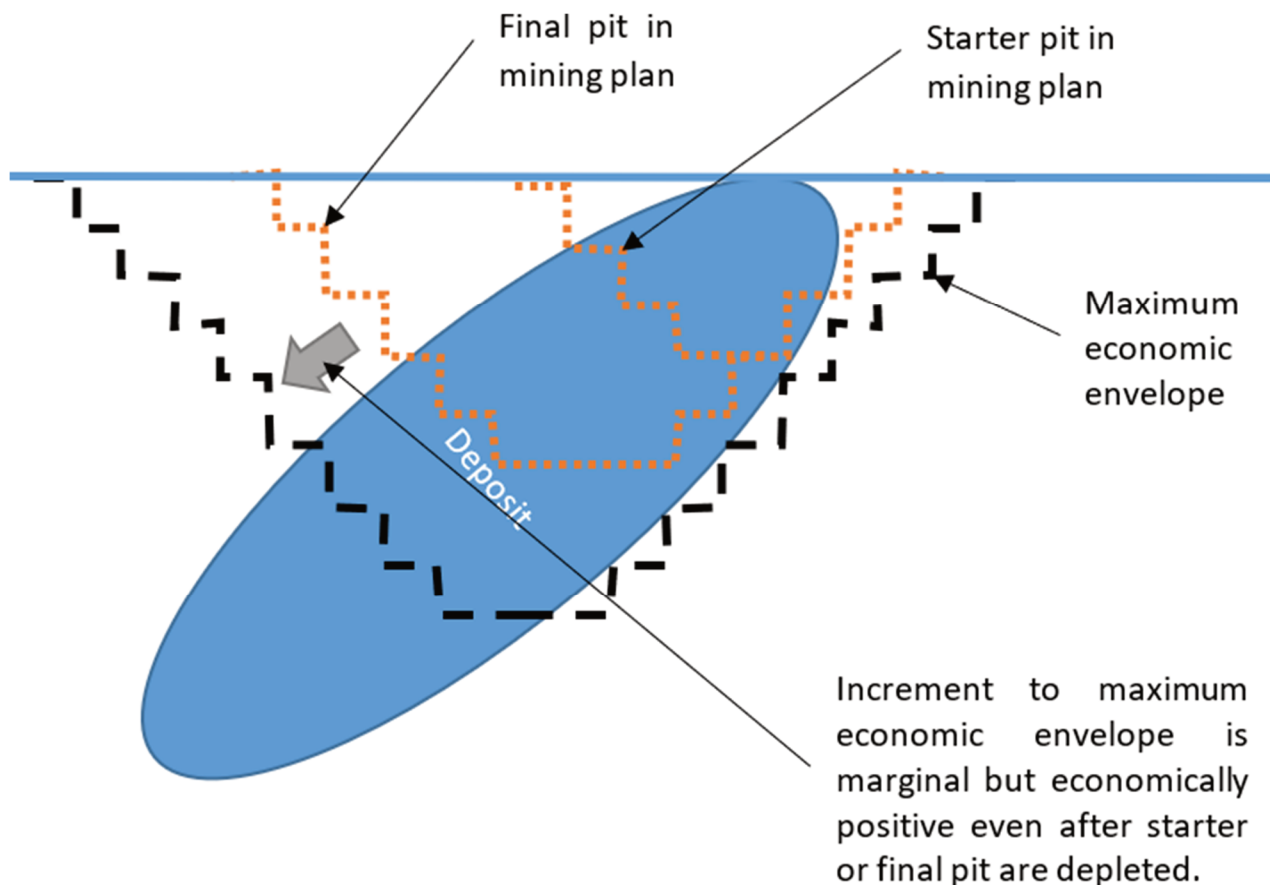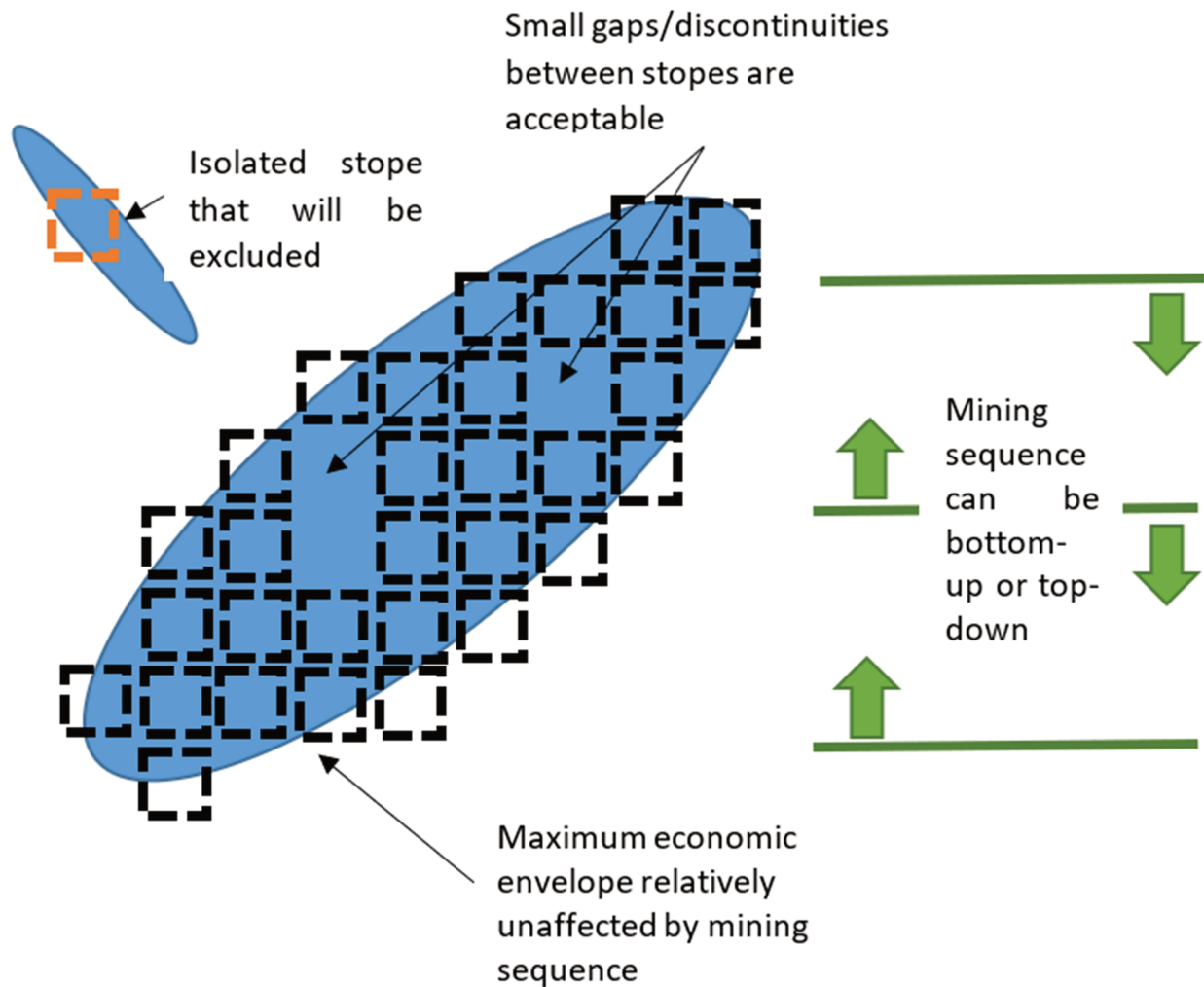

Figure 1   Long section schematic showing potential pit shells for mine planning and RPEEE constraining volumes

2.2   Underground selective stoping methods

Underground selective stoping methods are those where the deposit is extracted in a series of stable excavations (stopes). The size of these excavations is relatively small with adjacent stopes required to follow the minimum width and dip criteria for the method, but relatively un-influenced by their neighbour's geometry. Small gaps between adjacent stopes are allowable due to the relatively low cost of developing tunnels relative to the cost of mining and processing stope tonnes.

The Datamine™ Mineable Shape Optimiser (MSO) algorithm can be used to define a series of stopes that conform to the minimum mining width and dip. The MSO output should then be reviewed by the 'competent' or 'qualified' person in longitudinal projection, so that any isolated stopes that are far from the intended mine access and that could not reasonably be assumed to contribute to a future mine plan, can be identified and excluded. The final stope shapes can then be used as the constraining surface for the RPEEE criteria. Mining sequences for these stopes are flexible and a particular mine plan may be bottom up, top down or primary secondary. However, as with the open pit method, changing the order in which the stopes are mined, under an alternative mining strategy, will generally not affect the maximum economic envelope, so a constraining RPEEE volume can be defined that is relatively independent of the mining strategy (Figure 2).

Small gaps/discontinuities between stopes are acceptable

Isolated stope that will be excluded

Mining sequence can be bottom-up or top-down

Maximum economic envelope relatively unaffected by mining sequence

Figure 2   Long section schematic showing potential stope shapes for mine planning and RPEEE constraining volumes

2.3   Underground block caving methods

In underground block caving methods, the deposit is mined from a relatively small number of block caves. There is considerable flexibility with the elevation of a footprint of each block cave and the shape of the block cave, but the edges of the cave must be continuous and of sufficient span to achieve caving. There must be no pillars within a block cave to ensure the caving span is maintained and that material can flow to drawpoints. Importantly, the choice of mining strategy, in the elevation and span of the footprint, determines the remaining maximum economic envelope. Figures 3, 4 and 5 show examples of this difference in different example deposits.
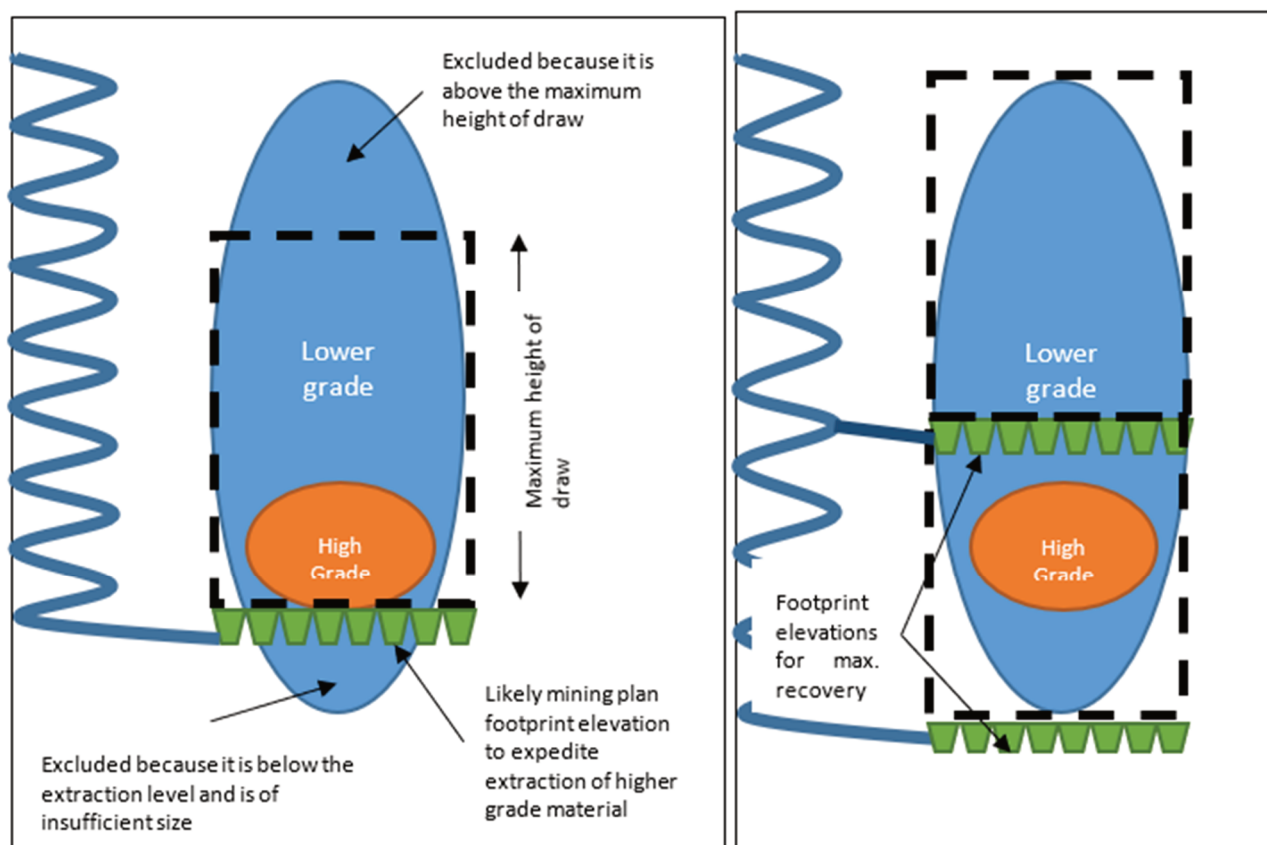
Figure 3 Long section schematic showing how higher grade at depth can result in a different maximum economic envelopes for alternative mining plans
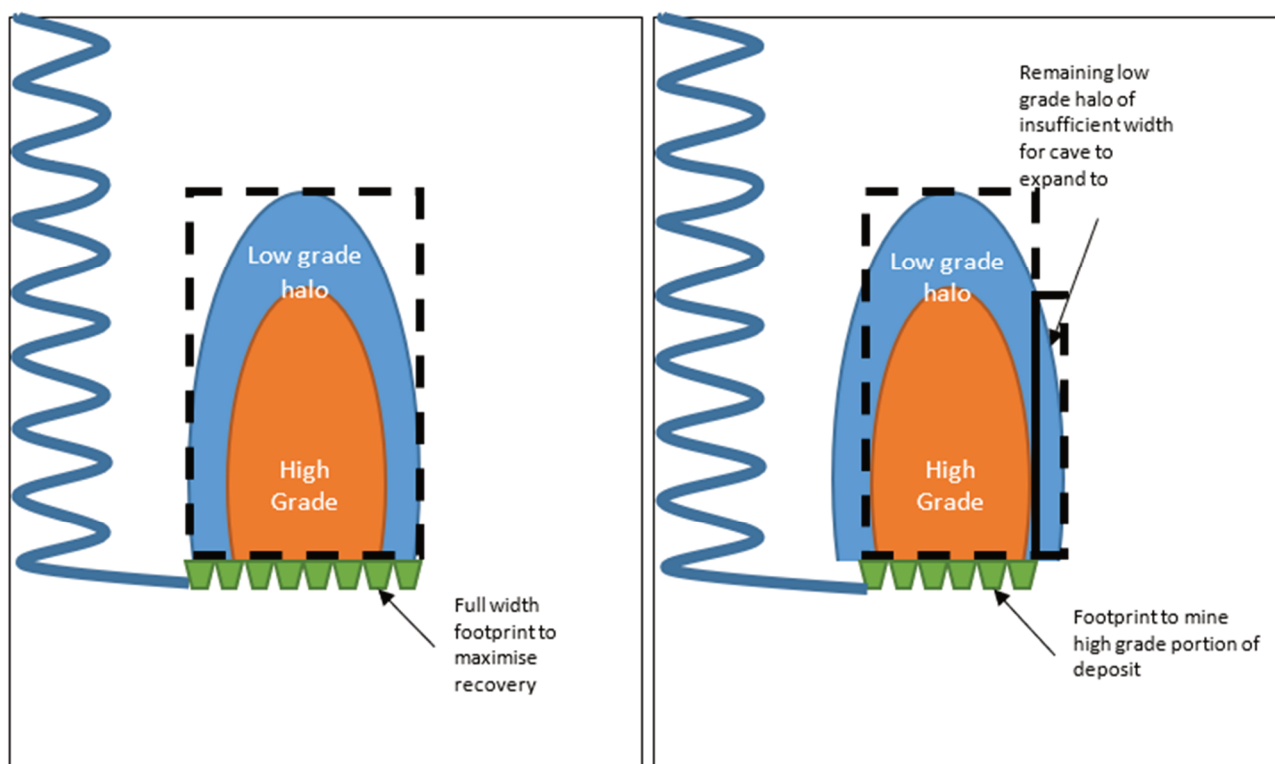
Figure 4 Long section schematic showing how a higher grade core with a lower grade halo can result in a different maximum economic envelopes for alternative mining plans
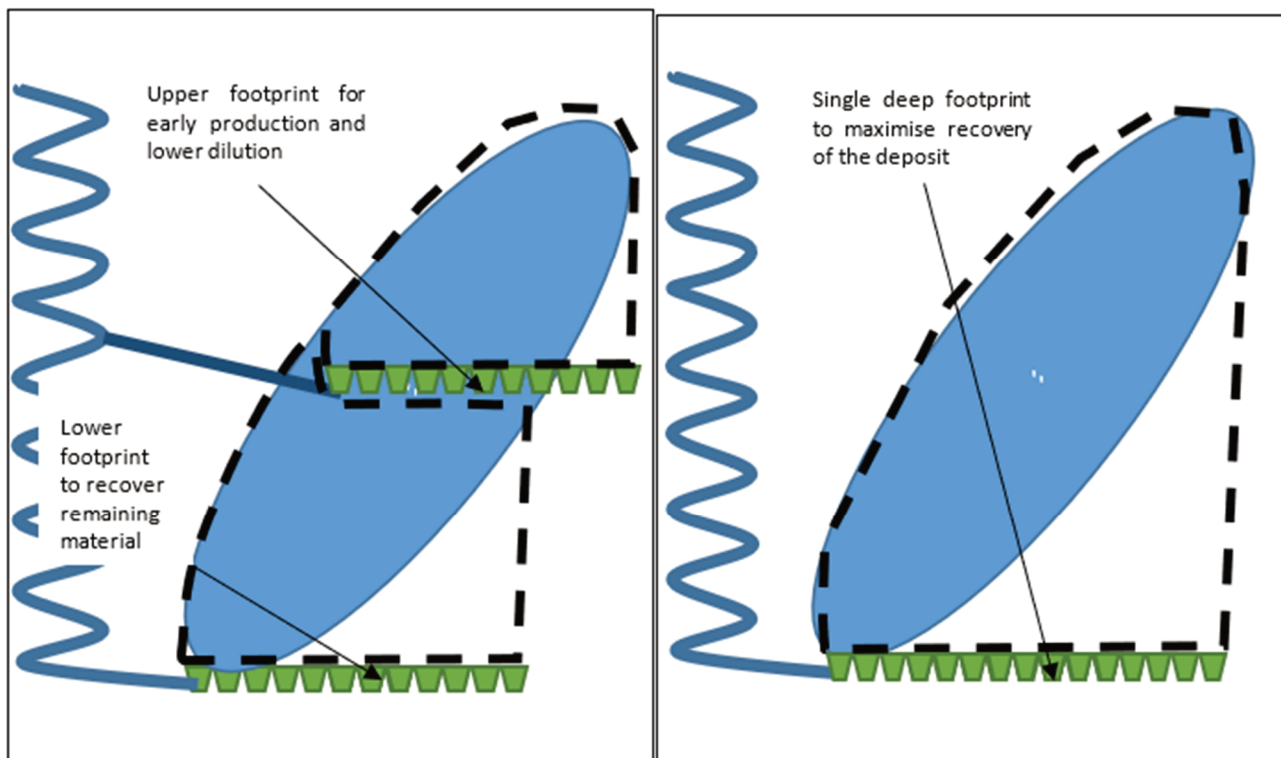
Figure 5   Long section schematic showing how a deposit dip can result in a different maximum economic envelopes for alternative mining plans

3   Possible approaches for defining RPEEE constraining surfaces for block caves

Because of the dependence of the maximum economic envelope on the choice of mining strategy, three potential methods are suggested to generate RPEEE constraining surfaces for block caving.

3.1   Approach 1

If a footprint elevation has been selected, then a maximum economic envelope can be generated for that elevation. For Approach 1, it is suggested that a maximum economic envelope for all potential footprint elevations is generated, and then the elevation that maximises the economic envelope is selected to define the RPEEE constraining volume.

To generate the maximum economic envelope, a footprint finding algorithm such as the one included in GEMCOM™ PCBC can be used. This algorithm calculates the best height of draw for each potential draw-column, while a user generated polygon is used to group the economically positive draw-columns into a practically minable footprint (Figure 6).

This approach has the advantage of being relatively straightforward and makes the RPEEE constraining volume representative of a shape that could be extracted by caving. However, the drawback is that it makes specific assumptions about the mining strategy, which are likely to differ from an actual mining strategy and that would most likely seek to maximise a metric such as NPV, IRR or PVR (Stewart & Butcher 2016) rather than maximise tonnage and/or contained metal. In some geometries, selection of the elevation(s) which maximise the economic envelope may also add significant planned dilution and exclude material that could be reasonably included in a good mining plan.
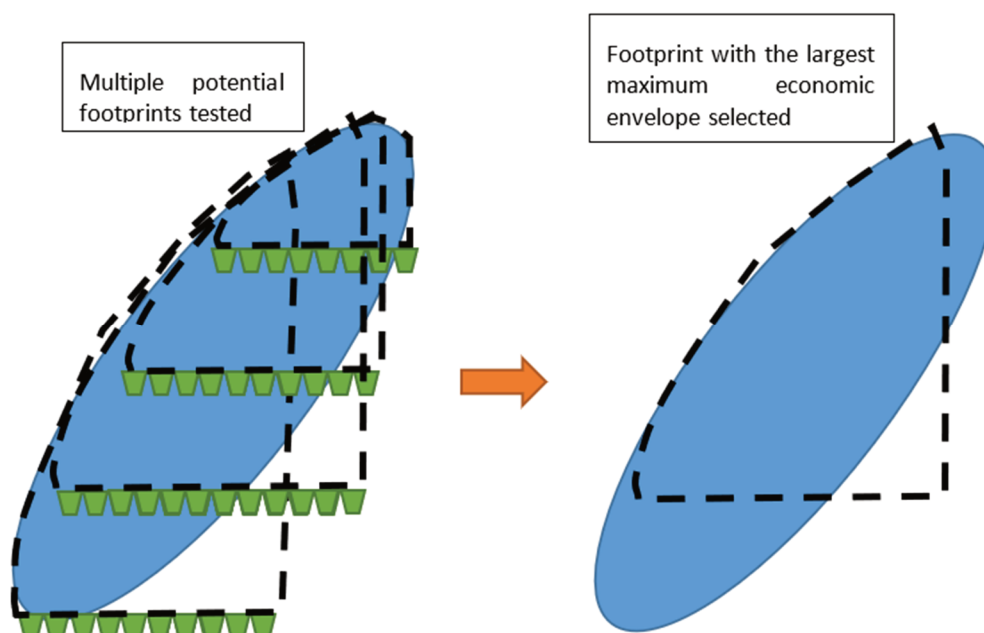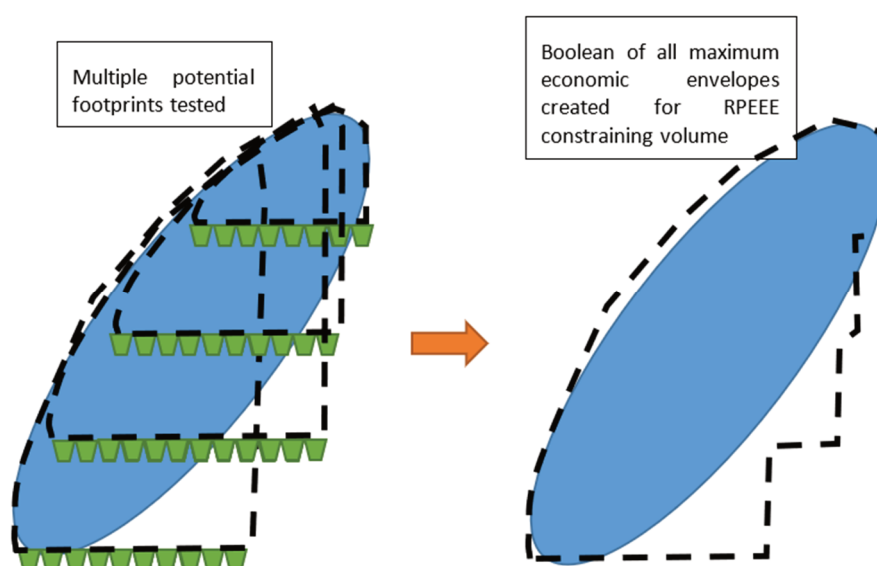
Figure 6 Long section schematic showing how the RPEEE constraining volume is generated using Approach 1

3.2 Approach 2

To avoid making the RPEEE constraining volume dependent on a particular (and likely inappropriately selected) mining strategy, Approach 2 defines the RPEEE constraining volume as the Boolean union of all of the maximum economic envelopes of all of the potential footprint elevations tested in Approach 1 (Figure 7).

This approach has the advantage that all material within the RPEEE constraining volume could be included within a valid and technically practical mining plan. However, to account for mining at a range of potential (but valid) elevations, significant volumes of planned dilution or 'must take' material according to CIM guidelines (CIM 2019) will be added. However, in a likely mining strategy, only the planned dilution for the selected elevation would be included. Although this is dilution, it is likely to be mineralised dilution. Therefore Approach 2 tends to provide an overly optimistic RPEEE constraining volume with higher tonnage and/or contained metal than the other approaches.

Figure 7 Long section schematic showing how the RPEEE constraining volume is generated using Approach 2
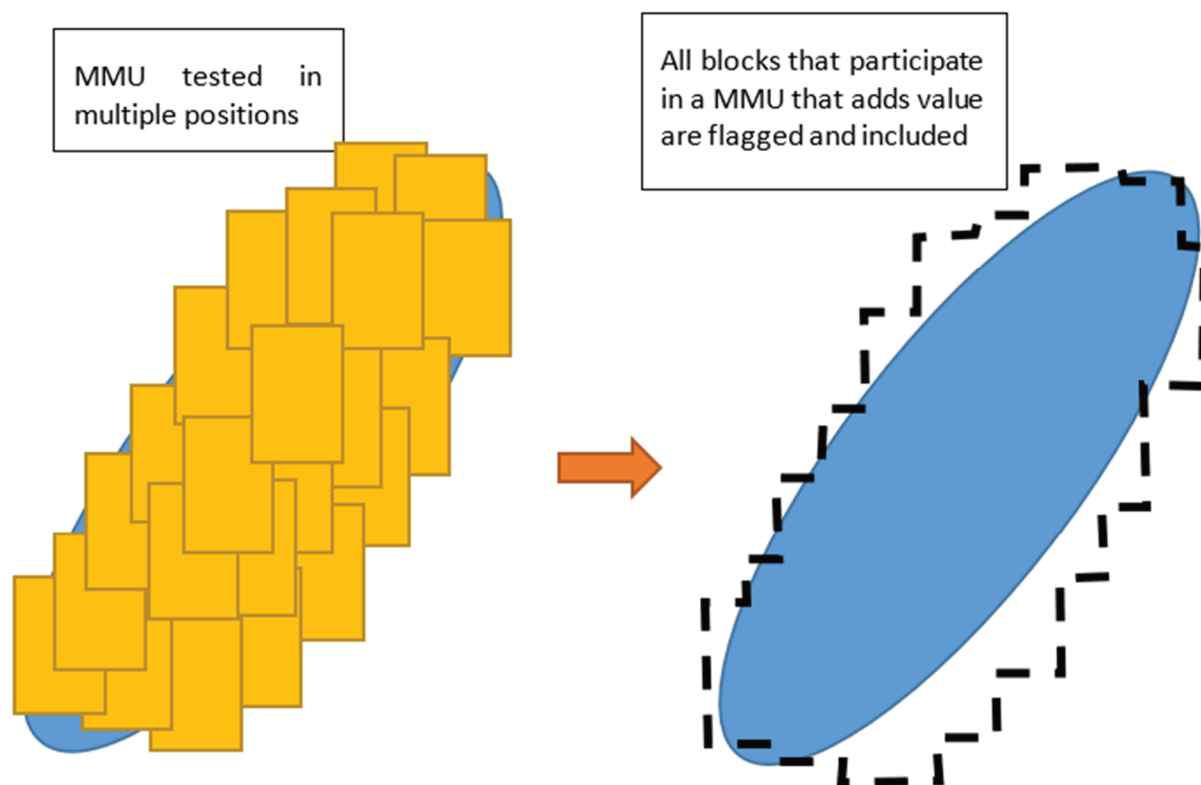
3.3   Approach 3

Approach 3 aims to maintain the independence of the RPEEE constraining volume from the mining strategy of Approach 2 while reducing the volume of inappropriate planned dilution.

The process for doing this is as follows:

1. Determine a minimum mining unit (MMU) suitable for block caving.

2. Find the highest value MMU, flag it as part of the maximum economic envelope and then deplete it from the model. Depleting it ensures that it cannot carry low grade material between it and other potential footprint elevations.

3. Repeat this process, so that all flagged blocks that make up the RPEEE constraining volume participate in an MMU that is above the cut-off but are not 'carried' by an area of high grade that could be extracted independently. This ensures that all the flagged material could reasonably be included in a mine plan. There will be no material whose inclusion is contingent on a particular mine plan as the basis for its inclusion (Figure 8).

While this process can be done manually as described, the Datamine™ MODENV algorithm achieves the same result. Specifically, MODENV will "process a block model and flag those blocks that when taken individually or with adjacent blocks will satisfy the minimum [cut-off or head] grade or economic value within a volume defined by the minimum envelope dimensions" (Datamine 2022).

Figure 8   Long section schematic showing how the RPEEE constraining volume is generated using Approach 3

Of the approaches, the authors consider Approach 3 to be most valid in earlier stage projects, where the mine plan is still under development and extraction levels and footprint spans are being refined. While it is likely that a particular mining strategy (e.g. one to minimise payback period) will not recover all of the flagged resource or may require some planned dilution, these changes are considered mining modifying factors, analogous to the effect of using rib pillars in a stoping mine.

When the mine plan is mature and unlikely to change, then Approach 1 will become more appropriate, but with the selected footprint elevations being those defined in the mine plan.

Note that for sublevel caving, the maximum economic envelope is less dependent on the choice of footprint. However, with an appropriately sized MMU Approach 3 can be used to define the RPEEE constraining volume for a deposit that is expected to be mined by sublevel caving.

4 Parameters for defining the RPEEE constraining volume for underground caving methods

4.1 Minimum mining unit

The size of the MMU is described by its horizontal span and its height. The minimum span must be sufficient to initiate and maintain caving. Laubscher's block caving manual (Laubscher 2000) describes the method for estimating the minimum hydraulic radius (HR) span from the modified rock mass rating (MRMR). However, a practical span is often greater than the minimum calculated from the HR to allow for some contingency and to account for the span becoming smaller in the possible event that an overhang is created when the cave propagates upwards. Therefore, benchmarking a minimum span from other caving operations is likely a better estimate of this parameter than a first principles analysis of the span required to just initiate caving.

The height of the MMU is limited by practical rather than technical criteria. Vertical mixing and the cost of the footprint are fixed and do not increase with draw-column height (Laubscher 2000). Because of this, a minimum MMU height is recommended to ensure that there is sufficient material to cover the costs of footprint establishment and the losses due to vertical mixing.

Given that there may be limited geotechnical data at early stages of a project when the RPEEE may be assessed, it is recommended that a sensitivity study is performed on different MMU sizes. If the size of the RPEEE constraining volume is very sensitive to the MMU size, then further investigation and justification of the most appropriate MMU size is recommended.

4.2 Metal price, costs and metallurgical factors

Metal price and metallurgical factors directly affect the cut-off grade used to define the RPEEE constraining volume. The method for estimating these in a caving RPEEE assessment is no different from that of any other mining method.

Costs can be loosely divided into operating, sustaining capital and establishment capital costs. For the estimation of the cut-off grade, operating costs and appropriate sustaining capital costs (Ponierwieski & Hall 2016) are used. This is in turn used to determine the total size of the RPEEE constraining volumes.

Capital costs can be significant for a block caving project, and typically affect whether the project will go ahead (rather than the size of the constraining RPEEE volumes). Gosson & Smith (2007) suggest that an assessment of whether the revenues of a project can cover the capital cost should form part of the RPEEE assessment. In practice, however, this is rarely undertaken for the reporting of a mineral resource. It is not required to report in accordance with the JORC Code (JORC 2012) nor is it recommended in the CIM best practice guidelines for resource reporting (CIM 2019) in order to report in accordance with NI 43-101.

In the case study presented below, the authors developed the RPEEE constraining volume approach on a project where a previous preliminary economic assessment (PEA) had found economic potential after considering capital costs. Because of this, a methodology to check this criterion for block caves was not required and hence is outside the scope of this paper.

5   Other considerations

5.1   Cave mixing

Cave mixing is a complex mining phenomenon, where differential velocities of material within the cave lead to some material from outside of the in situ column design to travel faster through the cave and be mined, while some material inside the in situ design columns travels more slowly and may not be recovered. For the purpose of the RPEEE criteria, this is accounted for in the selection of the MMU vertical size, but not used in the reporting of the portion of geological model in the RPEEE constraining volume, because mixing is a mining factor.

5.2   Planned dilution

If the deposit is thinner than the MMU at its extremities, then additional 'must take' diluting material is included in the RPEEE constraining volume to increase the span of these areas until they conform to the MMU. Following the CIM guidelines (CIM 2019) this 'must take' material should be included in the resource report.

5.3   Cut-off grade application

In an open pit, where mineralised material inside the final pit shell can be selectively mined block-by-block, it is appropriate to apply a cut-off grade to each block and only report the blocks that are above cut-off and inside the optimised pit shell in the mineral resource statement. Conversely, for an underground mining method, the cut-off grade has been applied in the generation of the optimised stope or cave shape and the material cannot be mined selectively inside the stope or cave. Therefore, all classified material at zero cut-off grade should be reported inside the stope or cave and included in the mineral resource statement.

6   Cascabel Alpala case study

The Alpala porphyry copper-gold-silver deposit lies with the 50 km^2 Cascabel concession in northern Ecuador (Artica 2021). The Cascabel Property is located within the Imbabura province, approximately 100 km north of the capital city of Quito and approximately 50 km north–northwest of the provincial capital, Ibarra. The northern border of the project lies approximately 20 km south of the Colombia–Ecuador border, and 75 km southeast of San Lorenzo, located on Ecuador's Pacific coast.

Geologically, the Alpala deposit is located within the Western Cordillera of Ecuador, mostly composed of a Cretaceous basaltic tholeiitic basement and Tertiary volcanic-clastic sequences and intrusive rocks. This sequence has been intruded by a series of Middle to Late Eocene (Bartonian) hornblende-bearing diorites, quartz diorites and tonalities that form plutons, stocks and dykes.

Mining Plus was commissioned by SolGold plc to prepare an MRE and subsequent technical report for Alpala, with an assessment of the RPEEE part of the MRE. This case study discusses the RPEEE criteria.

Because the project was still in the early stages of study without a fixed mining strategy, Approach 3 was used to generate a constraining volume, described as an underground optimised shape (UOS). Parameters used to generate this UOS were generally those used in the PEA (Cowley 2019) with the exception of the metal prices, which were based on third party metal price research. Of note is the size of the MMU (80 × 80 × 200 m). The relatively small span (80 m) was used as the MODENV algorithm used an MMU aligned with the XYZ grid. The deposit however trended northwest to southeast, so the true span of the MMU was across the diagonal representing a span of approximately 120 m.

The resulting RPEEE constraining volume included some unclassified material, which was included in the mineral resource statement and itemised as 'planned dilution' in the interests of transparency (Figure 9).
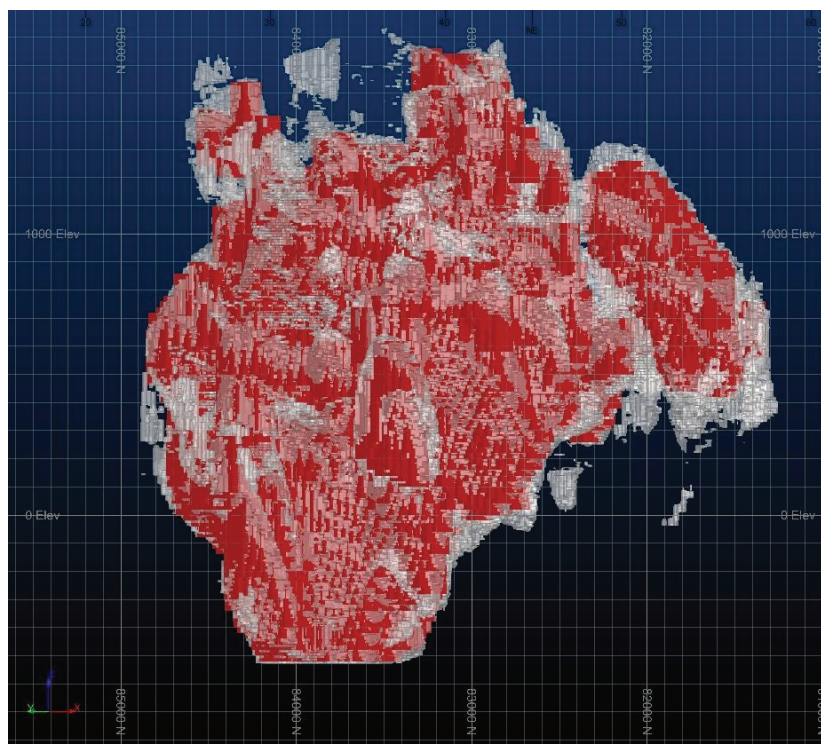
Figure 9 Perspective view towards northeast showing the UOS in red with estimated blocks above the cut in white

As stated above, an assessment of whether the revenues of the material within the RPEEE constraining volume would cover the capital establishment costs was not performed. However, given the successful completion of the PEA it was considered reasonable to assume that the project was economic overall.

7 Summary

Demonstrating that a resource has reasonable prospects for eventual economic extraction is an important part of the resource reporting process. If the deposit is massive and deep, and it is likely that it will be mined by block caving then the RPEEE assessment needs to account for this.

Whilst some parameters for the assessment process are analogous with the RPEEE assessment for other mining methods, such as the metal price, metallurgical factors and costs, block caving has some unique characteristics which need to be treated differently. Essentially the maximum economic envelope, which defines the extents of the resource that has RPEEE, depends on the footprint(s) location. However, for a given deposit, there are many different footprint location options, each with its own maximum economic envelope.

This paper has described three potential approaches for reducing this ambiguity associated with not knowing the footprint locations at the point of assessing the RPEEE where the authors consider the third approach most appropriate for early-stage projects. This third approach was used in the case study to determine the RPEEE constraining volume and then report the resource for the Alpala deposit.

Acknowledgement

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