USDA Forest Service
Tonto National Forest
Arizona

September 11, 2020

Process Memorandum to File

Post-DEIS Review of Alternative Mining Techniques

Prepared by:

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Revision History

- September 11, 2020. Initial draft created.

Purpose of Process Memorandum

The Tonto National Forest published the Draft EIS for the Resolution Copper Project in August 2019, with a 90-day public comment period. A number of public comments were received concerning the use of alternative mining techniques other than block caving, as has been proposed by Resolution Copper. These comments included a technical report by Dr. D. Chambers, Center for Science in Public Participation, submitted as an appendix to comment letter #8032 (Arizona Mining Reform Coalition et al), in which a number of issues are raised regarding the analysis of alternative mining techniques.

The purpose of this process memorandum is to signpost the process steps that have taken place since publication of the DEIS in order to assess and respond to comments about alternative mining techniques, document the conclusions reached, and the rationale for these conclusions.

Key Process Steps

The process followed for the assessment of alternative mining techniques, leading up to the publication of the DEIS, is documented in the project record in "Process Memorandum to File - Summary of Process Steps taken during Review of Alternative Mining Technique", July 31, 2019 (Project Record #0003300).

This process memo lays out the steps taken during the initial assessment of alternative mining techniques as it was documented in the November 2017 Alternatives Evaluation Report, additional information received in December 2018, and evaluation of that additional information. The evaluation of the additional information is found in two documents in the project record:

- "Process Memorandum to File - DRAFT - Review of Stakeholder Analysis of Alternative Mining Techniques", March 24, 2019 (Project Record #0003293)
- "Memorandum regarding spreadsheet analysis of mining economics: "Dave Chambers, CSP2, 2/14/05 - updated with 2018 copper prices" by Dr. C. Kliche, March 24, 2019 (Project Record #0003115)

After publication of the DEIS and receipt of public comments, the following additional process steps were taken by the NEPA team to assess these issues:

- January 21, 2020. First meeting of reconvened Geology, Subsidence, and Seismicity workgroup, in which Chambers (and other) comments were presented and discussed (Project Record #0003673). Action items included:
    - Have Dr. Kliche review the Chambers comments
    - Have Resolution Copper review the specific assumptions made by Chambers with respect to the ore deposit
- January 29, 2020. Review of Chambers report by Dr. C. Kliche on behalf of Tonto National Forest (Attachment 1 of this process memo)

- February 21, 2020. Second meeting of reconvened Geology, Subsidence, and Seismicity workgroup, with further discussion of the Chambers comments (Project Record #0004196). Action items included:
    - Obtain more industry-standard and recent references on mining techniques
    - Explore further safety considerations of alternative mining techniques
- February 26, 2020. Memorandum received from Resolution Copper contractor Itasca, titled "Response to Action Item GS-2. Comments on Subsidence from the Center for Science in Public Participation (Chambers, 2019)" (Project Record #0004198). However, note that the responses in this memorandum only apply to subsidence analysis, not to alternative mining techniques.
- March 18, 2020. Powerpoint presentation received from Resolution Copper contractor Itasca, titled "Literature Review to Identify Techniques for Mining Method Selection Resolution Copper EIS" (Project Record #0004199)
- March 20, 2020. Additional information received from Dr. Kliche to supplement literature review conducted by Itasca (documented in this process memo)
- March 24, 2020. Memorandum received from Resolution Copper contractor Pierce Engineering, titled "Safety Considerations in Mining Method Selection at Resolution" (Project Record #0004200)
- March 24, 2020. Third and final meeting of reconvened Geology, Subsidence, and Seismicity workgroup, with minor wrapup discussion of submitted information (Project Record #0004197).
- June 9, 2020. Additional information received from Dr. Kliche regarding updated mining costs (documented in this process memo)
- June 12, 2020. Additional information received from Dr. Kliche regarding safety considerations of alternative mining techniques (documented in this process memo)
- April – September 2020. Responses to comments drafted and revisions made to EIS and supporting materials.

Overview of Concerns Raised by Chambers and Others

Many comments received on alternative mining techniques were generic in nature, either expressing that the Tonto National Forest did not evaluate other techniques (which is not correct, as demonstrated in the record) or prioritized profitability over environmental protection (which is also not correct, as profitability has never been assessed as part of the analysis). These topics are dealt with in previous assessments, as described above; see specifically the discussion of reasonableness in Project Record #0003293.

Substantive technical comments on alternative mining techniques focused on the following:

- That data were not made available to the NEPA team by Resolution Copper, and were insufficient for the NEPA team to evaluate alternative mining techniques.
- That inappropriate or outdated references were used in the assessment.
- That incorrect ore grade terminology was used in the assessment.

Additional Evaluation Undertaken in Response to DEIS Comments

Availability of Data

The Chambers comments note: "Dr Kliche had to work without any data support from Resolution Copper." This is an incorrect statement. Dr. Kliche was provided adequate data to make a reasonable estimate of the relationship between grade and tonnage, which was the key aspect of the evaluation of reasonableness. Dr. Kliche directly addresses this issue in his response to the Chambers comments (see Attachment 1):

> *This is patently false. I cannot say that I had unlimited access to all the data I needed for a perfect estimate of the grade/tonnage relationship for the Resolution Copper deposit, but I was provided, without hesitation, enough good data to make a reasonable estimate of that relationship. This information, in the form of horizontal slices at 100 ft intervals from bottom to top through the Resolution Copper block model showing grade classes of the blocks, was gracefully and without hesitation provided after a meeting on 3/23/17 between myself and Mses. Vicky Peacy and Kim Heuther, and Mr. Bill Hart (noted on pg 1 of "Draft Technical Memorandum for Alternative Mining Methods, Resolution Copper Mining, LLC, Superior, AZ", C.A. Kliche, July 7, 2017).*
>
> *The reason, of course, for requesting this information from Resolution Copper was to try to estimate the tonnage available above various cut-off grades which may be available for mining via some other more costly mining method (ie: cut-and-fill).*
>
> *The personnel I worked with on this at Resolution Copper could not release to me all of the data I requested due to its proprietary nature. We negotiated. And they released the best they thought they could, given the proprietary nature of the mine model and of the tonnage/grade distribution.*

Note that the information referenced by Dr. Kliche is in the project record (Project Record #0001320).

Chambers also notes that a specific report was unavailable ("Geologic and Mineral Resource Model - Suitability for Declaration of Mineral Resources and Support for Mine Plans to Develop a Block or Panel Cave Mine" Harry M. Parker, Amec Foster Wheeler E&C Services Inc., March 14, 2017). This document was not referenced in the DEIS and so was not posted to the website. But it certainly was available to the NEPA team and is part of the project record, along with other supporting material for the NEPA analysis.

Mining References – Selection of Mining Method

As noted above, the reconvened Geology, Subsidence, and Seismicity workgroup compiled additional pertinent references with respect to mining techniques, in order to respond to comments that the references used by Dr. Kliche were outdated. This literature review was conducted to identify classical references for mining method selection.

The Itasca submittal from March 18, 2020 is in the project record, but is also included with this process memo as Attachment 2.

Itasca reviewed six classic mining references. Their conclusion is that "All of the mining method techniques arrived at similar conclusions, with Block Caving as the preferred mining method." (Attachment 2, p. 15) While block caving was identified as the clear preferred method, several other methods were identified as pertinent: top slicing, sub-level caving, and square set stoping.

On March 20, 2020, Dr. Kliche provided additional insights into these mining techniques, and provided some details (included with this process memo as Attachment 3). He noted:

> *Some items of consideration re the three methods:*
>
> - *All three of the methods are included in my Table 1 of the Technical Memorandum dated July 7, 2017.*
> - *Top Slicing and Sublevel-Caving are also caving methods. If either of these methods are employed, there will be a caving crater (see the 3rd pict under Sub-level Caving on the attached description sheet--LKAB's Kiruna iron ore mine in Sweden).*
> - *Sub-level Caving is more applicable to thick, steeply-dipping vein-type deposits (again, Kiruna's iron ore deposit) and not a massive, deep deposit like Resolution's.*
> - *Top Slicing could be applicable to the Resolution deposit. However, Top Slicing, like Square Sets, requires a great deal of artificial support (usually timber--large, mature timber), although material such as steel beams and concrete posts (at a substantial cost above timber) can be used. The required timber amounts could/would leave a substantial dent in the Tonto National Forest.*
> - *Square Set Stoping is not a caving method.*
> - *Square Set Stoping could include backfilling of the sets with tailings... in fact, that's often done where it's utilized.*
> - *Square Set Stoping, due to the high cost of this technique, could only be employed in higher grade areas within the deposit. The reserves available to recovery via this technique would have to be determined (ie... a COG for this technique would have to be determined, the reserves above this COG would have to be determined, then a decent mining plan would have to be devised to see if these "reserves" are recoverable utilizing this method (or another in combination with Square Sets).*
> - *All this timber is a fire hazard (as well as a CO_2-producing hazard when it decomposes)--extremely so, given the geothermal gradient of the Resolution deposit.*
> - *Backfilling of the square sets with tailings would reduce the fire hazard and the CO_2 hazard due to the cutting off of the oxygen supply to the timbers.*

- *All three of these techniques are more labor- and equipment-intensive than Block Caving… higher cost.*

Square set stoping is not a caving method and would allow for backfill, and therefore could offset the impacts of subsidence. Indeed, Dr. Kliche evaluated this technique in the November 2017 Alternatives Evaluation Report, and noted several of the downsides (SWCA 2017a, Appendix C, p. 5): "Too deep may have serious ground pressure issues. Very expensive; high grade ore a necessity. Need a ready source of timber. Labor intensive."

In other words, this technique is similar to other cut-and-fill techniques evaluated. It requires a higher cut-off grade of ore, and therefore substantially reduces the volume of the ore deposit, beyond a level considered reasonable (an 80% reduction in ore volume, for a shift from 1% to 2% cut-off grade).

Mining References – Per Ton Costs

Dr. Kliche also reviewed the per-ton mining costs in light of the comments and compiled more updated information (included with this process memo as Attachment 4). The Alternatives Evaluation Report cited a cost of $9.10/ton for block caving, compared to $68.03/ton for cut-and-fill (SWCA 2017a, Appendix C, p. 8). The updated information compiled by Dr. Kliche indicates that block caving can run from $7.99/ton to $10.68/ton, depending on production rate and adit versus shaft entry. This is compared to cut-and-fill mining which can run from $62.68/ton to $140.09/ton. Dr. Kliche also compiled information from 11 currently operating mines that use stoping or cut-and-fill techniques (not block caving), and found that actual per ton costs range from $57.51/ton to $303.97/ton.

Conclusions from Evaluation of Additional References

In all cases, review of additional references only confirms the basic conclusions of the alternatives evaluation.

- Based on industry-standard literature and approaches, block caving is the most likely technique to be selected based on the characteristics of the deposit, and cut-and-fill techniques largely would not be selected.
- The costs of cut-and-fill are at a minimum five times the cost of block caving. This is important not for reasons of profitability, but because techniques with higher operational costs require higher grade ore, or cut-off grade. As demonstrated with data specific to the Resolution ore deposit, even a 1-percent increase in cut-off grade (from 1% to 2%) results in the loss of at least 80% of the deposit. This fundamental tradeoff does not meet the standard for reasonableness that the Forest Service must consider. Comments also took issue with these numbers, indicating that the above assumption of an increase from 1% to 2% is not substantiated, because specific cut-off grades were not calculated for individual mining techniques. The NEPA team acknowledges that the numbers used represent estimates of cut-off grade for different techniques, not

economic calculations. These estimates are not arbitrary, however, but are informed by specific per-ton mining costs described above, and the basic understanding that higher per-ton mining costs require higher cut-off grades is not in question.

- Stepping back to look at the big picture, the DEIS comments also noted: "It should be the goal of DEIS to understand the ore body holistically, so that if alternative mining techniques were hypothetically mandated, it would be possible to understand the economics behind them."

  Indeed, this holistic look is what the NEPA team endeavored to do. Per-ton mining costs and cut-off grade were only one part of the analysis. The ore deposit was also evaluated against industry-standard practices for evaluating mining techniques, regardless of cost. Block-caving was clearly the mining approach that would be considered most reasonable for the specific characteristics of the Resolution ore deposit.

Ore Grade Terminology

The Chambers comments quote several statements and claim they are inconsistent with reference to the ore deposit as "high-grade" or "low-grade". This terminology is not inconsistent, but a matter of context and semantics. Dr. Kliche explores this in detail (see Attachment 1). To summarize, referring to the Resolution Copper deposit as "low-grade" is entirely appropriate in the context of comparing porphyry copper deposits (~1 percent copper) to copper-sulfide vein deposits like that mined at the Magma Mine (up to 8% copper). Referring to the Resolution Copper deposit as "high-grade" is also appropriate when comparing different porphyry copper deposits. Most of these deposits have one percent or less copper, whereas the Resolution Copper deposit has 1.54% copper.

More importantly, the use of terminology has no bearing on the analysis itself. These terms do not supercede the quantitative estimates of grade/tonnage that Dr. Kliche relied upon for the analysis of reasonableness of cut-and-fill mining.

Overall Changes to FEIS due to DEIS Comments

Substantial additional analysis was undertaken by the NEPA team in order to evaluate the comments received on the August 2019 DEIS with respect to alternative mining techniques. Overall, none of the additional evaluation provided new information contrary to that previously assessed, or reached conclusions different from those leading into the DEIS. The approaches used to assess alternative mining techniques remain reasonable and the dismissal of those techniques from detailed evaluation remains valid.

Given the interest in this topic, however, further explanation is warranted in the FEIS to clearly describe the approaches and rationale used in this decision.

Literature Cited

Kliche, C. 2017. Technical Memorandum for Alternative Mining Methods, Resolution Copper Mining, LLC, Superior, AZ. November 1, 2017.

SWCA Environmental Consultants. 2017. Resolution Copper Project and Land Exchange Environmental Impact Statement DRAFT Alternatives Evaluation Report. Prepared for U.S. Forest Service. Phoenix, Arizona: SWCA Environmental Consultants. November.

Attachment 1 – January 29, 2020 Memorandum from Dr. C. Kliche

Charles A. Kliche, P.E., PhD
1624 Pevans Parkway
Rapid City, SD 57701
Cell: (605) 343-1947 Charles.kliche@sdsmt.edu

TO: Mr. Chris Garret, P.HGW.
SWCA Project Manager

FROM: Charles A. Kliche, P.E., PhD

DATE: January 29, 2020

RE: Response to "Comments on the Resolution Copper Draft Environmental Impact Statement," dated October 28, 2019 by Dr. David M. Chambers

I read through Dr. Chambers' Appendix A, "Comments from the Center for Science in Public Participation," dated October 28, 2019, with great interest.

I was also quite interested to see that Dr. Chambers included a brief Background statement of himself, to wit:

> "David Chambers has 40 years of experience in mineral exploration and development – 15 years of technical and management experience in the mineral exploration industry, and for the past 25+ years he has served as an advisor on the environmental effects of mining projects both nationally and internationally. He has Professional Engineering Degree in physics from the Colorado School of Mines, a Master of Science Degree in geophysics from the University of California at Berkeley, and is a registered professional geophysicist in California (# GP 972). Dr. Chambers received his Ph.D. in environmental planning from Berkeley. His recent research focuses on tailings dam failures, and the intersection of science and technology with public policy and natural resource management."

From this statement, although it's brief, Dr. Chambers has experience in mineral exploration and (I will give him this) development, plus environmental advocacy. He does not have stated experience in ore reserve estimation and modeling; mine planning, mine design, and selection of appropriate mining methods; or the scheduling of the optimal extraction of the ore body (based upon economics [cost of mining utilizing the selected mining method, commodity price, recovery, dilution and other factors], ground conditions, location in space [within the mineralized zone] of a specific "block" of ore/waste, ore zone development factors [needed shafts, drifts, draw points, etc], equipment selection, ventilation requirements, and a host of other factors).

Dr. Chambers in the **Alternative Mining Methods**section of his report stated:

> "Underground mining alternatives to block caving were eliminated from further consideration in the DEIS. These methods were eliminated from detailed consideration

in the DEIS based largely on two factors, the cost of mining and the feasibility of large-scale tailings backfill."

This, in my opinion, is a pretty bold statement, lacking facts to back it up.

The Resolution deposit is a deep, massive, relatively low grade (this will be discussed later), disseminated porphyry copper deposit. Most of the massive porphyry copper deposits in the southwest U.S. are relatively shallow and have been/are being mined by the open pit surface mining technique. Three exceptions are Henderson and Questa (both moly mines), and San Manuel, all of which were/are being mined by underground block caving.

In a nutshell, the decision to mine via some underground technique vs open pit mining is mainly an economic one: Theoretically, if the cost of removing a ton of ore via surface mining exceeds the cost of removing that ton of ore via the chosen underground technique (and the numerous underground techniques must be considered one-by-one), then underground mining is employed. It's a break-even analysis: At some point in surface mining it becomes too costly to support the removal of a ton of "ore" due to the cost of drilling, blasting, loading, hauling, associated waste removal, processing, G&A, etc. It then becomes necessary to look at underground techniques and whether this block will support its share of the cost of shaft sinking, drifting, drilling, blasting, significantly less waste removal, the mining method employed, processing, G&A, etc.

Because each underground mining method has a different cost associated with it, as well as significantly different development techniques, this will affect the cut-off grade (lowest grade of mineable material utilizing that technique), which, in turn, affects the tons above cut-off grade available for mining. A high cost technique will have a high cut-off grade and lower tons available; a low cost method will have a lower cut-off grade and more tons available above that COG.

Now, to say Resolution Copper failed to consider these things is also to accuse them of being negligent in their due diligence to their stockholders and to the public.

Often times experience rules out certain mining methods from consideration almost immediately (eg: stull stoping would be ruled out immediately due to its applicability, as would open stoping, and a number of other techniques [see Table 1, beginning on pg 3, of "Draft Technical Memorandum for Alternative Mining Methods, Resolution Copper Mining, LLC, Superior, AZ", C.A. Kliche, July 7, 2017]).

Dr. Chambers in the **<u>Ore Resources</u>**section of his report stated (3rd bullet point):

"The Kliche report identifies a number of significant **facts** (emphasis mine) about the proposed mine, including:

- **a loss**(emphasis mine) of 12 to 15% of the ore due to the block caving method."

On pg 9 of "Draft Technical Memorandum for Alternative Mining Methods, Resolution Copper Mining, LLC, Superior, AZ", C.A. Kliche, July 7, 2017, it is clear that this is a quote from Lewis and Clark's *Elements of Mining*, and pertains **to all block caving mines, <u>in general</u>**, according to the authors, and not specifically to the Resolution deposit. This loss depends a great deal on the edge shape and edge effects of the blocks/panels with respect to the draw points.

Dr. Chambers in the **<u>Resource Sterilization</u>**section of his report stated:

> "Since the draw angle is relatively steep in the Resolution ore body (cave angles of 70 to 78 degrees – DIES (sic) 2019), then **in addition to the 12 to 15% of the ore that will be lost due to dilution in block caving** (emphasis mine), after mining at proposed levels has ceased, any ore located in the same horizontal horizon will also likely be lost to future mining. The ore located below the existing mining levels would still be accessible."

Dr. Chambers confuses ***dilution*** with ***ore loss***. Plus, he jumps again to the conclusion that something stated in general for block caving pertains specifically to the Resolution mine.

Dilution **-** the contamination of ore with inferior grade ore and/or waste and/or backfill material.

Ore loss **-** a missed ore block that remains in the stope after conclusion of production.

Lewis and Clark's *Elements of Mining* is one of the go-to, older, respected textbooks on basic mining. However, one cannot attribute what Lewis and Clark say <u>in general</u> about block caving to Resolution Copper, specifically. I did not see any published figures from Resolution Copper on expected ore loss and dilution.

Furthermore, both ore loss and dilution are extremely important: dilution tends to reduce the head grade, and ore loss tends to reduce the recoverable tonnage of ore. I am quite certain the Resolution planning and mine design engineers have determined an expected percentage for both.

Dr. Chambers in the **<u>Ore Grade</u>**section of his report stated:

> 1- "Dr Kliche had to work without any data support from Resolution Copper. He noted that his estimate was:
>
> > "***based on limited information provided by RCM****, of the total tons of potentially mineable material above a cut-off grade of 2% which lies at or above the -2,500 ft level.*" (Kliche 2017, emphasis added [by Chambers])
>
> 2- Dr Kliche also noted some data was taken from a report produced for Resolution Copper, *Geologic and Mineral Resource Model - Suitability for Declaration of Mineral Resources and Support for Mine Plans to Develop a Block or Panel Cave Mine, Letter prepared exclusively for Resolution Copper Mining (RCM), by Harry M. Parker, Amec Foster Wheeler E&C Services Inc., March 14, 2017*, which was not made available in the DEIS support documents. It too might provide more information on Resolution Copper's predicted production costs, but it is evidently not available for public review.
>
> 3- Dr Kliche notes in his introductory remarks that this is a "relatively low grade ... resource". (Kliche 2017). This view underlies his mining cost analysis. But, this is not a low grade copper resource. In fact, Resolution Copper itself has called the deposit "***large, high-grade****, hypogene copper-molybdenum deposit*" (Hehnke et al 2012, emphasis added [by Chambers])

4- Figure 9, from Mudd et. al. (2012), document that the average copper grade worldwide is decreasing with time, and in 2012 was approximately 0.5 – 0.7% Cu. The Resolution deposit is roughly three times this grade level.

Mudd et. al. (2012) rate Resolution as the 16th largest deposit of contained copper in the world, and the second largest in the US, behind the Pebble deposit. However, this is based only on the proposed mine. If the 2 billion tons of ore below existing deposit were included, Resolution would probably rise to the number seven position worldwide.

The proposed Pebble mine also plans to have an underground mine, at a similar depth to Resolution and utilizing block caving, but its deep ore grade is closer to 0.6% Cu equivalent. This suggests mining Resolution with block caving should be very lucrative.

A similar grade analysis to that of Mudd et. al. can be seen in, Figure 3, from Kloppenburg (2017), showing Resolution to be one of the highest grade copper porphyry deposits in the world."

I numbered Chambers' pertinent comments in the **Ore Grade**section 1 - 3 and will comment on each in turn.

Dr. Chambers seems to not like the words "limited" and "relatively" (both discussed below).

#1: This is patently false. I cannot say that I had unlimited access to all the data I needed for a perfect estimate of the grade/tonnage relationship for the Resolution Copper deposit, but I was provided, without hesitation, enough good data to make a reasonable estimate of that relationship. This information, in the form of horizontal slices at 100 ft intervals from bottom to top through the Resolution Copper block model showing grade classes of the blocks, was gracefully and without hesitation provided after a meeting on 3/23/17 between myself and Mses. Vicky Peacy and Kim Heuther, and Mr. Bill Hart (noted on pg 1 of "Draft Technical Memorandum for Alternative Mining Methods, Resolution Copper Mining, LLC, Superior, AZ", C.A. Kliche, July 7, 2017).

The reason, of course, for requesting this information from Resolution Copper was to try to estimate the tonnage available above various cut-off grades which may be available for mining via some other more costly mining method (ie: cut-and-fill).

The personnel I worked with on this at Resolution Copper could not release to me all of the data I requested due to its proprietary nature. We negotiated. And they released the best they thought they could, given the proprietary nature of the mine model and of the tonnage/grade distribution.

#2: I am surprised Parker's memo is not in the DEIS support documents library. It's attached. You should, though, make sure it can be released for public viewing.

#3:"relatively low grade .... resource" vs "large, high-grade, hypogene copper-molybdenum deposit".

It's a matter of semantics.

By definition, a porphyry copper deposit is low grade: According to *The Dictionary of Mining, Mineral, and Related Terms*, *2nd edition*, a **porphyry copper deposit** is "A large body of rock, typically porphyry, that contains disseminated chalcopyrite and other sulfide minerals. Such deposits are mined in bulk on a large scale, generally in open pits, for copper and by-produce molybdenum. Most deposits are 3 - 8 km across and of low grade (less than 1% Cu)."

Dr. Chambers points out that the published tons and gradeof the Resolution Copper deposit (1969M st at 1.54% Cu) when plotted on a figure taken from Kloppenburgh, 2017, shows it ranks right up there with Butte, Bingham Canyon, Grasberg, El Teniente and Chuqui at, however, a lower total tonnage but higher grade.

So, it **is** a high grade deposit compared to other large, disseminated porphyry copper deposits.

So what? The ore deposit is also much deeper than the others and the wall rock temperature plus water inflow at depth make mining the deposit difficult and expensive. And the others are all porphyry copper deposits mined either by open pit or block caving techniques... none of them are mined by cut-and-fill.

Furthermore, Resolution may have called the deposit a "large, high-grade, hypogene copper-molybdenum deposit" back in 2012, but on page 88 of Vol. 1, General Plan of Operations Resolution Copper, they described it as "... the deep, **relatively low-grade** (emphasis mine), and widely disseminated porphyry deposit that makes up the Resolution Project... ", which is also how I described it. It **is** relatively low grade, compared to a high-grade copper sulfide vein, like what was mined by cut-and-fill methods at the Magma Mine, Superior, AZ from 1911 through 1964 (about 4.75% Cu to almost 8.0% Cu).

Again: So what? It's a matter of semantics.

One final comment:

Dr. Chambers stated his position and the position of similar-thinking people via his comment in the Summary beginning at the bottom of page #7 through the top of page #8 of his report:

> "For the operators of a large, rich, ore body to take into account a multitude of significant environmental and social resource losses that can be prevented **by conducting responsible mining**(emphasis mine) instead of maximizing economic profit, which will have little long-term benefit in the area of the mine, is not too much for a responsible land manager, like the US Forest Service, to require."

The bolded and underlined above ("by conducting responsible mining") is an elusive catch phrase I've heard over and over again by environmental advocates. But, what does it mean? And, who defines "responsible mining"?

According to best practices within the U.S. mining community, and according to the appropriate rules and regulations of the state and federal agencies involved in the permitting process, the Resolution Copper project will be conducted responsibly.

However, according to Dr. Chambers and the environmental community, unless Resolution Copper does mining their way, then they are irresponsible. Yet, the majority of the people stating such know absolutely nothing about the science, mechanics, and engineering practices of mining

In my opinion, that little phrase is the heart of the entire Chambers report.

Sincerely,

Charles A. Kliche, P.E., PhD
Professor Emeritus
Mining Engineering and Management
South Dakota School of Mines and Technology

Attachment 2 – Literature Review to Identify Techniques for Mining Method Selection, Itasca, March 18, 2020

Literature Review to Identify Techniques for Mining Method Selection
Resolution Copper EIS

Tryana Garza-Cruz & Matthew Pierce

Introduction

- A literature review was conducted to identify classical references for mining method selection in response to action item #GS-3 (Resolution Geology/Subsidence Working Group Meeting 2/11/2020).
- Selection of a feasible mining method requires the comparison of the characteristics of the deposit with those essential for different mining methods
- In general, most selection techniques deal primarily with:

1. The physical and geologic characteristics of the deposit
2. The ground conditions of the hanging wall, footwall and ore zone

Selection Method Techniques

- A literature review was performed to identify techniques for mining method selection
- The following are common classical references for mining method selection:

1. Boshkov and Wright
2. Hartman
3. Morrison
4. Laubscher
5. Nicholas
6. KDI & KMI

Boshkov and Wright

- The classification system proposed by Boskov and Wright (1973) is one of the first qualitative classification schemes developed for underground method selection. Therefore, their system assumes that the possibility of surface mining has already been eliminated.
- The results of this classification scheme results in four methods that may be applicable.

Table 23.4.1. Applications of Underground Mining Methods

Type of Ore Body	Dip	Strength of Ore	Strength of Walls	Commonly Applied Methods of Mining
Thin beds	Flt	Stg	Stg	Open stopes with casual pillars Room and pillar Longwall
		Wk or Stg	Wk	Longwall
Thick beds	Flt	Stg	Stg	Open stopes with casual pillars Room and pillar
		Wk or Stg	Wk	Top slicing Sublevel caving
		Wk or Stg	Stg	Underground glory hole
Very thick beds				Same as for masses
Very narrow veins	Stp	Stg or Wk	Stg or Wk	Resuing
Narrow veins (widths up to economic length of stull)	Flt			Same as for thin beds
	Stp	Stg	Stg	Open stopes Shrinkage stopes Cut and fill stopes
			Wk	Cut and fill stopes Square set stopes
		Wk	Stg	Open underhand stopes Square set stopes
			Wk	Top slicing Square set stopes
Wide veins	Flt			Same as for thick beds or masses
	Stp	Stg	Stg	Open underhand stopes Underground glory hole Shrinkage stopes Sublevel stoping Cut and fill stopes Combined methods
			Wk	Cut and fill stopes Top slicing Sublevel caving Square set stope Combined methods
		Wk	Stg	Open underhand stopes Top slicing Sublevel caving Block caving Square set stopes Combined methods
			Wk	Top slicing Sublevel caving Square set stopes Combined methods
Masses		Stg	Stg	Underground glory hole Shrinkage stopes Sublevel stoping Cut and fill Combined methods
		Wk	Wk or Stg	Top slicing Sublevel caving Block caving Square set stopes Combined methods

Wk = weak; stg = strong; flt = flat; stp = steep.
Source: Boshkov and Wright, 1973 (permission: Society for Mining, Metallurgy, and Exploration, Inc.).

Hartman

- Hartman (1987) developed a flow chart selection process to identify the mining method based on the geometry of the deposit and the ground conditions of the ore zone. This system is similar to the Boshkov and Wright method but is aimed at more specific mining methods.

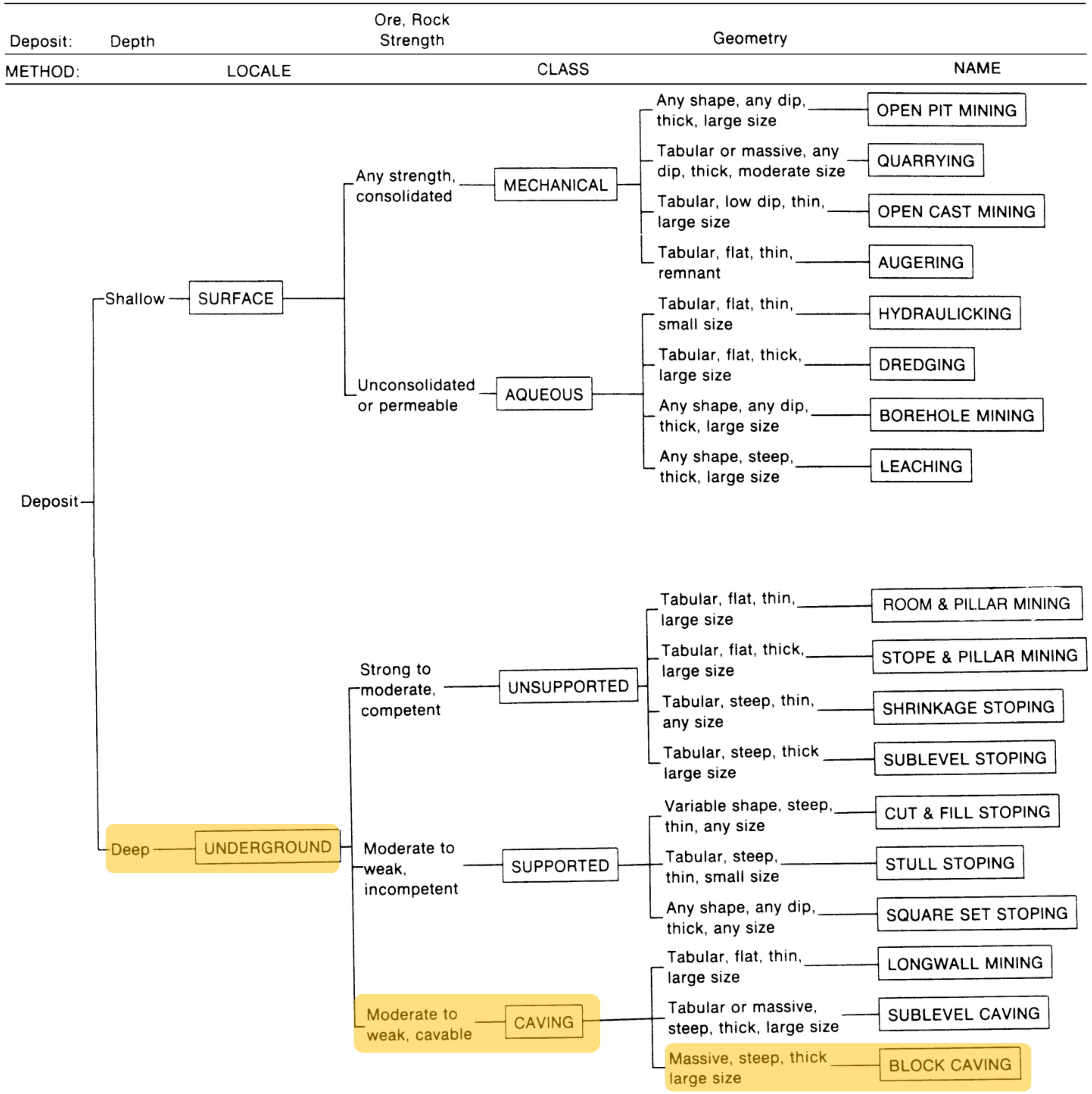


Fig. 23.4.1. Hartman's chart for selection of a mining method (Hartman, 1987).

Morrison

- Morrison (1976) developed a system using general definitions of ore width, support type and strain energy accumulation

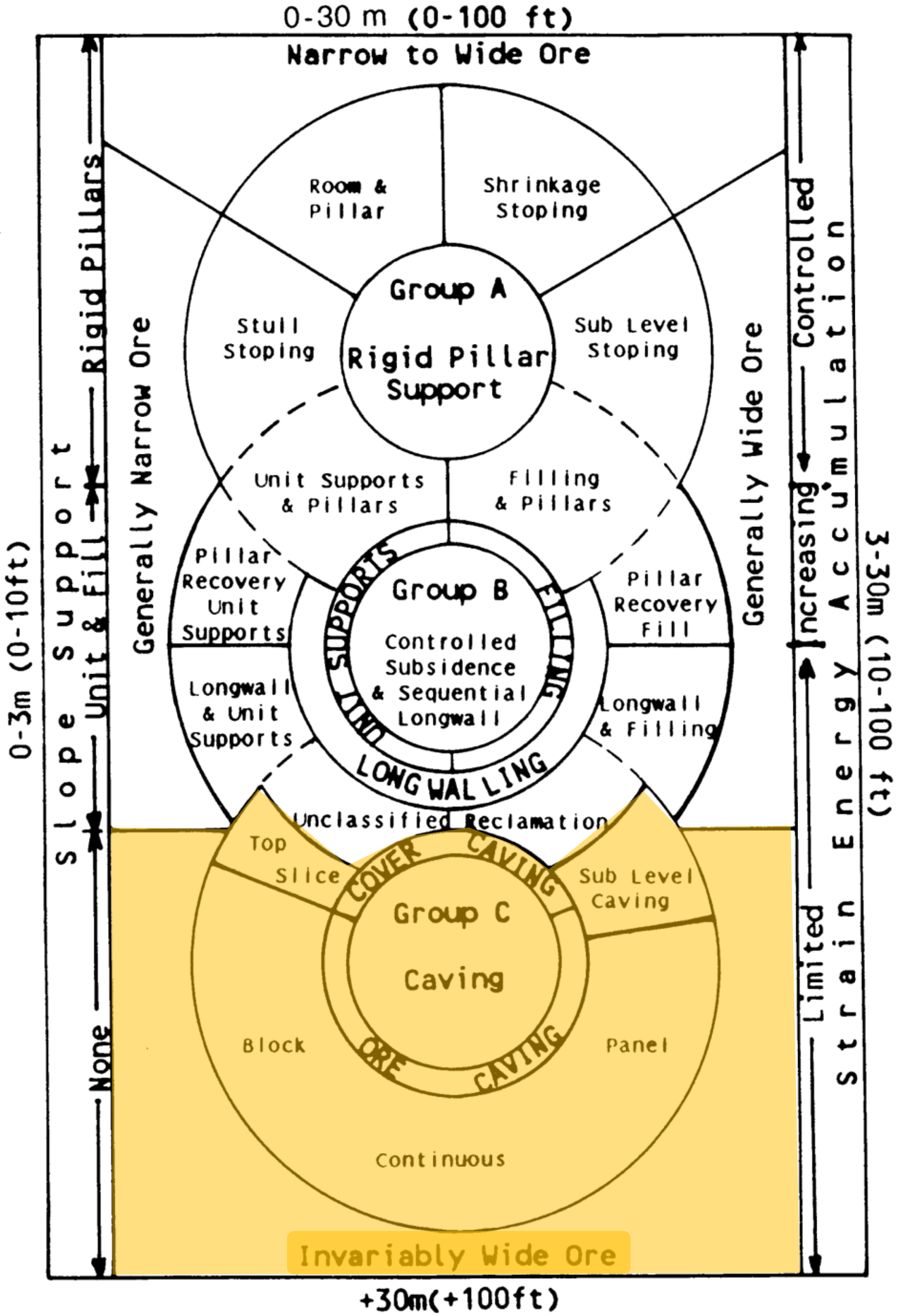
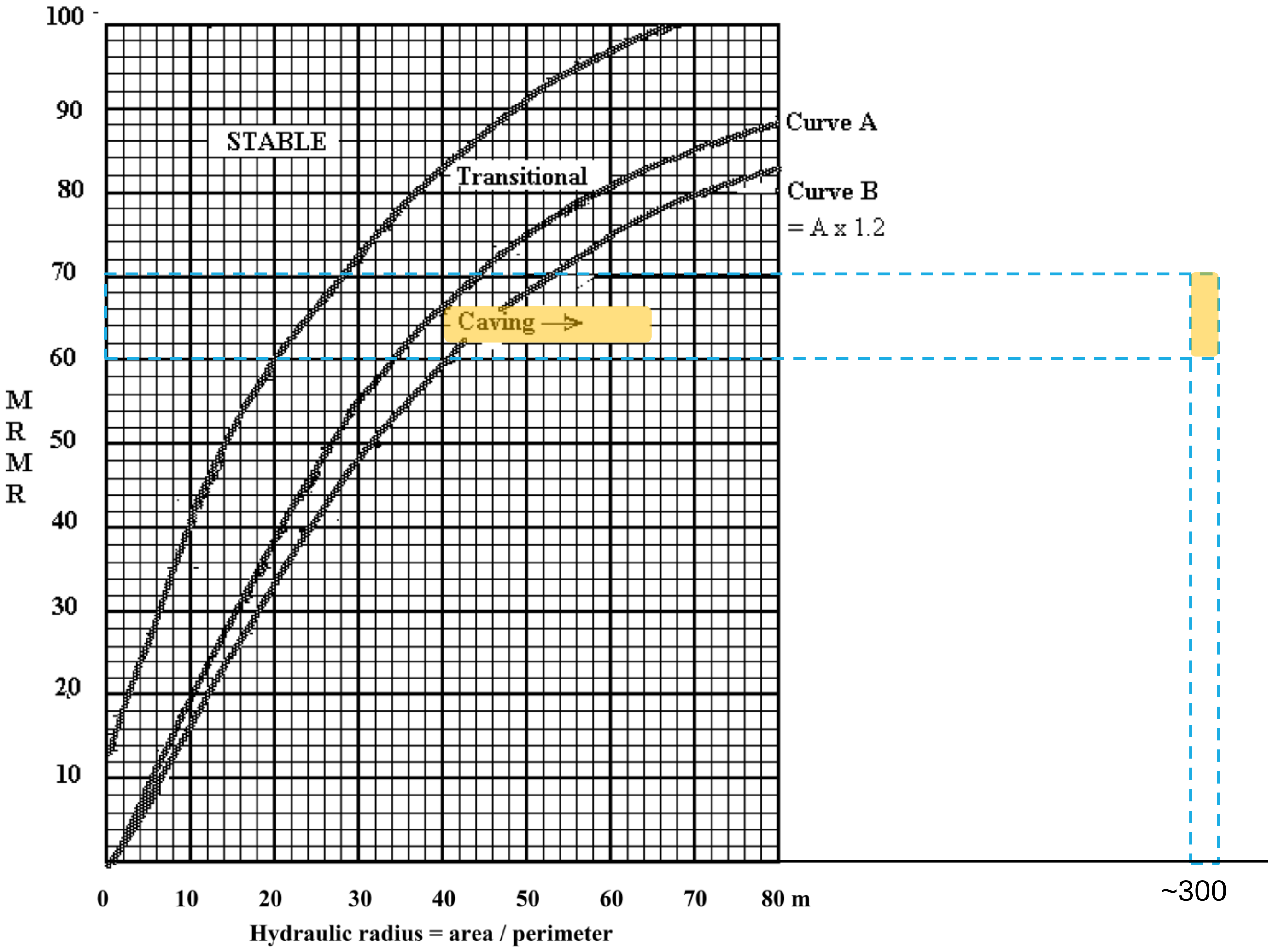


Fig. 23.4.2. Morrison's chart for selection of a mining method (Morrison, 1976).

Laubscher

- Laubscher (1981, 1990) developed a selection process based on his rock mass classification system. Laucher’s scheme is aimed at mass mining methods, primarily block caving vs stoping, with his main emphasis being on caveability.



Nicholas

- Nicholas (1981) developed a quantitative classification system. The system relies on a series of steps that classify:

1. The ore geometry and grade distribution
2. The rock mechanics characteristics of the ore zone, HW and FW
3. Numerical ranking based on addition of scores
4. Using a weighting factor of the categories

Table 23.4.2. Definition of Deposit Geometry and Grade Distribution

1) *General Shape/Width*	
equi-dimensional	all dimensions are on the same order of magnitude
platy—tabular	two dimensions are many times the thickness, which does not usually exceed 325 ft (100 m)
irregular	dimensions vary over short distances
2) *Ore Thickness*	
narrow	< 30 ft (< 10 m)
intermediate	30–100 ft (10–30 m)
thick	100–325 ft (30–100 m)
very thick	> 325 ft (> 100 m)
3) *Plunge*	
flat	< 20°
intermediate	20°–55°
steep	> 55°
4) *Depth Below Surface*	
provide actual depth	
5) *Grade Distribution*	
Uniform. The grade at any point in the deposit does not vary significantly from the mean grade for that deposit.	
Gradational. Grade values have zonal characteristics, and the grades change gradually from one to another.	
Erratic. Grade values change radically over short distances and do not exhibit any discernible pattern in their changes.	

Source: Nicholas, 1981.

Table 23.4.3. Rock Mechanics Characteristics

1) *Rock Substance Strength* (uniaxial strength/overburden pressure)			
weak	< 8		
moderate	8–15		
strong	> 15		
2) *Fracture Frequency*	No. of Fractures per (ft)	(m)	% RQD
very close	> 5	> 16	0– 20
close	3–5	10–16	20– 40
wide	1–3	3–10	40– 70
very wide	< 1	< 3	70–100
3) *Fracture Shear Strength*			
weak	clean joint with a smooth surface or fill with material with strength less than rock substance strength		
moderate	clean joint with rough surface		
strong	joint is filled with a material that is equal to or stronger than rock substance strength		

Sources: Nicholas, 1981.

Nicholas cont’d

Table 23.4.4. Ranking of Geometry/Grade Distribution for Different Mining Methods

Mining Method	General Shape			Ore Thickness				Ore Plunge			Grade Distribution		
	M	T/P	I	N	I	T	VT	F	I	S	U	G	E
Open Pit Mining	3	2	3	2	3	4	4	3	3	4	3	3	3
Block Caving	4	2	0	−49	0	2	4	3	2	4	4	2	0
Sublevel Stoping	2	2	1	1	2	4	3	2	1	4	3	3	1
Sublevel Caving	3	4	1	−49	0	4	4	1	1	4	4	2	0
Longwall Mining	−49	4	−49	4	0	−49	−49	4	0	−49	4	2	0
Room and Pillar Mining	0	4	2	4	2	−49	−49	4	1	0	3	3	3
Shrinkage Stoping	2	2	1	1	2	4	3	2	1	4	3	2	1
Cut and Fill Stoping	0	4	2	4	4	0	0	0	3	4	3	3	3
Top Slicing	3	3	0	−49	0	3	4	4	1	2	4	2	0
Square Set Stoping	0	2	4	4	4	1	1	2	3	3	3	3	3

M = Massive
T/P = Tabular or Platy
I = Irregular

N = Narrow
I = Intermediate
T = Thick
VT = Very Thick

F = Flat
I = Intermediate
S = Steep

U = Uniform
G = Gradational
E = Erratic

ing of Rock Mechanics Characteristics for Different Mining Methods

5b: Hanging Wall

Mining Method	Rock Substance Strength			Fracture Spacing				Fracture Strength		
	W	M	S	VC	C	W	VW	W	M	S
Open Pit Mining	3	4	4	2	3	4	4	2	3	4
Block Caving	4	2	1	3	4	3	0	4	2	0
Sublevel Stoping	−49	3	4	−49	0	1	4	0	2	4
Sublevel Caving	3	2	1	3	4	3	1	4	2	0
Longwall Mining	4	2	0	4	4	3	0	4	2	0
Room and Pillar Mining	0	3	4	0	1	2	4	0	2	4
Shrinkage Stoping	4	2	1	4	4	3	0	4	2	0
Cut and Fill Stoping	3	2	2	3	3	2	2	4	3	2
Top Slicing	4	2	1	3	3	3	0	4	2	0
Square Set Stoping	3	2	2	3	3	2	2	4	3	2

Key:

Rock Substance Strength
W = Weak
M = Moderate
S = Strong

Fracture Spacing
VC = Very Close
C = Close
W = Wide
VW = Very Wide

Fracture Strength
W = Weak
M = Moderate
S = Strong

Nicholas cont’d

5a: Ore Zone

Mining Method	Rock Substance Strength			Fracture Spacing				Fracture Strength		
	W	M	S	VC	C	W	VW	W	M	S
Open Pit Mining	3	4	4	2	3	4	4	2	3	4
Block Caving	4	1	1	4	4	3	0	4	3	0
Sublevel Stoping	−49	3	4	0	0	1	4	0	2	4
Sublevel Caving	0	3	3	0	2	4	4	0	2	2
Longwall Mining	4	1	0	4	4	0	0	4	3	0
Room and Pillar Mining	0	3	4	0	1	2	4	0	2	4
Shrinkage Stoping	1	3	4	0	1	3	4	0	2	4
Cut and Fill Stoping	3	2	2	3	3	2	2	3	3	2
Top Slicing	2	3	3	1	1	2	4	1	2	4
Square Set Stoping	4	1	1	4	4	2	1	4	3	2

5c: Footwall

Mining Method	Rock Substance Strength			Fracture Spacing				Fracture Strength		
	W	M	S	VC	C	W	VW	W	M	S
Open Pit Mining	3	4	4	2	3	4	4	2	3	4
Block Caving	2	3	3	1	3	3	3	1	3	3
Sublevel Stoping	0	2	4	0	0	2	4	0	1	4
Sublevel Caving	0	2	4	0	1	3	4	0	2	4
Longwall Mining	2	3	3	1	2	4	3	1	3	3
Room and Pillar Mining	0	2	4	0	1	3	3	0	3	3
Shrinkage Stoping	2	3	3	2	3	3	2	2	2	3
Cut and Fill Stoping	4	2	2	4	4	2	2	4	4	2
Top Slicing	2	3	3	1	3	3	3	1	2	3
Square Set Stoping	4	2	2	4	4	2	2	4	4	2

Table 23.4.6. Weighting Factors

Ore Geometry	1.0	1.0	1.0
Ore Zone Ground Conditions	1.33	0.75	1.0
Hanging Wall Ground Conditions	1.33	0.6	0.8
Footwall Ground Conditions	1.33	0.38	0.5

Nicholas cont'd

Mining Method	Geometry/Grade Distribution	Rock Mechanics Characteristics									Total un-weighted			**Grand Total**		
		Ore			HW			FW								
Open Pit Mining	14	10	to	11	10	to	11	10	to	11	44	to	47	**37**	**to**	**39.3**
Block Caving	16	10	to	7	9	to	7	8	to	9	43	to	39	**37.2**	**to**	**33.1**
Sublevel Stoping	12	-46	to	6	-46	to	6	3	to	5	-77	to	29	**-69.3**	**to**	**25.3**
Sublevel Caving	15	6	to	9	8	to	7	5	to	7	34	to	38	**29.9**	**to**	**33.1**
Longwall Mining	-143	7	to	4	9	to	7	9	to	10	-118	to	-122	**-124.3**	**to**	**-128.4**
Room and Pillar Mining	-46	4	to	7	4	to	7	6	to	8	-32	to	-24	**-35.8**	**to**	**-29.4**
Shrinkage Stoping	12	6	to	8	9	to	7	7	to	8	34	to	35	**28.7**	**to**	**29.6**
Cut and Fill Stoping	7	8	to	7	8	to	7	10	to	8	33	to	29	**26.4**	**to**	**23.6**
Top Slicing	13	6	to	7	9	to	7	7	to	8	35	to	35	**29.7**	**to**	**29.6**
Square Set Stoping	7	9	to	6	8	to	7	10	to	8	34	to	28	**27.4**	**to**	**22.6**

KDI & KMI

- Nieto (2010) developed a selection method based on defined field key deposit indicators (KDI) and comparing them to the KDIs that are favorable to a series of mining methods considered.
- Key mining method indicators (KMI) are used to further complement KDI rankings by analyzing every method's KMI performance based on the expected productivity of the mining operation being considered.
- This method was modified after Harmann and Mutmansky, 2002)

Table 1 — Ore strength KDI definitions (Hartmann & Mutmansky).

Relative strength	Example material	Compressive strength (psi)	KDI value
Very weak	Coal	< 6,000	1
Weak	Weathered sandstone	6,000 – 14,500	1-2
Moderate	Limestone	14,500 – 20,000	2
Strong	Granite	20,000 – 32,000	3
Very strong	Quartz	> 32,000	4

Table 2 — Deposit shape KDI definitions.

Deposit Type	Shape	Width	Extent	KDI Value
Tabular	Flat	Thin to moderate	Horizontal	1
Lenticular	Flat, elliptical	Thin to moderate	Horizontal	2-3
Massive	Any	Thin to thick	Horizontal & vertical	4

Table 3 — Deposit orientation KDI definitions.

Inclination Category	Dip Angle	KDI value
Low	0-5°	1
Moderate	5-25°	2
Fairly steep	25-45°	3
Steep	45-90°	4

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KDI & KMI cont'd

Table 4 — Deposit size KDI definitions.

Deposit Size	KDI Value
Thin (small)	1
Moderate	2
Fairly Thick	3
Thick (large)	4

Table 5 — Ore grade KDI definitions.

Ore grade	KDI value
Low	1
Moderate	2
Fairly High	3
High	4

Table 6 — Ore uniformity KDI definitions.

Ore uniformity	KDI value
Variable	1
Moderate	2
Fairly Uniform	3
Uniform	4

Table 7 — Deposit depth KDI definitions.

Deposit depth	KDI value
Shallow	1
Moderate	2-3
Deep	4

Table 24 — Key mining indicator (KMI) performance in underground mining methods.

Key Mining Indicators (KMIs)	unsupported					supported	caving		
	room-and-pillar	stope-and-pillar	shrinkage stoping	sublevel stoping	VCR	cut and fill	longwall	sublevel caving	block caving
Operating Cost	moderate	low	high	moderate	moderate	Highest	low	low	low
Capital Investment	high	moderate	low	moderate	moderate	moderate	high	moderate	high
Development	moderate	moderate	high	high	moderate	low	high	high	high
Dilution	moderate	low	low	moderate	moderate	low	low	moderate	high
Subsidence	moderate	low	low	low	low	low	high	high	high
Production Rate	high	high	moderate	high	high	moderate	high	high	high
Productivity	high	high	low	high	high	moderate	high	moderate	high
Development Rate	rapid	rapid	rapid	moderate	moderate	moderate	moderate	moderate	slow
Depth Capacity	limited	limited	limited	moderate	moderate	high	moderate	moderate	moderate
Selectivity	low	high	moderate	low	low	high	low	low	low
Recovery	moderate	moderate	high	moderate	moderate	high	high	high	high
Flexibility	moderate	high	moderate	low	low	high	low	moderate	low
Stability of openings	moderate	high	high	high	high	high	high	moderate	moderate
Health and safety	good	good	good	good	good	moderate	good	good	good
Mechanization	high	high	low	high	high	high	high	high	high
Ventilation	good	fair	poor	good	good	poor	fair	fair	good
Continuous	yes	no	no	no	no	no	yes	no	no
Gravity-Assist	poor	fair	good	good	good	good	poor	fair	good

Sources: Modified after Hartmann & Mutmansky, 2002

KDI & KMI cont'd

Table 26 — Key Deposit Indicator (KDI) attributes favorable to underground mining methods (modified after Hartman and Mutmansky, 2002).

Key Deposit Indicators (KDIs)	Field Data KDI's	unsupported								supported		caving							
		room-and-pillar favorable KDI Value		stope-and-pillar favorable KDI Value		shrinkage stoping favorable KDI Value		sublevel stoping favorable KDI Value		VCR favorable KDI Value		cut and fill favorable KDI Value		longwall favorable KDI Value		sublevel caving favorable KDI Value		block caving favorable KDI Value	
Ore strength	1-2	weak to moderate	1,2	moderate to strong	2,3	strong	3	moderate to strong	2,3	moderate to strong	2,3	moderate to strong	2,3	any	1,2,3,4	moderate to fairly strong	2,3	weak to moderate, cavable	1,2
Rock Strength	1-2	moderate to strong	2,3	moderate to strong	2,3	strong to fairly strong	3,4	fairly strong to strong	4	fairly strong to strong	4	weak to fairly weak	1,2	weak to moderate, cavable	1,2	weak to fairly strong, cavable	2,3	weak to moderate, cavable	1,2
Deposit shape	4	tabular	1	tabular, lenticular	1,2,3	tabular, lenticular	1,2,3	tabular, lenticular	1,2,3	tabular, lenticular	1,2,3	tabular to massive	1,2,3,4	tabular	1	tabular or massive	1,4	massive or thick tabular	1,4
Deposit dip	4	low	1	low to moderate	1,2	fairly steep	3,4	fairly steep	3,4	fairly steep	3	moderate to fairly steep	2,3	low	1	fairly steep	3,4	fairly steep	3,4
Deposit thickness size	4	thin	1	large, moderate, thick	1,2,3,4	thin to moderate	1,2	fairly thick to moderate	2,3	fairly thick to moderate	2,3	thin to moderate	1,2	thin	1	thick	4	very large, thick	4
Ore grade	1	moderate	2	low to moderate	1,2	fairly high	3,4	moderate	2	moderate	2	fairly high	3,4	moderate	2	moderate	2	low	1
Ore uniformity	3	fairly uniform	3	variable	1	uniform	4	fairly uniform	3	fairly uniform	3	moderate, variable	1,2	uniform	4	moderate	2	fairly uniform	3
Depth	4	shallow to moderate	1,2	shallow to moderate	1,2	shallow to moderate	1,2,3	moderate	2,3	moderate	2,3	moderate to deep	2,3,4	moderate to deep	2,3	moderate	2,3	moderate	2,3
Total hits	7		2		4		1		3		2		4		2		5		7

Summary

	Open Pit	Top Slicing	Block Caving	Sublevel Caving	Sublevel Stoping	Shrinkage Stoping	Square Set Stoping
Boshkov and Wright		X	X	X			X
Hartman			X				
Morrison		X	X	X			
Laubscher			X				
Nicholas	X		X	X			
KDI & KMI			X				

All of the mining method techniques arrived at similar conclusions, with Block Caving as the preferred mining method.

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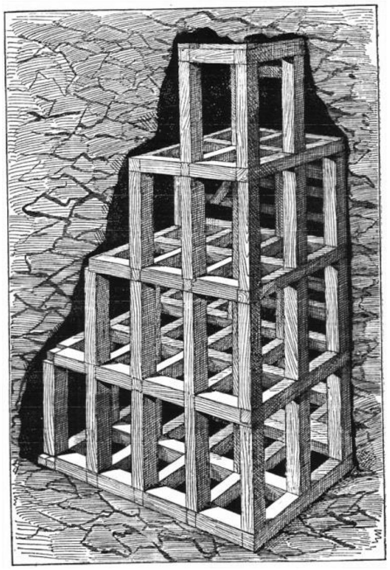
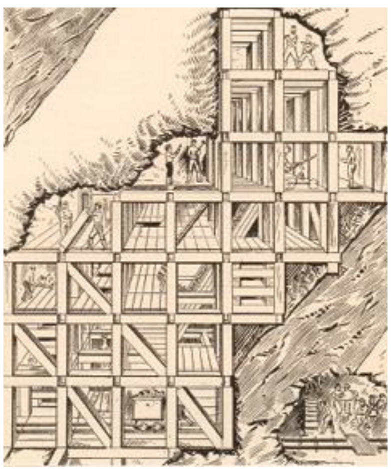
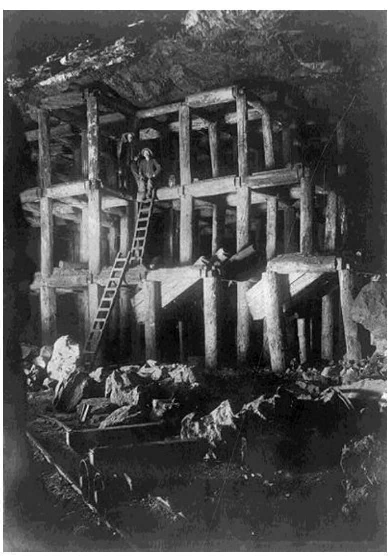
Attachment 3 – Summary of Top slicing, Sub-level caving, and Square set stoping (provided by Dr. Kliche)

Square Sets







Square sets is most applicable in mining deposits in which the ore is structurally weak. Also, the surrounding rock may be fractured, faulted an altered to such an extent that it is also very weak. The geometry of the deposit is such, and the value of the ore of sufficient magnitude, that caving methods may not be employed. The method is flexible in that sets can be extended in any direction or can be terminated as irregularities in the shape of the ore body are encountered.

For stopes, narrow veins and small ore bodies, timbering with stulls (a timber prop set between the walls of a stope, or supporting the mine roof) as needed or in a regular manner may give temporary support. Because of its ultimate failure by crushing or decay, timbering is seldom considered permanent. However, in large ore bodies stulls cannot be used, and some other form of timber support is required.

In 1860, Philip Deidesheimer was called to the Ophir mine in the Comestock lode in Nevada to solve the problem of timbering the large stopes. After some experimenting he devised the system now known as timbering with square sets (see figs 1 & 2). Timbering was of units or hollow cubes with a timber along each edge.

Square sets vary in dimension at different mines, but in general should give a clear opening of at least 5 ft each way between posts to afford sufficient working space in the stope. A clear height of about 6 ½ ft is about the minimum height desirable, and at a number of mines posts are 7 ft high in the clear, particularly on main levels or sill floors.

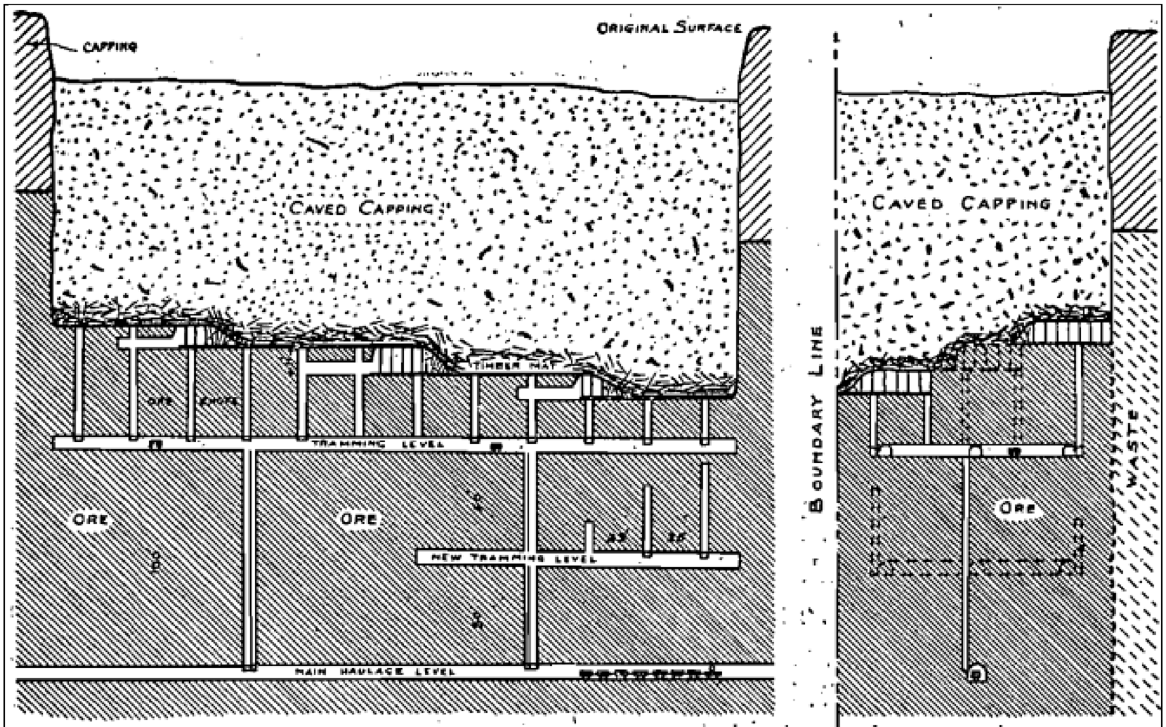
Square sets can be filled with waste rock or tailings for better support and for disposal of the waste material.

A significant amount of timber is required, if timber sets are proposed.

If steel or concrete sets are to be used, then a very rich deposit is required to support the cost.

- Weak ore.
- Strong overburden rock that does not cave.
- High value ore.
- Hanging & footwall rock may be either strong or weak.
- Fire hazard, if timbers used, especially with oxidizing sulfide materials.

Top Slicing



Longitudinal Section. End Section.

FIG. 8.—TOP SLICING.

In the top slicing method the ore is removed in a series of horizontal slices beginning at the top of the ore body immediately beneath the capping. The later is allowed to cave after each slice of ore is mined. As each horizontal section of ore is removed, the ground above is temporarily supported by timber.

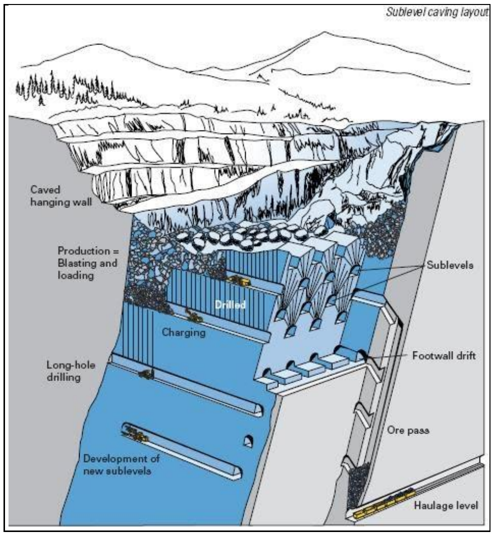
The most suitable type of deposit for mining by top slicing is ore which is of large horizontal extent and which is too weak to stand without support except over a short span. The most vital requirement is a weak capping which will cave when it is undermined. Development for top slicing consists of driving a series of drifts and crosscuts at some distance below the mining level and then raising to the top of the ore for mining.

For both top slicing, and sublevel methods of mining, it is absolutely essential that the capping be weak enough to cave when it is undermined.

Top slicing is more readily adaptable for deposits of large horizontal extent, whereas sublevel caving can be employed to mine deposits which are more irregular in outline. In both cases, the ore should be moderately weak but strong enough to stand temporarily.

- Much timber is required for top slicing, and an low-cost, adequate supply of low-priced timber is necessary.
- If the top of the ore is very irregular, it is advisable to use some other method of mining, such as square set mining or cut-and-fill stoping, to provide a cushion over the first slice and to remove the irregularities in the ore, before top slicing is

Sub-level Caving

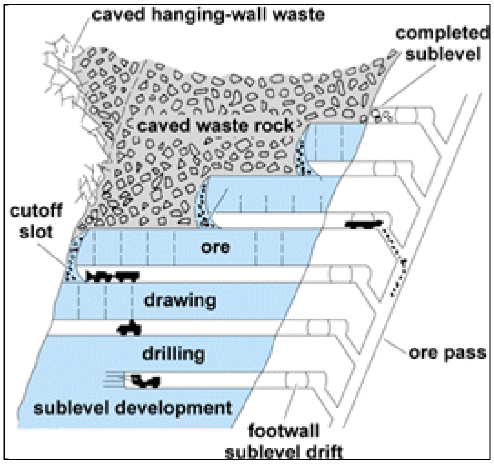


A stoping method in which relatively thin blocks of ore are caused to cave by successively undermining small panels. The ore deposit is developed by a series of sublevels spaced at vertical intervals of 18 to 25 or 30 ft and occasionally more. Usually only one or two sublevels are developed at a time, beginning at the top of the ore body. The sublevels are developed by connecting the raises by a longitudinal subdrift from which timbered slice drifts are driven right and left opposite the raises to the ore boundaries or to the limits of the block. Usually alternate drifts are driven first, and caving back from them is begun and continued while the intermediate slices are being driven.

The caving is begun at the ends of the slices by blasting out cuts and retreating in the same manner toward the raises.

Successively lower sublevels are developed and caved back until the entire block has been mined.

This method is intermediate between block caving and top slicing, since part of the ore is mined as top slicing and part is caved.



Kiruna iron ore mine, Sweden

Attachment 4 – Dr. Kliche Update on Mining Costs

Adit Entry Operating Costs in $/tonne (2016 dollars) Cost Mine

Production Rate (tonnes ore/day)	200	800	1000	1200	2000	4000	8000	14000	20000	30000	45000
Cut and Fill	$ 134.12		$ 76.55		$ 62.68						
Mechanized Cut and Fill	$ 89.13		$ 46.82		$ 41.21						
Shrinkage	$ 107.90		$ 61.09		$ 55.55						
Vertical Crater Retreat		$ 55.62			$ 48.29	$ 42.61					
Sublevel Longhole		$ 35.55				$ 21.08	$ 19.00				
Room and Pillar				$ 41.78			$ 23.06	$ 17.07			
Sublevel Caving						$ 47.69	$ 22.33	$ 20.01			
Block Caving									$ 9.88	$ 8.59	$ 7.99

Shaft Entry Operating Costs in $/tonne (2016 Dollars) Cost Mine

Production Rate (tonnes ore/day)	200	800	1000	1200	2000	4000	8000	14000	20000	30000	45000
Cut and Fill	$ 140.09		$ 79.34		$ 64.33						
Mechanized Cut and Fill	$ 94.84		$ 48.70		$ 43.22						
Shrinkage	$ 112.59		$ 63.93		$ 57.60						
Vertical Crater Retreat		$ 58.84			$ 49.70	$ 25.92					
Sublevel Longhole		$ 38.20				$ 22.51	$ 20.01				
Room and Pillar				$ 45.88			$ 24.34	$ 18.49			
Sublevel Caving						$ 30.55	$ 24.71	$ 21.12			
Block Caving									$ 10.68	$ 9.55	$ 9.03

Mining Costs by Operator and Location

Mine	US $/tonne	Company	Location	Mine Type	Date
Nevada Gold Mines	$ 101.97	JV Barrick and Newmont	Nevada, USA	drift and fill/ longhole stoping	Q1 2020
Cortez	$ 77.26	Barrick	Nevada, USA	drift and fill/ longhole stoping	Q1 2020
Carlin	$ 104.13	Barrick	Nevada, USA	drift and fill/ longhole stoping	Q1 2020
Turquoise Ridge	$ 125.49	Barrick	Nevada, USA	drift and fill/ longhole stoping	Q1 2020
Hemlo	$ 96.26	Barrick	Ontario, CA	Longhole/ Alimak	Q1 2020
Jundee	$ 59.05	Northern Star Resources Limited	Western Austrailia	up hole, long hole open stoping	Q1 2020
Kalgoorlie	$ 57.51	Northern Star Resources Limited	Western Austrailia	Open Stoping	Q1 2020
Pogo	$ 166.75	Northern Star Resources Limited	Western Austrailia	Variable	Q1 2020
Eleonore	$ 140.61	Newmont	Quebec, Canada	Longhole Retreat	Q1 2020
Musselwhite	$ 303.97	Newmont	Opapamiskan Lake, Ontario	Cut and Fill* Did not operate Q3 or Q4 2019	Q1 2020
Cerro Negro	$ 206.05	Newmont	Argtentina	Longhole stoping	Q1 2020
Note: Costs in Q1 2020 were likely impacted by COVID-19					

Calculations

Mine	Cost per ou	Ounces Mi	Total Cost	Total Tonn	Cost/tonne	Cost/tonne (US)
Jundee	737	60767	44785279	530878	84.36077	59.05254
Kalgoorlie	798	77067	61499466	748618	82.15066	57.50547
Pogo	897	56571	50744187	213021	238.2121	166.7485
Eleonore	790	61000	48190000	342727.3	140.6074	
Musselwhite	2616	15000	39240000	129090.9	303.9718	
cerro negro	640	72000	46080000	223636.4	206.0488	