12. Mining methods and method selection

12.1 Mining excavations

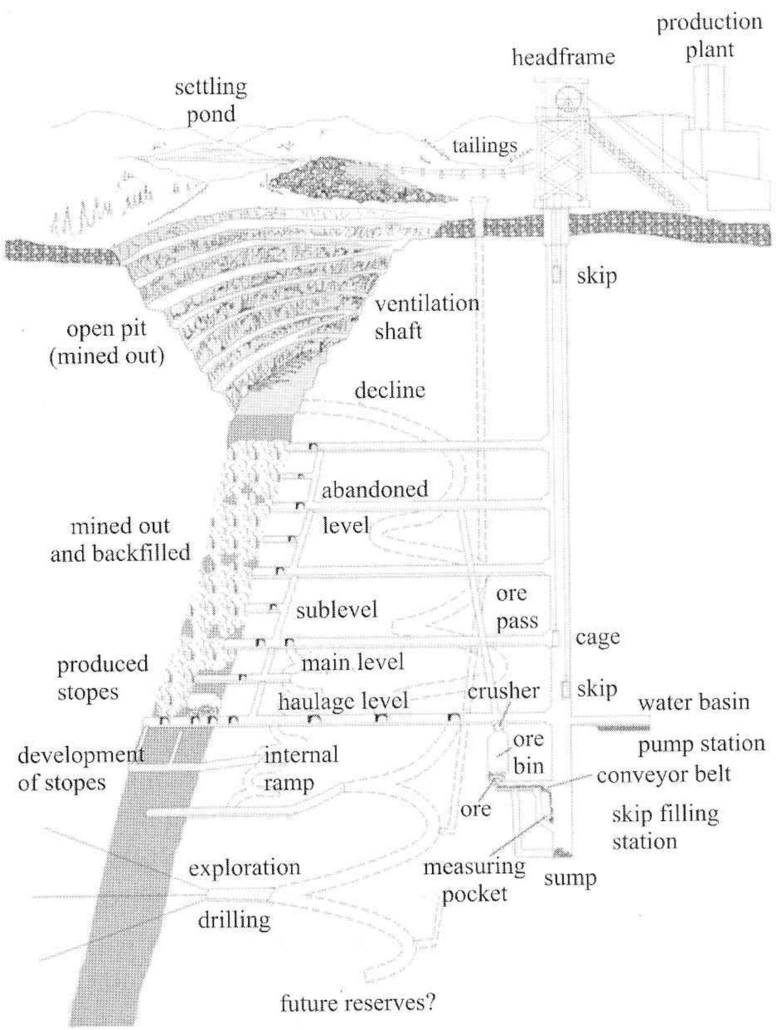


Fig.12.1 Basic infrastructure for an underground mine

12.1 Mining excavations

- Stopes or ore sources
  - Indicates the site of ore production in an orebody.
  - Generally largest excavations during the exploitation of the deposit.
  - Stope design exercises a dominant role in designing other excavations.
  - Those geomechanical properties are closely related to mining methods.
- Stope access and service openings
  - Operational life approximates that of adjacent stoping activity.
  - Include drill headings, slot raises, openings for personnel access to stope, and ore production and transport openings.
  - Located in orebody rock or within the orebody peripheral rock.
- Permanent access and service openings
  - Must meet rigorous performance specification for the complete mining activity.
  - Include service and ore hoisting shafts, ventilation shafts and airways, and haulage drives.

12.2 Rock mass response to stoping activity

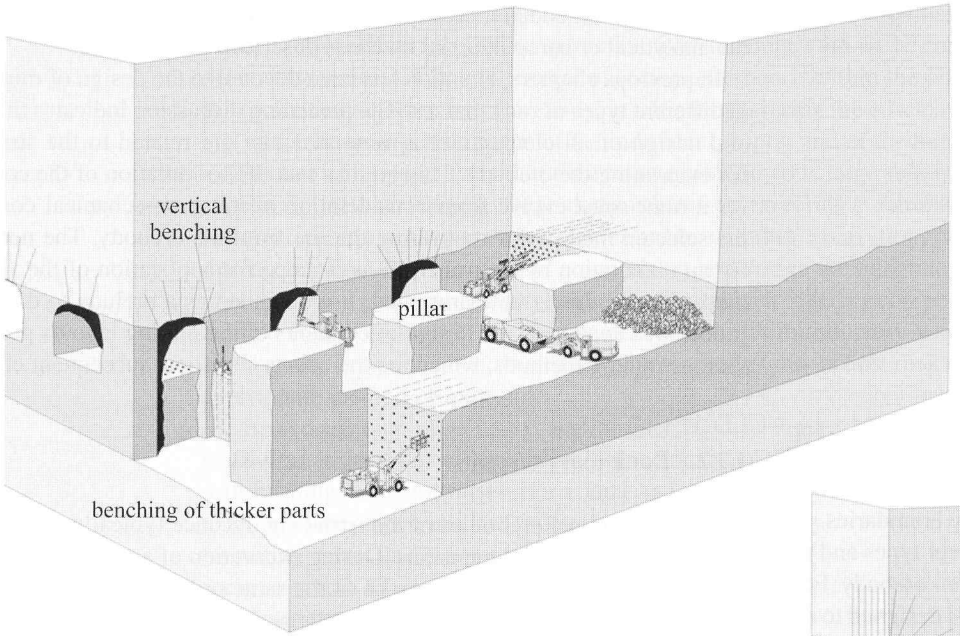


Fig.12.2 Room and pillar

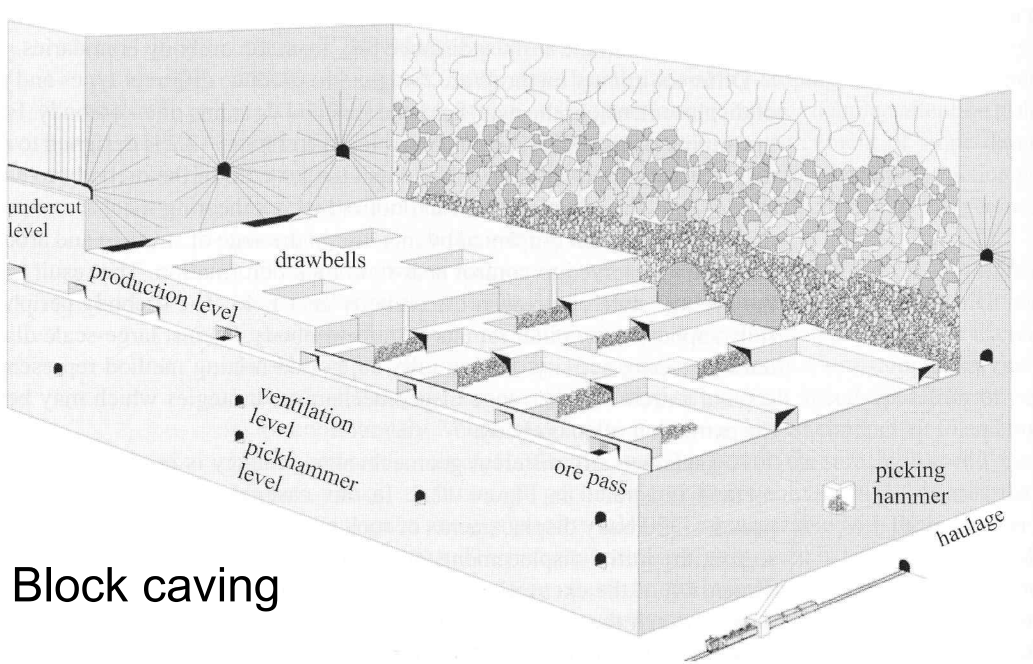


Fig.12.3 Block caving

12.2 Rock mass response to stoping activity

- Supported method (full support): room and pillar

- Restrict rock displacements in the near and far field of the orebody to elastic orders of magnitude.
- Keeps pseudo-continuous behavior of the host rock.
- Successful only if compressive stresses can be sustained by the near-field rock.
- Mining increases the strain energy in support elements and the near-field rock.
- Mining objective is to prevent the sudden release of the strain energy.

- Caving method (free displacement)

- Initial displacements are of the same order of magnitude as the vertical dimension of the excavation.
- Mining is initiated by generating pseudo-rigid body displacements of rock.
- Successful where low states of stress in the near field can induce discontinuous behavior of both the orebody and overlying country rock, or the stress is high enough to initiate fracturing.

12.2 Rock mass response to stoping activity

- Mining objective is the prevention of strain energy accumulation and the continuous dissipation of the energy.

12.3 Orebody properties influencing mining method

- Geometric configuration of orebody
- Indicates the relative dimensions and shape of an orebody.
- Ex) seam or stratiform deposits of sedimentary origin; veins, lenses, and lodes of hydrothermal emplacement or metamorphic processes; regular shapes of porphyry copper orebodies.
- Disposition and orientation
- Concerned with depth, dip, conformation ,etc.
- Mining in a heavily faulted environment may require a capacity for flexibility and selectivity in stoping due to sharp changes in ore distribution.
- Size
- Large, geometrically regular deposits may be suitable for mining using a mechanized, mass-mining method such as block caving.
- Small deposits of the same ore type may require selective mining.

12.3 Orebody properties influencing mining method

- Geomechanical setting

  Response of a rock mass to a particular mining method depends on

- Rock material properties: strength, deformation characteristics such as elastic, plastic, and creep properties, and weathering characteristics.
- Rock mass properties: geometric and mechanical properties of discontinuities (joints, faults, and shear zones).
- Pre-mining state of stress.
- Other adverse properties: a tendency to re-cement by some chemical action, rapid oxidation of a sulphide, abrasive and comminutive properties, major continuous faults, aquifers in the potential influence zone of mining, frequent seismic events

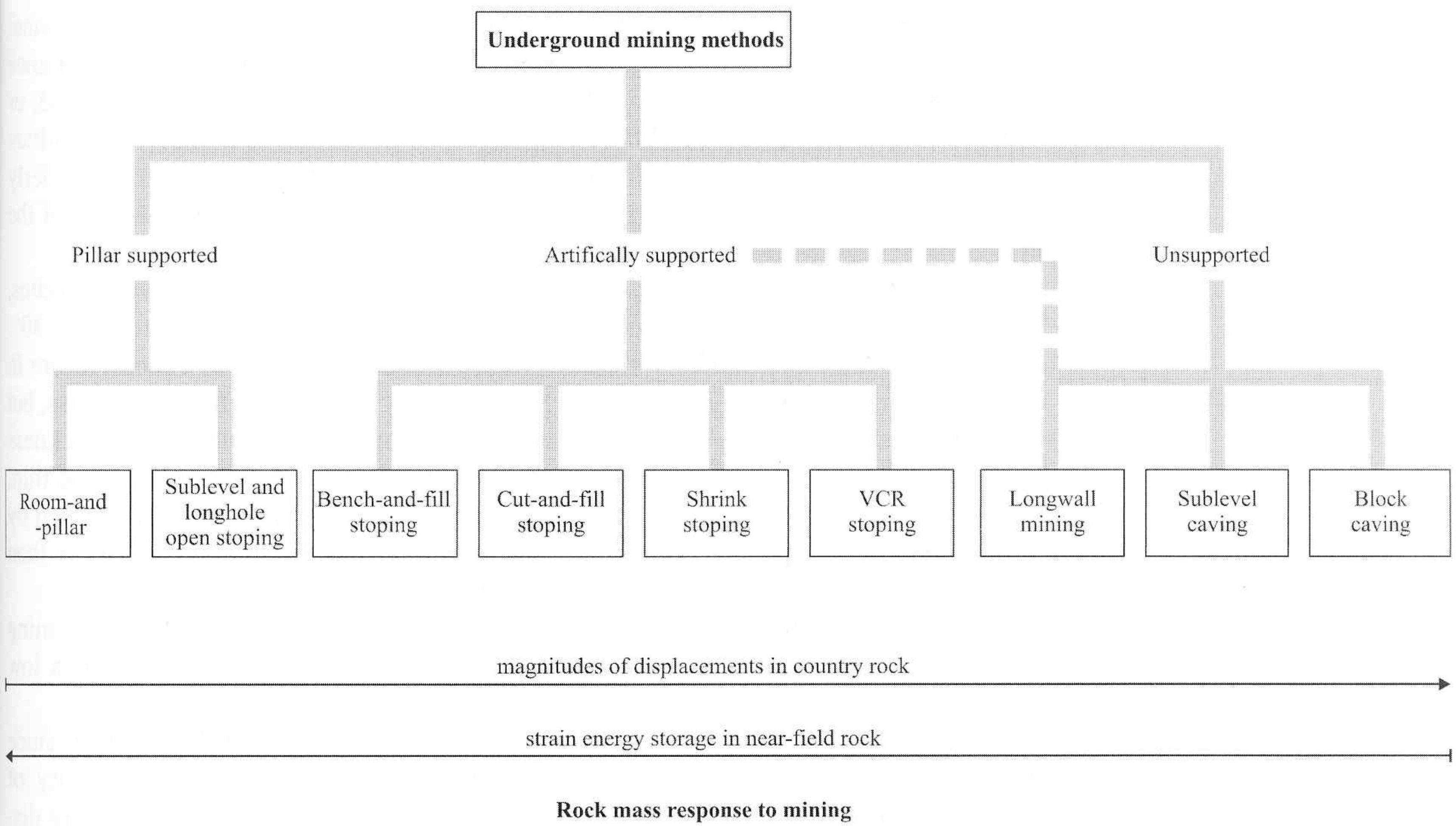
- Orebody value and spatial distribution of value

- Average grade defines the size and value of the deposit.
- Marginal grade of ore may be excluded from the production.
- Devising a mining strategy for recovering higher-grade domains is required where grade varies.

12.3 Orebody properties influencing mining method

- Engineering environment
- Caving methods have a more pronounced impact on the mine external environment : effect on groundwater flow pattern, change in the chemical composition of groundwater, change in surface topography through subsidence.
- Different mining methods impose different load on the mine internal environment such as ventilation air stream

12.4 Underground mining method



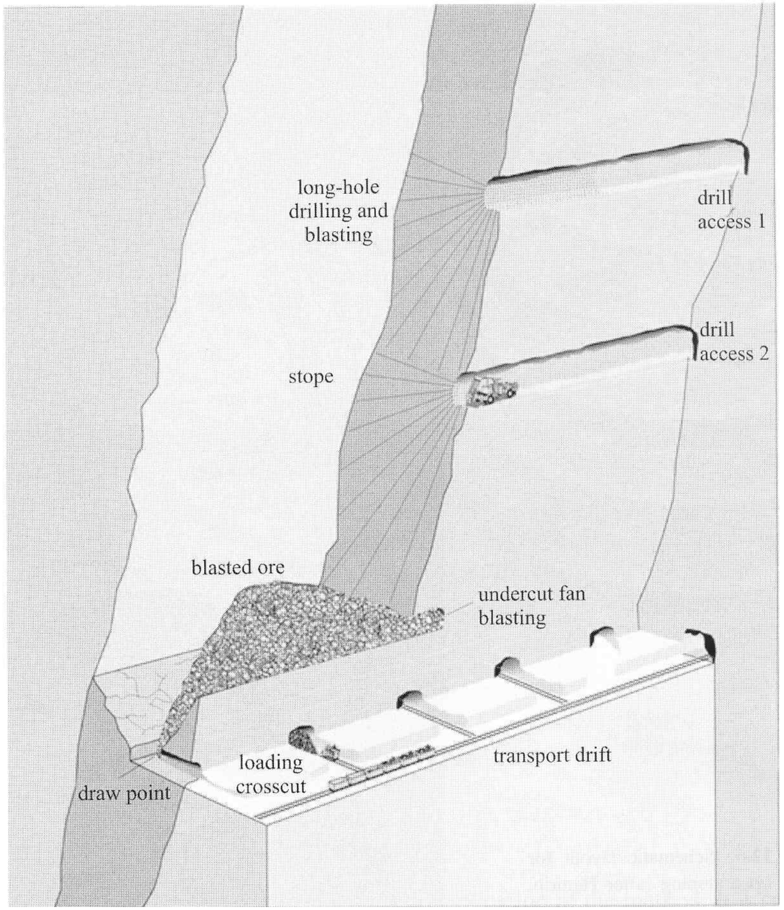
12.4 Underground mining method

- Room-and-pillar mining

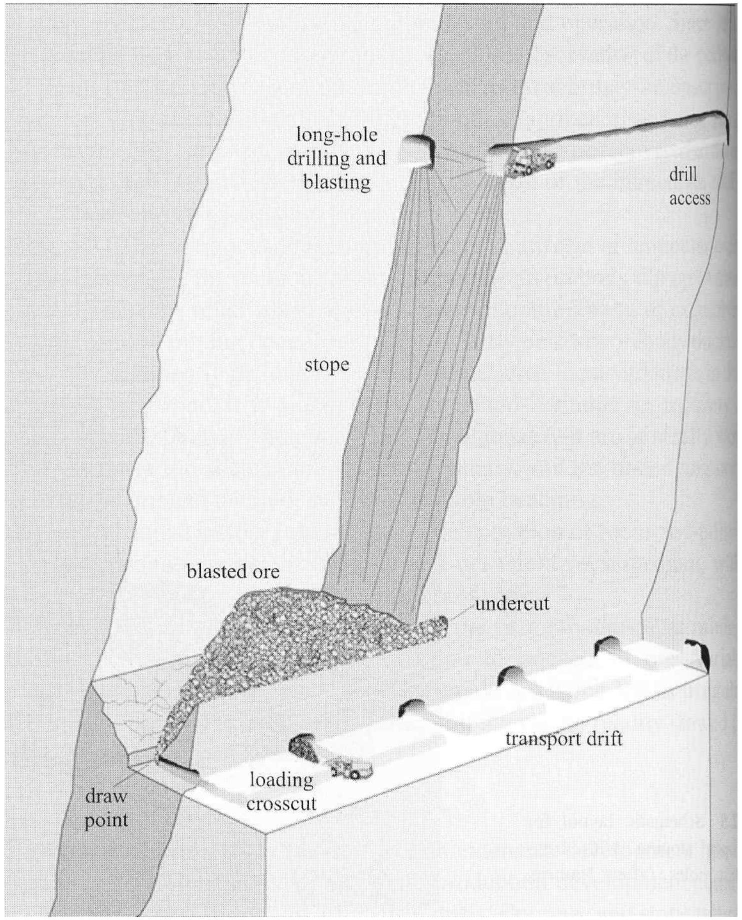
- Normally applied in flat-lying stratiform or lenticular orebodies admitting an orebody dip up to about 30°.
- Rooms serve the multiple roles as ore source, access opening, transport drift, and airway.
- Pillars are normally arranged in a regular grid array to simplify planning, design and operation.
- Pillars may be permanently unmined or recovered in the orderly retreat from a mine panel.
- Orebody must be relatively shallow to prevent commitment of excessive ore in pillars: orebodies of 6 m or greater height are worked by multiple passes.
- Requirement: strong, competent orebody and near-field rock medium, and a low frequency of crossing joints in the immediate roof rock.
- Highly selective extraction of ore is possible.

12.4 Underground mining method

- Sublevel open stoping



Sublevel open stoping



Bighole open stoping

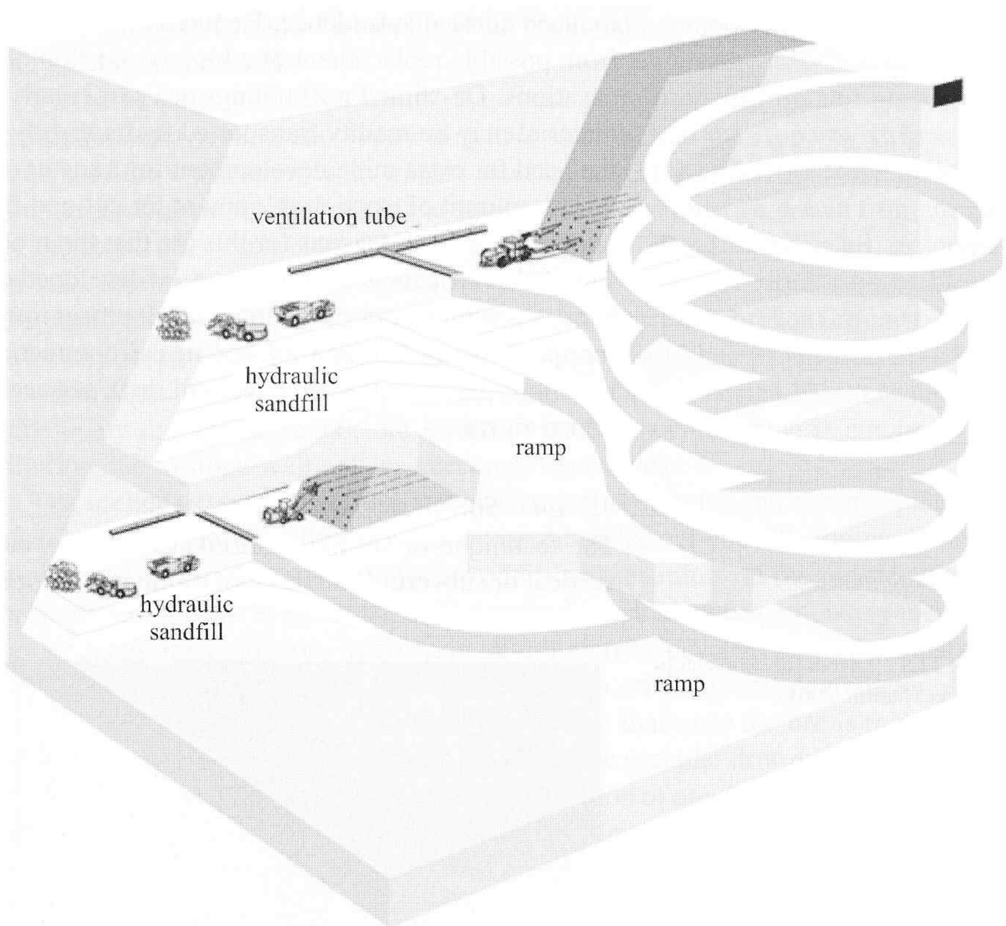
12.4 Underground mining method

- Sublevel open stoping

- Ore is fragmented in the stope using ring-drilled or long parallel blast holes, and moved to the drawpoints for extraction.
- Bighole open stoping uses longer blast holes with larger diameter of 140~165 mm: sublevel spacing increases from typically 40 m to 60 m.
- Applied in massive or steeply dipping stratiform orebodies with dip angle higher than the angle of repose of the broken rock.
- Strength of orebody and country rock must be sufficient to provide stable walls, faces and crown for the excavation.
- Selective mining is precluded by the requirement for regular stope outlines.
- Blast hole penetration of stope walls, due to drilling inaccuracy, leads to dilution: the resulting minimum orebody width is about 6 m.

12.4 Underground mining method

- Cut-and-fill stoping



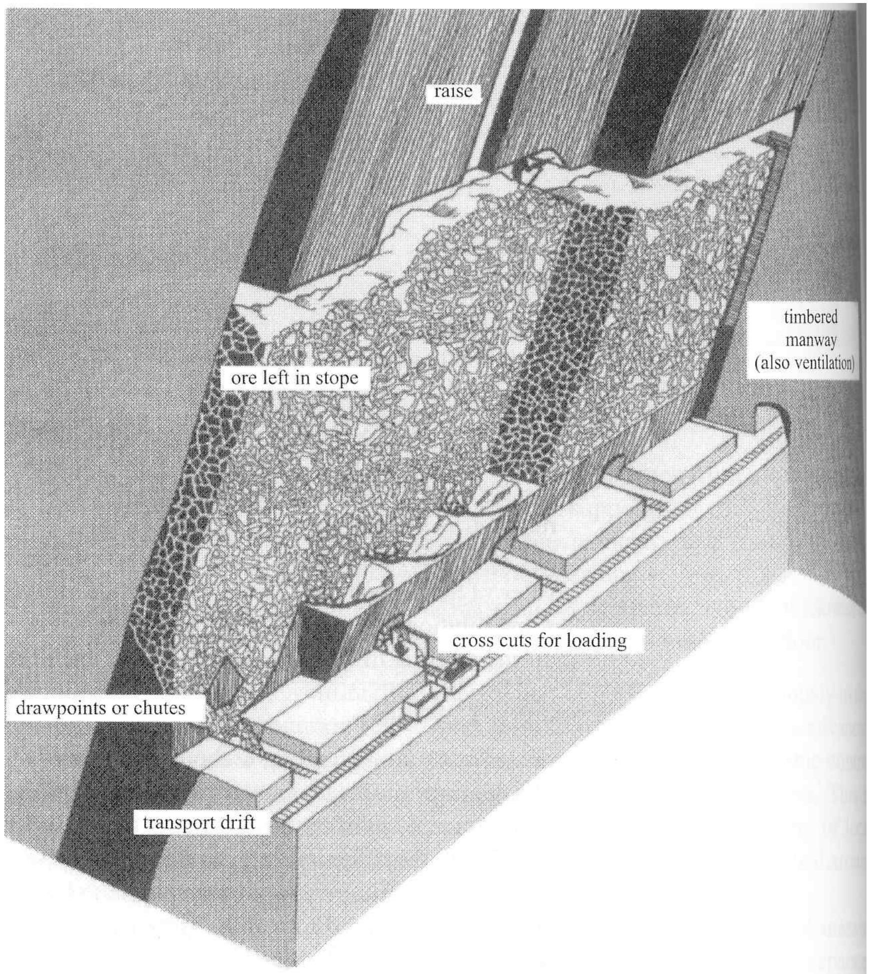
12.4 Underground mining method

- Cut-and-fill stoping

- Mostly mining proceeds up-dip in an inclined orebody.
- Drilling & blasting about 3 m thick → scaling & support → ore loading & transport → backfilling of depth equal to the thickness of sliced ore.
- Reliable control of the performance of rock is important: controlled blasting, rock support, and backfilling are adopted.
- Applied in veins, inclined (35°~90°) tabular orebodies, and massive deposits.
- Stope spans may range 4 ~ 40 m with 10 ~ 12 m of reasonable upper limit.
- Suitable for low rock mass strength conditions.
- Relatively labor-intensive method: ore grade must be sufficiently high.
- Provides both flexibility and selectivity in mining.
- Significant environmental benefits by use of backfill: limited possibility of surface subsidence, reduction in surface storage of mined wastes, relatively small amount of stope delvelopment compared with open stoping.

12.4 Underground mining method

- Shrink (Shrinkage) stoping



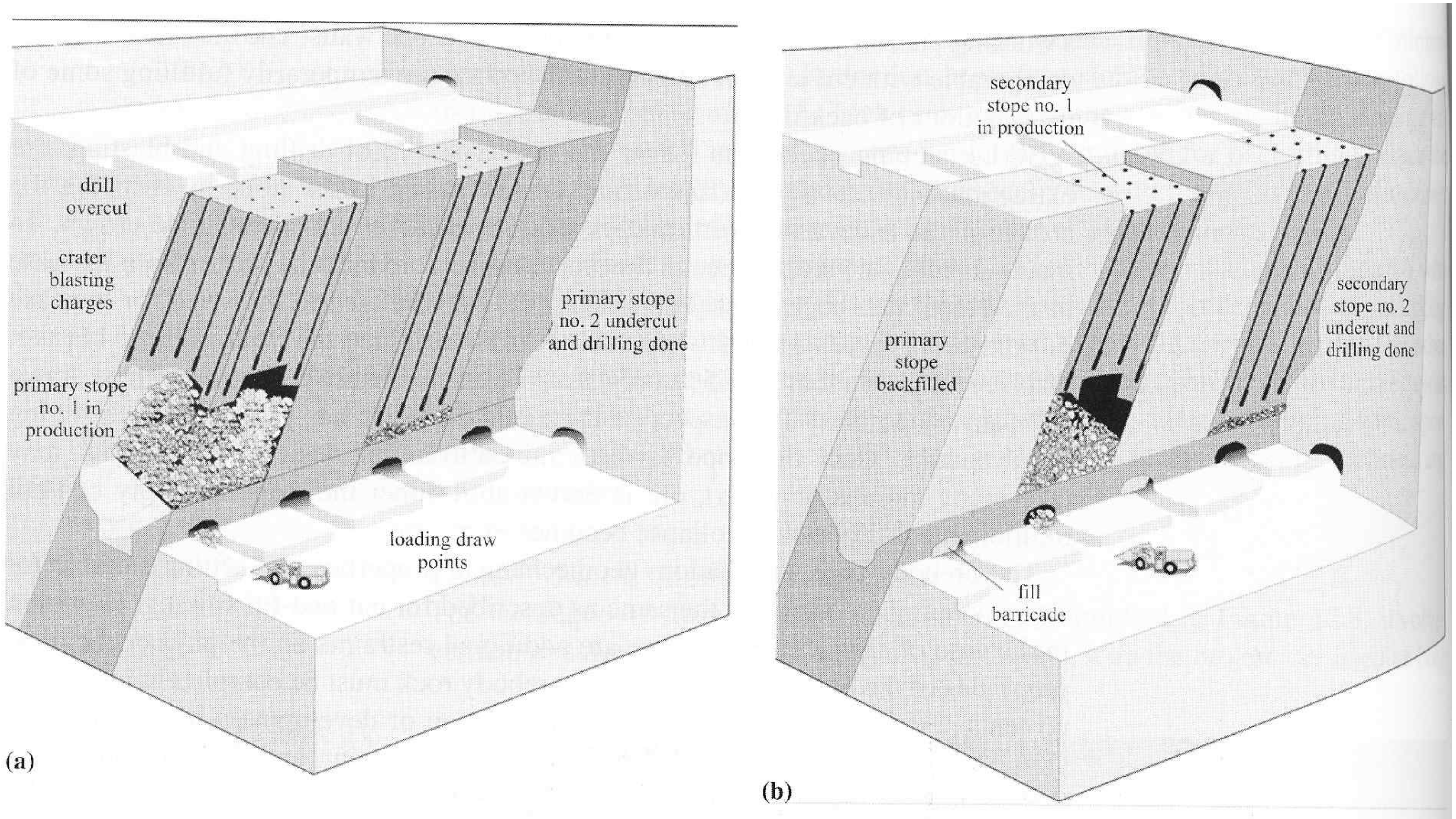
12.4 Underground mining method

- Shrink (Shrinkage) stoping

- Applied to vertical or subvertical advance of mining in a stope.
- Broken ore used as both a working platform and temporary support.
- Drilling & blasting $\rightarrow$ ore extraction $\rightarrow$ scaling & supporting.
- 30~35% of the freshly broken ore is drawn from the base of the stope after each blast (void ratio of blast rock is about 50~55%): disadvantage in production scheduling.
- After the stope has been completely mined ore is drawn until the stope is empty or until dilution due to stope-wall collapse becomes excessive.
- Orebody should have no tendency for oxidation, hydrolysis, dissolution, or development of cementitious materials (promoted by water). It must also be strong and resistant to crushing and degradation during draw.
- Labor intensive mining method less productive than sublevel stoping, vertical crater retreat, and cut-and-fill methods.

12.4 Underground mining method

- Vertical crater retreat (VCR) stoping



(a) Primary stopes (b) secondary stopes

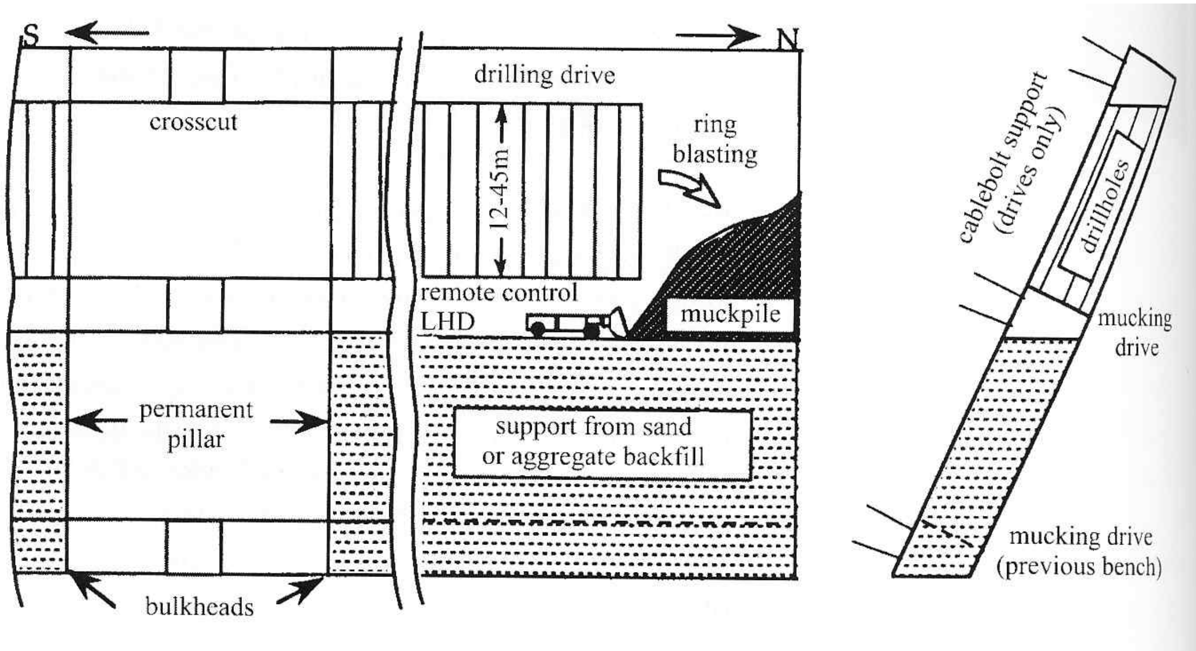
12.4 Underground mining method

- Vertical crater retreat (VCR) stoping

- Applied to the cases where conventional shrink stoping is feasible although narrow orebody width (< 3 m) may not be tractable, or to the cases where sublevel development is difficult or impossible.
- Use of long and subvertical blast holes eliminates the need for entry of operating personnel into the developing mine void.
- After each blasting, sufficient ore is drawn from the stope to provide a suitable expansion void for the subsequent blast.

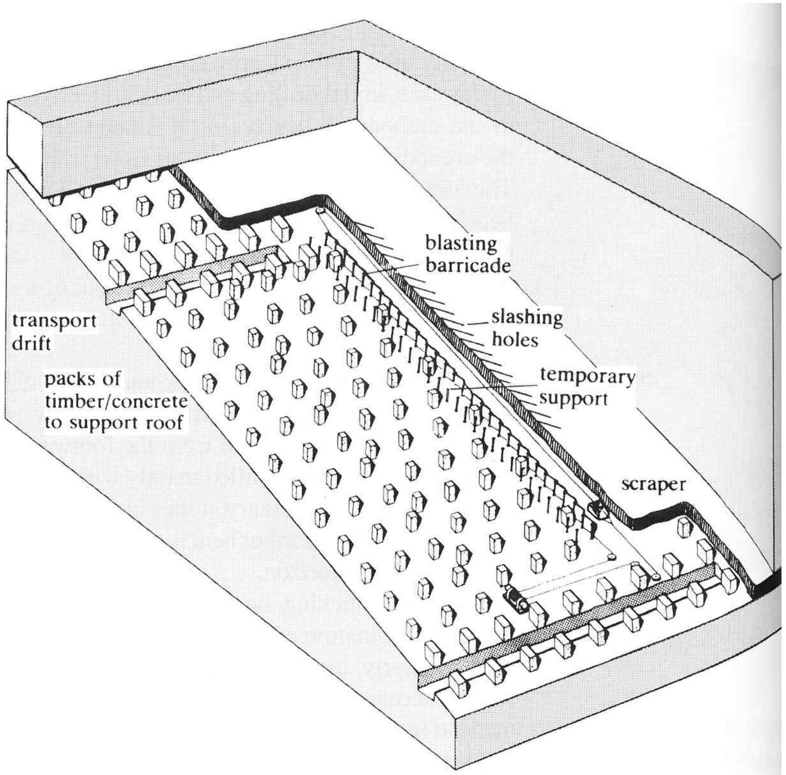
12.4 Underground mining method

- Bench-and-fill stoping
- Developed in early 1990s as a more productive alternative to cut-and-fill method.
- Initially drilling and extraction drives are mined along the ore length and width.
- A bench slot is created between these two horizons at the end of orebody.

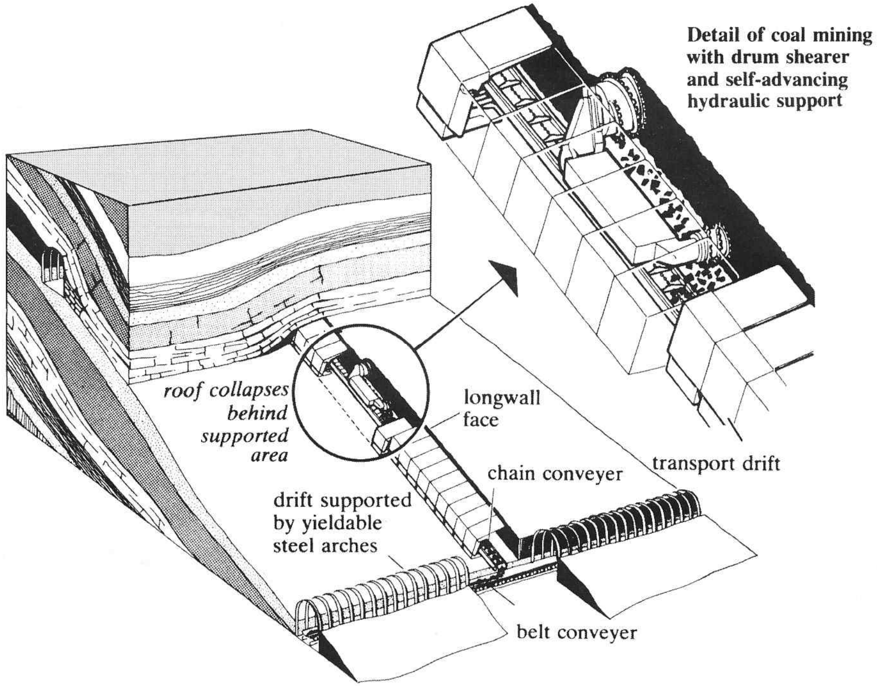


12.4 Underground mining method

- Longwall mining



Longwall mining in hard rock



Longwall mining in soft rock

12.4 Underground mining method

- Longwall mining

- Applied to a flat-lying (< 20°) stratiform orebody when high area extraction ratio is required and a pillar mining method is precluded.
- Applicable to both metalliferous mining in hard-rock and coal mining in soft rock.
- Requires a reasonably uniform distribution of grade and a high degree of continuity of orebody.

1) In hard-rock

- Seeks to maintain pseudo-continuous behavior of the near-field rock mass.
- Mining advances along strike by blasting rock from the ore face.
- Ore is drawn by scraper down dip into a transport gully.
- Temporary support such as yielding props is emplaced near the mining face, while resilient support such as timber and concrete brick packs are constructed in the void behind the face.
- State of stress around the working area of a single stope is invariant during further stope advance

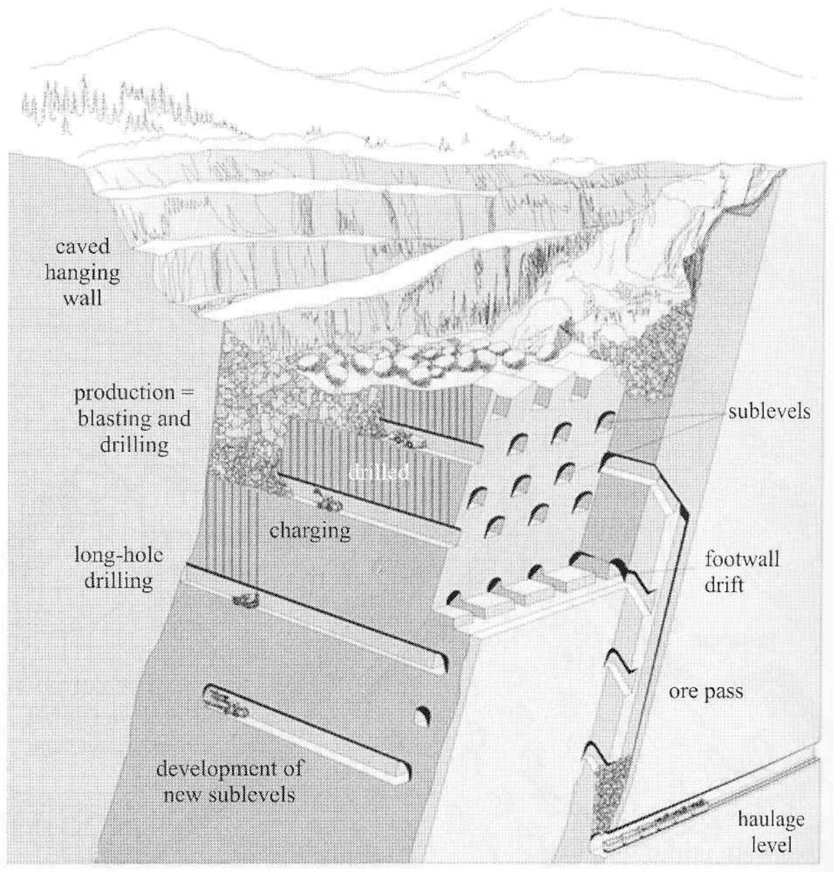
12.4 Underground mining method

2) In soft rock: coal mine

- Mechanical ploughing or shearing on the coal seam → loading the broken ore on to a chain conveyer → advancing the hydraulic roof supports → roof collapsing behind the supported area.

12.4 Underground mining method

- Sublevel caving

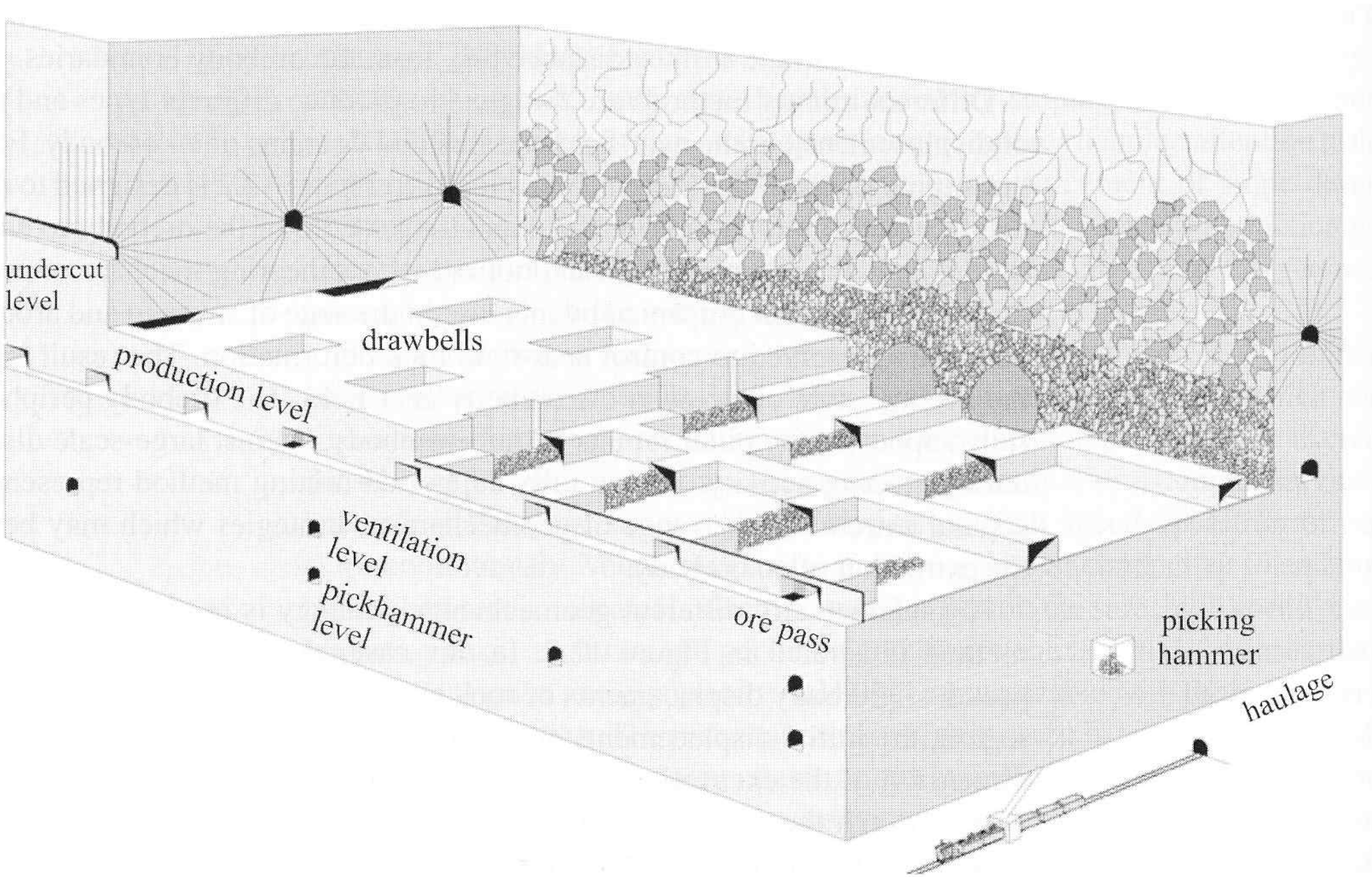


12.4 Underground mining method

- Sublevel caving
- Induces free displacement of the country rock overlying an orebody.
- Ore and waste are fragmented using blast holes drilled upwards from headings.
- Explosive consumption in blasting is high.
- Mining progresses downwards in an orebody, with each sublevel being progressively eliminated as mining proceeds.
- Headings serve as both drill drifts and transport openings.
- Suitable for steeply dipping orebodies which have sufficient grade to accept dilution exceeding 20 %.
- Produces significant disturbance of the ground surface.
- Recently the spacings of sublevels and drawpoints have been significantly increased reducing some of the cost disadvantages.

12.4 Underground mining method

- Block caving



12.4 Underground mining method

- Block caving

- A kind of mass mining method with high production rates at relatively low cost.
- Applicable only to large orebodies with a height of more than 100 m which have a fairly uniform distribution of grade.
- Disintegration of ore and country rock takes place by natural mechanical processes involving fractures, stress distribution, limited strength of the medium, and gravity.
- When the temporary pillars in an undercut excavation are removed, failure and progressive collapse of the undercut crown occurs.
- Removal of fragmented ore on the extraction horizon induces flow in the caved material.
- Initial and induced geomechanical conditions in an orebody determine the success of block caving.
- The most favorable rock structural condition for caving: at least two prominent subvertical joint sets with subhorizontal set.

12.5 Mining method selection

- The mining principles and methods have evolved to meet the geomechanical and operational problems of various cases.
- Final choice of mining method will reflect both the engineering properties of the orebody and its setting, and the engineering attributes of the various methods such as mining scale, production rate, selectivity, personal ingress requirements and extraction flexibility.
- For the large, often low grade orebodies, selecting the proper mining method is difficult: block caving is generally preferred due to low labor requirement, and low cost per tonne.
- Basic prerequisites to applying block caving method are that caving can be initiated in the orebody, and that it will propagate steadily through the orebody.