ABSTRACT

A review of the most widely used global extraction sequences in sublevel is undertaken. The review includes techniques used to extract massive as well as single or multiple steeply dipping tabular orebodies. The paper also deals with thick flat lying orebodies suitable for open stoping. Techniques used to minimize the effect of stress re-distributions on a global scale are discussed for all the extraction sequences analyzed.

INTRODUCTION

One of the limiting factors affecting the design of an underground excavation is the maximum void space that a rockmass can sustain without failure. This failure may take place as a function of either movement along planes of weakness, or through a combination of intact rock failures and geological discontinuities. In most orebodies suitable to open stoping, the volume that may be safely excavated, such that stope wall failures are avoided, is many times smaller than the orebody itself. Consequently, a series of individual stopes must be excavated to achieve full orebody extraction.

One of the most important tools that a design and planning engineer has for controlling the overall behaviour of a rockmass is the extraction sequence of the stopes contained within a given area of an orebody. Extraction sequences are fundamental to achieve production targets safely and economically throughout a stoping life. In most underground mines, a number of sources in various stages of development, production and filling are being extracted at anyone time. Stopping sources are likely to be scheduled from a number of locations and extraction methods.

In cases where fill is not used, the main concern is the sequencing of the stopes such that early over stressing of permanent pillars is avoided. When fill is used, a number of extraction strategies are available to optimize pillar recovery. In general a stoping sequence is driven by ore grade requirements, operational issues such as existing development and fill availability as well as induced stress considerations. A technically sound strategy is to avoid creating blocks of highly stressed rock within an orebody. This can be achieved by retreating stopes to an orebody abutment instead of creating pillars located within central orebody areas. In general, an overall stope extraction sequence is influenced by the nature of the orebody in question.

EXTRACTION SEQUENCES IN MASSIVE OREBODIES

Massive orebodies can be extracted using multiple stopes (primary, secondary and when required tertiary) in conjunction with mass blasting techniques and cemented fill. A number of sequencing options can be used including temporary rib, crown and transverse pillars, strike slots with continuous or discontinuous advance and chequer board sequences. Each overall extraction sequence can be engineered to manage the in-situ stress re-distributions on a global scale. Ideally, the initial stopes are extracted within a chosen area of an orebody and subsequent stopes are retreated systematically towards orebody abutments taking into account the stress re-distributions, production tonnages requirements and access constraints.
Temporary rib, crown and transverse pillars

One extraction option used in extremely competent rock masses is to mass blast secondary stopes into adjacent primary stopes to create very large, but stable openings. At Mount Charlotte orebody top down mining was implemented by mining one or two stopes along the strike followed by mass blasting of adjacent rib and crown pillars allowing unconsolidated rock fill to cascade from above onto the broken ores as shown in Figure 1. Ore was extracted from drawpoints, located at the bottom of the stopes, and mucking stopped when dilution from the rock fill became excessive. This procedure was repeated along a particular stoping block until all ore was mined. Stoping then started on the immediate lower block on a similar fashion, and fill (dry waste rock) was continually added at a surface glory hole. Pillar failures, arching of crowns, blasthole closure and fault movement were experienced with progressive stoping block depth at Mount Charlotte (Ullah, 1997).

![Figure 1. Section view showing stoping blocks and details of top down extraction sequence at Mount Charlotte (After Ullah, 1997)](image)

In order to increase recovery and achieve stability, the resulting voids can either be filled using consolidated fill or unconsolidated fill with the individual stopes separated
by rib (longitudinal) and transverse pillars (See Figure 2). The latter option leaves a high proportion of ore tied up in the rib and transverse pillars, and methods such as sublevel caving retreat have been used to achieve complete recovery of these pillars (Alexander and Fabjanczyk, 1982).

Figure 2. Plan view showing rib and transverse pillars used to extract the massive 1100 orebody – Mount Isa Mines (Alexander and Fabjanczyk, 1982).

Slots with continuous or discontinuous advance

The concept of a discontinuous strike slot for a 12 stope extraction sequence is shown in Figure 3. Assuming the main principal stress to be normal to the long axis of the orebody, the primary secondary and tertiary stopes are designed with an overall stress management philosophy consisting of stress shadowing and orebody abutment retreat. Once the strike slot has been completed (stopes 1-4), all the remaining stopes are effectively stress shadowed from the main principal stress. The number on the stopes relates to the extraction sequence and the fill masses are only exposed on a single wall at a time. In addition, sufficient time is allowed for fill curing by carefully sequencing the adjacent stopes. Stopes at the orebody corners are sequenced last, such that cemented fill is not required.
Figure 3. Plan view showing discontinuous strike slot sequence for a massive orebody.

Stress shadowing during stope sequencing occurs when two or more excavations are aligned along a major principal stress trajectory. Stresses re-distribute, and some areas may be stress relieved as the rock lies in the shadow cast by the excavations. In addition, stress may be intensified in other areas, depending upon the distance between the excavations (See Figure 4). Consequently, in order to relieve stress at the early stages of an extraction sequence suggests that either transverse pillars or discontinuous transverse/strike slots should be avoided, as stress concentrations are likely to develop within those geometries.

Figure 4. Plan view showing stress shadowing across a series of stopes.
At the Creighton Mine in Canada, a series of central stopes were extracted adjacent to each other to form a continuous slot within the initial mining block in order to create a stress shadow for the remaining stopes (See Figure 5). In order to form a continuous strike slot, the fill from the initial stope must be cured before extraction of the immediately adjacent stopes can proceed. Production from the first three stopes is slowed by the requirements to not expose the initial fill mass simultaneously in both sides. This means that the third stope within the strike slot must wait until the second stope fill mass has cured. However, later on the extraction sequence (stopes 7, 8, 10 & 11) are sequenced to expose fill masses in both sides as shown in Figure 5. A better alternative for stope sequencing is shown conceptually before in Figure 2, where the fill masses are exposed on a single surface and the adjacent stopes sequenced to provide enough time for the filled stopes to cure.

Figure 5. Plan view showing continuous stoping sequence (After Trotter, 1991).

**Chequer board extractions**

Another alternative for extraction of massive orebodies is to adopt a chequer board pattern of extraction that starts with primary stopes filled with consolidated fill followed by secondary and tertiary stope extraction of stope pillars having multiple fill mass exposures. The stoping front can either move longitudinally or adopt a continuous retreat strategy depending upon the level of in-situ stress and the production tonnage requirements. Figure 6 shows the massive 1100 orebody at Mount Isa Mines, in which a north to south global sequence has continuously stepped out to access primary stoping blocks. The extraction was designed with large, 40m by 300-400m east-west transverse pillars for access, ventilation and services (Grant and DeKruijff, 2000).
The advantages of a properly designed chequer board extraction sequence includes stable primary stopes which must be timely tight filled to provide support to the remaining stopes and crown pillar (Alexander and Fabjanczyk, 1982). A disadvantage is the large amount of ore tied up within the remaining tertiary stope pillars, where localized stope design can be complex and a function of existing development and the number of fill exposures as mine life progresses. A chequer board sequence is dependent upon successful mass blasting practices and the development of stable fill masses that provide support to adjacent rock masses with minimal dilution during multiple fill exposures.

EXTRACTION SEQUENCES IN STEEPLY DIPPING OREBODIES

In the case of steeply dipping and relatively narrow orebodies, the most common orebody access is via crosscuts off access drives that are connected to ramps usually located in the footwall of the orebodies. The crosscuts intersect the orebodies from footwall to hangingwall and ore drives are developed from the crosscuts along the strike of the intersected orebodies.

Top down or bottom up bench stoping

In cases where bench stoping is used (Villaescusa et al, 1994), the stopes can be retreated towards the crosscuts using either a top-down or a bottom-up sequence as shown in Figure 7.
A top down bench stope extraction sequences usually requires permanent rib pillars to minimize dilution between individual stopes along strike. In addition, a series of crown pillars maybe required to control overall stability, dilution and to isolate any unconsolidated fill that may be introduced into the upper stopes as extraction progresses downward (See Figure 8). A bottom up sequence requires fill in order to provide a working floor as the extraction proceeds upward. The need for a crown pillar is minimized by the use of rib pillars along the strike of the orebody and the beneficial impact of the fill masses (Villaescusa and Kuganathan, 1998).
Flexibility and productivity in bench stoping can be greatly enhanced with the introduction of two access crosscuts as shown in Figure 9. Although costly, this configuration increases tonnage and allows for an optimized stress re-distributions as the initial stopes can be located in the centre of the mining block with subsequent retreat towards the abutments.

![Diagram of double access to bench stoping](https://example.com/diagram.png)

Figure 9. Longitudinal view of a sequence of extraction with double access.

**Primary and secondary stope extraction**

In cases where multiple lift sublevel stoping is used to mine relatively wide orebodies, a series of primary and secondary stopes can be designed for extraction along the strike of a deposit. Stope extraction in multiple levels increases production and flexibility. Primary stopes are excavated smaller than secondary stopes (pillars) to minimize the use of cemented fill and the secondaries are designed large enough to enable safe recovery between primary stopes. This method has been applied widely in single tabular orebodies such as the Lead Mine in Mount Isa Mines in Queensland and the Kanowna Belle gold mine in Kalgoorlie. Figure 10 shows the stoping sequence for a mining block where the extraction sequence was based upon a primary stope extraction and filling with consolidated fill, before the secondary pillars were extracted. The numbers on the figure refer to the stope extraction sequence.
In excellent rock mass conditions, a pillar stope can also be mass blasted into the void formed by one (forming a doublet) or two (forming a triplet) adjacent primary stopes as shown in Figure 12 (Bywater & Fuller, 1983).

In other cases, stope extraction in conjunction with unconsolidated fill and separated by permanent pillars can be used to extract low grade orebodies (See Figure 11). In such cases the value of the ore does not justify the use of cemented fill and the stope retreat is towards the permanent pillars. The dates on Figure 11 refer to an actual extraction sequence, which is advancing to the central portion of the orebody away from the abutment, and likely to concentrate stresses on mine infrastructure such as decline access which in this case are centrally located.

Figure 10. Longitudinal view of a complete stoping block extraction using primary and secondary stoping geometries.

Figure 11. Permanent pillars left between primary stopes showing extraction dates.
Figure 12. Long section view of 8 & 5 orebodies at Mount Isa Mines showing layout and extraction sequence (After Bywater & Fuller, 1983).

The main advantages of primary and secondary stoping sequences are an initial high degree of flexibility and productivity and low cost during primary stoping. The overall cost is minimized by the use of unconsolidated fill within the secondary stopes. A disadvantage is that stress re-distributions may cause rock mass damage within secondary pillars late in the extraction sequence. The effects of stress can be minimized by avoiding undercutting of individual stopes and by mass blasting those highly stressed regions within a stoping block. Multiple lift primary and secondary stopes have been used very successfully to achieve complete extraction with minimal dilution within the steeply dipping lead orebodies at Mount Isa Mines (Bywater et al, 1985).

PILLARLESS, CENTRE-OUT SEQUENCES

Pillarless, centre-out mining sequences have been proposed to eliminate the need for secondary stopes (Morrison, 1995). The perceived advantage from such sequences is the slow rate of convergence of the host rocks as extraction from small stopes proceeds from the centre towards the orebody abutments (See Figure 13). It is argued that the slow rate of convergence is likely to minimize the magnitude of any local seismic events. In addition, the small single lift stopes may reduce the amount of released seismic energy. Such pillarless stoping sequence was used in Block 3, at the Golden Giant Mine in Canada and named pyramid retreat, as mining progresses in a triangular shape (Potvin and Hudyma, 2000). The Golden Giant pyramid retreat sequence is illustrated in Figure 14.
Although continuous advancing stoping is a good idea on paper, it is very difficult to implement in practice, especially when fill is introduced into the system. The overall productivity is severely constrained by the individual stope cycle times as stopes must be mined, filled and cured before an adjacent stope can be extracted. With active mining on a large number of sub-levels, substantial development, scheduling and logistic challenges are experienced throughout the stoping block (Potvin and Hudyma, 2000). As an example, the extraction of stope #6 Figure 14, although very early in the stoping sequence, requires seven operational sublevels.
A pillarless stoping sequence requires rapidly curing cemented backfill with minimal drainage delays in all the stopes, which may increase the operating cost. In addition, tight backfill of the stope crowns is rarely achieved, especially when cemented rockfill is used (See Figure 15). Introducing hydraulic fill to achieve tight fill is time consuming, expensive and sometimes not practical. Consequently, large crowns, which require extensive rock reinforcement, are exposed by the method. In some cases, damage from stress concentration (cracking through intact rock or geological structures) at each stope brow is also experienced. This may create difficulties during drilling and blasting, and make the reinforcement schemes inefficient, as very large slabs parallel to the stope edges are released.
Primary and secondary 1-4-7 and 1-5-9 stoping sequences

A compromise to a pillarless sequence is to use a general triangular retreat shape but using a short lift primary and secondary stope arrangement. This system has been implemented at the Williams mine in Canada and is illustrated in detail on Figure 16. This methodology allows for a number of primary stopes to be mined simultaneously, hence increasing the productivity within a mining block. Because of the detrimental effects of the stress re-distributions on the pendant pillars formed in the sequence, secondary pillar stopes must be recovered as early as possible in the extraction sequence. In general, no more than two sublevels are mined ahead of a pillar before recovering it and both sides of a pillar can not be mined simultaneously (Potvin and Hudyma, 2000):
A variation to this method has been implemented for the George Fisher orebody in Australia, where a 1-5-9 stoping sequence has been selected for extraction (Neindorf and Karunatillake, 2000). Stopes 1-5-9 are extracted as two lift primaries and filled with consolidated fill (See Figure 17). This is followed by another set of primary two lift stopes (3-7-11), also filled with consolidated fill. Following the fill cure within the primary stopes 1-3-5-7-9-11, a set of single lift stopes (2-6-10) is then extracted and filled with unconsolidated fill. This creates a pendant pillar, which has many degrees of freedom and relies on the fill support from the primary stopes for stability. Finally, the single lift stopes 4-8-12 are extracted and filled with unconsolidated fill before the entire sequence is repeated up-dip. The extraction of stopes 4-8-12 also creates pendant pillars.

![D orebody 1, 5, 9 Sequence](image)

Figure 17. Longitudinal section view of George Fisher orebody (Neindorf and Karunatillake, 2000)

A disadvantage of a 1-5-9 (or 1-4-7) extraction sequence using short lift stopes is their inefficient stope mucking characteristics. The method effectively requires (a bottom up) moving drawpoint sequence (even in primary stopes), which necessarily follows the vertical retreat of the stopes as shown in Figure 18. This implies that mucking is carried out in areas that had previously been subjected to stress distribution and stope blasting at the stope crowns. Each stope access becomes a stope drawpoint and a significant amount of reinforcement using cablebolting is required in all the stopes access and exposed backs. Reinforcement can be largely inefficient within the bottom of pendant secondary pillars where remote mucking is required for 100% of the tonnage. Furthermore, additional footwall development access in waste may be required on each sublevel, as more than one access may be required for effective mucking of each individual stope.
MULTIPLE STEEPLY DIPPING OREBODIES

The extraction sequence for multiple, steeply-dipping parallel orebodies, which are accessed by a common crosscut off a footwall ramp, requires additional consideration as the extraction of the orebodies at any particular location is inter-related. The extraction of a stope in a series of closely spaced orebodies is likely to influence the other orebodies in the sequence. In the case of orebodies separated by ‘thin’ pillars (i.e. thickness between orebodies less than half the stope height) the stope hangingwall conditions are usually best protected by extracting the orebodies from footwall to hangingwall, filling after each stope, before extracting the following orebody. A permanent crosscut is required to access the hanginwall orebodies following extraction of the footwall orebody.

The extraction of the closely spaced orebodies shown in Figure 19 is aimed to minimize the effects that stopes might have on each other. The stopes interact as the block extraction sequence advances up-dip towards a region of high induced stress below a mining block extracted earlier. Within this sequence the footwall stopes are always extracted one or two lifts ahead of the hangingwall stopes, effectively creating a ‘leading’ stope geometry. The sequence is devised to stress shadow the rest of the stopes in a particular lift from excessive induced stress damage, as well as to minimize the effects of blasting, as most hangingwalls are mined in undisturbed ground. In some cases, the leading orebodies may experience stress-related crown damage, and adequate rock reinforcement must be provided to minimize failures. Alternatively, the leading orebody must be selected following considerations of rock mass strength, orebody width and orebody grade. In cases where very high stress is experienced it may be advisable to select a narrow orebody (located anywhere on the sequence) as the leading orebody.

Figure 18. Isometric view of single lift sublevel stoping (Potvin et al, 1989).
Figure 19. Footwall stope extracted ahead of other stopes in the same lift (Villaescusa, 1997).

EXTRACTION SEQUENCES IN SHALLOW DIPPING OREBODIES

Large tabular orebodies where the dip angle does not allow the flow of broken ore utilizing gravity can be extracted using a type of sublevel stoping called uphole retreat panel stoping (Kaesehagen and Boffey, 1998). Typically, an orebody can be divided into panels, running parallel to the strike of the orebody and defined down dip as shown in Figure 20. The stopes are extracted by developing a footwall extraction drive where drilling, blasting and mucking operations can be carried out. The stopes are accessed from a footwall drive, with a slot established at the far end of the panels, and the stopes are progressively blasted retreating back to the access end of a panel. Cablebolt reinforcement is provided from the hangingwall drives located within the primary stopes. In addition, permanent pillars can be left within the secondary stopes to provide additional hangingwall support.
Flat lying orebodies can also be extracted by individual stopes in conjunction with cablebolting drives and mine fill operations. The stopes are extracted by developing a trough undercut horizon in waste to allow the flow of ore to the stope drawpoints. Downhole drilling is undertaken from a series of hangingwall drives, where cablebolt reinforcement is also provided (See Figure 21). This method results in an increased lead time in stope preparation as well as additional costs, as non-economical material is developed.

The overall stope extraction retreats up-dip and towards the access end of the drilling drives. Experience indicates that only half of the back of a previously extracted stope (down-dip) can be filled effectively. The methodology consists on extracting stopes having either single or double drilling drives, depending upon their location with respect to the orebody abutment and with respect to each other in the extraction sequence. Alternating single and double drilling drives is likely to optimize hangingwall reinforcement, as the extraction progresses up-dip.

CONCLUSIONS

Global extraction sequences in sublevel stoping are fundamental to achieve production targets safely and economically throughout an entire stoping life. For massive orebodies a number of sequencing options can be used including temporary rib, crown and transverse pillars, strike slots with continuous or discontinuous advance and chequer board sequences. For tabular orebodies extraction sequences that use primary and secondary or pillarless approaches can be used. In general, the sequences are driven by the orebody nature and geometry, ore grade requirements, operational issues and induced stress considerations.
REFERENCES


