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UNDERGROUND MINING METHODS, PLANNING AND GROUND CONTROL

D.G.F. HEDLEY

ELLIOT LAKE LABORATORY

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by

D.G.F. Hedley

CHOICE OF MINING METHOD

The factors affecting the choice of a mining method can be divided into three main groups: geometrical, ground control and economic.

Geometrical factors include length, width and thickness, dip, continuity and total tonnage of the orebody. In Canada there are two main types of orebodies. Thin tabular deposits are generally mined by room-and-pillar methods if they are gently-dipping (e.g., Elliot Lake uranium mines), or shrinkage, longitudinal cut-and-fill if they are steeply-dipping (e.g., Kirkland Lake gold mines). Massive deposits such as in Sudbury or Timmins are mined by blasthole methods or transverse cut-and-fill panels.

Ground control factors include the properties of the orebody and surrounding rock, depth below surface, tectonic stresses, geological structures such as faults or dykes and overlying features such as lakes or buildings. These factors generally define what type of support is required either as pillars or artificial support. Dimensions of stopes are strongly influenced, especially at depth, since a characteristic of the Canadian Shield is that the horizontal tectonic stress is about double the vertical gravitational stress. Obviously the surface features play a part since caving methods cannot be used under lakes or towns.

Economic factors include ore grades, development and stoping costs, environmental costs and skills of the available labour force. The first three factors are self-evident since the costs of mining cannot exceed the value of the ore. Environmental factors are becoming increasingly important both underground (i.e., dust, radiation, toxic fumes), and on surface (i.e., tails disposal). The character of the Canadian mining industry has changed significantly over the last two decades with extensive mechanization and the replacement of expensive mining methods by bulk mining techniques. Consequently, in most parts of the country, it would be difficult to find a labour force experienced in square-set mining, and in some parts it is difficult to find workers experienced in operating jackleg drills and slushers.

More often than not there are trade-offs among the various factors in deciding the most suitable mining method for a particular orebody. Only rarely does one factor predominate, such as the rockburst problem forcing a change from room-and-pillar to longwall mining in the South African gold mines.

GROUND CONTROL CLASSIFICATION OF MINING METHODS

Professor Morrison in the 1960's developed a classification system based on ground control principles as illustrated in Figure 1. Some of the mining methods are no longer used and some of the newer methods are not included, but it is still a useful framework.

Mining methods are divided into three core groups as follows:

Group A - Rigid Pillar Support

- Pillars are designed to carry load without failure
- Hanging wall is not allowed to subside.

Group B - Yielding Pillar Support and Longwall

- Pillars allowed to fail and yield
- Hanging wall is allowed to subside in a controlled fashion.

Group C - Caving

- Complete caving of the orebody and/or overlying ground with little control.

Around each of the core groups are the satellite mining methods, which can

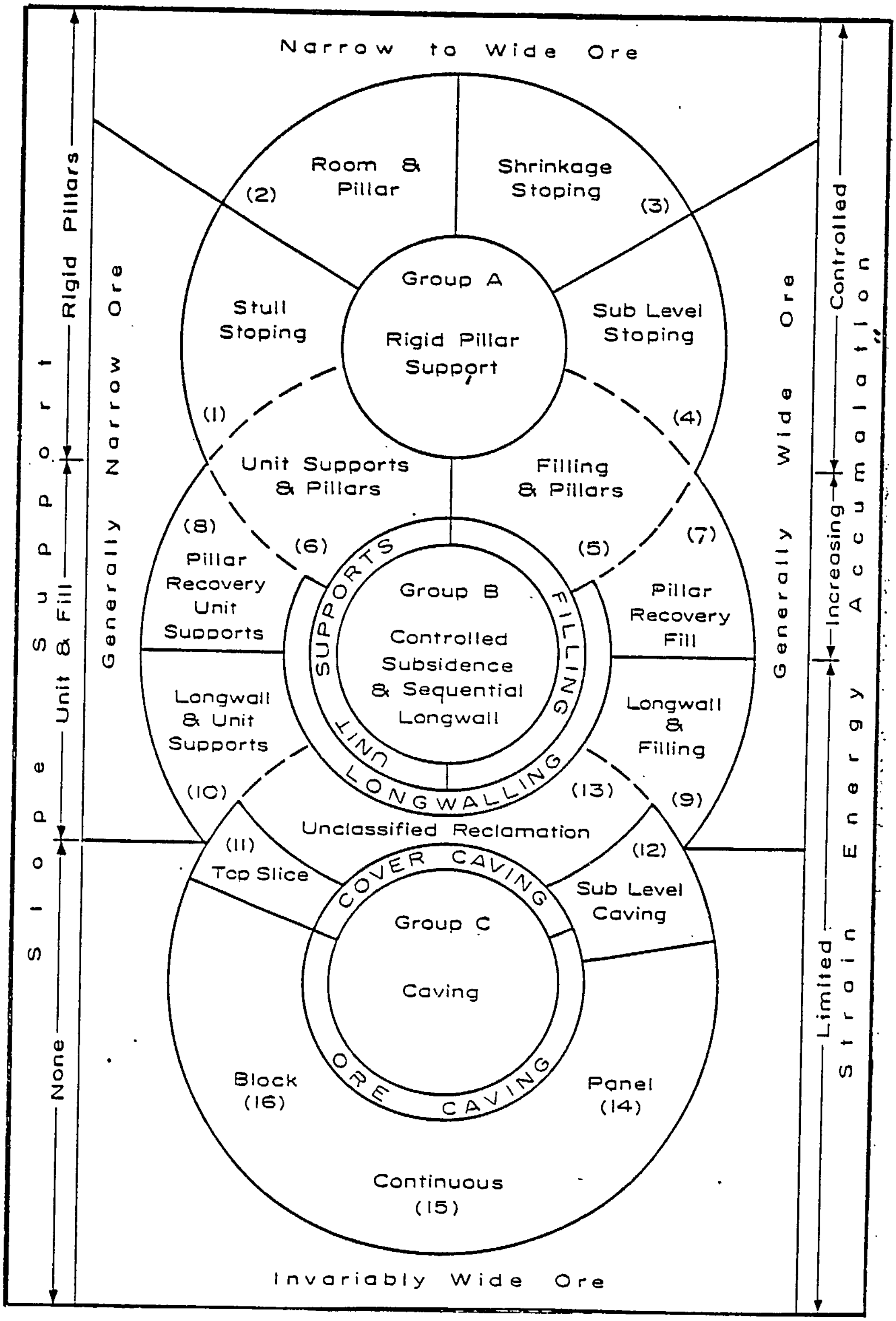

Fig. 1 - Classification of mining methods based on ground control techniques (after Morrison, 1970).

overlap representing transition zones where some compromise with a basic principle is allowable.

Group B is also divided into support practice between backfilling methods and unit supports (e.g., post pillars, props, cribs), also the range of longwall practice is indicated. Group C is also divided between cover caving and ore caving.

Around the edge of the diagram the width of the orebody is related to different mining methods. Here the system breaks down somewhat in that backfilling methods can be done in narrow as well as wide orebodies.

The classification of strain energy accumulation should more accurately be called potential energy dissipation. In Group A methods, pillars are below their failure stress and the dissipation of energy is controlled. Over the transition and pillar recovery phases, pillar stresses are increasing and some yielding/failure is occurring. Energy dissipation increases and the stronger, more brittle rocks are rockburst-prone. In the longwall and caving methods failure is occurring progressively as is the release of energy.

Some brief comments on each of the mining methods are as follows:

Rigid Pillar Methods 1 to 4

1. Stull Stoping

   Rib and crown pillars are left for permanent support with wooden posts (i.e., stulls) providing local support of the stope walls. Not much used these days.

2. Room and Pillar

   A systematic layout of pillars is used for permanent support. This method is predominantly used in gently-dipping tabular orebodies (e.g., Elliot Lake uranium, coal and potash mines). Ore thickness can vary from 3 m to over 30 m (e.g., Gaspe Copper Mine). With increasing depth a higher percentage of the orebody is tied up in pillars and there is a tendency to convert to longwall or yielding pillar methods.

3. Shrinkage Stoping

Crown/sill pillars are left for permanent support. Broken ore provides support to the stope walls. When ore is completely removed it becomes an open stope and pillar method. Used in steeply dipping orebodies, up to about 6 m thick. Generally converted to cut-and-fill at depth.

4. Sub-Level Stoping

This method is largely confined to steeply-dipping, wide orebodies, using either ring drilling or longhole drilling. Over the past decade this method has undergone significant developments and has become the prime bulk mining technique (i.e., blasthole stoping and vertical retreat mining). Due to improvements in drilling and material handling the sub-levels have been eliminated and now just an overcut and undercut are developed.

Transitional Methods 5 and 6

In these methods some type of support is introduced to control failure and dilution from the walls, while the pillars are still adequate. Backfill is used in methods 5 and an example would be primary stoping in transverse cut-and-fill. In method 6, cribs, mat packs, and concrete packs are used in narrow and gently-dipping deposits.

Pillar Recovery Methods 7 and 8

These methods generally include a sequence or longwall aspect and only differ in the method of support. If the surface is expendible, these methods represent the end phase of methods 1 to 6. In the old days, square sets with or without backfill were used to recover pillars. Now cemented fills using overhand, underhand or even vertical retreat techniques are used. In room-and-pillar mining, partial or complete robbing of the pillars would represent this end phase.

Longwall and Sequential Methods 9 and 10

With these methods we have passed from the range of competent rigid pillar support to some degree of controlled ground failure. Pillars and remnants, because of stress concentrations, have become a liability to be avoided as far as possible. However, the concept of small yielding pillars is retained. Examples of longwall and filling include post-pillar mining and longitudinal cut-and-fill, whereas longwall and unit supports cover coal mining practice as well as the longwall operations in South African gold mines.

Caving Methods 11 to 16

11. Top Slicing

An orebody is mined from the top down in horizontal slices below a timber mat, in a longwall sequence. Not much used these days.

12. Sub-Level Caving

This is a natural development from top slicing. The mat is eliminated and the cut deepened. Drilling and blasting is used to cave the ore and overlying rock.

13. Unclassified Reclamation

This method is included in recognition that most mining methods can go wrong. If the amount of ore left justifies the cost, some type of recovery can be attempted, probably using a longwall sequence and/or caving.

14, 15, 16. Panel, Continuous and Block Caving

These are mass production methods not much used in Canada (exception, the underground asbestos mines in Quebec). Generally need a weak orebody so that caving occurs naturally, otherwise blasting is required and it becomes sub-level caving.

MINE PLANNING

The design or planning of underground excavations is where the 'preventive' phase of rock mechanics occurs, as opposed to the 'curative' phase of trying to solve problems after they have occurred. Planning is especially important in deep mines where ground conditions play a significant role. In a Canadian hardrock context, deep mining is usually considered to be below 1000 m, although there are exceptions.

A set of general planning guidelines was formulated by Coates (1981) in his handbook on 'Rock Mechanics Principles'. These are outlined below with examples.

a) All recoveries should be planned.

This means there should be an overall strategy in extracting an orebody, for instance starting at the bottom and mining up, or advancing from the shaft to the boundary. At this stage a decision is required on whether to attempt 100% recovery or recognize that the last ton of ore is uneconomic.

Figure 2 shows the layout of a cut-and-fill, post-pillar operation, which was started at the bottom of the orebody and advanced upwards. Extraction was about 85% with the remaining 15% written off in the post-pillars.

Figure 3 is a plan of a room-and-pillar mine where stopes are scattered in an almost random configuration.

b) Pillars should be mined as soon as possible.

Pillars serve various functions and once they have served that function they should be mined. In some cases, such as supporting the roof in room-and-pillar mining, or as water barriers, they serve a permanent function and are never removed.

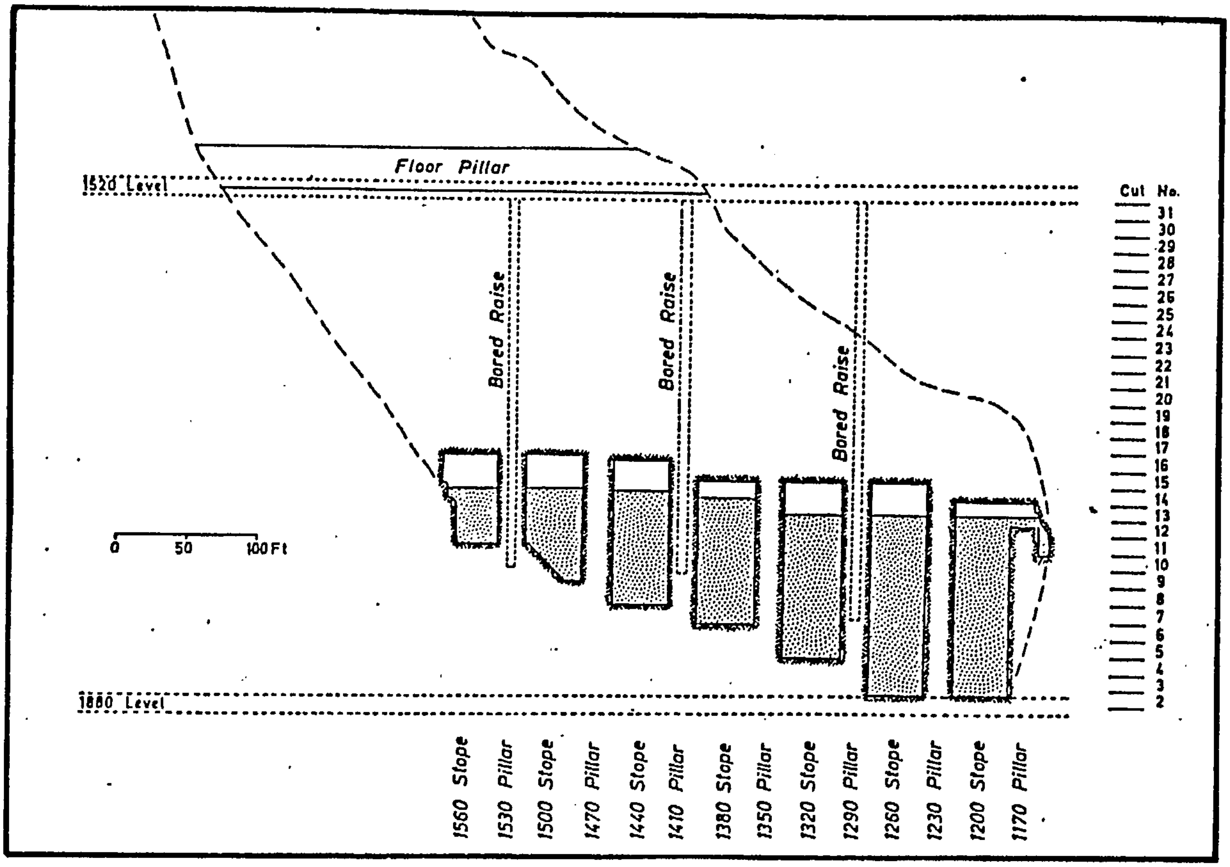

Fig. 2 - Cut-and-fill with post pillars starting at bottom of orebody.

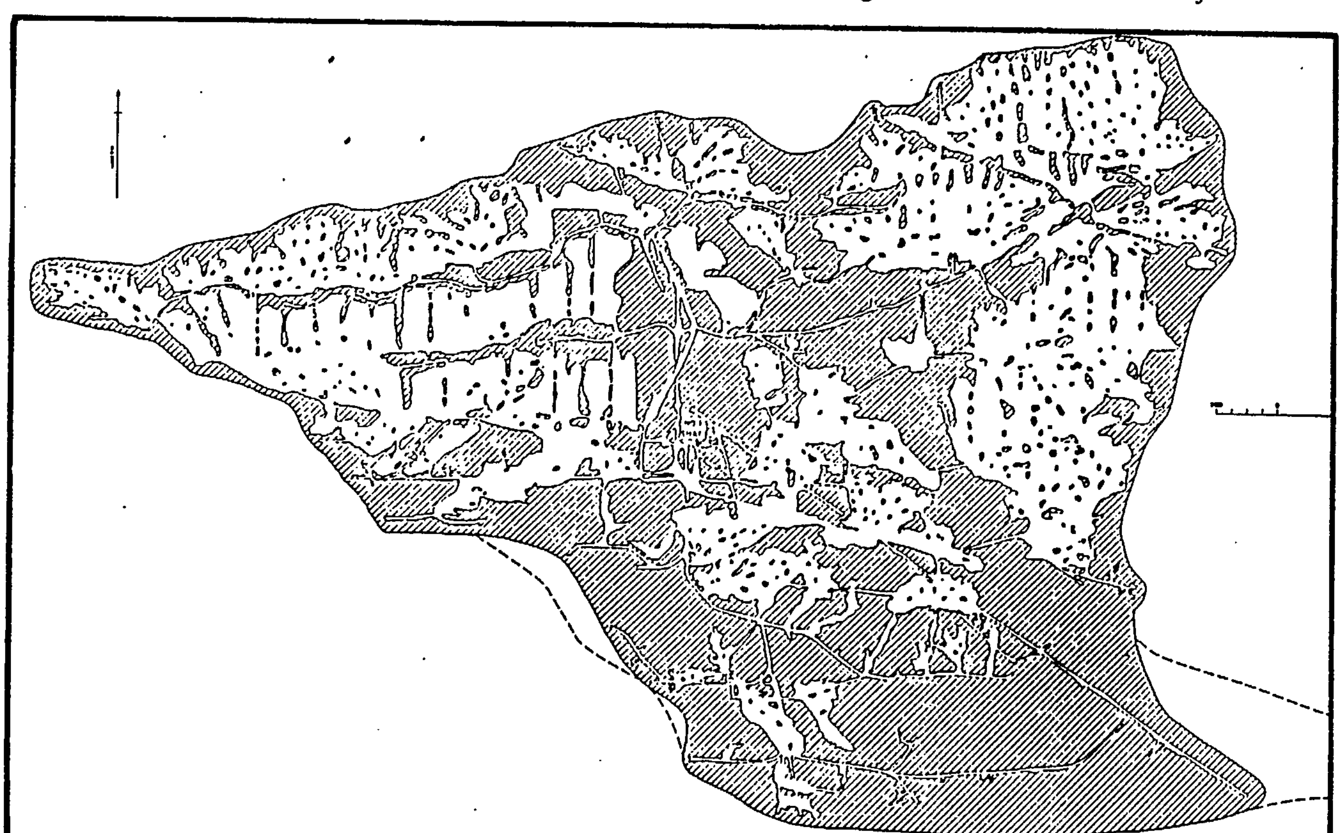

Fig. 3 - Plan of room-and-pillar mining with scattered stopes.

In cut-and-fill and blasthole stoping the main purpose of rib pillars is to support the hanging wall and footwall to control dilution during primary stoping. Once the primary stopes are mined and backfilled the sooner the rib pillars are mined the better. Time does not improve rock strength and could result in pillar deterioration. Also the service openings have to be maintained to recover the pillars. Eventually the deterioration could become so severe that the pillars are written off.

Figure 4 shows a blasthole operation where significant caving of the pillars occurred before the backfill could be introduced into the primary stopes.

c) Longwall mining.

Longwall layouts come from coal mining with the concept of keeping working faces in straight lines to avoid high stress concentrations. Other than the South African gold mines, its use in a 'pure' sense is limited in hardrock mines. However, variations of the longwall principle are applicable in that a stoping front can be advanced along a straight line. Figure 5 shows a transverse cut-and-fill sequence using a longwall front.

Where small pillars of waste (or low grade) rock are to be left, normally they should be blasted (i.e., destressed), otherwise they may be a source of rockbursts.

d) Barrier and protection pillars.

Barrier pillars are used to separate stoping blocks so that several panels can be worked at the same time. Other uses are to isolate panels so that pillar failure in one panel does not progress throughout the mine. An example of a stabilizing pillar layout is shown in Figure 6 which is a plan of a deep uranium mine at Elliot Lake.

The problem with barrier pillars is that they become very highly

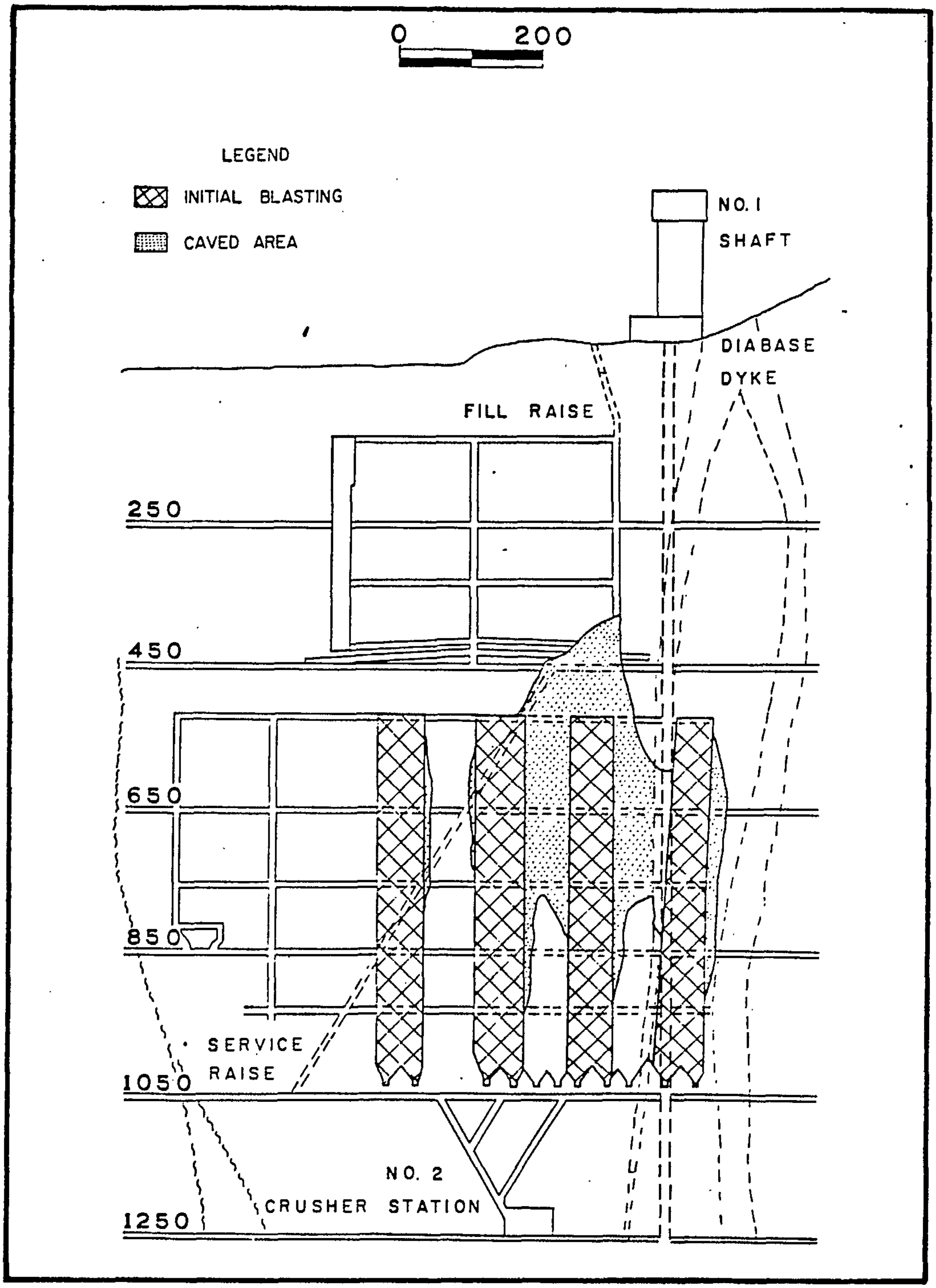

Fig. 4 - Longitudinal section of blasthole stoping, with pillar collapse.

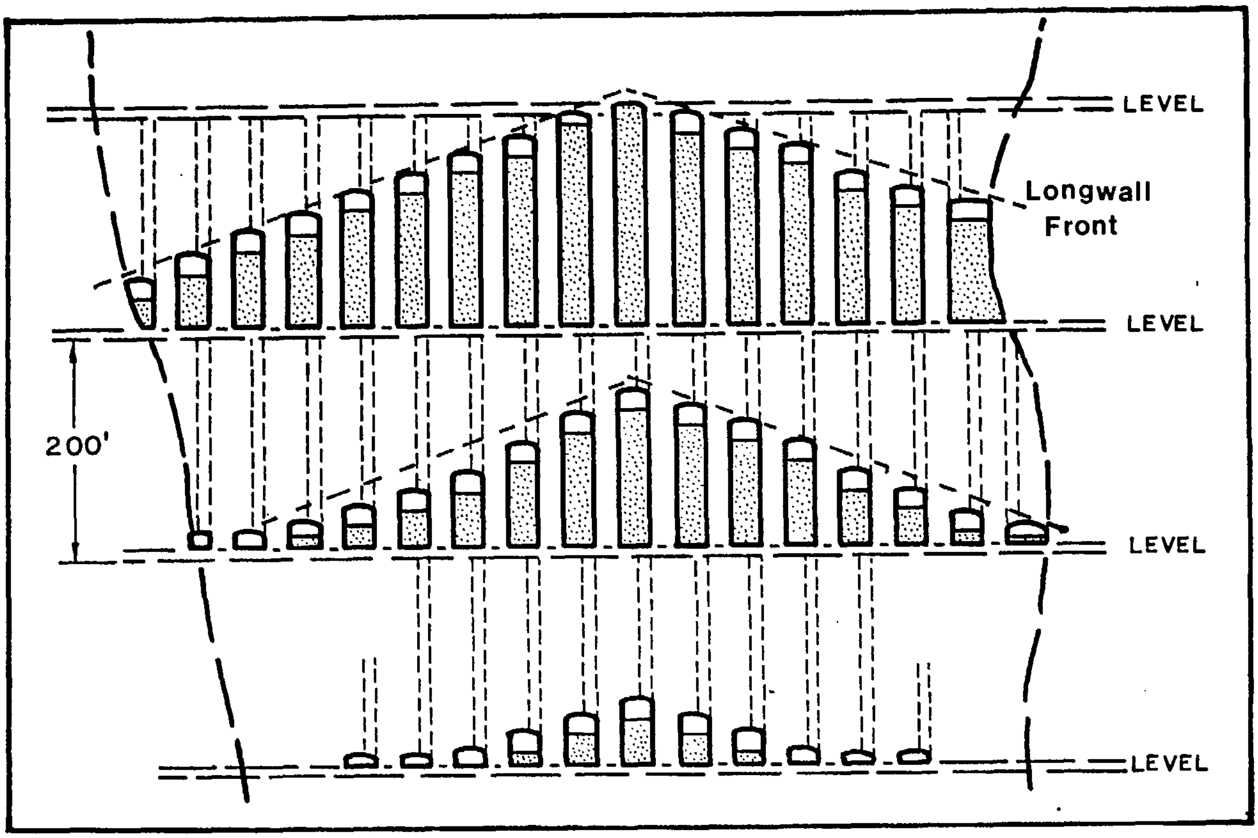

Fig. 5 - Transverse cut-and-fill mining advanced in a longwall configuration.

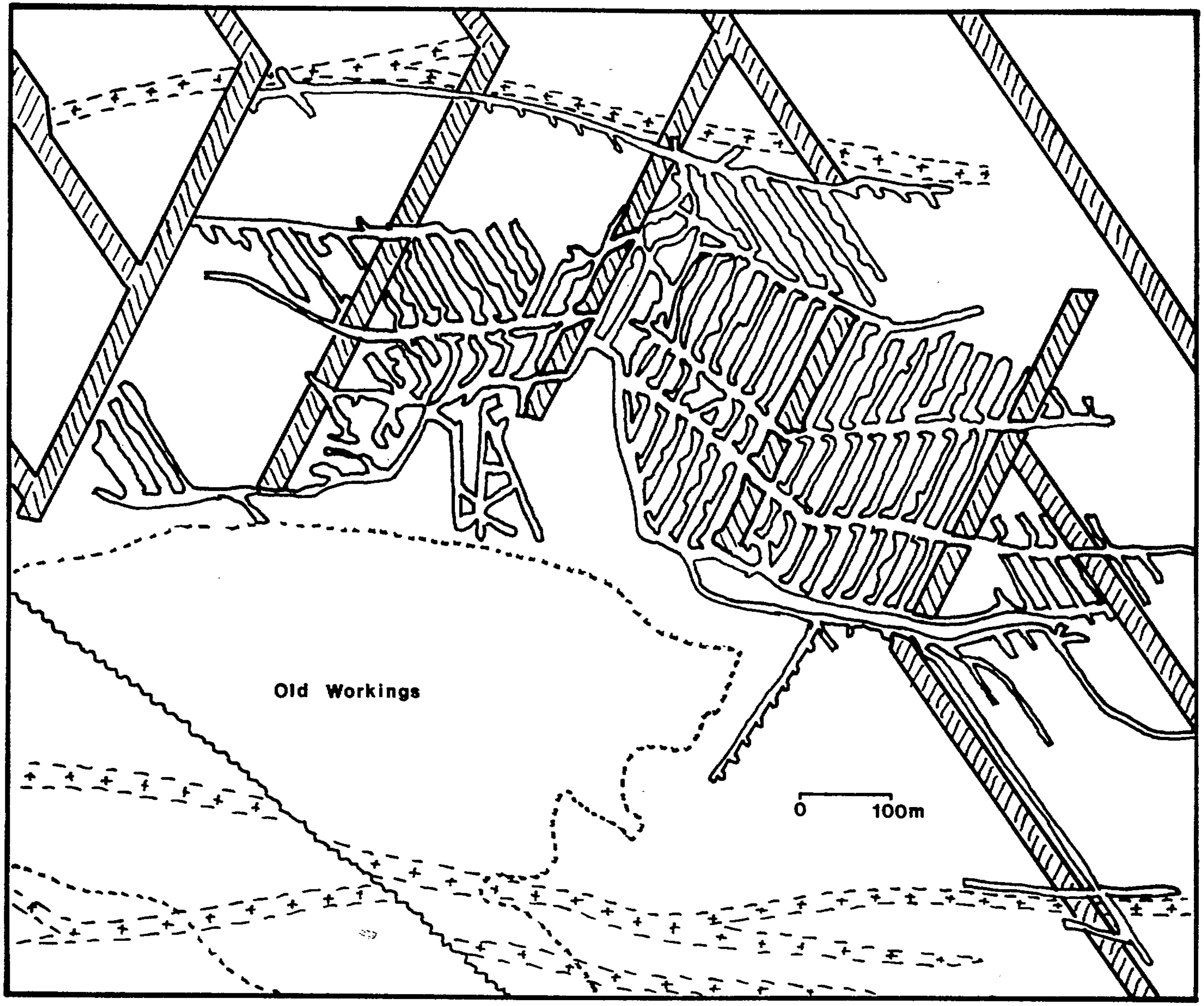

Fig. 6 - Stabilizing pillar layout at a deep uranium mine at Elliot Lake.

stressed and it is difficult to recover them. Also there is a tendency to put main service openings, including lunch rooms and refuge stations, within barrier pillars for protection. Initially, these barrier pillars do provide protection, but with the panels on either side mined out the stresses increase with even higher concentrations around the service openings. Often these facilities would be better off opposite stopes where they are stress relieved. There is a general rule in South African gold mines that no access openings are located in barrier pillars and travelways are kept as far as possible from barrier pillars.

Another problem is with pillars left to protect shafts. Figure 7 is a longitudinal section at one particular mine, where a particularly severe rockburst in a shaft pillar completely destroyed the shaft. If the pillar had been mined first, under the lowest stress conditions, perhaps movement of the shaft could have been accommodated without major damage. Certainly, at the time of the pillar burst the problem was unsolvable.

e) Sudden joining of two large mining areas.

This condition should be avoided. Originally, this concept was explained in terms of expansion 'domes' around individual stopes as illustrated in Figure 8. If the intervening pillar is removed or suddenly fails the expansion dome is almost quadrupled. Although expansion domes do exist around stopes the reason for violent failure is more likely to be due to the increase in convergence and the resultant energy liberated.

When mining sill or crown pillars it is better to start at one end and retreat, as illustrated in Figure 9, rather than continuing to take horizontal slices, since the merging of the two zones will be more gradual.

f) Location of service openings.

Both expansion and compression zones exist around stopes as shown in

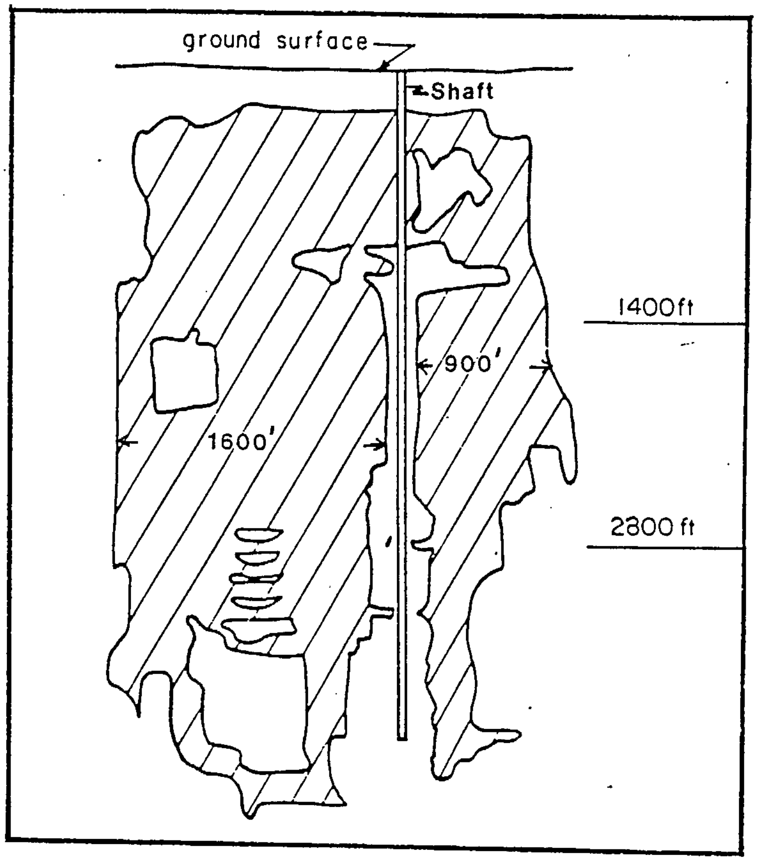

Fig. 7 - Layout of a mine at the time of a major rockburst in the shaft pillar.

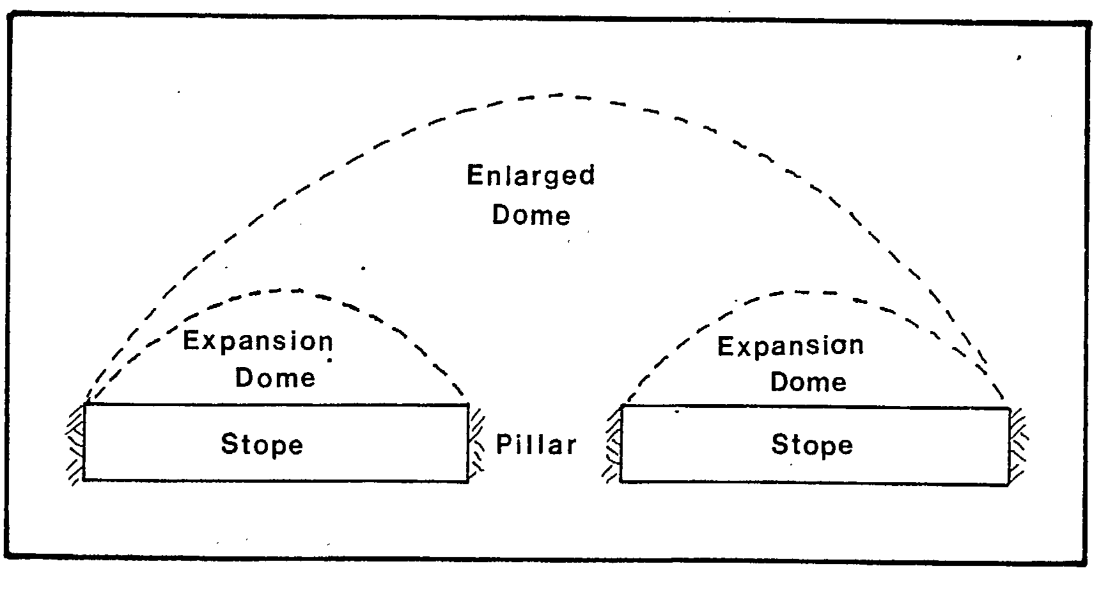

Fig. 8 - Enlargement of an expansion dome due to mining of a pillar.

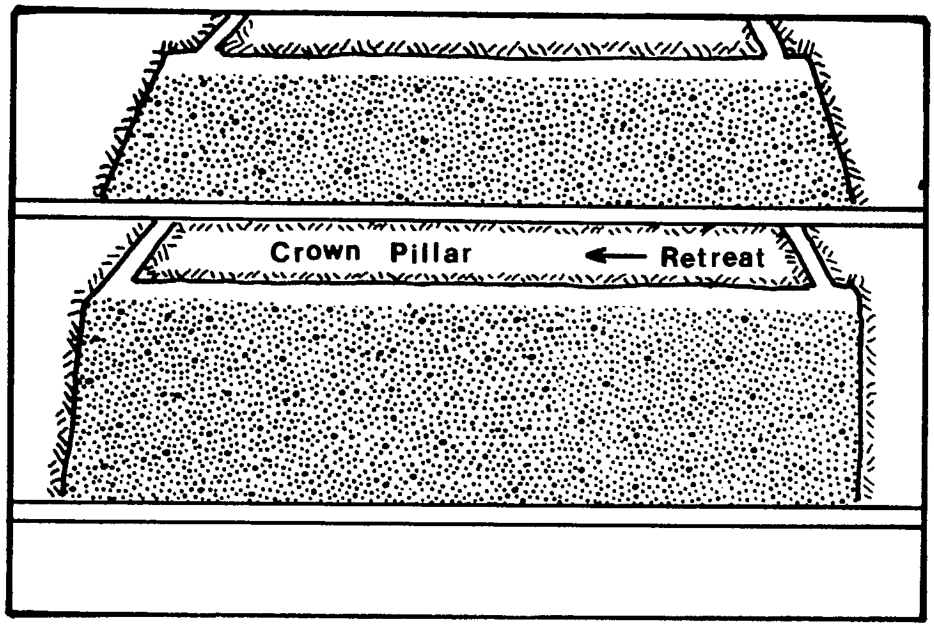

Fig. 9 - Preferred method of crown pillar recovery.

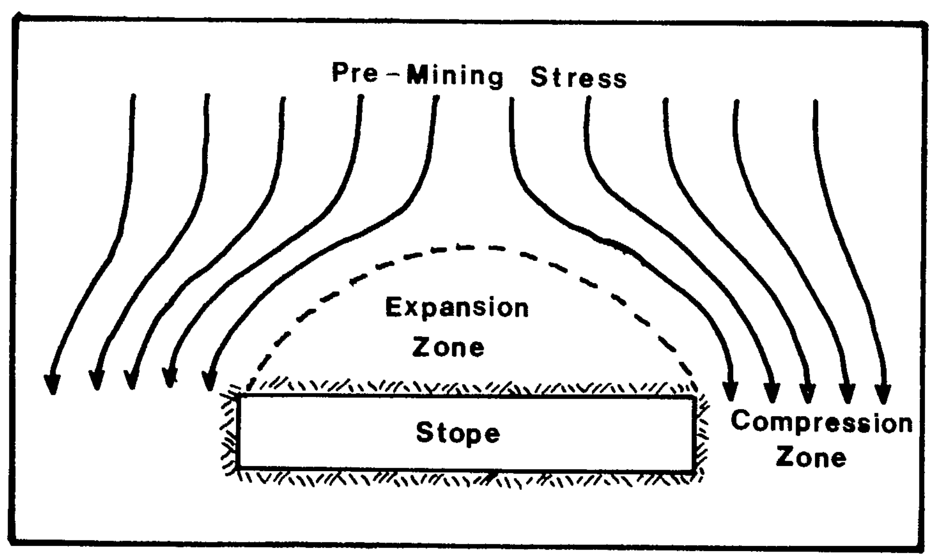

Fig. 10 - Zones of expansion and compression due to mining a stope.

Figure 10. Access openings within these zones can experience sloughing, cracking or collapse. In general, more damage including rockbursts are associated with compression zones, especially since the drift itself further concentrates the stress.

g) Major weakness planes.

Such weakness planes can be faults, dykes or water-bearing zones. Quite often it is difficult to transfer stress through these structures and it tends to concentrate on one side of a fault, as illustrated in Figure 11. By mining away from the weakness plane the difficult ground conditions are handled under the lowest stress regime possible.

h) Multi-vein mining.

Figure 12 illustrates two veins in close proximity. If vein 1 is mined before vein 2, then it will be necessary to mine in a highly stressed abutment zone while mining vein 2. If the longest vein is mined first then the shorter vein is always in a relaxed zone. This is only important if the veins are close together.

i) Alignment of pillars.

Alignment is only important when seams or veins are close together. For example, pillar alignment is critical in the Elliot Lake uranium mines when the reefs are 6 m apart, however, when the reefs are 30 m apart alignment is neither necessary nor practised.

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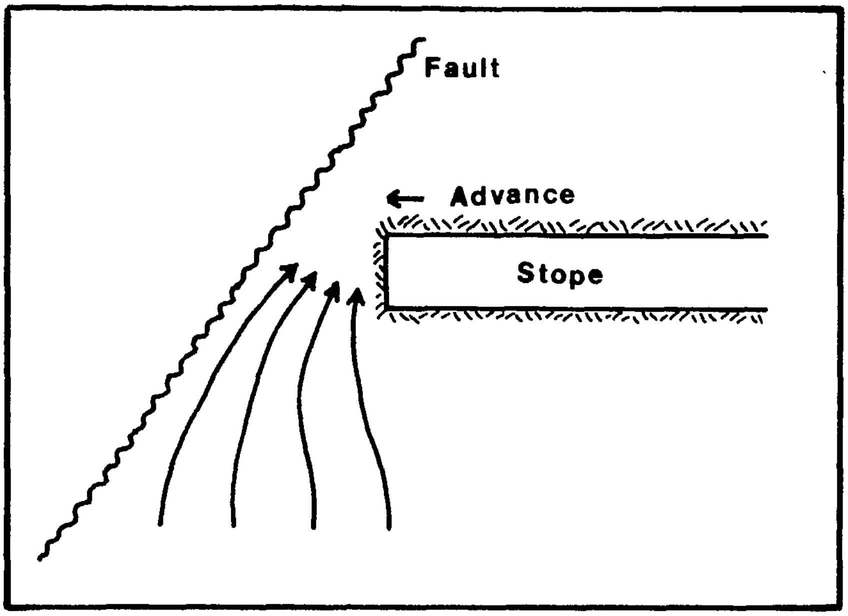

Fig. 11 - Stress concentration caused by a stope advancing towards a fault.

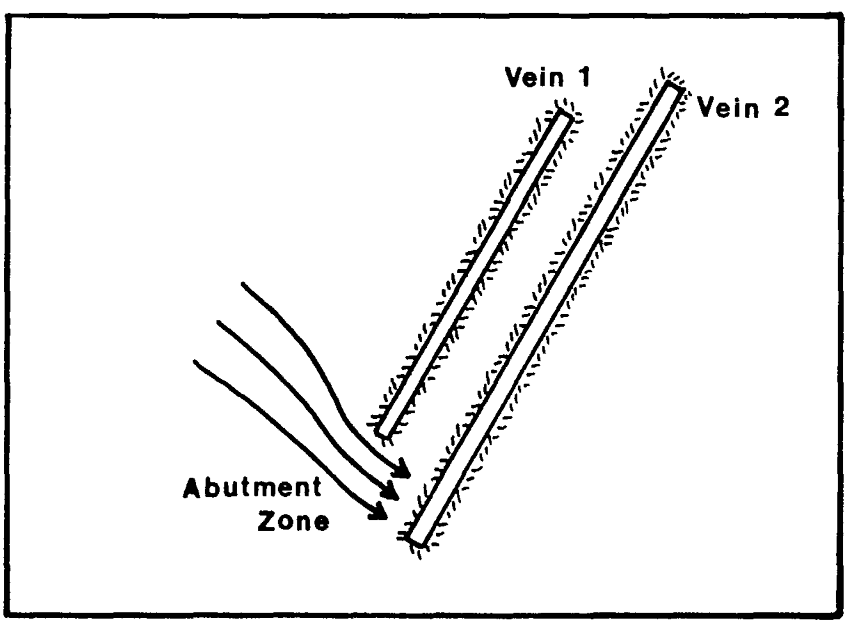

Fig. 12 - Abutment zone caused by mining vein 1 first.