Cave mining—the state of the art

by D.H. Laubscher*

Synopsis

Caving is the lowest-cost underground mining method provided that the drawpoint spacing, drawpoint size, and ore-handling facilities are designed to suit the caved material, and that the drawpoint horizon can be maintained for the life of the draw. In the near future, several open-pit mines that produce more than 50 kt per day will have to examine the feasibility of converting to low-cost, large-scale underground operations. Several other large-scale, low-grade underground operations will experience major changes in their mining environments as large dropdowns are implemented.

These changes demand a more realistic approach to mine planning than in the past, where existing operations have been projected to increased depths with little consideration of the change in mining environment that will occur. As economics force the consideration of underground mining of large, competent

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Introduction

Cave mining refers to all mining operations in which the orebody caves naturally after undercutting and the caved material is recovered through drawpoints. This includes block caving, panel caving, inclined-drawpoint caving, and front caving. Caving is the lowest-cost underground mining method provided that the drawpoint size and handling facilities are tailored to suit the caved material and that the extraction horizon can be maintained for the life of the draw.

The daily production from cave-mining operations throughout the world is approximately 370 kt per day, with the following breakdown from different layouts:

	kt
Grizzly	90
Slusher	35
LHD*	245
Total	370

* Load–haul–dump units

By comparison, South African gold mines produce 350 kt per day.

In the near future, several mines that currently produce in excess of 50 kt per day from open-pit mines will have to examine the feasibility of implementing low-cost, large-scale underground mining methods. Several cave mines that produce high tonnages from underground are planning to implement dropdowns of 200 m or more. This will result in a considerable change in their mining environments. These changes will necessitate detailed mine planning, rather than the simple projection of current mining methods to greater depths.

As more attention is directed to the mining of large, competent orebodies by low-cost underground methods, it is necessary to define the role of cave mining. In the past, caving has been considered for rockmasses that cave and fragment readily. The ability to better assess the cavability and fragmentation of orebodies, and the availability of robust LHDs, an understanding of the draw-control process, suitable equipment for secondary drilling and blasting, and reliable cost data have shown that competent orebodies with coarse fragmentation can be cave-mined at a much lower cost than with drill-and-blast methods. However, once a cave layout has been developed, there is little scope for change.

Aspects that have to be addressed are cavability, fragmentation, draw patterns for different types of ore, drawpoint or drawzone spacing, layout design, undercutting sequence, and support design.

Table I shows that there are significant anomalies in the quoted performance of different cave operations.

Table I

Quote	Explanation
96% of ore recovered for 100% mineral extraction	Under-evaluation of the orebody and dilution zone
The correct drawpoint spacing, but there has been 200% overdraw with 30% waste dilution entry	A case of highly irregular draw and under-evaluation of the dilution
15% dilution entry in spite of correct drawpoint spacing and uniform fragmentation	Drawpoints being drawn in isolation
Ore from the lower 100 m of the draw column still reporting in the drawpoint, even though 260 m of ore has been drawn	A large range in fragmentation, and irregular, high values in the dilution zone

orebodies by low-cost methods, the role of cave mining will have to be defined. In the past, caving was generally considered for rockmasses that cave and fragment readily. The ability to define cavability and fragmentation, the availability of large, robust load-haul-dump units, a better understanding of draw-control requirements, improved drilling equipment for secondary blasting, and reliable cost data have shown that competent orebodies with coarse fragmentation can be exploited by cave mining at a much lower cost than by drill-and-blast methods.

It is common to find that old established mines, which have developed standards during the course of successfully mining the easy tonnage in the upper levels of the orebody, have a resistance to change and do not adjust to the ground-control problems that occur as mining proceeds to greater depths, or as the rock types change. Mines that have experienced continuous problems are more amenable to adopting new techniques to cope with a changing mining situation. Detailed knowledge of local and regional structural geology, the use of an accepted rockmass classification to characterize the rockmass, and knowledge of the regional and induced stress environment are prerequisites for good mine planning. It is encouraging to note that these aspects are receiving more and more attention.

The Laubscher rockmass classification system that provides both rockmass ratings and rockmass strength is necessary for design purposes. The rockmass ratings (RMR) define the geological environment, and the adjusted or mining rockmass ratings (MRMR) consider the effect of the mining operation on the rockmass. The ratings, details of the mining environment, and the way in which this affects the rockmass and geological interpretation are used to define the cavability, subsidence angles, failure zones, fragmentation, undercut-face shape, cave-front orientation, undercutting sequence, overall mining sequence, and support design.

Factors Affecting Caving Operations

Twenty five parameters that should be considered before the implementation of any cave mining operation are set out in Table II. The parameters in capital letters are a function of the parameters that follow in the same box. Many of the parameters are uniquely defined by the orebody and the mining system, and are not discussed further. The parameters considered later are common to all cave-mining systems and need to be addressed if any form of cave mining is contemplated.

Cavability

Monitoring of a large number of caving operations has shown that two types of caving can occur. These have been defined as stress and subsidence caving.

Stress caving occurs in virgin cave blocks when the stresses in the cave back exceed the strength of the rockmass. Caving can stop when a stable arch develops in the cave back. The undercut must be increased in size, or boundary weakening must be undertaken to induce further caving.

Subsidence caving occurs when adjacent mining has removed the lateral restraint on the block being caved. This can result in rapid propagation of the cave, with limited bulking. Figure 1 illustrates the effect of removing the lateral restraint from block 16 at Shabani. Block 16 had a hydraulic radius of 28 with an MRMR of 64 and a stable, arched back. The adjacent block, no. 7, was caved and resulted in a reduction in the MRMR in block 16 to 56, at which stage caving occurred. For a range of MRMR, Figure 1 illustrates worldwide caving and stable situations.

The stresses in the cave back can be modified to an extent by the shape of the cave front. Numerical modelling can be a useful tool, helping the engineer to determine the stress pattern associated with several possible mining sequences. An undercut face, concave towards the caved area, provides better control of major structures. In orebodies with a range of MRMR, the onset of continuous caving will be based on the lower rating zones if these are continuous in plan and section. This is illustrated in Figure 2B, where the class 5 and 4B zones are shown to be continuous. In Figure 2A, the pods of class 2 rock are sufficiently large to influence caving, and the cavability should be based on the rating of these pods.

All rockmasses will cave. The manner of their caving and the resultant fragmentation size distribution need to be predicted if cave mining is to be implemented successfully. The rate of caving can be slowed down by control of the draw since the cave can propagate only if there is space into which the rock can move. The rate of caving can be increased by a more rapid advance of the undercut, but problems can arise if this allows an air gap to form over a large area. In this situation, the intersection of major structures, heavy blasting, and the influx of water can result in damaging airblasts. Rapid, uncontrolled caving can result in an early influx of waste dilution.

The rate of undercutting (RU) should be controlled so that rate of caving (RC) is faster than the rate of damage (RD):

$$RC > RU > RD.$$

Table II

Parameters to be considered before the implementation of cave mining

CAVABILITY	PRIMARY FRAGMENTATION	DRAWPOINT/DRAWZONE SPACING
Rockmass strength (MRMR) Rockmass structure *In situ* stress Induced stress Hydraulic radius of orebody Water	Rockmass strength (MRMR) Geological structures Joint/fracture spacing Joint condition ratings Stress or subsidence caving Induced stress	Fragmentation Overburden load and direction Friction angles of caved particles Practical excavation size Stability of host rockmass (MRMR) Induced stress
DRAW HEIGHTS	LAYOUT	ROCKBURST POTENTIAL
Capital Orebody geometry Excavation stability	Fragmentation Drawpoint spacing and size Method of draw	Regional and induced stresses Rockmass strength/modulus Structures Mining sequence
SEQUENCE	UNDERCUTTING SEQUENCE (pre/advance/post)	INDUCED CAVE STRESSES
Cavability Orebody geometry Induced stresses Geological environment Rockburst potential Production requirements Influence on adjacent operations Water inflow	Regional stresses Rockmass strength Rockburst potential Rate of advance Ore requirements	Regional stresses Area of undercut Shape of undercut Rate of undercutting Rate of draw
DRILLING AND BLASTING	DEVELOPMENT	EXCAVATION STABILITY
Rockmass strength Powder factor Rockmass stability (drillhole closure) Required fragmentation Height of undercut	Layout Sequence Production Drilling and blasting	Rockmass strength Regional and induced stresses Rockburst potential Excavation size Draw height Mining sequence
PRIMARY SUPPORT	PRACTICAL EXCAVATION SIZE	METHOD OF DRAW
Excavation stability Rockburst potential Brow stability	Rockmass strength *In situ* stress Induced stress Caving stresses Secondary blasting	Fragmentation Practical drawpoint spacing Practical size of excavation
RATE OF DRAW	DRAWPOINT INTERACTION	DRAW COLUMN STRESSES
Fragmentation Method of draw Percentage hangups Secondary breaking requirements	Drawpoint spacing Fragmentation Time frame of working drawpoints	Draw-column height Fragmentation Homogeneity of ore fragmentation Draw control Draw-height interaction Height-to-base ratio Direction of draw
SECONDARY FRAGMENTATION	SECONDARY BLASTING/BREAKING	DILUTION
Rock-block shape Draw height Draw rate—time-dependent failure Rock-block workability Range in fragmentation size Draw-control program	Secondary fragmentation Draw method Drawpoint size Size of equipment and grizzly spacing	Orebody geometry Fragmentation size distribution Fragmentation range of unpay ore and waste Grade distribution of pay and unpay ore Mineral distribution in ore Drawpoint interaction Secondary breaking Draw control
TONNAGE DRAWN	SUPPORT REPAIR	ORE/GRADE EXTRACTION
Level interval Drawpoint spacing Dilution percentage	Tonnage drawn Point and column loading Brow wear Secondary blasting	Mineral distribution Method of draw Rate of draw Dilution percentage Ore losses
SUBSIDENCE		
Major geological structures Rockmass strength Induced stresses Depth of mining		

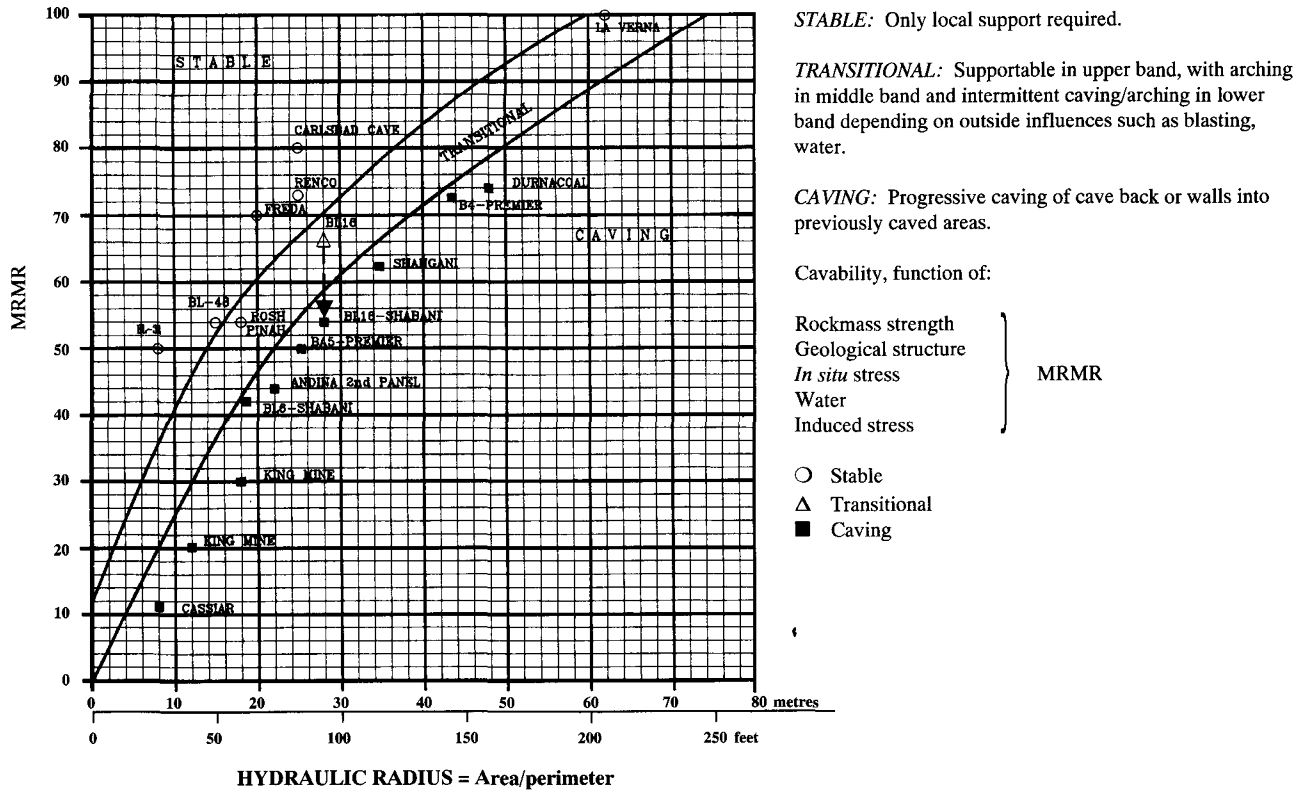


Figure 1—A stability diagram for various mines worldwide

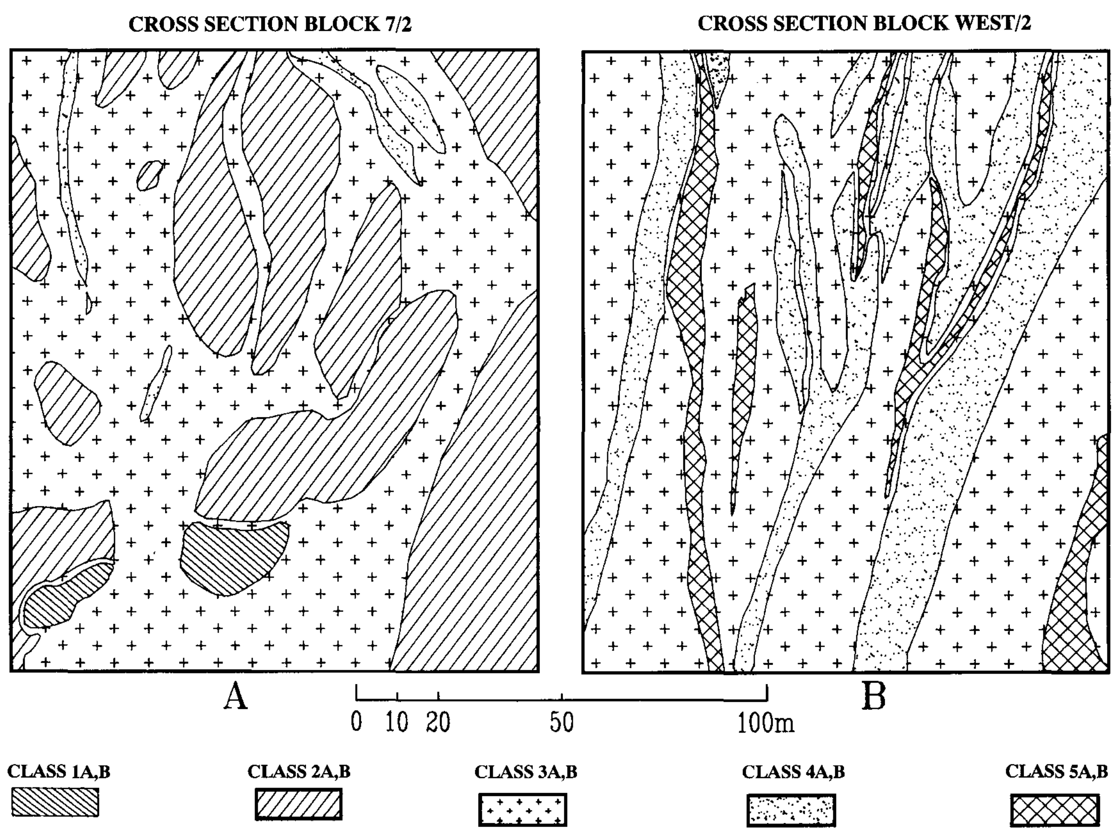


Figure 2—Geomechanics classification data

Good geotechnical information, as well as monitoring of the rate of caving and rockmass damage, is needed to fine-tune this relationship.

Fragmentation

In caving operations, fragmentation has a bearing on the following:

- Drawpoint spacing
- Dilution entry into the draw column
- Draw control
- Drawpoint productivity
- Secondary blasting/breaking costs
- Secondary blasting damage.

The input data needed for the calculation of the primary fragmentation and the factors that determine the secondary fragmentation as a function of the caving operation are shown in Figure 3.

Caving results in **primary fragmentation**, which can be defined as the size distribution of the particles that separate from the cave back and enter the draw column. The primary fragmentation from stress caving is generally finer than that from subsidence caving owing to the rapid propagation of caving in the latter case, with disintegration of the rockmass, primarily along favourably oriented joint sets, and little shearing of intact rock. The orientation of the cave front or back with respect to the joint sets and direction of principal stress can have a significant effect on the primary fragmentation.

Secondary fragmentation is the reduction in size of the original particle that enters the draw column as it moves through the draw column. The processes to which particles are subjected determine the fragmentation size distribution in the particles that report to the drawpoints. A strong, well-jointed material can result in a stable particle shape at a low draw height. Figure 4 shows the decrease in fragmentation for different draw heights and less-jointed (coarse) to well-jointed (fine) rockmasses. A range in rockmass ratings will result in a wide range in fragmentation size distribution as compared with that produced by rock with a single rating, since the fine material produced by the former tends to cushion the larger blocks and prevents further attrition of these blocks. This is illustrated in Figure 2B, in which class 5 and class 4 material is shown to cushion the larger primary fragments from class 3. A slow rate of draw allows a higher probability of time-dependent failure as the caving stresses work on particles in the draw column.

Fragmentation is the major factor determining drawpoint productivity. Experience has shown that 2 m^3 is the largest size of block that can be moved by a 6 yd LHD and still allow an acceptable rate of production to be maintained. In Figure 5 the productivity of a layout using 3,5 yd, 6 yd, and 8 yd LHDs and a grizzly are related to the percentage of fragments larger than 2 m^3. The usage of secondary explosives is based on the amount of oversize that cannot be handled by a 6 yd LHD.

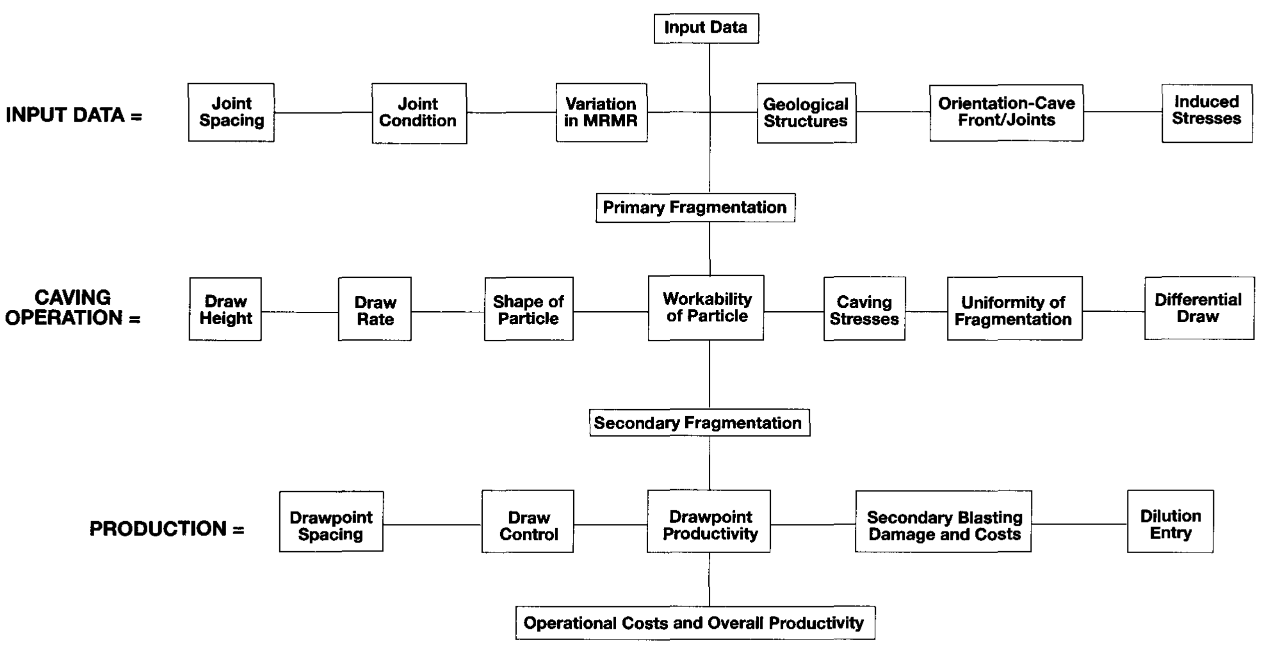


Figure 3—Input data for the calculation of fragmentation

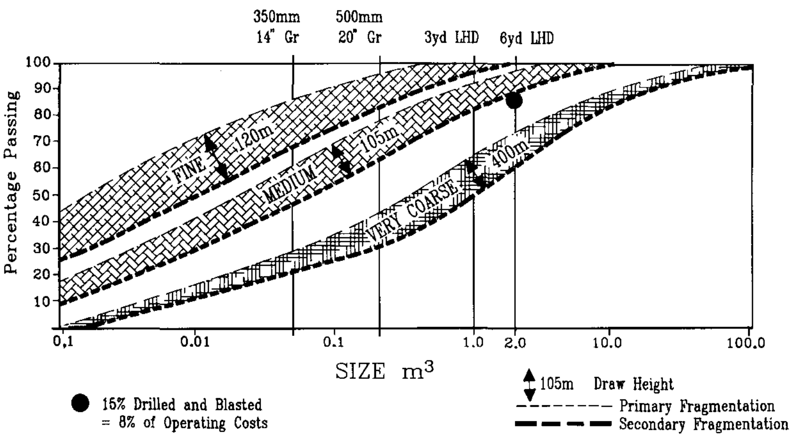


Figure 4—Size distribution of cave fragmentation

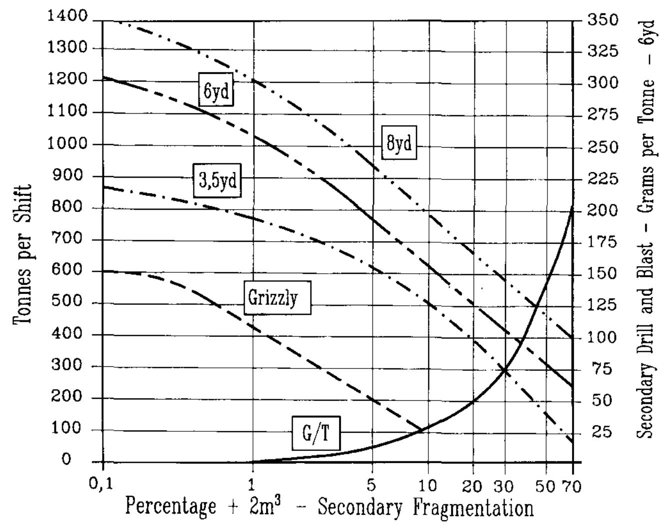


Figure 5—LHD productivity on a round trip of 100 m with 60 per cent utilization

A computer simulation program has been developed for the calculation of primary and secondary fragmentation.

Drawzone Spacing

Drawpoint spacings for grizzly and slusher layouts reflect the spacing of the drawzones because of the close spacing of the drawpoints. However, in the case of LHD layouts with a nominal drawpoint spacing of 15 m, the drawzone spacing can vary across the major apex (pillar) from 18 to 24 m, depending on the length of the drawbell (Figure 6). This situation occurs when the length of the drawpoint crosscut is increased to ensure that the LHD is straight before it loads. In this case, the major consideration, optimum ore recovery, is prejudiced by incorrect usage of equipment or a desire to achieve idealized loading conditions.

Sand-model tests have shown that there is a relationship between the spacing of drawpoints and the interaction of drawzones. Widely spaced drawpoints develop isolated drawzones, with diameters defined by the fragmentation. When drawpoints are spaced at 1,5 times the diameter of the isolated drawzone (IDZ), interaction occurs. The interaction improves as the drawpoint spacing is decreased, as shown in Figure 7. The flow lines and the stresses that develop around a drawzone are shown in Figure 8. The sand-model results have been confirmed by observation of the fine material extracted during cave mining and by the behaviour of material in bins. The question is whether the interactive theory based on isolated drawzones can be wholly applied to coarse material, where arch spans of 20 m have been observed. The collapse of large arches will affect the large area overlying the drawpoint, as shown in Figure 9. The formation and failure of arches lead to wide drawzones in coarse material, so that the drawzone spacing can be increased to the spacings shown in Figure 9. The frictional properties of the caved material must also be recognized. Low-friction material could flow greater distances when under high overburden load, and this could mean a wider drawzone spacing.

There is still a need to continue with three-dimensional model tests to establish some poorly defined principles, such as interaction across major apexes when the spacing of groups of interactive drawzones is increased. Numerical modelling could possibly provide the solutions for the draw behaviour of coarse-fragmented cave material.

Draw Control

The draw-control requirements are shown in Figure 10 and Table III. The grade and fragmentation distribution for the dilution zone must be known if sound draw control is to be practised. Figure 11 shows the value distribution for columns A and B. Both columns have the same average grade of 1,4 per cent, but the value distribution is different. The high grade at the top of column B means that a larger tonnage of dilution can be tolerated before the shutoff grade is reached.

In LHD layouts, a major factor in poor draw control is the drawing of fine material at the expense of coarse material. A strict draw-control discipline is required in that the coarse ore must be drilled and blasted at the end of the shift in which it reported in the drawpoint.

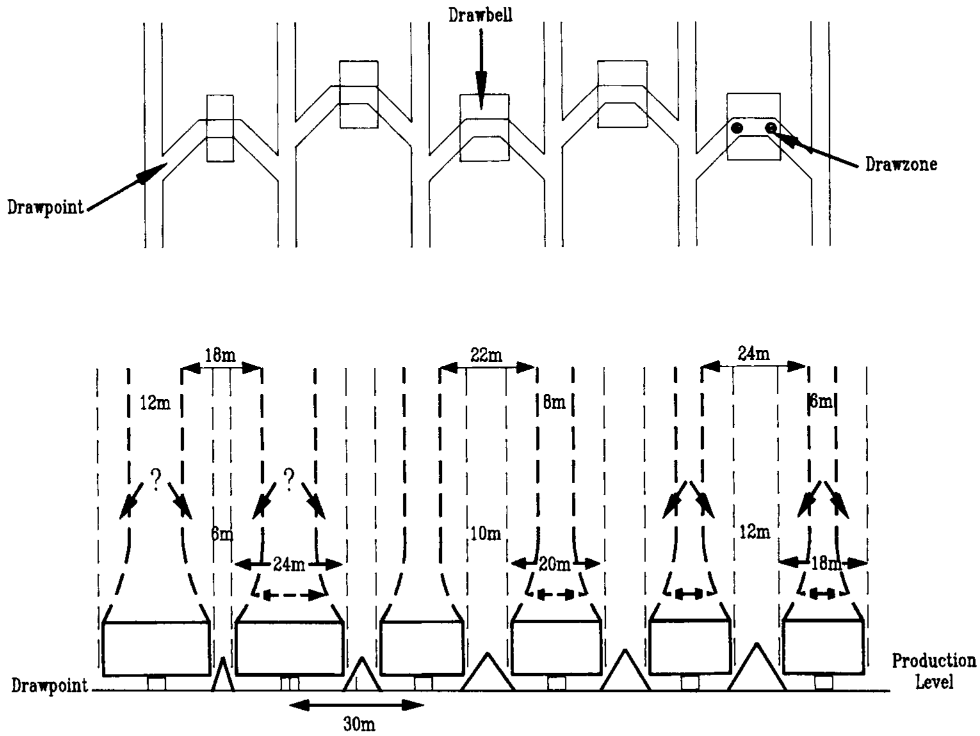


Figure 6—Maximum and minimum drawzone spacing (isolated drawzone = 10 m area of influence = 225 m²)

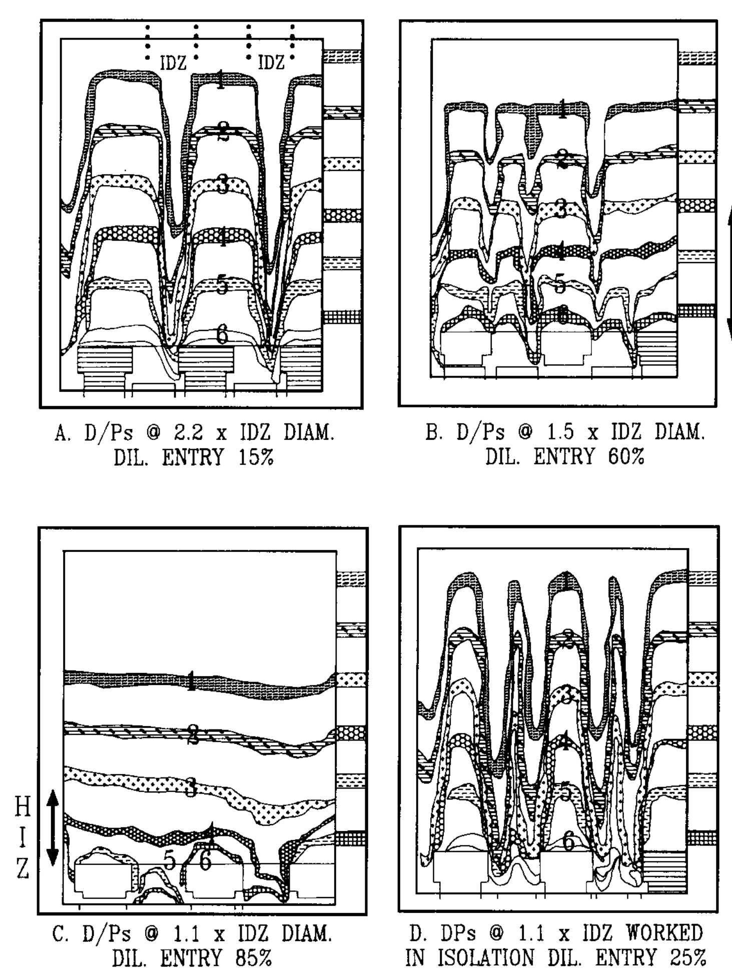


Figure 7—The results of three-dimensional sand-model experiments

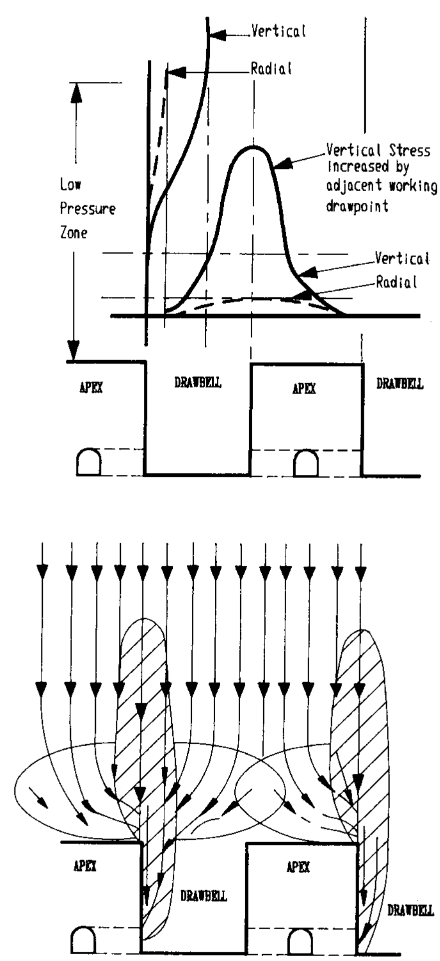


Figure 8—Flow lines and inferred stresses between adjacent working operations

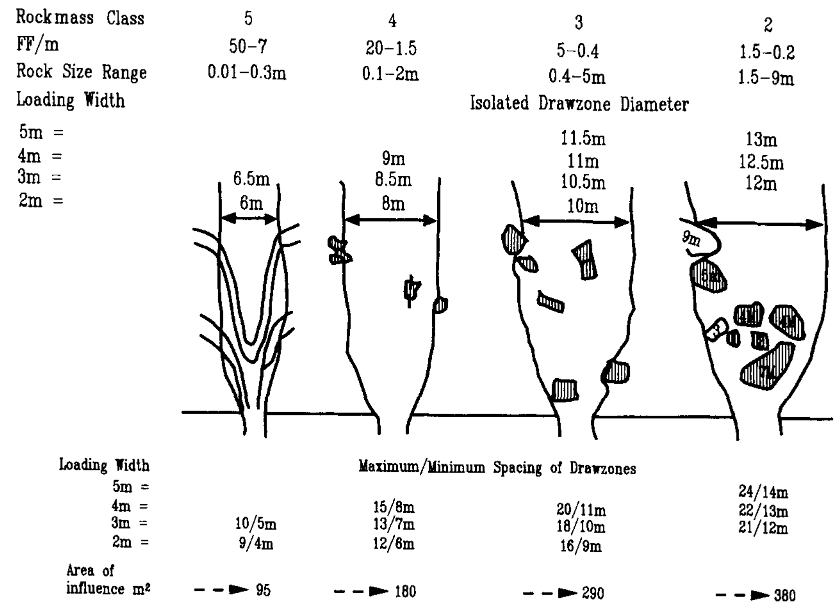


Figure 9—Maximum/minimum spacing of drawzones based on isolated drawzone diameter

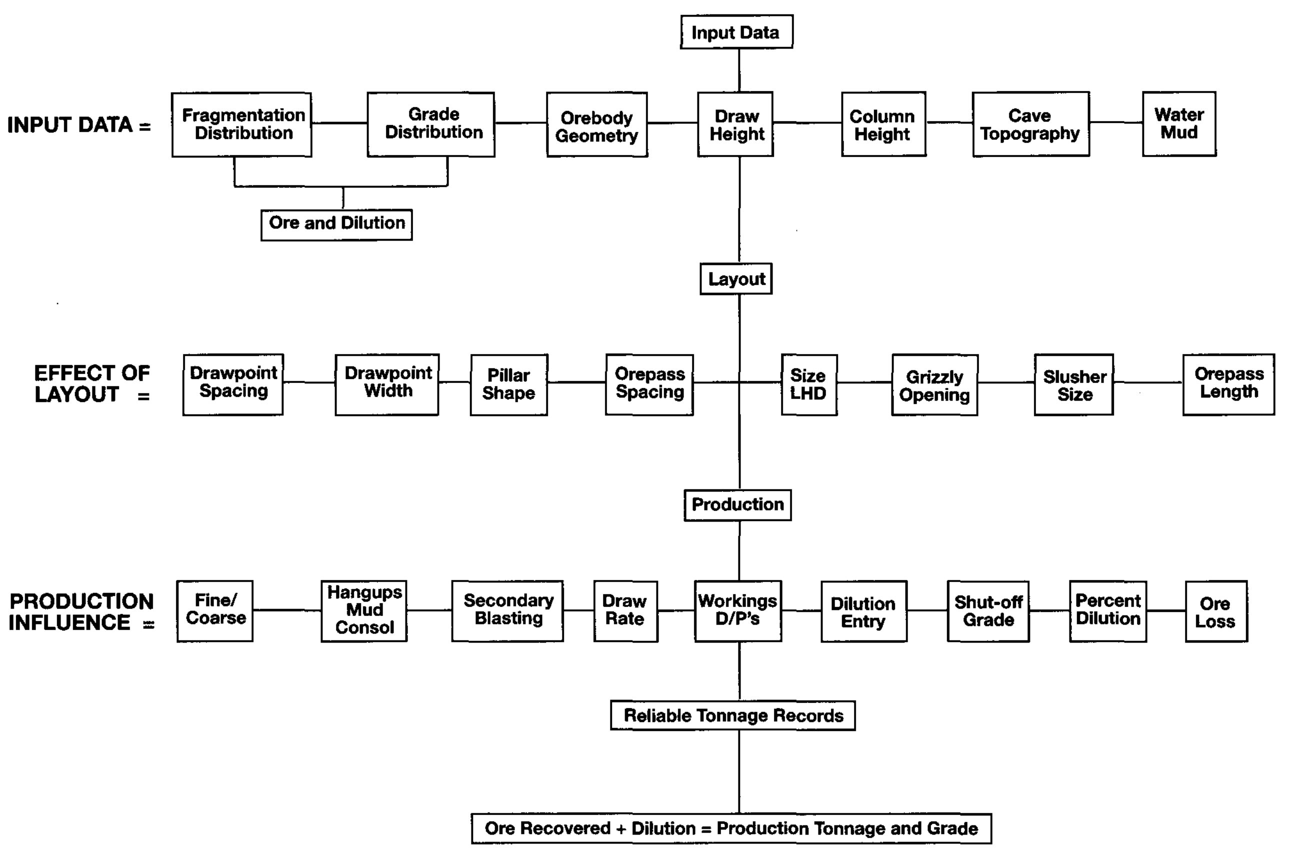


Figure 10—Draw-control requirements

It has been established that the draw will angle towards less dense areas. This principle can be used to move the material overlying the major apex by the differential draw of lines of drawbells so that zones of varying density are created.

Dilution Entry

The percentage of dilution entry is the percentage of the ore column that has been drawn before dilution appears in the drawpoint, and is a function of the amount of mixing that occurs in the draw columns. The mixing is a function of the following:

Table III

Draw control

Objective	Application
Reduce dilution	Calculation of tonnage
Improve ore recovery	Recording of tonnages produced
Avoid damage to pillars	Controlling the draw

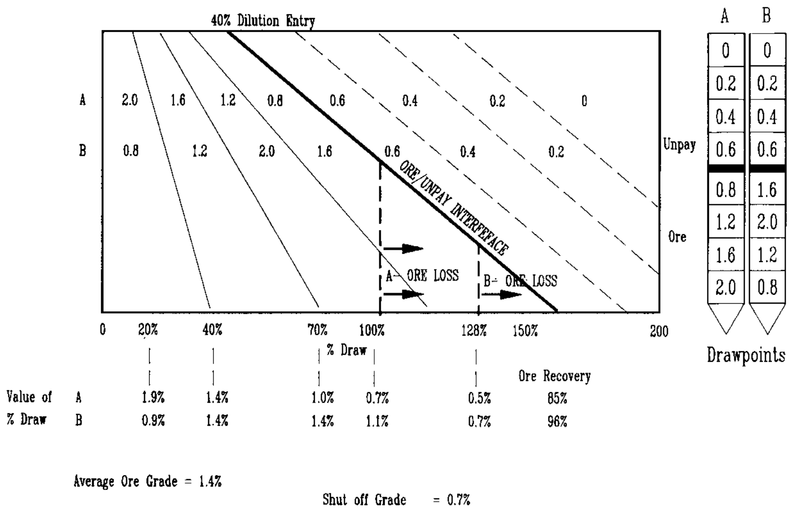


Figure 11—Grade analysis

- Ore draw height
- Range in fragmentation of both ore and waste
- Drawzone spacing
- Range in tonnages drawn from drawpoints.

The range in fragmentation size distribution and the minimum drawzone spacing across the major apex will give the height of the interaction zone (HIZ). This is illustrated in Figure 12. There is a volume increase as the cave propagates, so that a certain amount of material is drawn before the cave reaches the dilution zone. The volume increase or swell factors are based on the fragmentation and are applied to column height. The following are typical swell factors: fine fragmentation 1,16, medium 1,12, coarse 1,08.

A draw-control factor is based on the variation in tonnages from working drawpoints. This is illustrated in Figure 13. If production data are not available, the draw-control engineer must predict a likely draw pattern. A formula based on the above factors has been developed to determine the dilution entry percentage:-

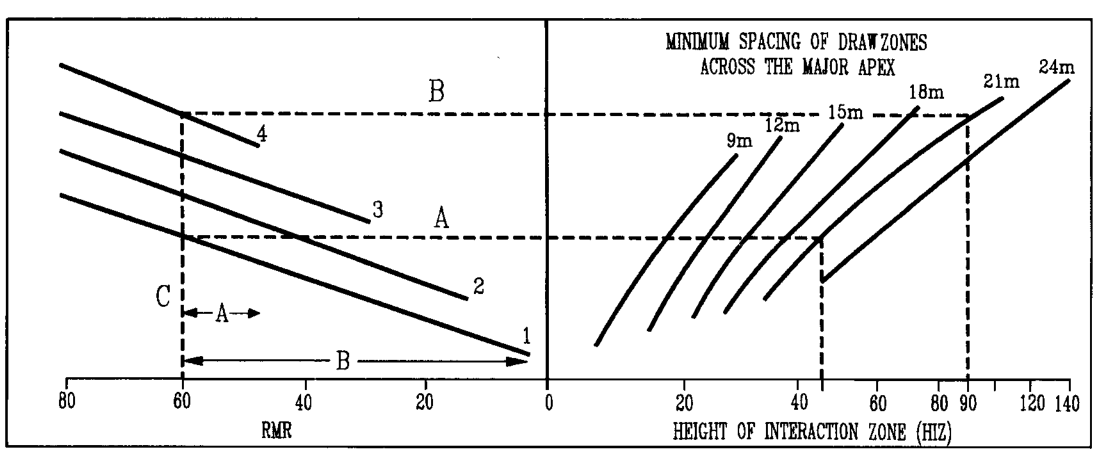
$$\text{Dilution entry} = (A - B)/A \times C \times 100,$$

where

A = Draw-column height × swell factor
B = Height of interaction
C = Draw-control factor.

The graph for dilution entry was originally drawn as a straight line, but underground observations show that, where there is early dilution, the rate of influx follows a curved line with a long ore 'tail', as shown in Figure 14. Figure 15 shows that dilution entry is also affected by the attitude of the drawzone, which can angle towards higher overburden loads.

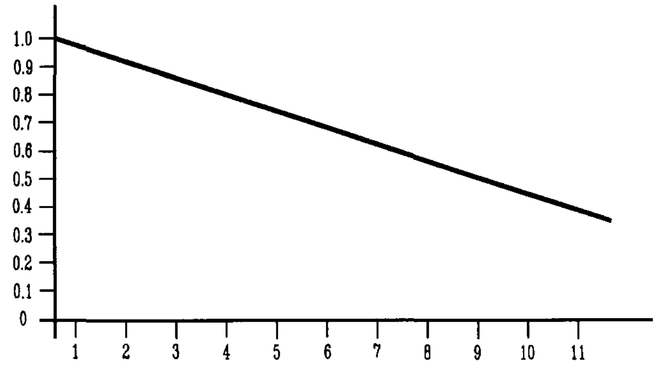
RMR OF ALL MATERIAL IN THE POTENTIAL DRAW COLUMN TO BE USED IN CALCULATION AS FINES FLOW MUCH FURTHER THAN COARSE



RMR Range	Curves	Examples	Ratings	Range	D.Z.Spacing	H.I.Z
0 - 14	NO.1	A	50 - 60	10	21m	45m
15 - 29	NO.2					
30 - 49	No.3					
+50	No.4	B	5 - 60	55	21m	90m

VERTICAL LINE "C" LOCATED AT HIGHEST RATING OF MATERIAL IN DRAW COLUMN

Figure 12—Height of the interaction zone (HIZ)



Standard Deviation x 100 of Tonnage of Working Drawpoints

D/Ps	W/1	E/1	W/2	E/2	W/3	E/3	W/4	E/4
Monthly Tonnage	2000	800	1000	2500	600	1500	800	1800

Mean = 1375 Standard Deviation = 682/100 = 7

Draw Control Factor = 0.6

Figure 13—The draw-control factor

$$\frac{A-B}{A} \times C \times 100 = \text{Dilution Entry}$$

A = Ore Draw Column Height x Swell Factor = 168m
B = Height of Interaction Zone = 90m
C = Draw-control Factor = 0.6

$$\frac{168 - 90}{168} \times 0.6 \times 100 = 28\%$$

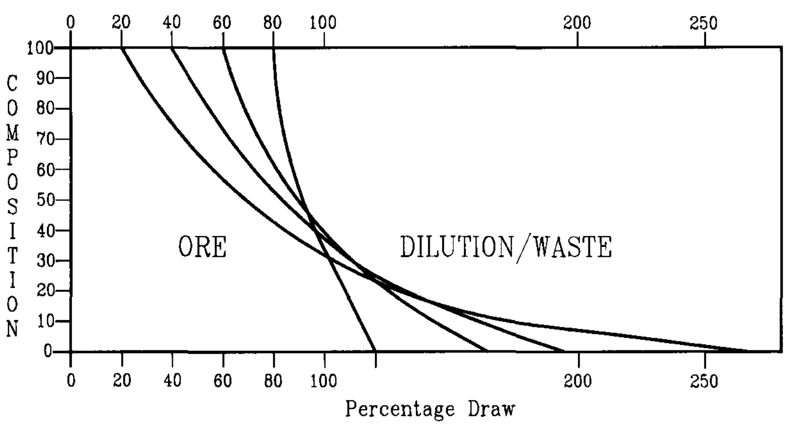


Figure 14—Calculation of dilution entry

Layouts

A factor that needs to be resolved is the correct shape of the major apex. It is considered that a shaped pillar will assist in the recovery of fine ore. Where coarse material results in major arching, a square-topped major apex (pillar) is preferable in terms of arch failure and brow wear, as shown in Figure 16. The main area of brow wear is immediately above the drawpoint. If the vertical height of pillar above the brow is small, as shown in Figure 16A, failure of the top section will reduce the strength of the lower section and result in aggravated brow wear.

More thought must be given to the design of LHD layouts in order to provide the maximum amount of manoeuvring space for the minimum size of drift opening so that larger machines can be used within the optimum drawzone spacings. Another aspect that needs attention is the design of LHDs to reduce the length and increase the width. Whilst the use of large machines might be an attraction, it is recommended that caution be exercised and that a decision on machine size be based on the correct assessment of the required drawzone spacing in terms of fragmentation. The loss of revenue that can result from high dilution and ore loss far exceeds the lower operating costs associated with larger machines.

Eight different horizontal LHD layouts and two inclined drawpoint LHD layouts are in use at various operating mines. An example of an inclined LHD layout is shown in Figure 17.

Undercutting

Undercutting is one of the most important aspects of cave mining since, not only is a complete undercut necessary to induce caving, but the undercut method can reduce the damaging effect of induced stresses.

The normal undercutting sequence is to develop the drawbell and then to break the undercut into the drawbell, as shown in Figure 18. In environments of high stress, the pillars and brows are damaged by the advancing abutment stresses. The Henderson Mine technique of developing the drawbell with long holes from the undercut level reduces the time interval and extent of damage associated with post undercutting. In order to preserve stability, Henderson Mine has also found it necessary to delay the development of the drawbell drift until the bell has to be blasted (Figure 19).

The damage caused to pillars around drifts and drawbells by abutment stresses is significant, being the major factor in brow wear and excavation collapse. Rockbursts are also located in these areas. The solution is to complete the undercut before the development of the drawpoints and drawbells. The 'advanced undercut' technique is shown in Figure 20.

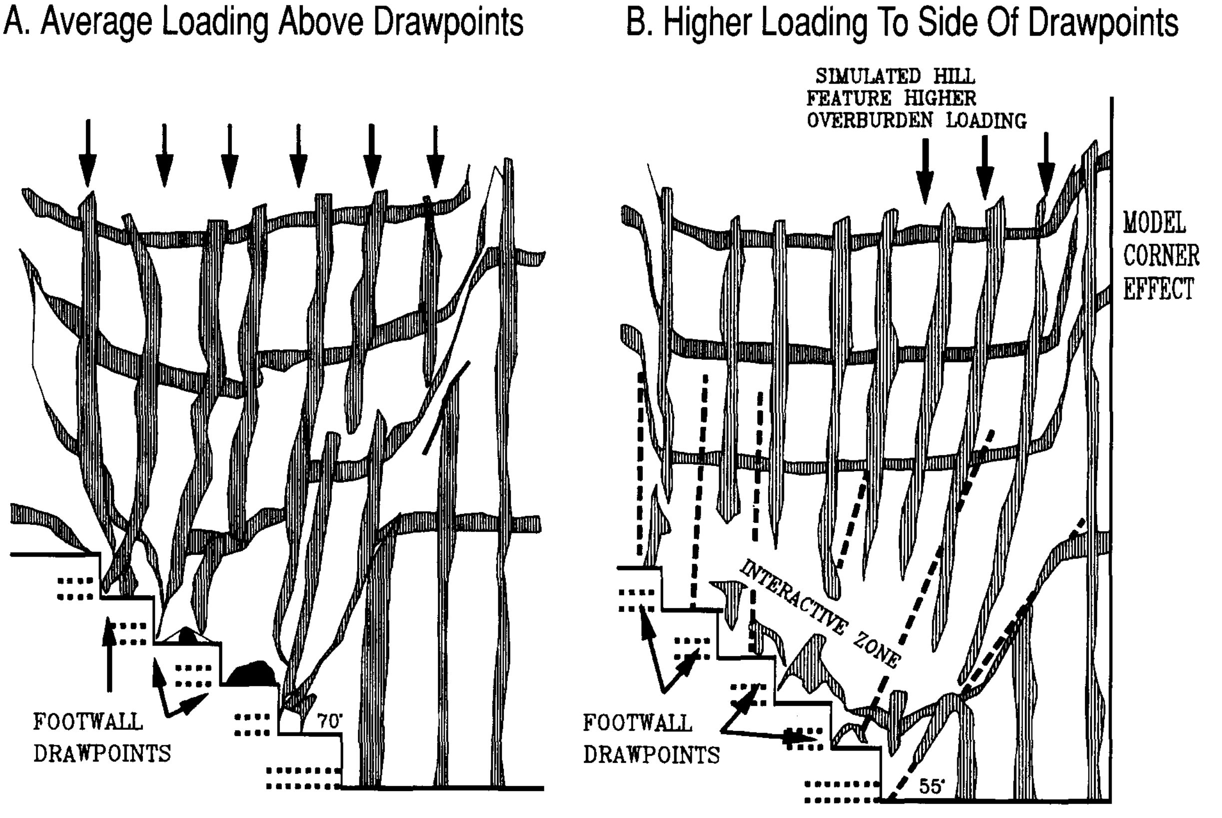


Figure 15—Inclined drawpoint layout showing the effect of different overburden loading (three-dimensional sand-model experiments)

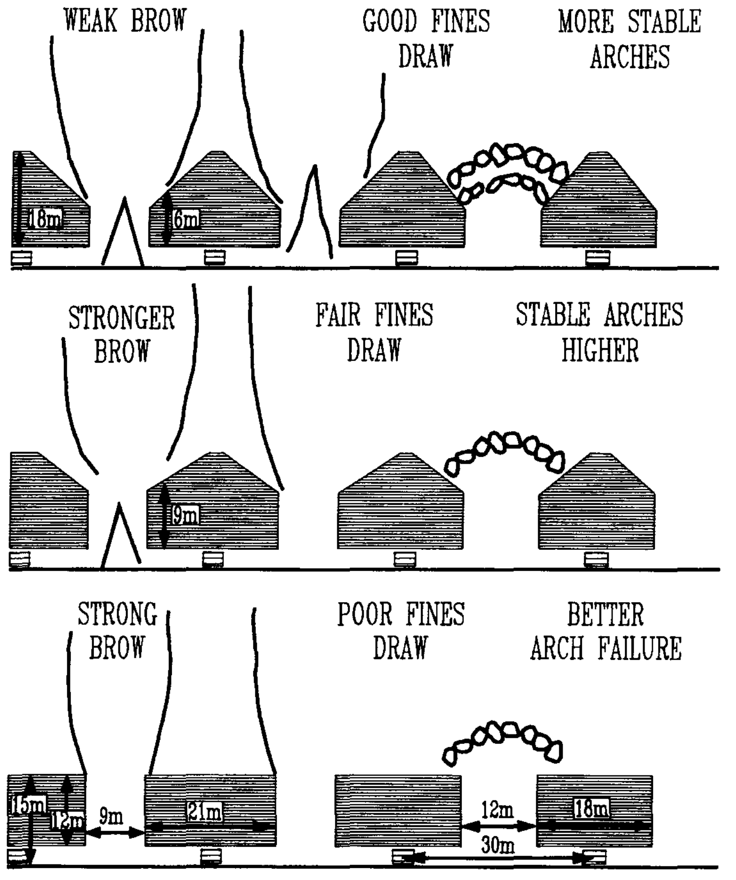
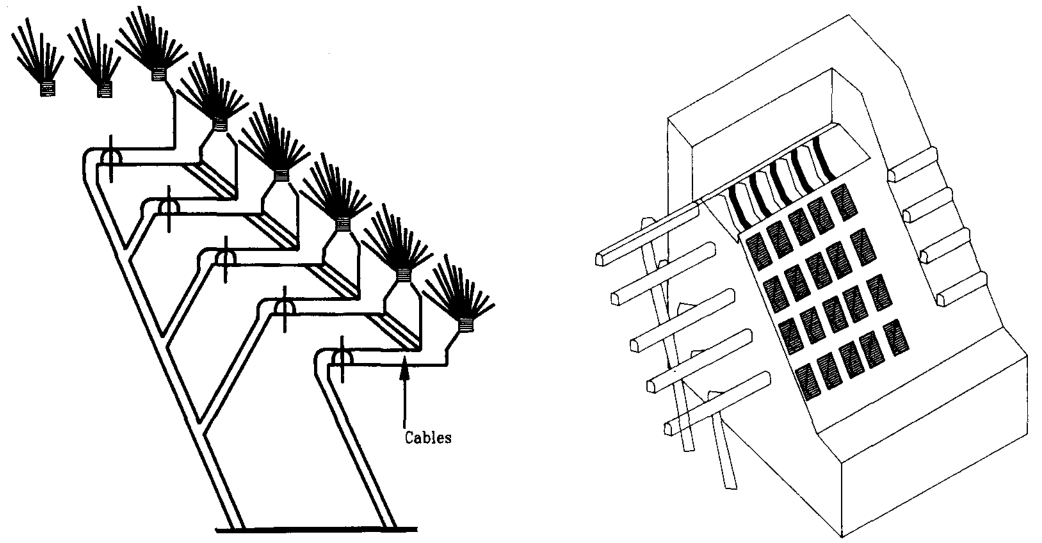


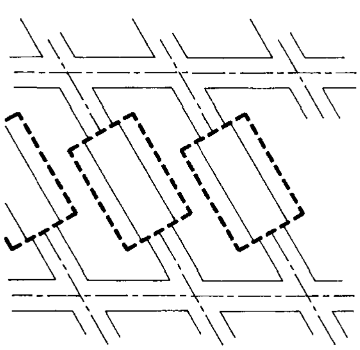
Figure 16—Shapes of major apex/pillars



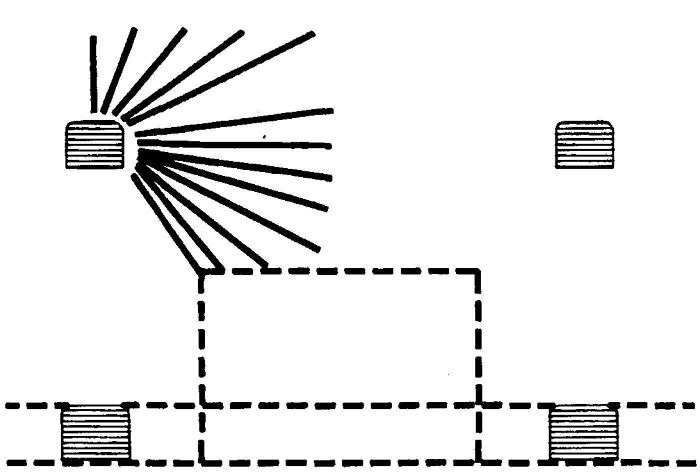
Inclination - 40°

Spacings	DIP	STRIKE	VERTICAL
	12	10	10
	15	12	12.5
	18	12/15	15

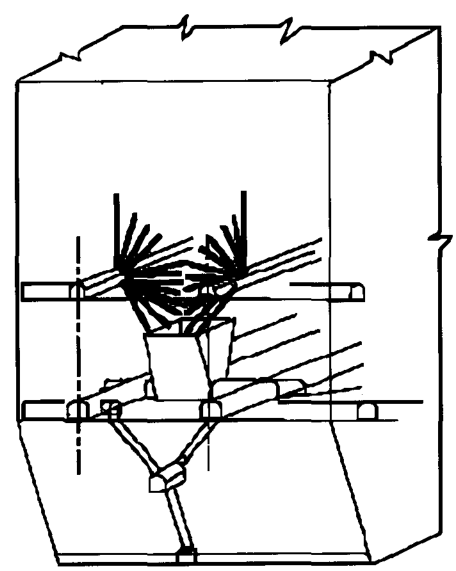
Figure 17—An example of the layout of an inclined drawpoint



A. Production Level Layout Detail



B. Cross Section



C. Isometric View of Blockcaving with LHD

Figure 18—LHD layout at El Teniente

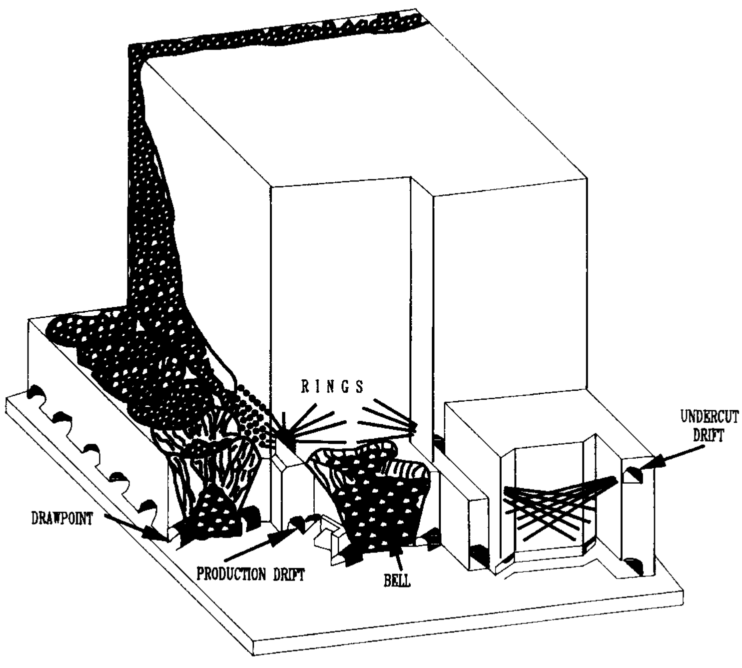


Figure 19—Isometric view of a panel-cave operation

In the past it was considered that the height of the undercut had a significant influence on caving and, possibly, the flow of ore. The asbestos mines in Zimbabwe had undercuts of 30 m with no resultant improvement in caving or fragmentation. The long time involved in completing the undercut often led to ground-control problems. Good results are obtained with undercuts of minimum height provided that complete undercutting is achieved. Where gravity is needed for the flow of blasted undercut ore, the undercut height needs to be only half the width of the major apex. This results in an angle of repose of 45 degrees and allows the ore to flow freely.

Support Requirements

In areas of high stress, weak rock will deform plastically and strong rock will exhibit brittle, often violent, failure. If there is a large difference between the RMR and MRMR, yielding support systems are required. This is explained in Figure 21.

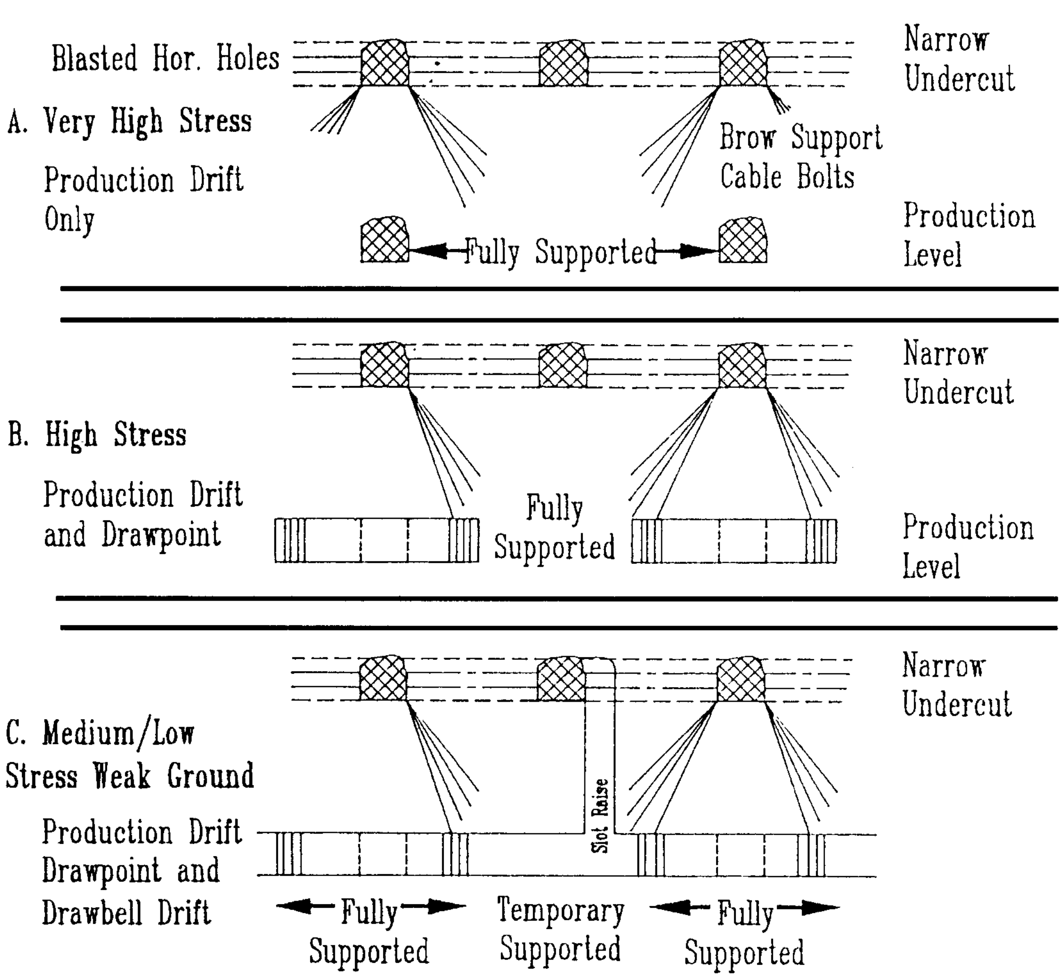


Figure 20—Different sequences of advanced undercutting

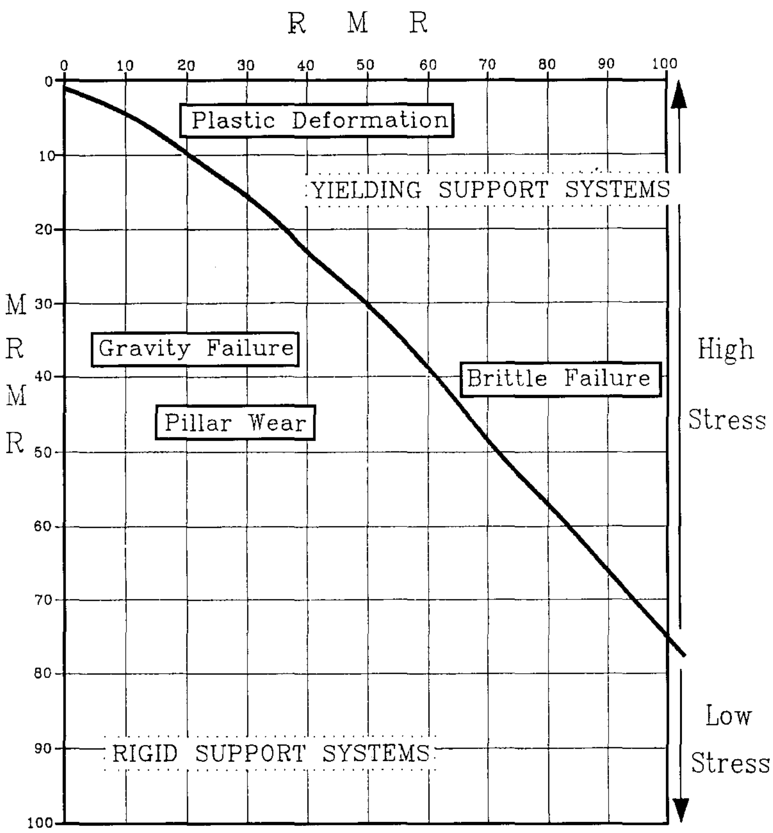


Figure 21—Support requirements for caving operations

Pre-stressed cables have little application in underground situations unless it is to stabilize fractured rock in a low-stress environment. The need for effective lateral constraint of the rock and of lining surfaces such as concrete cannot be too highly emphasized. Support techniques are illustrated in Table IV.

Conclusions

- Cavability can be assessed provided accurate geotechnical data are available and the geological variations are recognized. The mining rockmass rating (MRMR) system provides the necessary data for the empirical definition of the undercut dimension in terms of the hydraulic radius.
- Numerical modelling can assist the engineer in understanding and defining the stress environment.
- Fragmentation is a major factor in an assessment of the feasibility of cave mining in large competent orebodies. Programs are being developed for the determination of fragmentation, and even the less sophisticated programs provide good design data. The economic viability of caving in competent orebodies is determined by LHD productivity and the cost of breaking large fragments.

Acknowledgements

This paper presents an update of the technology of cave mining. It is not possible to quote references since the bulk of the data supporting the contents of this paper have not been published and the basic concepts are known to mining engineers. However, it is appropriate to acknowledge the contributions from discussions with the following people in Canada, Chile, South Africa, and Zimbabwe: R. Alvarez, P.J. Bartlett, N.J.W. Bell, T. Carew, A.R. Guest, C. Page, D. Stacey, and A. Susaeta. Thanks are due to P.J. Bartlett for assisting in the final preparation of the paper. The simulation program for the calculation of primary and secondary fragmentation referred to in the text was written by G.S. Esterhuizen at Pretoria University.

Table IV

Support techniques

Support element	Low stress	High stress
Bolts — Length — Spacing — Type	= 1 m + (0,33 *W* x *F*) = 1 m = Rigid rebar	= 1 m + (0,5 *W* x *F*) = 1 m = Yielding, e.g. cones
Mesh	0,5 mm x 100 mm aperture	0,5 mm x 75 mm or 50 mm aperture
Deep-seated support	Cables = 1 m + 1,5 *W*	Steel ropes = 1 m + 1,5 *W* Long cone bolts
Shotcrete linings	Mesh-reinforced shotcrete	Mesh-reinforced shotcrete
Arches	Rigid steel arches Massive concrete	Yielding steel arches Reinforced concrete
Surface restraint	Large washers (triangles) Tendon straps	Large plate washers Yielding-tendon straps
Corners	25 mm rope-cable slings	25 mm rope-cable slings
Brows	Birdcage cables from undercut level Inclined pipes	Birdcage cables from undercut level Inclined pipes
Repairs	Grouting Extra bolts and cables Plates, straps, and arches	Grouting Extra bolts, ropes, plates, straps, and yielding arches

W is the span of the tunnel and *F* is based on
MRMR = 0–20 : F = 1,4 MRMR = 21–30 : F = 1,30 MRMR = 31–40 : F = 1,2
MRMR = 41–50 : F = 1,1 MRMR = 51–60 : F = 1,05 MRMR > 61 : F = 1,0

- Drawpoint/drawzone spacings for coarser material need to be examined in terms of recovery and improved mining environments. Spacings must not be increased to lower operating costs at the expense of ore recovery.
- The interactive theory of draw and the diameter of the isolated drawzone can be used in the design of drawzone spacing.
- Complications occur when the drawzone spacing is designed on the primary fragmentation and the secondary fragmentation is significantly different. ◆

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2. The objective of the award is to promote post-graduate research on applied and fundamental aspects of ferro-alloy production, or the production of stainless and alloy steels in Southern Africa.
3. The research must be undertaken on a non-confidential basis, so that the results are publishable in the *Journal* of the SAIMM or any suitable internationally recognised journal, and specifically intended to form the basis of contributions to future INFACON Congresses. Topics for research may, in addition to production and uses of alloy steels, include related aspects such as environmental issues, raw materials and economics.
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5. The award is primarily intended to provide financial support in the form of a bursary to the applicant, but, at the discretion of the Awards Committee, may include amounts for operating expenses (such as local travel, library and computer costs and consumables) and for special equipment.
6. The award may be used to supplement other grants, provided that the non-confidentiality of the work is not prejudiced.
7. The academic status and research capability of the candidates will be a primary consideration for the selection of bursars. However, the suitability of the topic of research and the status and capabilities of the department will also be important considerations.
8. Applications should be submitted to:

   INFACON Bursary Committee
   South African Institute of Mining and Metallurgy
   P.O. Box 61127
   Marshalltown
   2107

   and should include the applicant's CV, a detailed description of the research topic and a supporting motivation from the Head of Department concerned indicating the supervisor and facilities available for the research. Applications should preferably reach the Committee before the end of February 1995.
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