Key deposit indicators (KDI) and key mining method indicators (KMI) in underground mining method selection

A. Nieto

Associate professor, Mining Engineering, Pennsylvania State University, State College, Pennsylvania

Abstract

This article is a review of previous discussions about underground mining method selection and classification with the purpose to clearly define and classify the two groups of variables (indicators) involved in the mining selection process: key deposit indicators (KDIs) and key mining method indicators (KMIs). This paper provides a simple and clear approach for the classification and selection of a feasible underground mining method based on a predetermined set of favorable deposit characteristics, which are defined as key deposit indictors (KDIs). This article also gives a summary of the key advantages and disadvantages associated with every underground mining method based on their key mining indicators (KMIs). The selection method given in this paper is based on defining field KDIs and comparing them to the KDIs that are favorable to every considered mining method. By cross validating a matrix of favorable KDIs, the paper presents a simple approach to rank several underground mining methods using a scale from favorable to less favorable accordingly to the ore deposit characteristics (KDIs). KMIs 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. To further assist the reader through the selection process, this paper gives basic sketches representing each of the primary underground mining methods discussed in this paper. Each method is given using the same 3D isometric view as spatial reference to assist the reader with visual interpretation and comparison between methods.

Key words: Mining method selection; Mining indicators; Underground mining; Surface mining

Introduction

The process of properly selecting an underground mining method for a particular ore deposit is critical to the ultimate success of the operation. An improperly selected method will increase costs, lower productivity and potentially cause unsafe working environments. Due to the complex nature of ore bodies, no two mines are completely alike and all operations must adapt to the particular conditions of their deposits.

There are dozens of considerations to be made when selecting the best method to mine an ore deposit (Hartman and Mutmansky, 2002). This paper divides them into two categories: key ore deposit indicators (KDIs) and key mining method indicators (KMIs). The fundamental approach for selecting the appropriate mining method is to examine the fixed characteristics of the mineral deposit in question and create a short list of method candidates. The advantages and disadvantages of each particular method may then be examined, weighted and compared in order to select the most appropriate manner to excavate the ore body.

Key Ore Deposit Indicators (KDIs)

The KDIs of a given mineral body are fixed and cannot be engineered or modified during the mining method selection process. As such, it is necessary to possess an intimate knowledge of the ore body before advancing with the method selection process. Key deposit indicators considered during the method selection process and their definitions are summarized in this section. KDIs and their attributes' relationship to underground mining methods are summarized in Table 26.

Ore strength. The compressive strength of the target material is an essential characteristic to identify. Unsupported mining methods, such as room-and-pillar, stope-and-pillar, sublevel-stoping and vertical crater retreat (VCR), depend on the strength of the ore rock to support the roof and overburden in order to prevent a mine collapse (Brackebusch, 1992a). Caving methods, such as block caving and longwall mining, depend on the strength of the ore to be suitable for controllable caving conditions.

A typical rock mechanics analysis will determine the unconfined compressive strength of a material. This value should be employed, since pillars do not experience naturally occurring confining stresses, although they may be applied artificially in order to increase a pillar's load-bearing capacity. Ranges of unconfined compressive strengths are utilized in this paper in order to help determine appropriate mining methods. The strength designations and ranges of values are given in Table 1.

It is important to note that the compressive strength of a rock is severely affected by fracturing and planes of weakness in the deposit. Fracturing is characterized by small, random

Paper number TP-09-028. Original manuscript submitted June 2009. Revised manuscript accepted for publication September 2010. Discussion of this peer-reviewed and approved paper is invited and must be submitted to SME Publications Dept. prior to Sept. 30, 2011.

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

breaks propagated throughout the sample. They may be caused by heat, vapor expansion (as in porphyry deposits) and tectonic movement. The degree of fracturing should be quantified during exploration and utilized to describe the bulk property of the deposit. A high degree of fracturing will reduce a material's tensile and compressive strength, leading to smaller openings and larger pillars. However, a high degree of fracturing may be positive in some mining methods, since it promotes caving and lowers blasting requirements.

Faulting is a breakage plane, caused by tectonic activity, along which movement has occurred. While fracturing affects the bulk properties of a deposit, faulting is mapped and classified separately. It occurs on a large scale and will often affect an entire deposit, while fracturing is generally more localized. Faulting will often affect the orientation and placement of openings on a mine-wide scale, while fracturing may change local pillar size or artificial support requirements.

Host rock strength. The strength of the rock surrounding the target material is also important to consider. Permanent openings and passageways must be developed in the host rock in order to access the ore, so the material's strength must be known prior to executing an appropriate design.

It is neither safe nor accurate to assume that the ore and host materials will have the same characteristics, so a separate rock mechanics analysis must be conducted to determine the properties of the host rock. The classifications for host rock strength are identical to those of ore strength, which are shown in Table 1.

Deposit shape. Ore deposits are classified into two broad categories: tabular and massive. A tabular deposit is flat and thin and has a broad horizontal extent. This classification typically refers to materials formed by sedimentation, such as coal seams. Similar in shape to tabular ore bodies, lenticular deposits are shaped like lenses and form from igneous processes. Most methods which exploit tabular deposits may easily be adapted to mine lenticular ones. The ore materials are often of higher grade than massive ores, but reserve tonnages are lower.

A massive deposit may possess any shape. The ore is often distributed in low concentrations over a wide area, with varying horizontal and vertical extents. Most frequently, the difference between ore and waste may be a function of grade rather than rock type. Massive deposits are unpredictable and require a considerable exploration investment in order to document and understand fully. For the purposes of mining method selection, massive deposits are often accompanied by a more specific clause, like "massive with large vertical extent." These additions are necessary, since the shape of a massive deposit is so variable and may be unsuitable for certain mining methods. The deposit shape KDIs are summarized in Table 2.

Deposit dip. Dip is defined as the magnitude of the inclination, below horizontal, at right angles to the strike. Strike is the line of intersection between the planar feature and a horizontal plane. The deposit dip is more relevant to tabular ore bodies than massive ones, although it may sometimes be a consideration for the latter. Deposit dips are categorized and defined in Table 3.

Both a flat coal seam and a near-vertical gold vein are classified as tabular, but the mining methods used to exploit them are dramatically different (Bibb and Hargrove, 1992). Several methods are highly dependent on gravity for material flow and cannot function in flat deposits. As such, deposit dip is a prime consideration for identifying a suitable mining method.

Deposit size. The volumetric size of an ore body must also be considered. Several of the methods discussed in this paper rely on large deposits with long mine lives to justify their high initial capital costs and promote economy of scale. Other methods simply would not work efficiently in ore bodies that were either too large or too small. Deposit size is characterized objectively by the terms small, medium and large. Also, deposit size refers to the relative thickness of tabular deposits. Thickness plays a substantial role in opening stability and may prevent certain equipment from functioning efficiently or mining methods from being effective. The deposit size KDIs are listed in Table 4.

Ore grade. Ore grade is defined as the concentration of

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

target material in its host rock or the quality of the ore rock itself. A gold ore may contain as low as 0.1 oz/ton and still be economical, while iron ore grades may approach 60% by weight. Coal is generally measured in BTU/ton. Regardless of the method for designating ore quality, the result is still the same: higher-grade ores are more valuable than lower-grade ones. Several of the methods discussed in this paper have high associated operating costs and necessitate high-grade ores in order to be economical. Other larger-scale methods may be suitable for large, low-grade deposits. Ore grades are categorized objectively and must be investigated on an individual site basis. The ore grade KDI terms are provided in Table 5.

Ore uniformity. The uniformity of ore in the mineral deposit is another consideration to be taken into account. It is never economical to excavate waste rock, unless it is necessary in order to reach the ore. A tabular deposit may be broken by faults or geologic forces (Erickson, 1992). A massive deposit may have concentrations of high-grade economical ores and other sections of low-grade waste rock. Some methods are well suited to flexibility, in that they can economically extract specific sections of a deposit without disrupting the operation. Other methods, such as block caving, prevent selectivity and must load and haul everything that comes down the ore chute (Bluekamp, 1981). An inconsistent feed of material may disrupt processing plant performance or require blending and rehandling of material. These situations can be anticipated and prevented with a thorough knowledge of the continuity of the ore body. A listing of ore uniformity designations is provided in Table 6.

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

Deposit depth. The final consideration for an ore deposit is its depth relative to the surface. Shallow deposits are generally more suited for surface mining. Very deep deposits may require supplementary ground control measures (additional costs) or large pillar sizes (lower recovery) in order to be safe. Some methods are more inherently suited to different depths than others. Shallow to moderate-depth deposits should almost always be considered for surface mining and be compared accordingly. Ultimately, deposit depth plays a very significant role in the determination of the ideal mining method for an ore body.

Key deposit indicators conclusion. The mining engineer must be familiar with the ore deposit's characteristics in order to properly perform the first step of mining method selection: eliminating unsuitable methods. For example, a longwall shearer could not effectively excavate a massive iron deposit, nor could block caving succeed economically in extracting a flat, tabular salt seam. It is implicit that after an initial selection process, more than one mining method may be suitable to exploit a given deposit. Thus, the engineer must further identify and analyze in detail every available variable related to the deposit in order to narrow down all the feasible options and make an ultimate selection. The specific available mining methods are discussed in the following sections by defining favorable deposit characteristics or indicators and by comparing their performance, advantages and disadvantages.

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

Key mining method indicators (KMIs)

This section defines and discusses the key performance mining indicators (KMIs) involved in each mining method described in this paper. Once KMIs are identified, their performances are evaluated according to each feasible mining method. Every mining method has several key indicators that will perform differently based on the characteristics of the ore deposit to be mined. As such, all key mining indicators must be clearly defined and understood prior to selecting the best mining method.

Operating cost. The mining operating cost is the unit price required to extract the ore from underground. A stripping cost of \$1.15/m^3 (\$1.50/yd^3) is an example of an operating cost. In mining, the operating cost is the sum of fixed and variable costs, where variable costs change in proportion with production and fixed costs, such as ventilation costs and upper management salaries, stay relatively constant. Some methods are labor-intensive or may require a large quantity of materials in order to operate, thereby necessitating higher-grade ores to compensate for the greater price of extracting them. Other methods cost very little once they are up and running and may be able to excavate large low-grade deposits economically (Bruce, 1982).

Capital cost and development time. Capital cost is defined as the amount of investment needed before the mine begins to generate revenue (Gentry and O'Neil, 1984). A small quarry excavating an outcropping limestone bed has little capital cost, since it can start extracting ore almost immediately. A sublevel stoping/VCR operation on an inclined vein must purchase equipment in advance and use it to excavate drifts and openings in the host rock, develop ore chutes and install a means of transporting ore to the surface before mining anything of value.

Higher capital costs are frequently associated with long development or start-up times. Equipment manufacturers sometimes have waitlists of several months or even years before delivery and assembly of a new machine. Many mining methods require extensive opening development prior to ore extraction, which takes time, in addition to substantial financial allocations.

Production rate. The production rate of a mine is highly dependent on the mining method and equipment employed. A high production rate can accommodate a large market share and overcome low ore grades if operating costs are low. It also facilitates the stockpiling and blending of ores of varying grade in order to maintain a consistent feed to the mill. Accordingly, with the economic nature of the commodity being mined and the local market, higher production is usually more desirable, since mines are generally operating in areas where selling more production units is advantageous.

Mechanization. Mechanization is a critical component of a modern mine. Utilizing machines to perform heavy labor and material transportation is much more efficient than manual labor and is frequently cheaper, given a longer mine life. A more highly mechanized operation will generally be both more productive and cost-efficient during mining. It will also be safer, in that fewer workers will be needed and thus the overall hazard exposure will be lower. Several methods lend themselves to a high degree of mechanization and should be considered in almost all circumstances.

Selectivity and flexibility. Selectivity and flexibility are significant contributors to the success of an operation. One must always assume that mining conditions, market prices and technology will change over the course of a mine's life, so the chosen method must be adaptable to the aforementioned fluctuations. If commodity prices were to drop substantially, a portion of the ore in a massive deposit may become uneconomical to mine. If the mining method is able to bypass the low-grade sections and continue mining economic material, the mine will continue to be successful. Also, areas with high stress concentrations and unsafe roof conditions can be abandoned and the operation can continue without delay. Flexibility is of paramount importance for the long-term profitability and adaptability of any mine and must be factored in when selecting a mining method.

Health and safety. The safety and health of a mine's workers should be the top priority of every operator. Several methods are inherently safer than others, in that the openings are more stable or personnel are less likely to be subjected to hazardous conditions. Although no modern methods are considered to be unsafe, it bears mentioning that specific health and safety concerns are often dictated by the selected mining method.

Environmental impact. The environmental impacts of an underground mine typically fall into three categories: subsidence, ground water contamination and air pollution. Subsidence is defined as the sinking of the surface above mine workings as a result of material settling into the voids created by mineral extraction. Subsidence is a serious phenomenon when the mine is near populated areas, since it may occur anywhere and at any time. The costs and social impacts associated with subsidence issues are tremendous and must be avoided. Several mining methods will almost unavoidably induce subsidence in the overlying surface. If they are to be selected, it must be assured that no external parties be damaged by the occurrence.

Groundwater contamination may result from several factors. Sulfide mines may produce acid mine drainage, which leaches into the water table during normal operation. Processing plants may discharge chemical-bearing fluids into streams or rivers. The seals under settling or storage ponds may fail and release toxins into the water system. Some mining methods have an inherently greater risk of contaminating groundwater; this must be acknowledged in advance and accounted for in preliminary mine planning.

Air contamination in underground mines is typically generated by the discharge of exhaust fumes from ventilation fans. These fumes may contain diesel particulate matter, mineral dust or chemical compounds.

Environmental damage is unacceptable in the modern mining environment and must be minimized at all costs. Subsidence may cause irreparable damage to the local ecosystem or it may affect neighboring communities (Filas, 1997). Groundwater and air contamination have broad and long-lasting effects and must be controlled at all times. Some methods are more inherently prone to environmental impacts than others; if selected, appropriate controls must be included in the engineering designs and subsequent operations at the site.

Mining methods discussion

There are a variety of mining methods that can be adapted to suit almost any ore deposit. Although openpit mining is a nearly universal solution for shallow deposits, underground methods are far more diverse and require an extensive knowledge base and investigation of the variables involved in order to be properly utilized (Hartman and Mutmansky, 2002). This section will discuss the primary methods used in modern underground mines, by first providing a general description and then highlighting key advantages and disadvantages. The methods are classified into three groups: unsupported, supported and caving. Unsupported methods include room-and-pillar, stope-and-pillar, shrinkage stoping, sublevel stoping and vertical crater retreat; the supported group includes cut-and-fill and the caving category includes longwall, sublevel caving and block caving.

The term "unsupported" refers to the fact that the particular mining method does not employ artificial roof or opening supports to maintain portal stability. These methods must use "natural" support, typically in the form of rock pillars left behind during mining, to uphold the roof. "Supported" indicates that additional means of opening support are used as consistently and as part of the basic mine plan (Bullock, 1982). These may include cemented tailings or metallic frames. "Caving" methods intentionally allow portions of the ore deposit and host rock to collapse, but they do so in a controlled manner. Some are designed to maximize gravity assist and minimize blasting, while others are employed for maximum ore recovery.

It is important to note that the mining methods introduced in this paper are hardly ever implemented by the book. The fundamental principles and extraction concepts as described in this section should serve as a general guide during mining selection. The variables and indicators of each method should be noted and then modified to suit each individual deposit. The following descriptions are intended to emphasize the advantages and disadvantages of each mining method, based on their key mining characteristics or indicators (KMIs), which would be present in virtually any iteration of the respective method. A summary of all mining methods and their KMIs is shown in Table 24.

Room-and-pillar. Room-and-pillar mining originated relatively recently and is employed to extract the vast majority of coal coming from underground mines throughout the world. The idea is to sink a shaft to the elevation of the coal seam and begin excavating the coal horizontally (Farmer, 1992). The heart of the operation is the continuous miner, which utilizes a large rotating drum to break the coal in front of it and then scoop it onto an internal conveyor. The conveyor feeds one or more shuttle cars, which take the coal to a mobile belt feeder, which in turn carries the coal to the surface for processing. The continuous miner excavates the coal seam in a grid-like pattern, driving entries 15-20 feet wide at the height of the seam. These openings run parallel to each other along the long axis of the workings. Crosscuts, driven in the same manner except perpendicular to the entries, connect the entries to complete the grid. Pillars are left behind to support the roof, hence the title "room-and-pillar." The optimal or favorable KDIs for room-and-pillar mining are shown in Table 8. A summary of all methods indicating favorable KDIs with nominal values is given in Table 26.

The room-and-pillar mining method enjoys several distinct advantages. The foremost of these advantages is the fact that mining operations are continuous in nature. Most mining sequences require drilling, blasting, loading, hauling and dumping. The invention of the continuous miner eliminated the steps of drilling and blasting by excavating the coal with a powerful rotating drum and loading shuttle cars concurrently. This substantially increases the overall efficiency of the method and improves general productivity. The nature of operations necessitates a highly mechanized site, which contributes to the low operating costs and high production rates associated with room-and-pillar mining. Continuous miners can cut through coal very easily, resulting in a rapid development rate. The grid layout of the mine allows for straightforward ventilation with consistent airflow to all working faces (Hartman et al., 1997). Since no chemicals are used underground, there are virtually no pollutants introduced into the neighboring groundwater.

The major disadvantage of room-and-pillar mining is that it can only be applied to a small number of known minerals. A continuous miner cannot operate efficiently, if at all, in harder rocks like limestone or granite and, thus, its principal advantages cannot be shared. Room-and-pillar has seen use in salt, trona and potash mining, but on a very small scale when compared to coal. Additionally, room-and-pillar requires a high capital investment to purchase equipment and perform development excavations. The coal itself is a very weak rock and is subject to breakage. Combined with its combustible properties and the confined environment of underground mining, coal mining has experienced a significant history of accidents and fatalities. The method is also limited by depth. The pillar size is dictated by the weight of the overburden above the seam, so the deeper the ore body, the larger the pillars must be. Larger pillars result in lower recoveries and overall mining efficiencies. Pillars can be recovered after the first pass by utilizing retreat mining, but opening stability is compromised and eventual subsidence is inevitable (Hartman and Mutmansky, 2002). Finally, there are

Table 8 — Room-and-pillar favorable KDIs.

Key Deposit Indicator	Favorable KDI	Value
Ore strength	Weak to moderate	1, 2
Host rock strength	Moderate to strong	2, 3
Deposit shape	Tabular	1
Deposit orientation	Flat to shallow	1
Deposit size/thickness	Large, thin	1
Ore grade	Moderate	2
Uniformity	Fairly uniform	3
Deposit depth	Shallow to moderate	1, 2

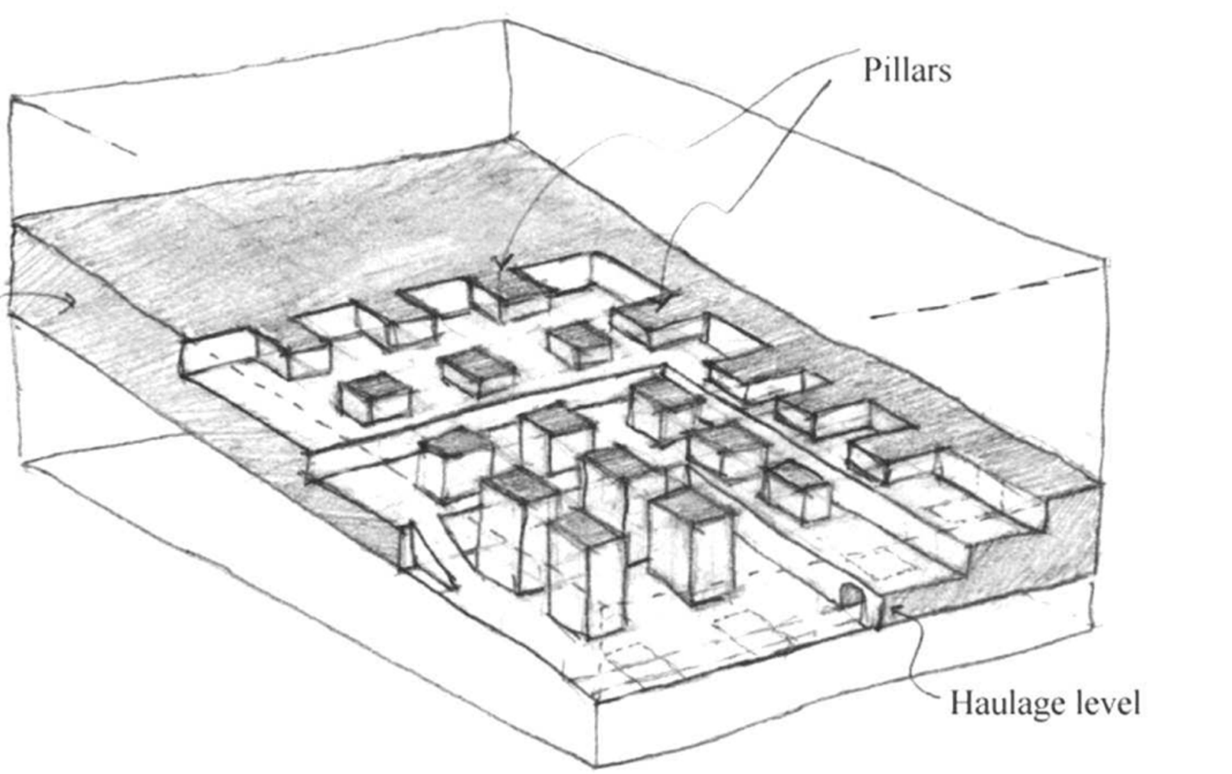

Figure 1 — Room-and-pillar method sketch (A. Nieto).

Table 9 — Room-and-pillar KMI advantages and disadvantages.

Advantages	Disadvantages
Continuous production	High capital costs
Rapid development rate	Limited depth capacity
Excellent ventilation	Very low selectivity
High productivity	Moderate subsidence
Moderate operating cost	Extensive development
Good recovery (with pillar extraction)	Moderate recovery (without pillar extraction)

Table 10 — Stope-and-pillar favorable KDIs.

Key Deposit Indicator	Favorable KDI	Value
Ore strength	Moderate to strong	2, 3
Host rock strength	Moderate to strong	2, 3
Deposit shape	Tabular or lenticular	1, 2, 3
Deposit orientation	Low to moderate	1, 2
Deposit size/thickness	Moderate, large, thick	1, 2, 3, 4
Ore grade	Low to moderate	1, 2
Uniformity	Variable	1
Deposit depth	Shallow to moderate	1, 2

very limited options for selectivity should the coal seam be interrupted or a section of low BTU content be encountered. The primary advantages and disadvantages of room-and-pillar mining are summarized in Table 9.

Stope-and-pillar. The distinctive classification between room-and-pillar and stope-and-pillar is due to the wide applicability in the U.S. of the room-and-pillar method adapted for non-coal mining (Haycocks, 1992). The stope-and-pillar mining method utilizes the same principle of excavating a grid and leaving pillars behind as room-and-pillar, but has been adapted to function in harder rocks and a wider variety of ore deposits. The optimal KDIs for stope-and-pillar mining are shown in Table 10. A sketch of the mining method is shown in Fig. 1. The rock is excavated with a standard drill-blast-load-haul-dump sequence utilizing a wide variety of equipment. Harder rocks allow for much smaller pillars and larger recoveries than room-and-pillar mines, but also decrease operational efficiency, because they prevent continuous excavation from occurring. Hard rock also contributes to a high degree of stability in mine openings and allows for more varied pillar designs and openings. As a result, stope-and-pillar operations can be much more flexible in their production plans and selective in the ores they extract. A large degree of mechanization is necessary, but brings about low operating costs and high development rates. With the exception of sulfide ores (which may oxidize and produce sulfuric acid when exposed to air), stope-and-pillar mines produce minimal environmental impacts and very rarely induce subsidence.

High capital costs accompany the great degree of mechanization associated with stope-and-pillar mining. These costs are also increased by the large amount of development necessary before beginning full-scale mining. Development costs are high because the machines require large openings to be transported and because the tougher rock is more difficult to excavate (and costs more as a result). Ventilation is also difficult. The larger openings require larger fans and the irregular mine plans complicate ventilation design. Most equipment is diesel operated, so hydrocarbon fumes are emitted and must

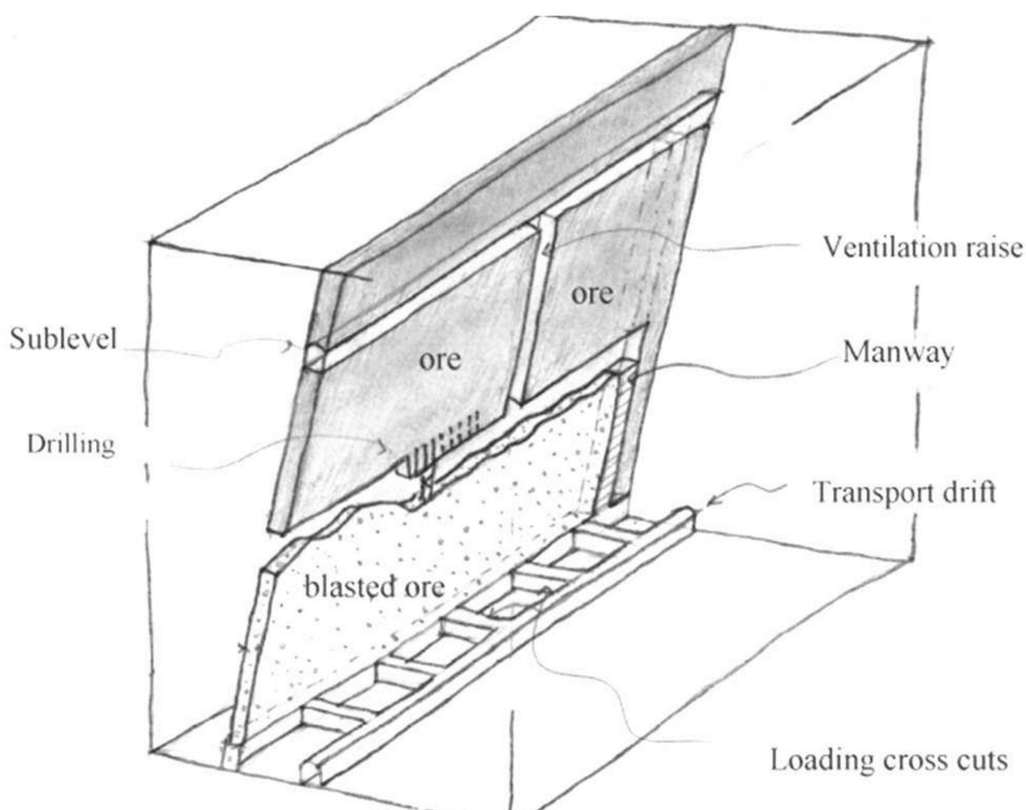

Figure 2 — Shrinkage stoping method sketch (A. Nieto).

Table 11 — Stope-and-pillar advantages & disadvantages.

Advantages	Disadvantages
Production rate	Moderate capital investment
High productivity	Fair ventilation
Rapid development rate	Limited depth capacity
High selectivity	Moderate recovery
High flexibility	
High stability openings	
High mechanization	

be ventilated to prevent accumulation and the subsequent health risks associated with it (McPherson, 1993). The primary advantages and disadvantages of room-and-pillar mining are summarized in Table 11.

Shrinkage stoping. The shrinkage stoping method is utilized in thin, steeply dipping tabular deposits and is relatively uncommon in new mines. A series of shafts are sunk along the hanging wall of the vein and horizontal drifts are driven to intersect it. An array of ore chutes are developed at the lowermost point of excavation and a conveyor or skip is installed nearby to transport material to the surface. Mining proceeds from bottom to top and begins by drilling and blasting a 1.8-to-3.6-m- (6-12-ft) high section of the vein. After it is mucked out by LHDs loading from the ore chutes, the mining crew enters the open stope on foot and drills into the ceiling to advance. Additional material is withdrawn from the muck pile, which rises continuously as mining progresses. Once the maximum height is reached, the LHDs work full time to remove the remainder of the muck pile and development commences on another segment of the deposit. The optimal KDIs for shrinkage stoping are shown in Table 12. A sketch of the mining method is shown in Fig. 2.

Table 12 — Shrinkage stoping favorable KDIs.

Key Deposit Indicator	Favorable KDI	Value
Ore strength	Strong	3
Host rock strength	Strong to fairly strong	3, 4
Deposit shape	Tabular, lenticular	1, 2, 3
Deposit dip	Steep to vertical	3, 4
Deposit size/thickness	Thin to moderate	1, 2
Ore grade	Fairly high	3, 4
Uniformity	Uniform	4
Deposit depth	Shallow to moderate	1, 2, 3

The advantages of shrinkage stoping include a low capital investment (since relatively little machinery is used), high recovery and rapid development rate once production commences. Since it is only used in thin deposits, opening stability is high and subsidence is rarely encountered.

One principal disadvantage of the method is the long startup time associated with it. This is caused by the large amount of development work required to create the ore chutes, openings for the LHDs to operate and drifts for the crews to access the stopes. Flexibility is very limited unless stopes are abandoned and costly development work is wasted. Production is inconsistent, since the LHDs are only working full time to withdraw ore from the chutes during a limited period of operation. Ventilation is also difficult to execute properly. Since the crews are working on top of an active muck pile (which is a very rough surface) on which mechanization is virtually impossible, labor costs escalate. A larger number of laborers means that there

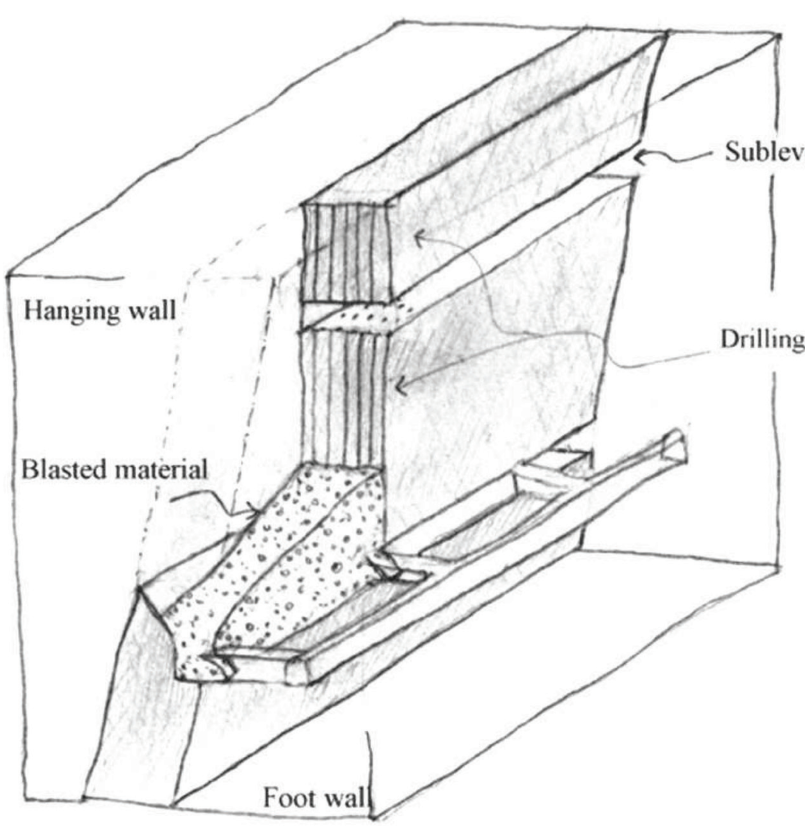

Figure 3 - Sublevel stoping method sketch (A. Nieto).

Table 13 — Shrinkage stoping advantages and disadvantages.

Advantages	Disadvantages
Low capital investment	High operating cost
Low dilution	High development
High Recovery	Low productivity
High stability openings	Low Mechanization
Rapid development rate	
Good gravity assist	

Table 14 - Sublevel stoping/VCR favorable KDIs.

Key Deposit Indicator	Favorable KDI	Value
Ore strength	Moderate to strong	2, 3
Host rock strength	Fairly strong to strong	4
Deposit shape	Tabular, lenticular	1, 2, 3
Deposit dip	Steep to vertical	3, 4
Deposit size/thickness	Fairly thick to moderate	2, 3
Ore grade	Moderate	2
Uniformity	Fairly uniform	3
Deposit depth	Moderate	2, 3

is more exposure to hazards (which is only heightened by the rough working surface) and that high operating costs are associated with shrinkage stoping. The primary advantages and disadvantages of shrinkage stoping are summarized in Table 13.

Sublevel stoping/vertical crater retreat. Sublevel stoping is used in steeply dipping tabular deposits of varying thickness. The concept is to sink shafts near the hanging wall and drive horizontal drifts to intersect the deposit (Haycocks and Aelick, 1992). Openings are then developed along the strike of the deposit and drill rigs create long blast holes to excavate vertical slices of the vein. Once blasted, the broken material is loaded from the bottom before being transported to the surface. Mining proceeds horizontally along the strike of the deposit and may involve more than one production level, depending on stope height and the vertical extent of the vein.

The difference between sublevel stoping and vertical crater retreat (VCR) has to do with drilling procedure and type of blast charge used to fragment the stopes. In sublevel stoping, drills develop a dense pattern of holes, which are then filled with explosives for blasting. VCR involves drilling a small number of large-diameter holes and then placing a powerful cylindrical charge near the bottom of the desired stope. The detonation of the charge fragments a spherical crater in the vein. This method is well-suited to thick deposits, since it has substantial horizontal propagation relative to standard sublevel stoping. The vertical extent of the blast is roughly equal to the horizontal, so multiple shots may be necessary in order to finish a single stope. A portion of the ore pile would be loaded between blasts to create room for the rock to expand during the next shot. After blasting, loading and hauling proceeds in the same way as sublevel stoping. The optimal KDIs for sublevel stoping and VCR are shown in Table 14. Images of both mining methods are shown in Figs. 3 and 4.

Sublevel stoping and VCR mining are, by nature, highly mechanized and have accordingly high production rates and low operating costs. Opening stability is high and the working environment is safe. Environmental impacts are minimal; subsidence does not occur, diesel contaminants are controlled with straightforward ventilation and no harmful chemicals are used underground.

A substantial disadvantage of sublevel stoping and VCR

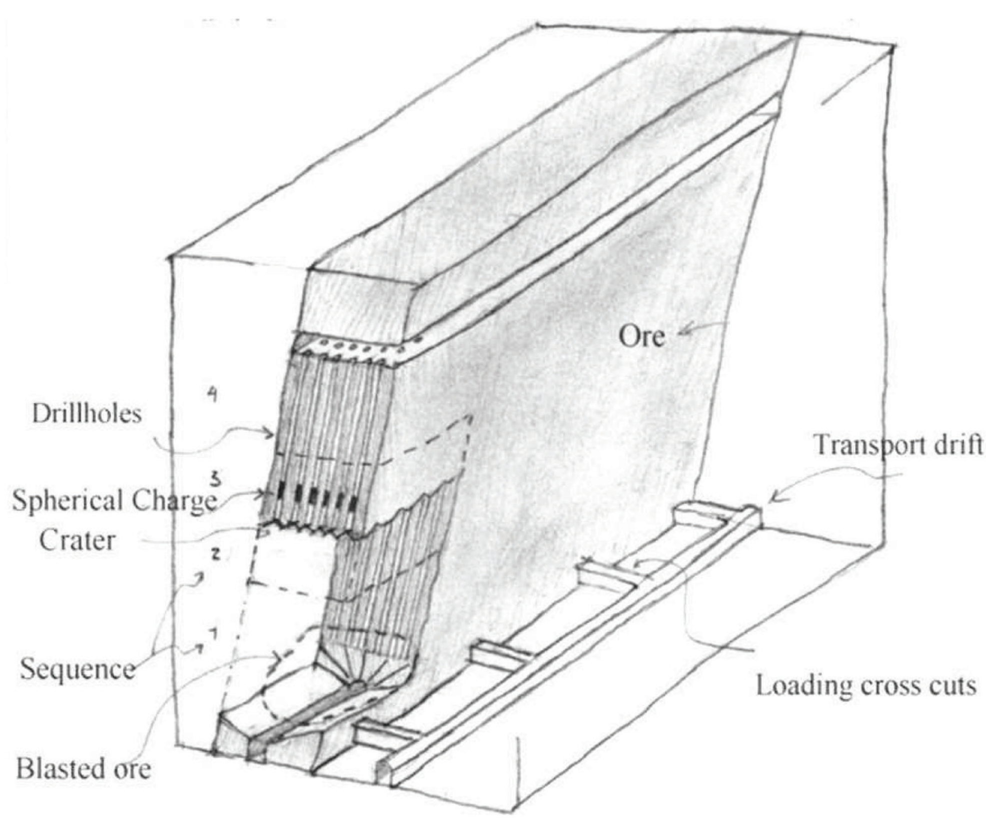

Figure 4 — Vertical crater retreat method sketch (A. Nieto).

Table 15 — Sublevel stoping/VCR advantages & disadvantages.

Advantages	Disadvantages
High production rate	High development (sublevel stoping)
High productivity	Moderate development (VCR)
High stability openings	Low flexibility
High mechanization	Low selectivity
Good ventilation	
Moderate recovery	

Table 16 — Cut-and-fill favorable KDIs.

Key Deposit Indicator	Favorable KDI	Value
Ore strength	Moderate to strong	2 ,3
Host rock strength	Weak to fairly weak	1, 2
Deposit shape	Any	1, 2, 3, 4
Deposit dip	Any	2, 3
Deposit size/thickness	Small to medium	1, 2
Ore grade	Fairly high	3, 4
Uniformity	Any	1, 2
Deposit depth	Moderate to deep	2, 3, 4

is a lack of selectivity and flexibility. All material must be removed from the stope (or else the material above it could not be accessed), so it is impossible to be selective. Also, mine plans are usually rigid and leave little room for deviation once initiated. The large open stopes are also prone to either moderate dilution or low recovery. This occurs because it is very difficult to blast precisely to the boundary between the ore and host rock. As such, the stopes will either leave ore behind on the inside stope walls or blast too far and fragment waste rock.

Development costs and startup time are relatively high, because sublevel stoping and VCR require an extensive network of passages in order to access the different levels of the vein. A large percentage of these must be in place before mining can commence, which is both costly and time consuming. The primary advantages and disadvantages of sublevel stoping are summarized in Table 15.

Cut-and-fill. Cut-and-fill mining involves excavating small stopes of high-grade ore and then backfilling with cemented tailings to artificially support the rock and nearby mine openings. Rooms are drilled and blasted conventionally and the fragmented ore is loaded with LHDs or other small loaders. Concrete forms are then built at the entrance to each room and cemented mill tailings are pumped in slurry form to the mine and then used to fill in the recently excavated stope (Brackebusch, 1992b). Mining progresses on a stope-by-stope basis, with specific target areas of the ore body dictated by ongoing assay work. The optimal KDIs for cut-and-fill mining are shown in Table 16. A sketch of this method is available in Fig. 5.

There are numerous very significant advantages to cut-and-fill mining. First, it is the most selective and flexible underground mining method available. The majority of work entails excavating stopes and backfilling them, while a small portion are utilized by developing connecting passageways and tunnels. It is easy to bypass a section of low-grade ore and target the more lucrative areas. If prices rise in the future, the operators can always return to unmined blocks to recover what was left behind. If they do elect to extract all stopes, it is possible to achieve 100% recovery of an ore body. This is because no pillars are necessary, since the backfill supports the roof in the same manner as the original rock and leads to minimal subsidence. Weak ore and host rocks can be mined

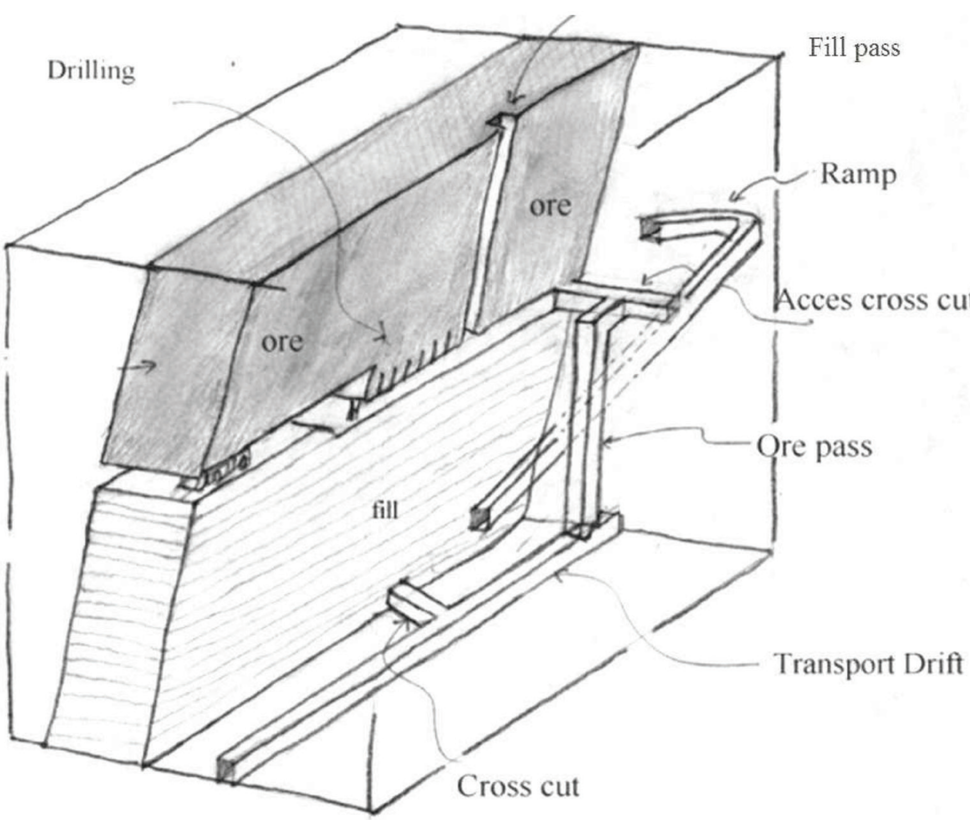

Figure 5 — Cut-and-fill method sketch (A. Nieto).

Table 17 — Cut-and-fill advantages and disadvantages.

Advantages	Disadvantages
Low development	High operating costs
Low dilution	Low production rate
High selectivity	Poor ventilation
High recovery	
High flexibility	
High opening stability	
Good gravity assist	

Table 18 — Longwall mining favorable KDIs.

Key Deposit Indicator	Favorable KDIs	Value
Ore strength	Any	1, 2, 3, 4
Host rock strength	Weak to moderate	1, 2
Deposit shape	Tabular	1
Deposit dip	Flat to shallow	1
Deposit size/thickness	Large, thin	1
Ore grade	Moderate	2
Uniformity	Uniform	4
Deposit depth	Moderate to deep	2, 3

by cut-and-fill, since they would normally require large pillars or extensive roof support to be viable with other methods. Alternatively, competent ore bodies can be mined at great depths and still maintain a high degree of opening stability.

Although the operation is highly mechanized, it is also labor-intensive and has a relatively low production and development rate. The operating cost is also quite high, since backfilling techniques are very expensive. There is also a potential for water contamination resulting from chemicals escaping the backfill slurry. Because of these disadvantages, cut-and-fill mining is usually limited to small and medium-sized high-grade ore bodies, although it can be adapted to a deposit of virtually any size, shape or depth. The primary advantages and disadvantages of cut-and-fill mining are summarized in Table 17.

Longwall. Longwall mining is combined with room-and-pillar to create the most efficient and highest-producing underground coal mines in the world. First, the main entries are driven with conventional room-and-pillar techniques using continuous miners. A series of panels branching perpendicular from the mains are outlined by a two-to-three entry room-and-pillar border, leaving a very large solid block of coal within its confines (Buchan, 1998). A longwall shearer, armored face conveyor and shield wall are assembled at the end of the panel before longwall mining commences. The shearer moves back and forth across the coal block, excavating 100% of the ore, causing the material to fall onto the conveyor and be transported away to the main belt conveyor system. The shields advance along with the shearer to hold up the roof directly above the equipment. The excavated area behind the shields is allowed to collapse. Mining progresses as continuous miners develop additional longwall panels and the shearers are moved from one to the next throughout the course of the mine life. The optimal KDIs for longwall mining are shown in Table 18. A sketch of a longwall panel may be found in Fig. 6.

Even more than room-and-pillar mining, the longwall method is exceptionally efficient and has outstanding production rates and low operating costs. The operation is almost completely mechanized and recovers an extremely high percentage

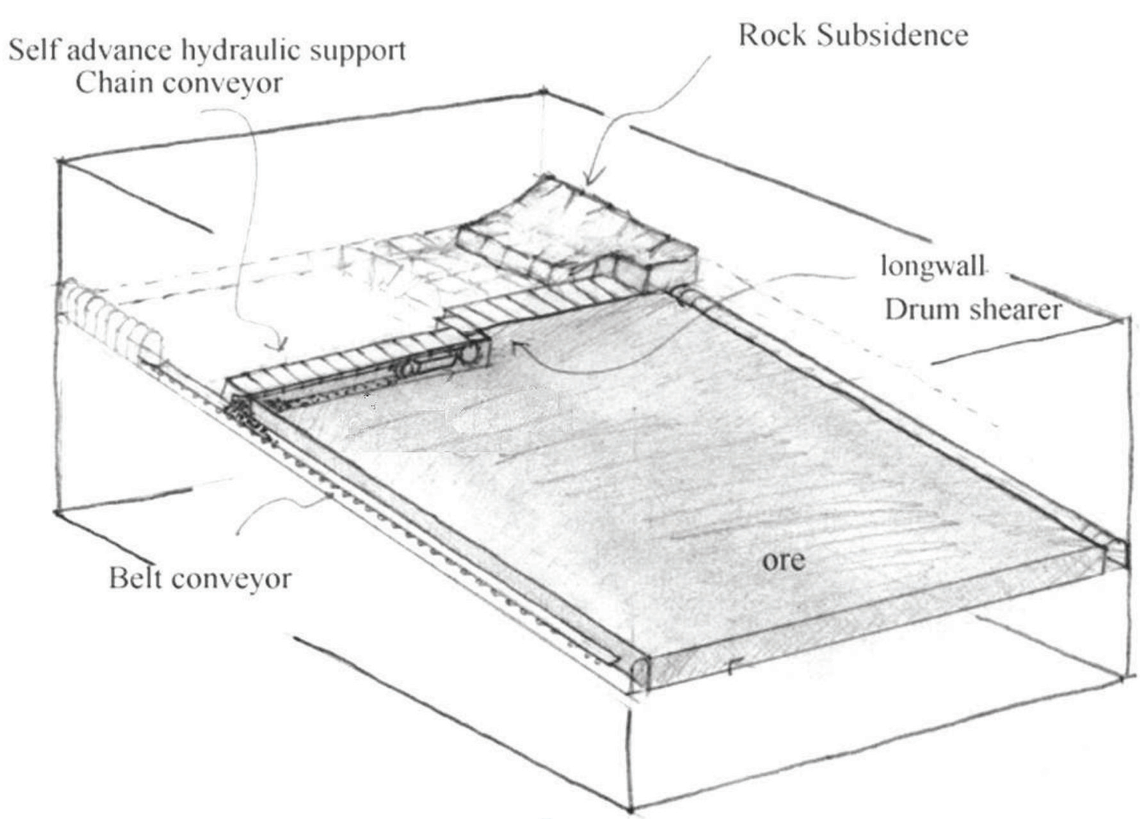

Figure 6 — Longwall method sketch (A. Nieto).

Table 19 — Longwall mining advantages and disadvantages.

Advantages	Disadvantages
Low operating cost	High capital investment
High productivity	High development
High recovery	Low selectivity
Low dilution	High subsidence
High production rate	Low flexibility
High mechanization	
Continuous method	

of the ore body. The working face is also very safe, since the roof is directly supported at all times by heavy-duty shields. If conditions allow, longwall mining is the most effective way to excavate a thin tabular deposit with weak ore strength.

There are, however, a few disadvantages to longwall mining. The first is that it requires a very substantial capital investment to purchase the highly specialized equipment to create a longwall section. The development time is significant, since the continuous miners have to initiate the main entries and excavate the border of the longwall panel before the shearer can be brought in. Longwall mining is also precluded near urban or semiurban areas, since subsidence is a substantial risk. Finally, there is zero selectivity once mining commences on the panel. Additionally, overall flexibility is low. The primary advantages and disadvantages of longwall mining are summarized in Table 19.

Sublevel caving. Sublevel caving operations are initially developed in a similar manner as sublevel stoping mines. Steeply dipping tabular deposits of varying thickness are excavated, but it is critical that both the ore and host rock be relatively weak and caveable (Cokayne, 1982). Rather than utilize drilling and blasting to fracture all of the rock, a single blast is used to initiate a self-caving system. LHDs tram up to the muck pile (which lies along the strike of the deposit) and begin loading out the ore. As the bottom of the pile is extracted, the weight of the mid and top sections of the pile causes the pile to shift forward. The void created between the muck pile and the hanging wall allows material from the vein to cave in on top of the muck pile and produce a continuous stream of ore. LHDs can load from various heights along the vein in order to control the caving effect. The optimal KDIs for sublevel caving are shown in Table 20. A sketch of sublevel caving is shown in Fig. 7.

Table 20 — Sublevel caving favorable KDIs.

Key Deposit Indicator	Favorable KDI	Value
Ore strength	Moderate to fairly strong	2, 3
Host rock strength	Weak to fairly strong	2, 3
Deposit shape	Massive or tabular	1, 4
Deposit dip	Steep to vertical	3, 4
Deposit size/thickness	Large to very large	4
Ore grade	Moderate	2
Uniformity	Moderate	2
Deposit Depth	Moderate	2, 3

Sublevel caving operations are highly mechanized and enjoy low operating costs and high production rates. Very high recoveries are obtainable, since no pillars are left behind during excavation. Most mine personnel will be inside mobile equipment at all times, so the mining environment is quite safe.

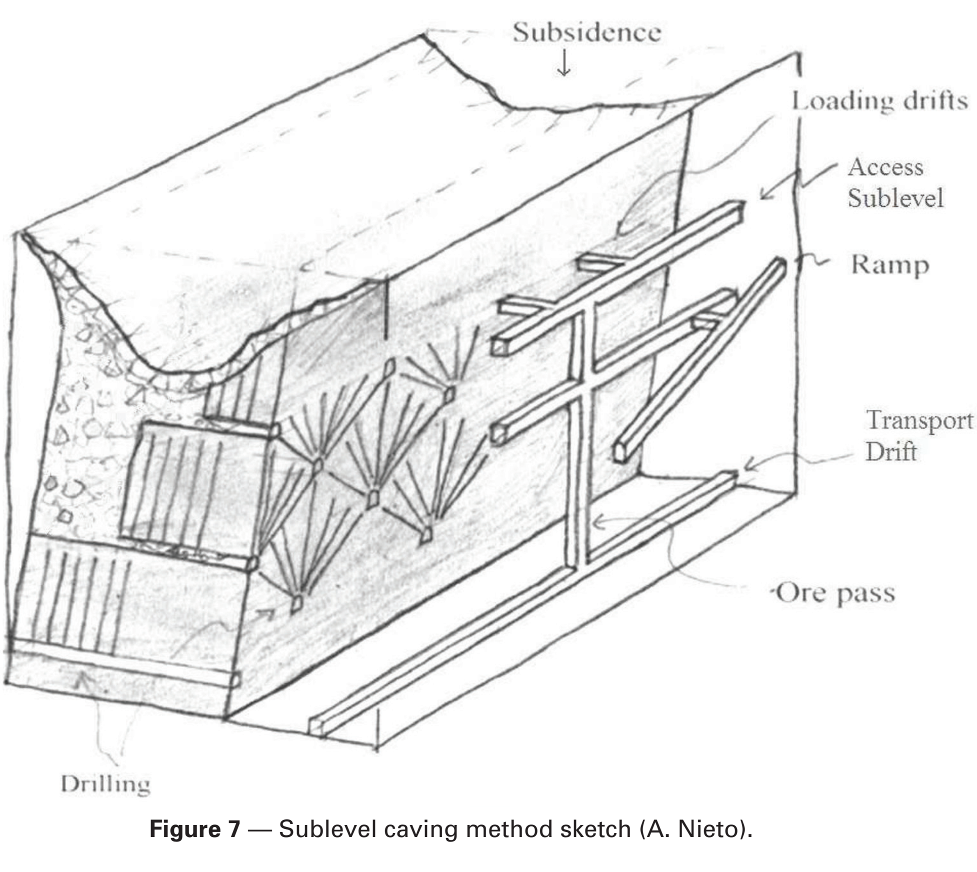

Figure 7 — Sublevel caving method sketch (A. Nieto).

Table 21 — Sublevel caving advantages and disadvantages.

Advantages	Disadvantages
Low operating cost	High development
High production rate	High subsidence
High recovery	Low selectivity
High mechanization	

Sublevel caving requires a similar amount of development work as sublevel stoping/VCR. As with other methods, this development is both expensive and time-consuming. As mining progresses, the ore and host rocks cave in together and mix with each other, so dilution is a significant issue, particularly if the two materials are not easily discerned from one another by brief visual examination. Finally, subsidence is guaranteed in the surrounding areas, since a large amount of material is caving in and being extracted. The primary advantages and disadvantages of sublevel caving are summarized in Table 21.

Block caving. Block caving requires a massive deposit with a large vertical extent or a steeply dipping tabular deposit of considerable thickness. Both the ore and host rock must be relatively weak and caveable. An extensive series of openings, haulage drifts, ore chutes and an underground crushing station are developed in advance before any ore extraction occurs (Bluekamp, 1981). Once the development workings are completely finished, a single blast is detonated directly above the ore chutes in order to initiate caving. The ore then falls through the chutes and is loaded out by LHDs. Once production is started, the ore continues falling through the chutes as the material above the development area caves in and pushes the ore downward. LHDs may load continuously for several years before the ore is exhausted. A depiction of block caving is available in Fig. 8. The optimal KDIs for Block Caving follow in Table 22.

Table 22 — Block caving favorable KDIs.

Key Deposit Indicator	Favorable KDI	Value
Ore strength	Weak to moderate	1, 2
Host rock strength	Weak to moderate	1, 2
Deposit shape	Massive or thick tabular	1, 4
Deposit dip	Steep to vertical	3, 4
Deposit size/thickness	Very large, thick	4
Ore grade	Low	1
Uniformity	Fairly uniform	3
Deposit depth	Moderate	2, 3

Table 23 — Block caving advantages and disadvantages.

Advantages	Disadvantages
Low operating cost	High capital investment
High production rate	Very high development
High productivity	High dilution
High recovery	High subsidence
High mechanization	Slow development rate
Good ventilation	Low selectivity
Good gravity assist	Low flexibility

The principal advantage of the block caving method is its exceptionally low operating cost, which is comparable to sur-

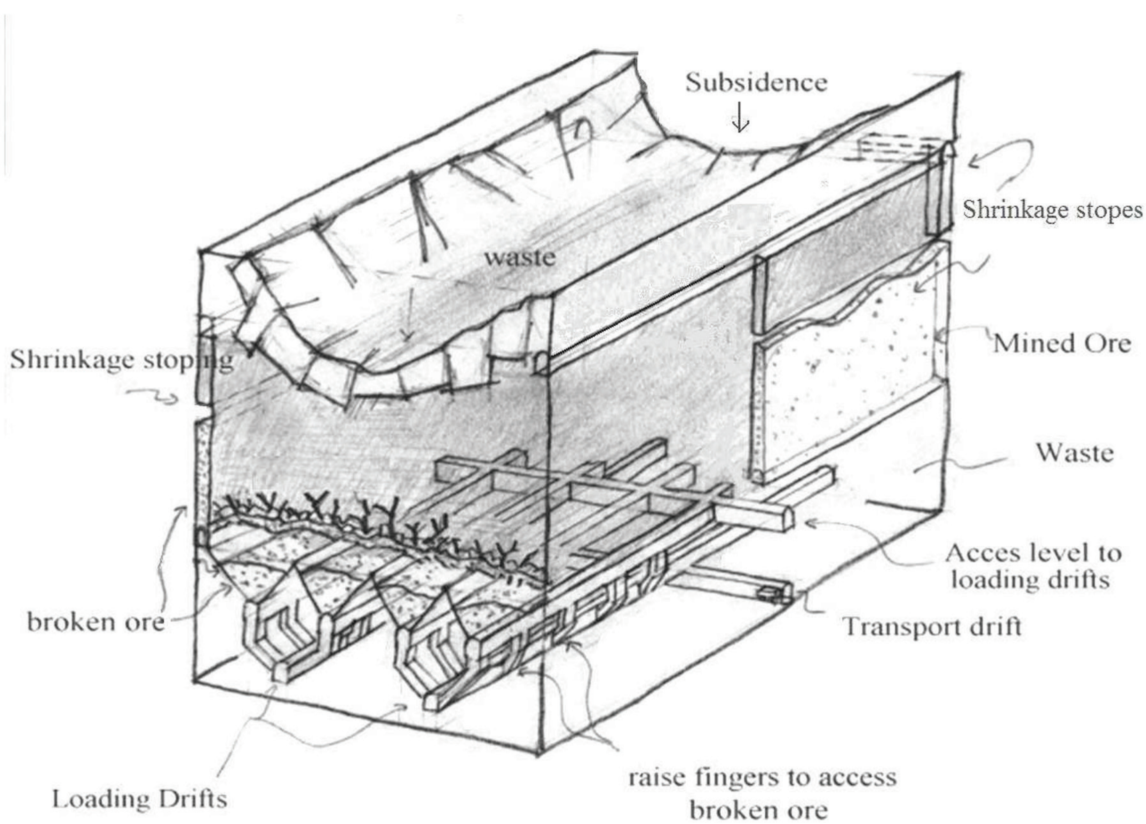

Figure 8 — Block caving method sketch (A. Nieto).

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

face openpit mines both in terms of unit costs and production rates (Folinsbee et al., 1981). Because of this, block caving is ideally suited for mining massive deposits with large vertical extents. Also, recoveries are very high and mine health and safety are excellent. The permanent workings established in the development phase of block caving must last the entire life of the mine, so they are designed with very high factors of safety and are well maintained throughout the mine life.

Some disadvantages include a complete lack of flexibility and selectivity during extraction, massive surface subsidence

Table 25 — General approach for mining method selection based on key deposit indicators KDIs (modified after Hartmann and Mutmansky, 2002).

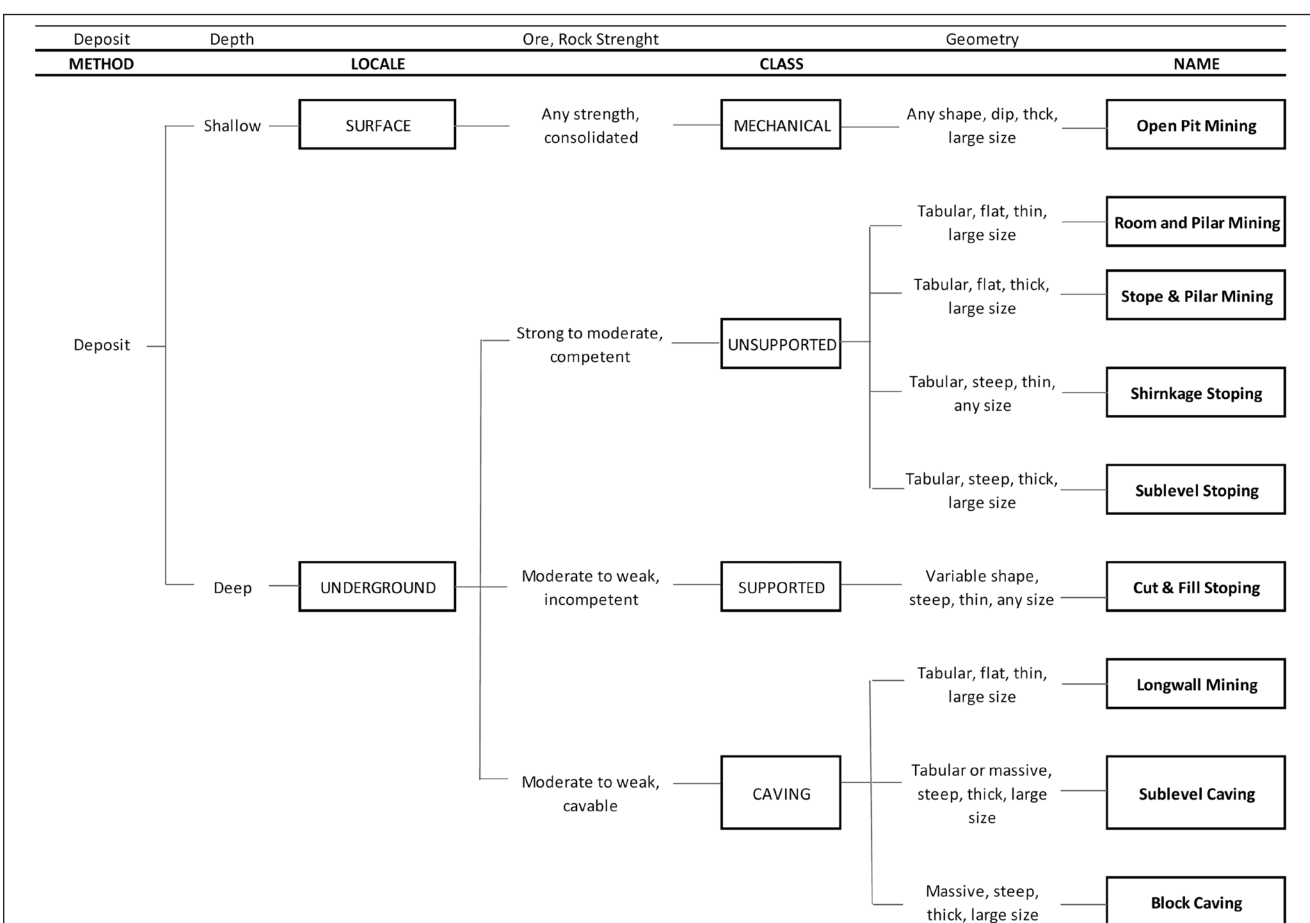

Table 26 — Key Deposit Indicator (KDI) attributes favorable to underground mining methods (modified after Hartmann and Mutmansky, 2002).

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		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		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		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		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		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		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		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		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																			

Table 27 — Case study, field data key deposit indicators (KDIs).

Key deposit indicators (KDIs)	Description	KDI value
Ore strength	7,000 psi	1
Rock strength	14,500 psi	2
Deposit shape	tabular	1
Deposit dip	5°	1
Deposit size--thickness	thin	1
Ore grade	moderate	2
Ore uniformity	fairly uniform	3
Depth	shallow to moderate	2

and high dilution. However, these attributes are rarely significant factors, since the ore bodies are generally low-grade and extremely large; predictable instances of dilution and a lack of selectivity make little difference in the long run. The most substantial disadvantage is the enormous capital investment and development time associated with block caving. Both the cost and duration of development work are much greater than any other underground mining method. Dozens of machines and years of work are necessary to excavate the extensive and complex network of openings below the ore body. However, once the development is completed and caving is initiated, negligible amounts of future development are necessary. The primary advantages and disadvantages of block caving are summarized in Table 23.

Case study, summary and conclusions

As discussed in this paper, the underground mining methods in use today are highly varied and have diverse advantages and disadvantages associated with them (Hartman and Mutmansky, 2002). Table 24 summarizes and gives those key mining indicators (KMIs) used in the mining methods discussed in this paper. Table 25 is a flowchart showing the progression of method selection based on depth, rock strength, and geometry (Hartman and Mutmansky 2002). This describes the general strategy of the logical path undertaken to eliminate unsuitable methods when using KDIs and before comparing the KMIs, advantages and disadvantages of each mining method being considered. Table 26 summarizes the favorable Key Deposit Indicators (KDIs) for each underground mining method and their nominal values based on a 1 to 4 nominal value scale.

A case study to support and illustrate the method selection process is given in Table 28. The selection process is relatively simple and starts by defining the eight KDIs previously discussed in this paper. The eight KDIs, as shown in Table 27, must be previously defined by geologists and mining experts from data gathered at the mine site.

As seen in Table 27, field data is translated to nominal KDI values on a scale of 1 to 4, as mentioned in the discussion of KDIs given in the first section of this paper. Once KDI values are defined, Table 26 must be completed by adding the nominal field data values given in Table 27 to the second column labeled “Field data KDIs.” Once the field data KDIs column has been completed in Table 28, the selection process continues, by comparing each of the eight field data KDI values to the favorable KDI values given for each mining method. Every field data KDI matching one of the mining method favorable KDIs, as seen in Table 28, will count as one “hit.” The total number of “hits” counted in each method (maximum eight hits per method) is recorded in the bottom row of Table 28. By

Table 28 — Case study, key deposit indicator (KDI)-based method comparison table.

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	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	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	1	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	1	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	1	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	2	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	2	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	**8**		**8**		**6**		**3**		**4**		**4**		**4**		**7**		**4**		**5**

reviewing the total number of hits for each method, all of the underground mining methods are ranked in order of favorability.

In this hypothetical case study based on the field data KDIs shown in Table 27, the mining method with the most hits is room-and-pillar, having the maximum possible score of eight hits. Longwall is ranked second with seven hits, stope-and-pillar third with six hits, etc. The resultant ranking serves as a preliminary reference to select a group of feasible mining methods. Once a group of feasible methods has been identified (in this case, room-and-pillar and longwall), Table 24, which describes the KMI performances of every mining method, may be used to complement the selection process by choosing the method which best matches the expected operational productivity.

The process of selecting the optimum mining method for a given deposit is complex and requires extensive collection of geological, metallurgical and mining related data. In addition to the analysis of multiple alternatives, a thorough understanding of the sociopolitical setting, pertinent environmental concerns and applicable regulations is critically important. Besides the substantial investment of time and money in any new mining endeavor, selecting the best mining method for a deposit is one of the single most critical steps to ensuring a successful operation.

This paper has discussed the primary key deposit indicators (KDIs) and the key mining method performance indicators (KMIs) involved in the process of mining method selection. Mineable ore deposits exist in all shapes and sizes and no two are alike. Thus, the best method selection process is not always evident. However, there are several key tasks which should always be undertaken during method selection for any ore deposit. The first step is to identify those methods which are unsuitable for mining the ore body. These will not be considered at any point during the more detailed evaluation. A parallel second step is to identify pertinent economic, environmental or political factors which may eliminate remaining methods. For example, the deposit may be located near communities which cannot be affected by subsidence, the capital structure of a mining group or corporation may prevent significant initial development costs, or the environmental effects associated with a method do not comply with local or national regulations.

After the second round of eliminating incompatible methods, multiple alternatives may still exist. The appropriate process for distinguishing between them is twofold: first, a comprehensive economic analysis of all suitable methods should be conducted; second, the intangible elements, such as production flexibility, of the methods should be documented and evaluated to determine their merit. The latter will only be necessary if the financial properties of two mining methods are very similar. It is important to note that a mining method more suited to the deposit's characteristics may be less economical than a different method. If this is the case, the less costly method will always be selected. Also, the production requirements must always be considered during the selection process, since some methods are simply not capable of outputs beyond a certain range. Additionally, rock mechanic properties and ground conditions are likely to change throughout the deposit. The chosen mining method must be safe and profitable in all possible scenarios. Finally, always conduct a due diligence and a prefeasibility analysis before actual development is initiated. This preventive technical and feasibility analysis of the mine will anticipate future constraints during the production stage. To substantiate a given selection method, it is imperative to evaluate multiple alternatives by defining to the finest degree possible every deposit and method indicator based on all available data and good knowledge of every factor and variable involved.

Acknowledgments

Alek Duerksen, a mining engineering graduate student, has been instrumental in the compilation of this study. I would like to thank Alek, as well as the referenced authors mentioned below, for their contribution to this paper.

References

Bibb, T.C., and Hargrove, K.H. 1992, "Coal mining: method selection," Sec. 21.4, *SME Mining Engineering Handbook*, 2nd ed., edited by H. L. Hartman, Littleton, CO: Society for Mining, Metallurgy and Exploration, pp. 1854-1866.

Bluekamp, P.R., 1981, "Block cave mining at the Mather Mine," *Design and Operation of Caving and Sublevel Stoping Mines*, edited by D. R. Stewart, New York: SME-AIME, pp. 321-327.

Brackebusch, F.W., 1992a, "Underground mining: unsupported methods," Sec. 19.0, *SME Mining Engineering Handbook*, 2nd ed., edited by H. L. Hartman, Littleton, CO: Society for Mining, Metallurgy and Exploration, pp. 1741-1748.

Brackebusch, F.W., 1992b, "Cut-and-fill stoping," Sec 19.1, *SME Mining Engineering Handbook*, 2nd ed., edited by H. L. Hartman, Littleton, CO: Society for Mining, Metallurgy and Exploration, pp. 1743-1748.

Bruce, C., 1982, "Ore body evaluation," in *Underground Mining Methods Handbook*, edited by W. A. Hustrulid, New York: SME-AIME, pp. 3-16.

Buchan, G., 1998, "Long panels for longwall mining at Cyprus Twentymile Coal," *Mining Engineering,* Vol. 50, No. 12, pp. 21-27.

Bullock, R.L., 1982, "General mine planning," *Underground Mining Methods Handbook*, edited by W. A. Hustrulid, New York: SME-AIME, pp. 113-137.

Cokayne, E.W., 1982, "Sublevel caving: introduction," *Underground Mining Methods Handbook*, edited by W. A. Hustrulid, New York: SME-AIME, pp. 872-879.

Erickson, A.J., 1992, "Geologic interpretation, modeling, and representation," Sec. 5.5, *SME Mining Engineering Handbook*, 2nd ed., edited by H. L. Hartman, Littleton, CO: Society for Mining, Metallurgy, and Exploration, pp. 333-343.

Farmer, I., 1992, "Room-and-pillar mining," Sec. 18.1, *SME Mining Engineering Handbook*, 2nd ed., edited by H.L. Harman, Littleton, CO: Society for Mining, Metallurgy, and Exploration, pp. 1891-1701.

Filas, B., 1997, "Coal," *Mining Environmental Handbook*, edited by J. J. Marcus, London: Imperial College Press, pp. 569-598.

Folinsbee, J.C., and Clarke, R.W., 1981, "Selecting a mining method," *Design and Operation of Caving and Sublevel Stoping Mines*, edited by D. R. Stewart, New York: SME-AIME, pp. 55-66.

Gentry, D.W., and O'Neil, T. J., 1984, *Mine Investment Analysis*, New York: SME-AIME, 502 pp.

Hartman, H.L., and Mutmansky, J.M., 2002, *Introductory Mining Engineering*, 2nd ed., New York: John Wiley & Sons Inc., 570 pp.

Hartman, H.L., Mutmansky, J.M., Ramanu, R.V., and Wang, Y.J., 1997, *Mine Ventilation and Air Conditioning*, 3rd ed., New York: John Wiley & Sons Inc., 730 pp.

Haycocks, C., 1992, "Stope-and-pillar mining," Sec. 18.2, *SME Mining Engineering Handbook*, 2nd ed., edited by H.L. Hartman, Littleton, CO: Society for Mining, Metallurgy, and Exploration, pp. 1702-1711.

Haycocks, C., and Aelick, R.C., 1992, "Sublevel stoping," Sec. 18.4, *SME Mining Engineering Handbook*, 2nd ed., edited by H. L. Hartman, Littleton, CO: Society for Mining, Metallurgy, and Exploration, pp. 1717-1731.

McPherson, M.J., 1993, *Subsurface Ventilation and Environmental Engineering*, London: Chapman and Hall, 905 pp.