MINING METHODS AND UNIT OPERATION

STUDY MATERIAL

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SYLLABUS

Module I

Surface Mining : Deposits amenable to surface mining ; Box Cut ; Objectives types parameters and methods, production benches- Objectives ,formation and benches parameters ,Unit Operation and associated equipments ,Classification of surface mining systems.

Module II

Underground Coal Mining: Deposits amenable to underground coal mining Classification of underground coal mining methods, Board and Pillar Methods –general description and applications and merits and demerits, selection of panel size operation involved and associated equipment.

Module III

Long Wall Methods –Type and their general description ,applicability ,merits and demerits ,Selection of face length and panel length ,operation involved and associated equipments, Methods for mining steeply inclined seam and thick seams hydraulic mining.

Module IV

Underground Metal Mining: Deposits amenable to underground metal mining shape, size &position of drifts and cross cut, Raises and Winzes, classification of underground metal mining methods.

Module V

Stoping Methods - General description, applicability, Oprations involved and associated equipments for room pillar mining, Stope and pillar mining, stope and piellar mining, shrinkage, stoping, sub level stoping ,cut and fill stoping, VCR methods, Sub level caving and caving .

Surface Mining

- **Surface mining** is a form of **mining** in which the soil and the rock covering the mineral **deposits** are removed. It is the other way of underground **mining**, in which the overlying rock is left behind, and the required mineral **deposits** are removed through shafts or tunnels.

- The traditional cone-shaped excavation (although it can be any shape, depending on the size and shape of the ore body) that is used when the ore body is typically pipe-shaped, vein-type, steeply dipping stratified or irregular.

- Although it is most often associated with metallic ore bodies, (e.g., Palabora copper, Mamatwan and Sishen iron-ore), it can be used for any deposit that suits the geometry – most typically diamond pipes – (e.g., Venetia, Koffiefontein and Finsch).

Surface mining is the predominant exploitation method worldwide

In the USA, surface mining contributes about 85% of all minerals exploitation (excluding petroleum and natural gas).

***Almost all metallic ore* (98%) and *non-metallic ore* (97%), and 61% of the coal is mined using surface methods in the USA (Hartman and Mutmansky, 2002).**

Primarily expensive transportation equipment), but generally results in:

- High productivity (i.e., high output rate of ore).
- Low operating costs.
- Safer working conditions and a better safety record than underground mining.

Steps of Surface Mining :

Operation:

- Strip out overburden (becomes spoils)
- Traditional surface mining methods fall into two broad categories based on locale:

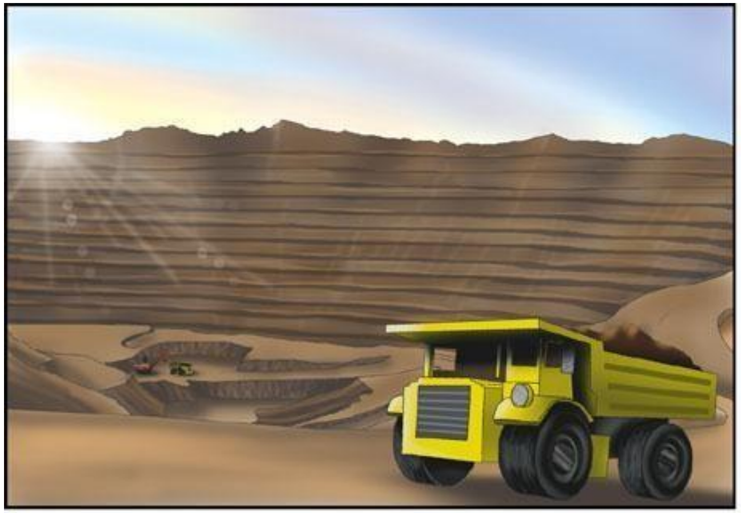
I) Mechanical excavation methods

{ such as: *Open-pit (or Open-cut or Open-cast)* Terrace; and Strip mining}.

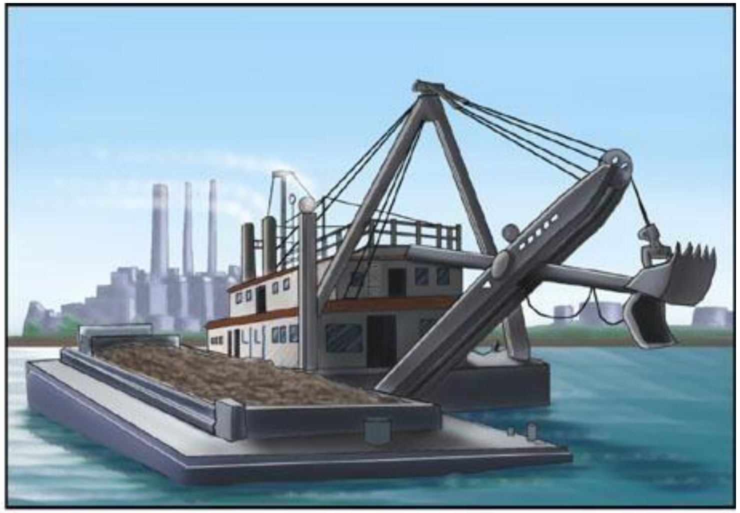
II) Aqueous methods {such as: *Placer and* In-situ leaching (ISL)/ *Solution mining*}.

Table : Subdivided surface mining *methods (Bohnit, 1992)*

Method	Subclass	Method
Mechanical excavation		▪ *Open-pit (or Open-cut or Open-cast) mining.* ▪ *Terrace mining.* ▪ *Strip (flat terrain) mining.* ▪ *Contour strip (hilly terrain) mining.* ▪ *Auger Mining* ▪ *Glory Holing* ▪ *Quarrying*
Aqueous	***Placer***	▪ *Panning* ▪ *Sluicing* ▪ *Dredging* ▪ *Hydraulic Mining*
	Solution	▪ *Heap Leaching* ▪ *In-situ leaching (ISL)*



(a) Open Pit Mine



(b) Dredging

(c) Area Strip Mining

(d) Contour Strip Mining

Figure shows major surface mining methods

MINERAL EXTRACTION OPEN PIT

- Used when ore bodies lie near the surface
- Large hole exposes the ore body
- Waste rock (overburden) is removed
- 2nd cheapest method, but has the largest environmental impact.

Basic Concept

Although the basic concept of an open pit is quite simple, the planning required to develop a large deposit for surface mining is a very complex and costly undertaking.

At one mine, it may be desirable to plan for blending variations in the ore so as to maintain, as nearly as possible, a uniform feed to the mill.

At another operation it may be desirable to completely separate two kinds of ore, as for example, a low-grade deposit where one kind of *"oxide"* ore must be treated by acid leach, but a second kind of *"sulfide"* ore must be treated by different methods.

The grade and tonnage of material available will determine how much waste rock can be stripped, and there is often an ultimate limit to the pit that is determined more by the economics of removing overburden than a sudden change in the ore deposit from mineral to non-mineral bearing material.

The ultimate pit limit and the slope of the pit walls are therefore determined as much by economics and engineering as by geological structure. Material that is relatively high grade may be left unmined in some awkward spot extending back too deeply beneath waste.

The typical large open pit mining operation that has been in production for 10 years and more is operating under conditions that could not possibly have been foreseen by the original planners of the mine.

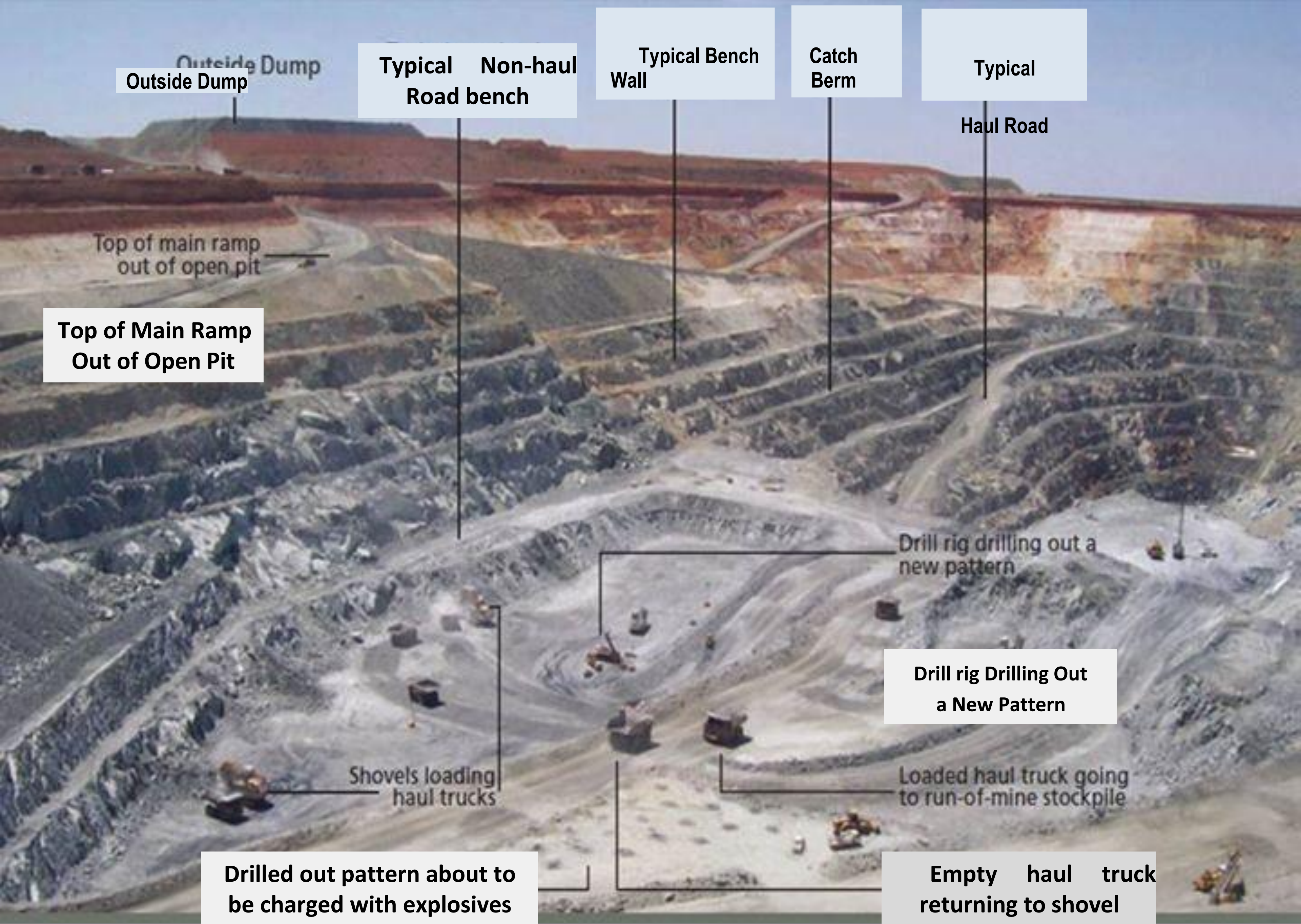
Metal prices, machinery, and milling methods are constantly changing so that the larger operations must be periodically reevaluated, and several have been completely redeveloped from time to time as entirely different kinds of mining and milling operations.

Sometimes the preliminary stripping of the waste overburden is contracted to firms specializing in earthmoving. Mining is usually done by track-mounted electric shovels in the large operations, and by rubber-tired diesel front-end loaders in the smaller operations. Scrapers are sometimes used in special situations.

Large bucket-wheel excavators of the kind used in European coal mines have not been applied to metal mining, because this equipment is best adapted to softer bedded, relatively flat-lying strata.

Open pit Mining method

- Mine working open to the surface.
- Funnel shaped hole in ground, with ramp spiraling down along sides, allows moderately deep ore to be reached.
- Operation designed to extract minerals that lie close to the surface
- It is used when the ore body is near the surface and little overburden (waste rock) needs to be removed.
- It is usually employed to exploit a near-surface deposit or one that has a low stripping ratio.
- Waste is first removed, then the ore is broken and loaded.
- Generally low grade, shallow ore bodies.
- Non-selective: all high and low grade zones mined
- Mining rate > 20,000 tons mined per day (tpd).
- It often necessitates a large capital investment butgenerally results in high productivity, low operating cost, and good safety conditions.
- Design issues:
    - Stripping overburden
    - Location of haul roads
    - Equipment size of trucks and fleet
    - Pit slope angle and stability



Typical Open Pit Mine

Haulage

Haulage is usually by truck, although railroads, inclined rails, and conveyor belts have been used.

The conveyance unloads directly into a primary crusher and crushed material is stored in coarse ore bins prior to shipment to the mill.

Blastholes

Blastholes are usually drilled vertically by self- propelled, track-mounted pneumatic or rotary drills Bulk explosives are loaded in the holes and large volumes of ore are broken in a single blast.

Sometimes the drill holes are routinely sampled and assayed to help plan the position of the shovels in advance of mining.

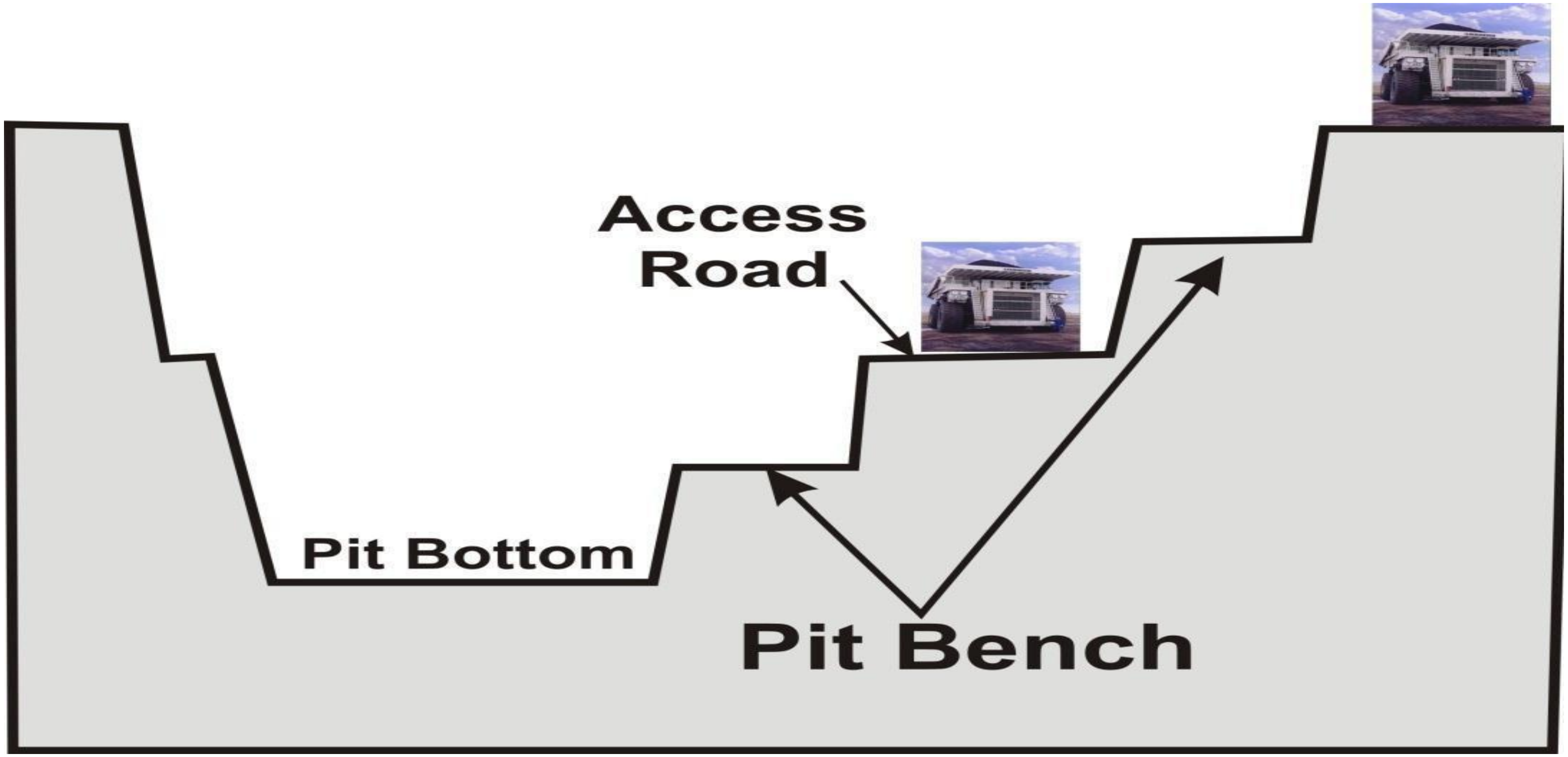
Blasthole assay control is especially desirable when exploration data are incomplete or lacking as in the case in the older pits which have long been mined past the limits of "ore" used in original planning.

Mining Trucks

This is a photograph of liebherr 360 ton (327 metric ton) haul truck.

This unit is powered by a 2750 horse power engine and weighs 443, 000 pounds (177 ton) .

Bench



Bench level intervals

Bench level intervals are to a large measure determined by the type of shovel or loader used, these are selected on the basis of the character of the ore and the manner in which it breaks upon blasting and supports itself on the working face.

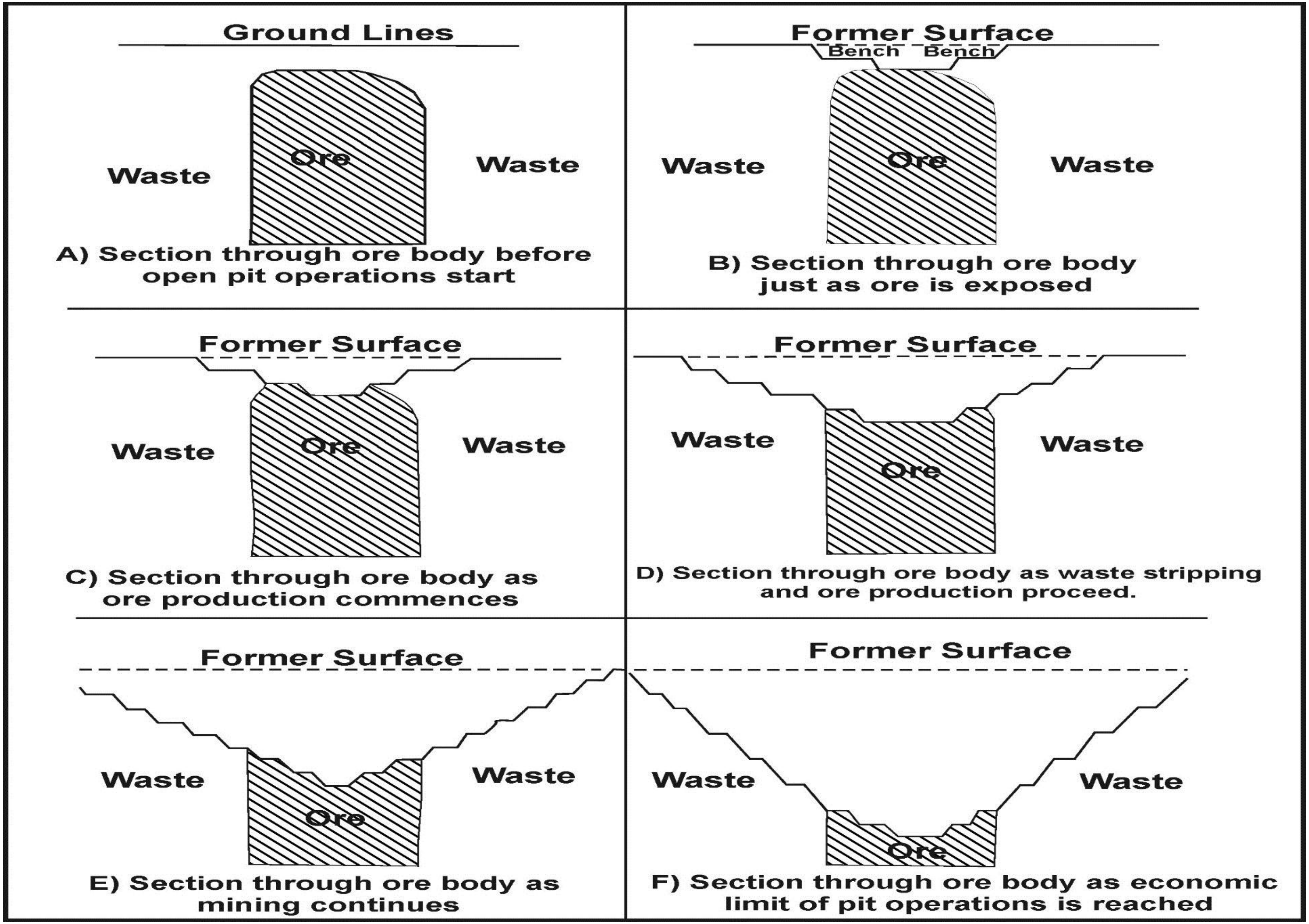
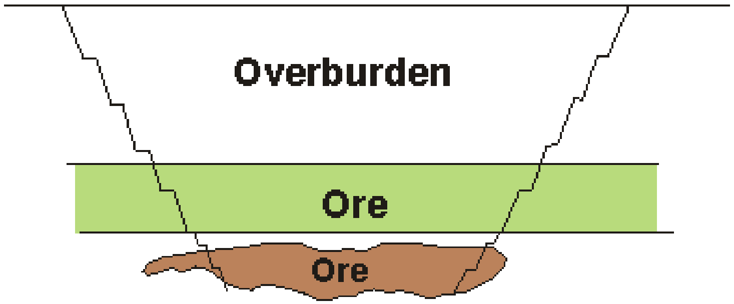


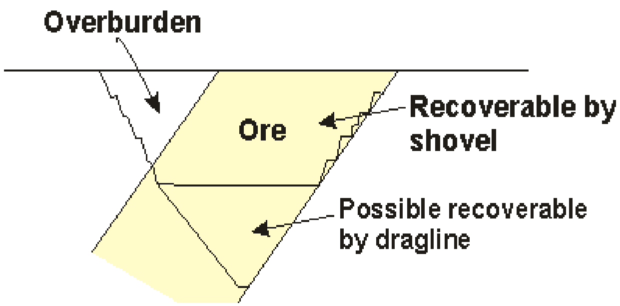
Figure: Open-pit mining sequence (for pipe-like orebody)

Various open-pit and orebody configurations



Flat lying seam or bed, flat terrain (Example platinum reefs, coal).

Massive deposit, flat terrain (Example iron-ore or sulphide deposits).

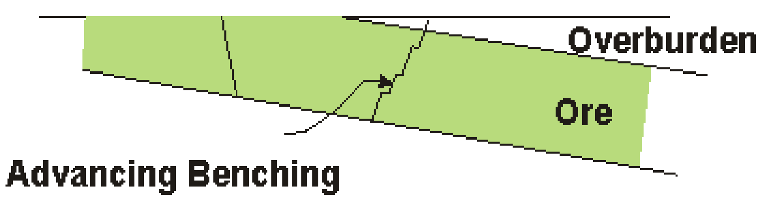


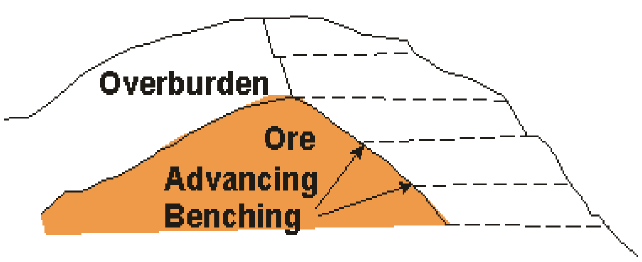
Dipping seam or bed, flat terrain

(Example anthracite).

Massive deposit, high relief (Example copper sulphide).

Thick bedded deposits, little overburden, flat terrain (Example iron ore, coal).





Terrace Mining

- Where the overburden is too thick {or the floor of the pit (i.e., The ore inclination) is too steeply dipping} to allow waste dumping directly over the pit (as is the case with a dragline and strip mining), it is necessary to use intermediate cyclic or continuous transport (e.g., trucks or conveyors) to transport the overburden to where it can be tipped back into the previously mined void.

- It is a multi-benched sideways-moving method, the whole mine moves over the ore reserve from one end to the other, but not necessarily in a single bench. The number of benches used is usually a function of the excavation depth and type of machinery used (typically between 10-15m bench height and 1-32 benches in the terrace).

- Where steeply dipping orebodies are encountered, the modified method is most often applied, a more typical 3 waste bench terrace operation with steeply dipping orebody. In this case, the pit dimensions are limited by seam exposure (pit length) and available working area (for mining and dumping faces) (pit width).

Strip Mining

Used for near-surface, laterally continuous, bedded deposits such as coal, stratified ores such as iron ore, and surficial deposits (nickel laterite or bauxite).

When orebodies are flat-lying and close to surface, it is sometimes economical to remove the overlying rock to expose the orebody.

Strip mining is ideally applied where the surface of the ground and the ore body itself are relatively horizontal and not too deep under the surface, and a wide area is available to be mined in a series ofstrips.

- The surface soil is stripped off and stockpiled for later land reclamation.
- A stripping dragline with a long-boom or long reach shovels are common.

The pits are shallower that open-pit mines, and the overburden is "***hind-cast***" directly into adjacent mined out panels.

It is a very low-cost, high-productivity method of mining.

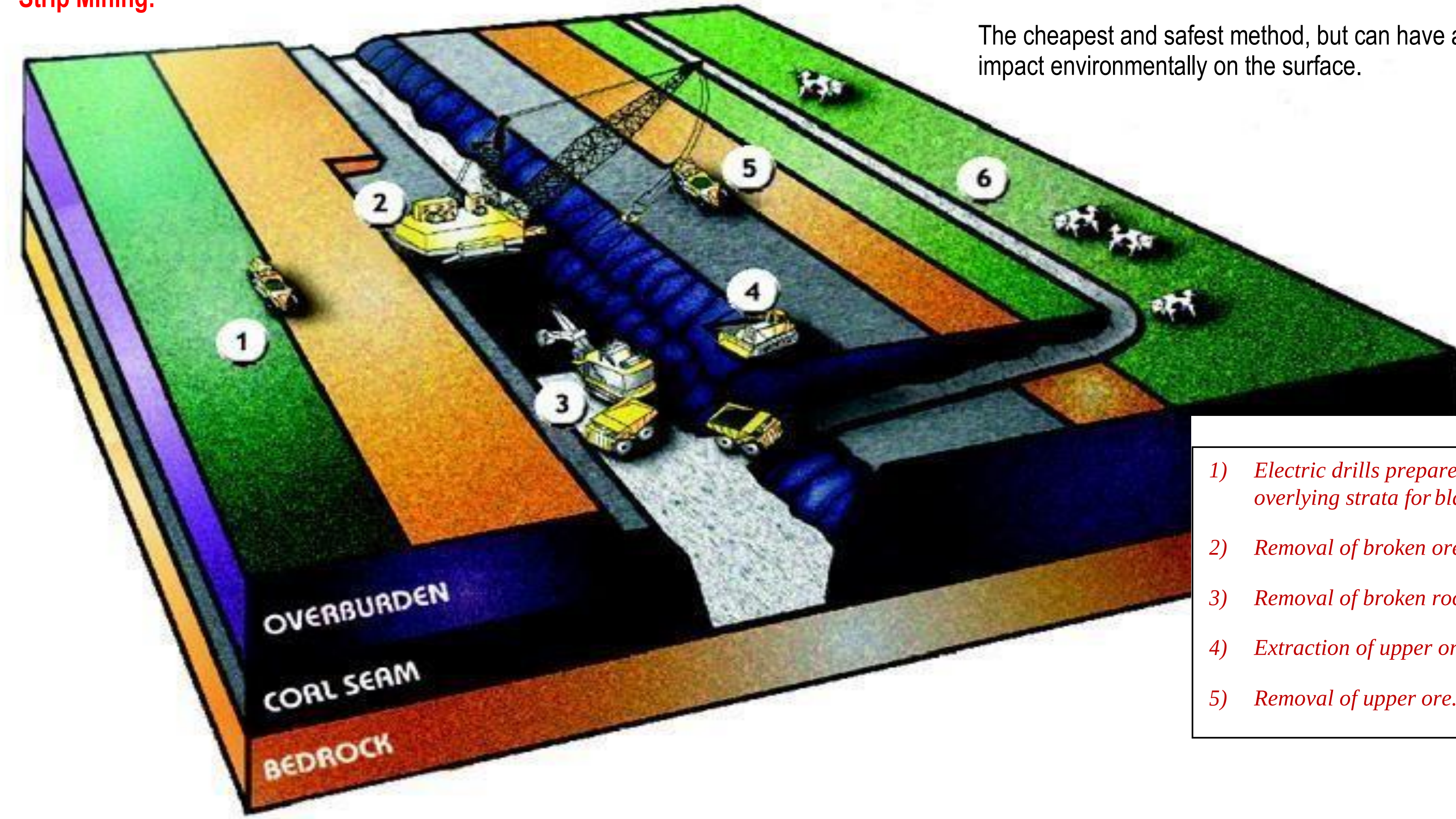
Typicalexamples of this type of mining are the larger tonnage coal mining operations in Mpumulanga.

Favorable conditions are:

- ***Relatively thin overburden*** (0-50 m maximum otherwise stripping ratio and cost of stripping becomes too high).
- ***Regular and constant surface topography and coal layers*** (not more than 20º variation from horizontal on the coal seam –topography can vary more since pre-stripping can be used to level it – but this is expensive to apply).
- Extensive area of reserves (to give adequate life of mine (LOM) and to cover all capital loan repayments–

Strip Mining:

The cheapest and safest method, but can have a significant impact environmentally on the surface.



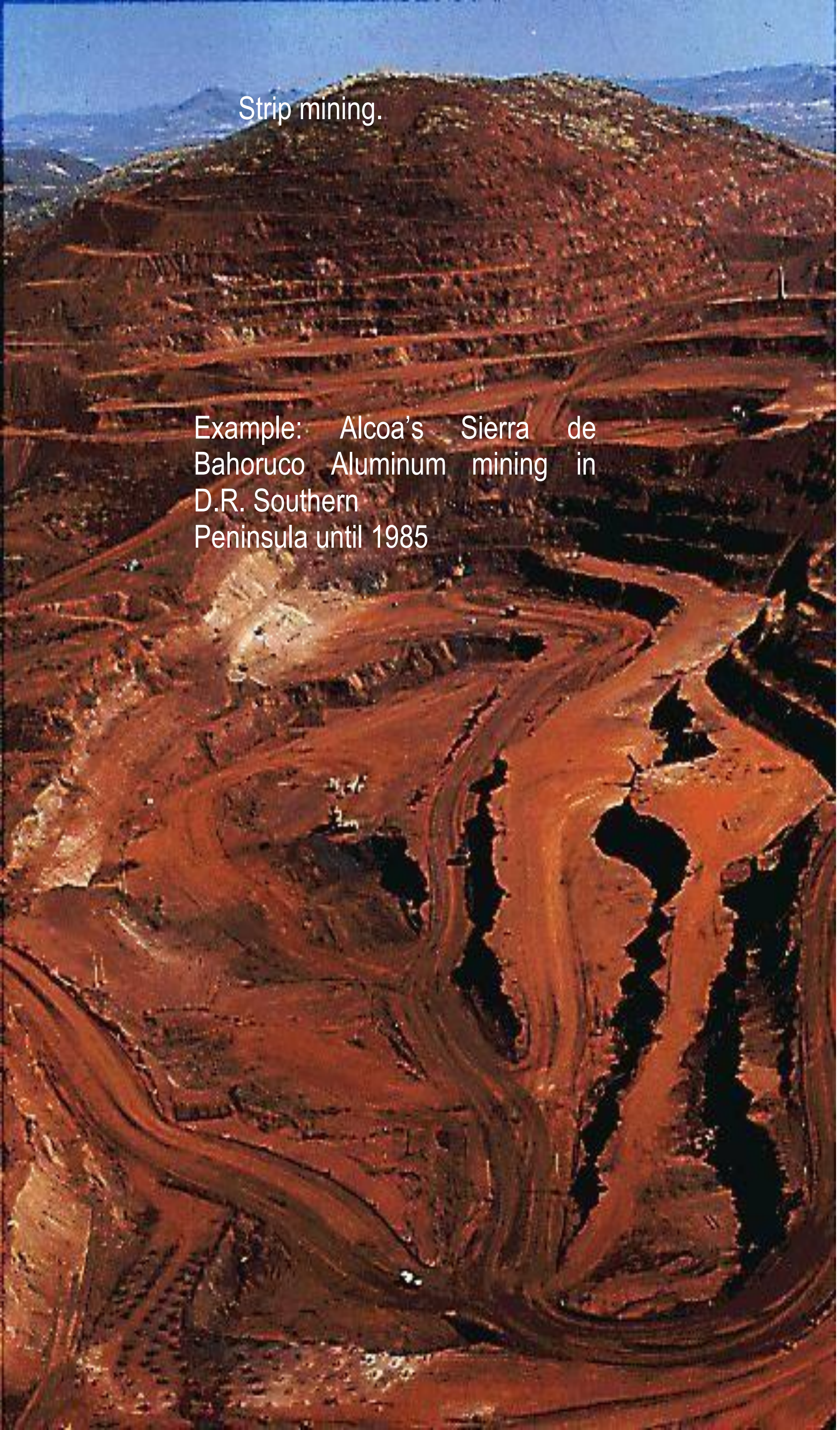
1) *Electric drills prepare the overlying strata for blasting.*
2) *Removal of broken ore.*
3) *Removal of broken rock.*
4) *Extraction of upper ore seam.*
5) *Removal of upper ore.*

The ore is close to the surface of the land (30m) but has one or more layers ofrock and dirt on top of it.

To mine the ore, these layers have to be taken off.

Strip Mining

- Large-scale continuous bucket excavators are gaining popularity.
- These large scale machines are designed for high capacity output and are tremendous in size, highly productive, and very expensive.



- **Strip-mining**: Blast, scoop off rock overburden, and then scoop out ore material. Fairly shallow.
- Economics of strip mining depend on stripping ratio
- Large land area can be involved, especiallyfor coal and bauxite.

"Strip mining" is the practice of mining a seam of mineral by first removing a long strip of overlying soil and rock (the overburden). It is most commonly used to mine coal or tar sand. Strip mining is only practical when the ore body to be excavated is relatively near the surface.

This type of mining uses some of the largest machines on earth, including bucket-wheel excavators which can move as much as 12,000 cubic meters of earth per hour.

There are two forms of strip mining. The more common method is:-

i) "***Area stripping***", which is used on fairly flat terrain, to extract deposits over a large area. As each long strip is excavated, the overburden is placed in the excavation produced by the previous strip.

ii) ***"Contour stripping"*** involves removing the overburden above the mineral seam near the outcrop in hilly terrain, where the mineral outcrop usually follows the contour of the land. Contour stripping is often followed by auger mining into the hillside, to remove more of the mineral. This method commonly leaves behind terraces in mountain sides.

Among others, strip mining is used to extract the oil-impregnated sand in the Athabasca Tar Sands in Alberta. It is also common in coal mining. Bucket-wheel excavators are widely used for this purpose, however, they are prone to damage and require many millions of dollars to repair.

Schematic of strip coal mine

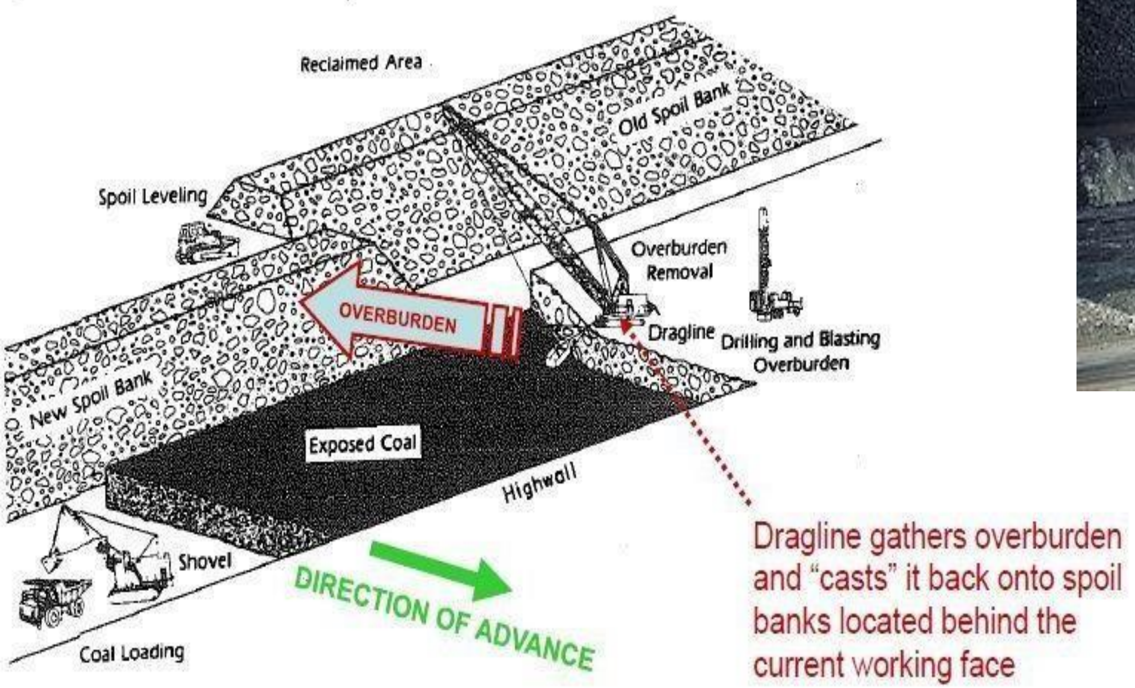


Figure from Hartman and Mutmansky, 2002.

Coal strip mine in Wyoming

- Significant "permanent" waste dumps are **not** needed.
- **Mine rehabilitation** can be carried out **progressively** at the same rate as mining.

Mining Process

OPEN CAST

SURFACE MINER

Drilling
|
Blasting
|
Loading
|
Hauling
|
Transporting
|
Processing/Washing

DRAG LINE

IN-PIT CRUSHING & CONVEYING

Drill machines (rotary/percussive)
|
SMS, emulsion, Primer, Nonel, etc
|
Shovels, Draglines, etc
|
Front-end loader, etc
|
Dumpers, Conveyors, etc
|
Coal washeries…

Selection of Mining Equipment

- Stripping Ratio – in case ofOpencast.
- Life of the mine.
- Infrastructure available.
- Proposed annual output.
- Technology available.

Different OC Machinery

1. Shovel + Dumper
2. Dragline
3. Surface Miner
4. Bucket Wheel Excavator
5. In-pit crushing + Spreader

Glory Holing

- This kind of operation is uncommon, as it involves a mine opening at the surface, from which ore is removed by gravity through raises connected to adit haulage ways beneath, and by tramming the ore to the surface on the haulage level.
- The glory hole method is best suited to mining on a hillside, and irregular deposits can be cleanly mined without dilution by waste wall rock. Narrow veins have been minedbygloryhole;inthesecasesthe“hole”becomesnarrowandlong.
- The benches are mined away as work descends to the bottom of the deposit or to the haulage way, so that spectacular steep side walls may result if the walls do not slough in.
- Mining can be quite selective, and little waste rock is thrown on the surface dumps.
- The principal environmental objection to the method is difficulty in reclamationof the surface of the mine area.

Auger Mining

Auger Mining refers to a method of removing coal, clay, phosphate, oil-shale, etc. from thin seams exposed in deep trenches or high-walls in strip mines.

The auger consists of two principal pieces.
The first is a cutting head, generally from
1.5 to 8 feet in diameter. It may be single or multiple.

The second is a prime mover, usually a skid mounted carriage, providing a mounting for the engine, drive head, and controls.

As coal arrives at the surface it is transported via a conveyor belt or a front-end loader to a waiting truck.

Quarrying

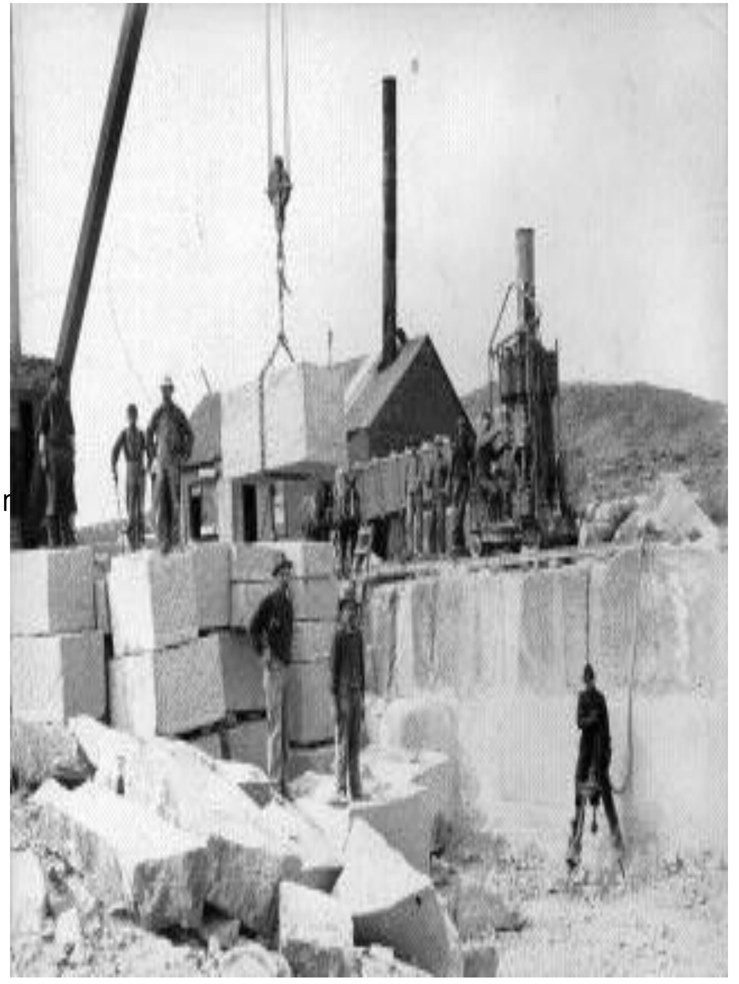
QUARRYING or Quarry Mining is usually restricted to mining dimension stone - prismatic blocks of marble, granite, limestone, sandstone, slate, etc.

These are used for primary construction of buildings or decorative facing materials for exterior and interior portions of buildings.

Quarries generally have benches with vertical faces from a few feet to 200 feet in height.

Blocks are drilled and wedged free in a highly selective manner using time consuming and expensive methods.

Planning of the excavation is based primarily on geological factors such as the direction a r attitude of bedding and joint systems.



Aqueous Extraction Methods

Depend on water or another liquid (e.g., dilute sulfuric acid, weak cyanide solution, or ammonium carbonate) to extract the mineral.

Placer mining:

Hydraulic mining
Dredging mining
In-situ leaching (ISL)/ Solution mining

Undersea Mining

Placer and solution mining are *among the most economical of all mining methods* but can only be applied to limited categories of mineral deposit.

Placer mining

- Placer deposits are concentrations of heavy minerals, usually within loose alluvium that can easily be excavated and washed.
- Placer minerals such as gold, tin, and tungsten minerals, are of relatively high value, but the value of the placer gravel itself may be very low, often less than a dollar per cubicyard.
- For deposits of such low grade to be worked they must be near water, on or near the surface of the ground, and should be only loosely consolidated so that drilling and blastingare not necessary.
- Placer mining affects large surface areas for the volume of material mined, is highly visible and has serious environmental problems with surface disturbance and streampollution.

- ***Placer mining*** is used to exploit loosely consolidated deposits like ***common sand and gravel or gravelscontaining***

  gold, tin, diamonds, platinum, titanium, or gems.

There are two types of placer mining:-

(i)(Hydraulic mining:

Generally used for weakly cemented near-surface ore deposits. Hydraulic mining of a placer gold deposit.

Hydraulic king utilizes a high-pressure stream of water that is directed against the mineral deposit (normally but not always a placer), under-cutting it, and causing its removal by the erosive actions of the water.

(ii)Dredging mining:

Generally used most often for mineral-sands and some near-shore alluvial diamond mining operations.

Dredging performed from floating vessels, accomplishes the extraction of the minerals mechanically or hydraulically.

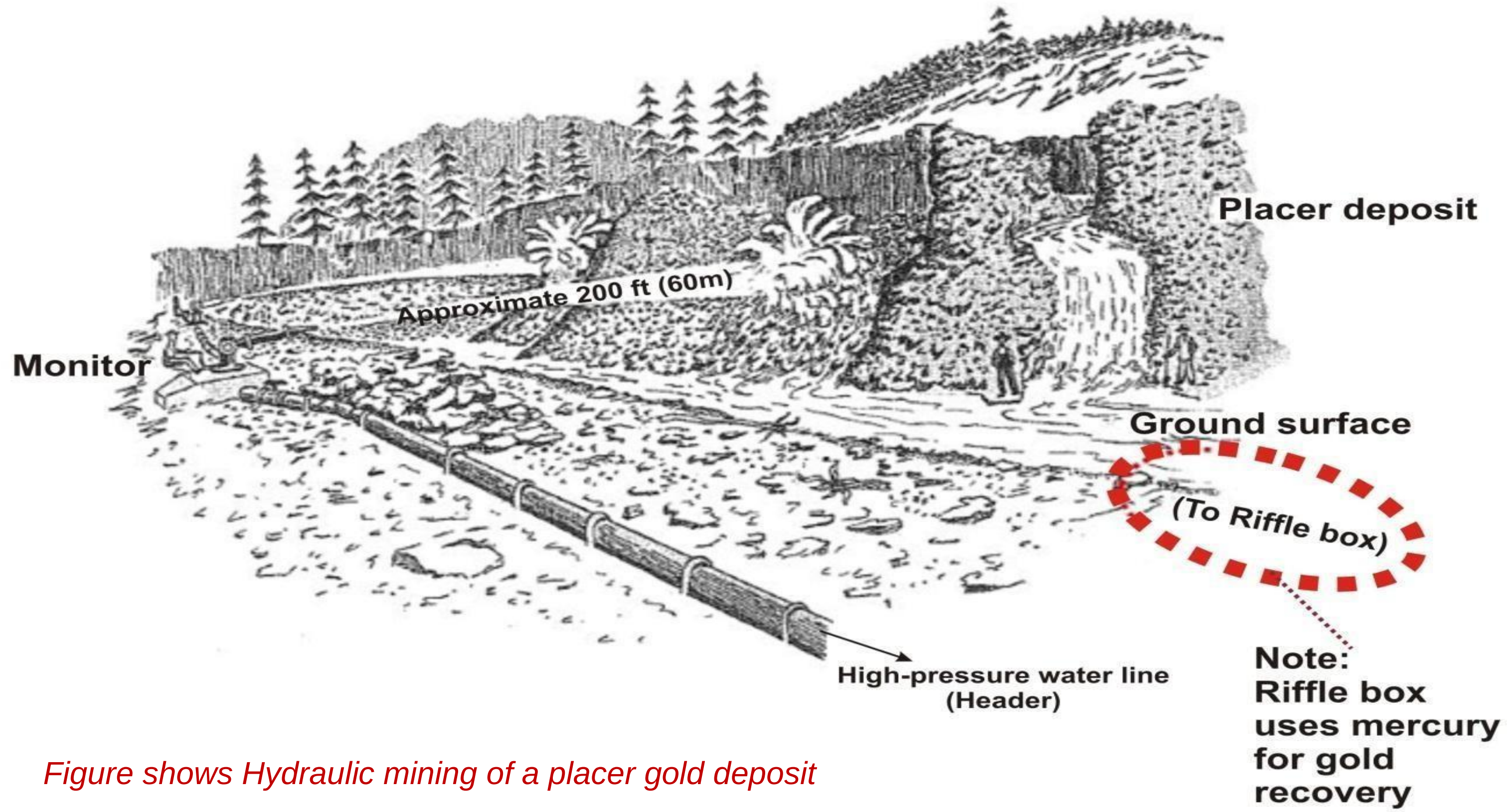


Figure shows Hydraulic mining of a placer gold deposit

i) Hydraulic Mining

- Hydraulic Mining involves directing a high- pressure stream of water, via a MONITOR or nozzle, against the base of the placer bank.
- The water caves the bank, disintegrates the ground and washes the material to and through sluice boxes, and / or jigs, and / or tables situated down-slope.
- Hydraulic mining totally disturbs large areas and puts much debris into the drainage system.
- Presently, hydraulicking is used primarily in Third World countries. It is closely controlled or prohibited in the U.S.

Dredging mining

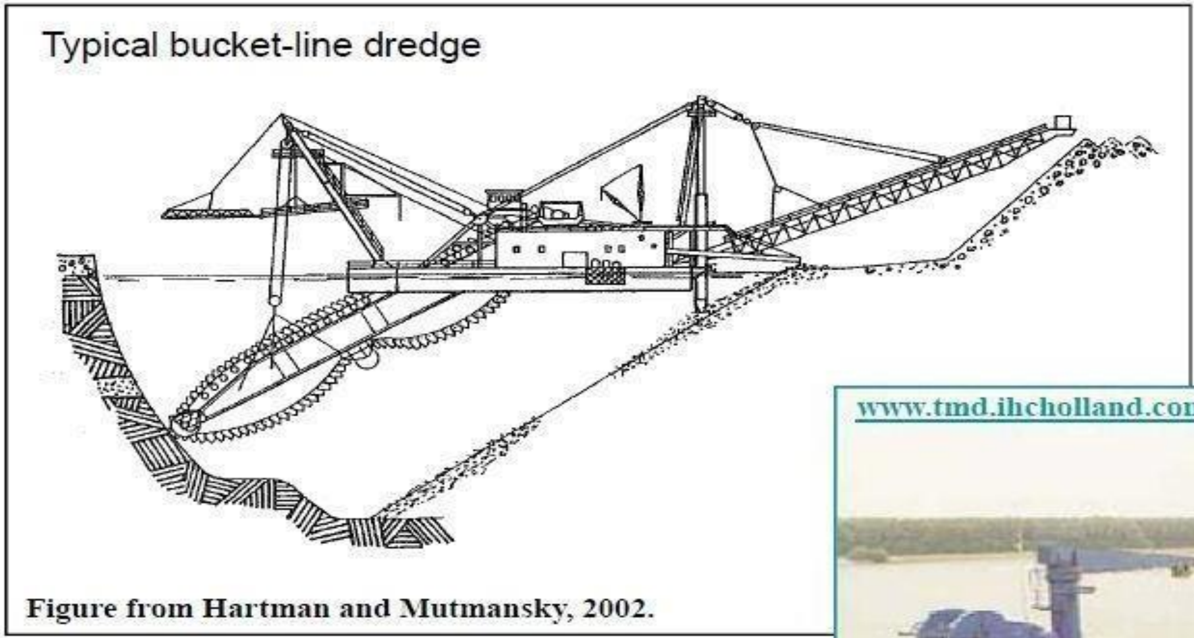


Figure from Hartman and Mutmansky, 2002.

"Dredging" is a method often used to bring up underwater mineral deposits. Although dredging is usually employed to clear or enlarge waterways for boats, it can also recover significant amounts of underwater minerals relatively efficiently and cheaply.

Dredging

- Large alluvial deposits are mined by ***floating washing plants*** capable of excavating the gravel, processing it in the washing plant, and stacking the tailings away from the dredge pond.
- A Dredge floats in water and digs the gravel by an endless string of buckets. Coarse material is screened out and dumped out the back. The fine material passes into a series of sluices where the gold in recovered.
- Several types of excavation methods are in use: ***DRAGLINE and BACKHOE PLANTS***.
- Dragline use in placer mining with washing plants is limited to shallow digging depths. Its bucket is less controllable on the bottom than the backhoe, and it is less able to dig into the bottom to clean up all the ore that may be there. However, it has the advantage of a longer reach.
- The digging reach of the backhoe extends to as much as 70 feet below the surface. It has the advantage of relatively low first cost, excellent mobility, and an ability to excavate hard material.

Coal mining

The process of extracting coal from the ground. Coal is valued for its energy content and since the 1880s, has been widely used to generate electricity. Steel and cement industries use coal as a fuel for extraction of iron from iron ore and for cement production. In the United Kingdom and South Africa, a coal mine and its structures are a colliery, a coal mine – a pit, and the above-ground structures – a *pit head*. In Australia, "colliery" generally refers to an underground coal mine. In the United States, "colliery" has been used to describe a coal mine operation, but this usage is less common today.

Coal mining has had many developments over the recent years, from the early days of men tunneling, digging, and manually extracting the coal on carts to large open cut and long wall mines. Mining at this scale requires the use of draglines, trucks, conveyors, hydraulic jacks and shearers.

Methods of extraction

Coal extraction methods vary depending on whether the mine is an underground mine or a surface (also called open cast) mine. Additionally coal seam thickness and geology are factors in selection of a mining method.

The most economical method of coal extraction for surface mines is the electric shovel or drag line. The most economical form of underground mining is the long wall, which is a shear blade that runs along sections of the coal seam.

Many coals extracted from both surface and underground mines require washing in a coal preparation plant.

Technical and economic feasibility are evaluated based on the following: regional geological conditions; overburden characteristics; coal seam continuity, thickness, structure, quality, and depth; strength of materials above and below the seam for roof and floor conditions.

Topography (especially altitude and slope); climate; land ownership as it affects the availability of land for mining and access;

Surface drainage patterns; groundwater conditions; availability of labor and materials; coal purchaser requirements in terms of tonnage, quality, and destination; and capital investment requirements

Surface mining and deep underground mining are the two basic methods of mining. The choice of mining method depends primarily on depth, density, overburden, and thickness of the coal seam; seams relatively close to the surface, at depths less than approximately 55 m (180 ft), are usually surface mined.

Coal that occurs at depths of 55 to 90 m (180 to 300 ft) are usually deep mined, but in some cases surface mining techniques can be used

.

For example, some western U.S. coal that occur at depths in excess of 60 m (200 ft) are mined by the open pit methods, due to thickness of the seam 20–25 metres (60–90 feet).

Coals occurring below 90 m (300 ft) are usually deep mined. However, there are open pit mining operations working on coal seams up to 300–460 metres (1,000–1,500 feet) below ground level, for instance Tagebau Hambach in German

UNDERGROUND MINING

Most coal seams are too deep underground for opencast mining and require underground mining, a method that currently accounts for about 60 percent of world coal production.

In deep mining, the room and pillar or bord and pillar method progresses along the seam, while pillars and timber are left standing to support the mine roof.

Once room and pillar mines have been developed to a stopping point (limited by geology, ventilation, or economics), a supplementary version of room and pillar mining, termed second mining or retreat mining, is commonly started.

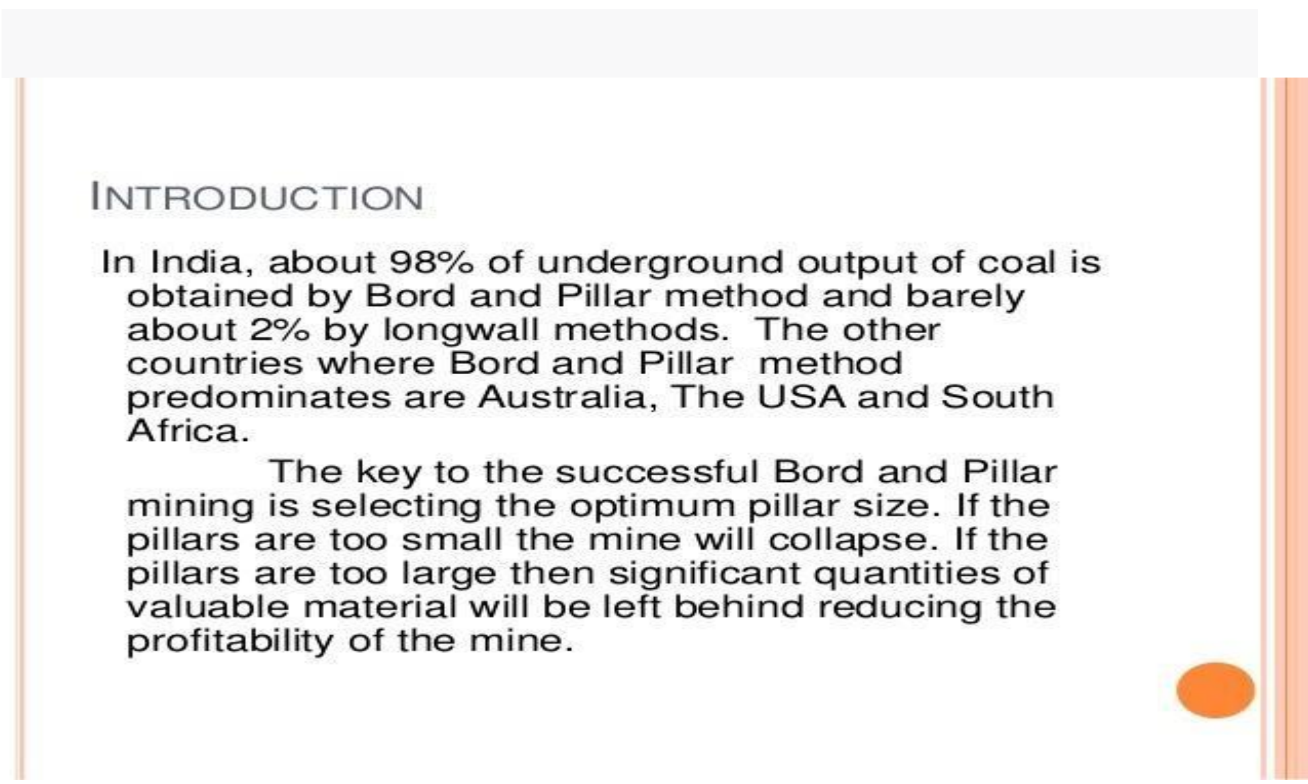
Miners remove the coal in the pillars, thereby recovering as much coal from the coal seam as possible. A work area involved in pillar extraction is called a pillar section.

Modern pillar sections use remote-controlled equipment, including large hydraulic mobile roof-supports, which can prevent cave-ins until the miners and their equipment have left a work area.

The mobile roof supports are similar to a large dining-room table, but with hydraulic jacks for legs.

After the large pillars of coal have been mined away, the mobile roof support's legs shorten and it is withdrawn to a safe area.

The mine roof typically collapses once the mobile roof supports leave an area.



INTRODUCTION

In India, about 98% of underground output of coal is obtained by Bord and Pillar method and barely about 2% by longwall methods. The other countries where Bord and Pillar method predominates are Australia, The USA and South Africa.

The key to the successful Bord and Pillar mining is selecting the optimum pillar size. If the pillars are too small the mine will collapse. If the pillars are too large then significant quantities of valuable material will be left behind reducing the profitability of the mine.

Basic principle of bord and pillar method

The development of mine by the method of working known as Bord and Pillar consists of driving a series of narrow roads, separated by blocks of solid coal, parallel to one another, and connecting them by another set of narrow parallel roadways driven nearly at right angles to the first set. The stage of formation of a network of roadways is known as development or first working. And these roadways are called BORD or GALLERY .

Applicability of bord and pillar method

The Bord and Pillar method is adopted for working.

1. A seam thicker than 1.5 m,
2. A seam free from stone or dirt bands. Stone or dirt bands, if present in a seam, can be easily disposed of for strip packing in long wall advancing method of mining.
3. Seams at moderate depth,
4. Seams which are not gassy,
5. Seams with strong roof and floor which can stand for long period after development stage is over,
6. Coal of adequate crushing strength.

Classification of Bord and Pillar Mining System

- Develop the entire area into pillars and then extract the pillars starting from the boundary
- Develop the area into panels and extract pillars subsequently panel wise. This is called panel system of mining
- "Whole" followed by "broken" working in which the mine is opened out by a few headings only and thereafter development and depillaring go on simultaneously

Design of Bord and Pillar Working

The main elements of Bord and Pillar workings are as follows –

1. Size of the Panel
2. Size of the Barrier
3. Size of Pillars

1. Size of the Panel

- The main consideration in deciding the size of the panel is the incubation period of the coal seam. The size is so fixed that the entire panel can be extracted within the incubation period without the occurrence of spontaneous fire. The period in Indian coalfields generally varies between 6 to 12 months. The other factors that influences the size is the rate at which extraction is done. With high rates of extraction made possible by mechanization, the size of the panel can be significantly increased. The extraction rate from depillaring districts in Indian coalfield averages about 250-300 tons per day per panel.

  Sometimes panel sizes are determined by strata control considerations.

2. Size of the Barrier

The width of the barrier depends on the load which it has to carry and its strength. Greater the depth of working, wider is the barrier and also softer the coal, the more, the width of the barrier. In practice, the width of the barrier enclosing pillars in a panel is usually the same as is the width of the coal pillars which are enclosed within the panel. In deep mines the width of the barrier may become quite large (up to 45 m) and so during extraction they are thinned down consistent with safety. Too much reduction in the width of the barrier is not advisable as in that case the barrier may be crushed and two goaves may be joined, thus encouraging safety.

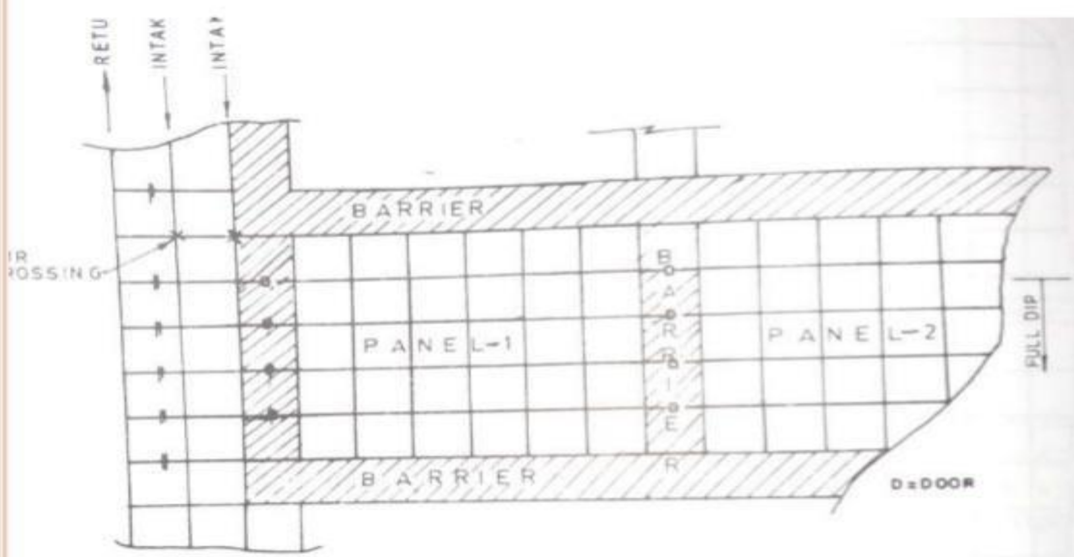


Figure 6.3 : Panel system of bord and pillar mining

3. Size of Pillars

The size of the pillars is influenced by the following:

- Depth from the surface and percentage extraction in the first workings or development.
- **Strength of the coal:** Seams with weak coal require large pillars. Effect of atmosphere and escape of gas also influence the size of pillars
- **The nature of the roof and floor :** These influence the liability to crush and creep. A strong roof tends to crush the pillar edges whilst a soft floor predisposes it to creep and both calls for large pillars.
- **Geological Considerations:** In the vicinity of faults, large pillars are required. Dip and presence of water also influences the decision as to the size of pillars.
- **Time dependant strain:** With time the strain goes on increasing, the load remaining constant and if the size of the pillar is not sufficiently large, then it may fail under the time dependant strain, although initially it might be stable

Size of Pillars

Also, with the passage of time, weathering takes place which reduce the strength of coal pillars. In India, the dimensions of pillars and the width and height of galleries are regulated by Regulation 99 of Coal Mines Regulation 1957. It is stipulated that the width of galleries shall not exceed 4.8 m and the height of the galleries shall not exceed 3 m. For width of galleries ranging from 3 m to 4.8 m, the dimensions of pillars for various depths of working are given in table -

Size of Pillars

Depth of the seam from the surface	Where the width of galleries does not exceed			
	3m	3.6m	4.2m	4.8m
	The distance between centers of adjacent pillars shall not be less than (in m)			
Not exceeding 60 m	12	15	18	19.5
Between 60-90 m	13.5	16.5	19.5	21
Between 90-150 m	16.5	19.5	22.5	25.5
Between 150-240 m	22.5	25.5	30.5	34.5
Between 240-360 m	28.5	34	39.5	45
Exceeding 360 m	39	42	45	45

Dimension of pillars and galleries at different depths

Size of Pillars

It may be seen that the pillar size increases with the increase in depth as well as with the galleries. As the depth of the working increases the strata pressure increases, the rate of increase being 0.2306 kg per cm2 per meter depth in Indian coalfields. Naturally, therefore, to support the increased strata pressure, the size of the pillars must be increased with depth. With the increase in width of galleries, the percentage extraction is increased which in turn results in greater strata pressure per unit area of solid pillar. To counteract that, the size of the pillars again requires to be increased with the increase in the width of the galleries. Percentage extraction in development at different depths are shown in table -

Size of Pillars

Depth of seam from surface	Where the width of galleries does not exceed			
	3 m	3.6 m	4.2 m	4.8 m
Not exceeding 60 m	43.7	42.2	41.2	43.17
Between 60-90 m	39.53	39.8	38.4	40.5
Between 90-150 m	33.06	33.5	33.8	34
Between 150-240 m	24.8	26.2	25.6	25.9
Between 240-360 m	9.95	19.7	20.1	20.2
Exceeding 360 m	14.8	16.4	17.8	19.0

Percentage extraction in development at different depths

Basic Principles of Pillar design

Pillar are insitu rock remnants left between adjacent underground openings. Rock pillar mainly serve as underground supporting element in large underground space. Without pillar it is very difficult to ground weight of overburden material or withstands lateral pressure in deep underground opening .

pillar design is essential exercise foir mining engineer for estimating factor of safety of underground working during development and depillaring . The pillar is design is carried out for both underground coal and metal mine. Conventional theory proposes that local stabilty is ensured if pillar strength exceeds the stress place on it .

The ratio of pillar's estimated strength to the pillars stress is expressed as the factor of safety. In order to estimate the safety factor , pillar strength and pillar load have to be known . The process of designing pillars involves determining there proper size according to the accepted load on the pillars.

PILLAR STRESS – pillar stress may calculated from the beam theory , numerical methods or photo elastic techniques, but it is most commonly estimated by the Tributary Area theory .

Tributary Area Concept: According to this concept, a pillar takes the weight of overlying rock up to a distance of half the opening width surrounding it. In the figure, W_o and W_p are widths of the opening and pillar respectively, while L_p is the length of the pillar. For square pillars, $W_p = L_p$.

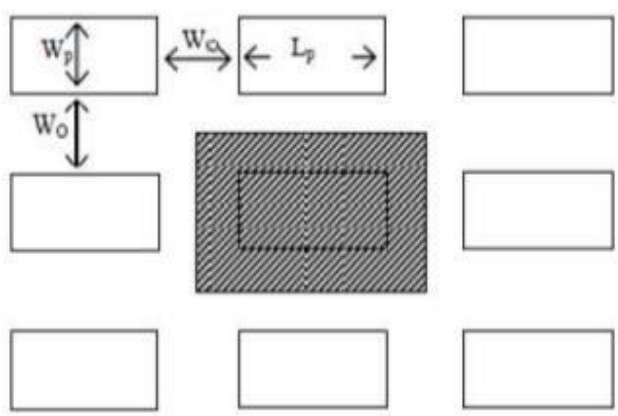


Fig No 3. The tributary area pillar loading concept

(Source: Bieniawski, Z. T., 1984)

The load on the pillar, P, is, therefore,

$$P = \left(L_p + W_o\right) \times (W_p + W_o)\gamma \times g \times h$$

Where γg is the weight of the rock per unit volume, and h is the depth of the pillar. The stress on the pillar σ_p is:

$$\sigma_p = \text{P/Area of pillar} = [(L_p + W_o) \times \left(W_p + W_o\right)\gamma \times g \times h]/[L_p + W_p]$$

$$= [(L_p + W_o) \times \left(W_p + W_o\right) \times \sigma_v]/[L_p + W_p]$$

Where σ_v is the vertical stress γgh. Another formula that works is

$$\sigma_{p=} 1.1 \times h \times [(L_p + W_o) \times \left(W_p + W_o\right)/(L_p + W_p)]$$

Pillar strength

Pillar strength has been a subject of research of many years with analytical formulas and increasingly numerical methods used to estimate the strength of a pillar based on the geometric shape , mining height and material strength . The most common feature of many these formulae is that they define the coal pillar strength in relation between width and height of the pillar. The most common formula are in form of

$$S_p = S_1\left(a + b\frac{w_p}{h}\right) \text{ or } S_p = K\frac{w_p^a}{h^b} \qquad (8.4)$$

where S_p = pillar strength; S_1 = strength of *in situ* coal or rock; w_p = pillar width; h = mining height; a and b are regression constant and K = a constant depending on the field

EFFECT OF SIZE OF PILLAR ON STRENGTH

Coal strength can be determined by laboratory and in-situ tests. The coal strength obtained from laboratory is usually larger due to smaller size of specimens . This is generally attributed coal contain natural discontinuities which have an effect in its strength. Larger specimen size the more cracks or fracture results smaller in strength . So this test not give correct results

Bieniawaski (1968) performed aseries of in-situ tests and found that for cubical specimen the strength is decreases with increase the specimen size . And become constant when it reach size of approximately 5 ft. for coal this means specimen may represent the strength of insitu coal pillar . Thr grph is as follows -

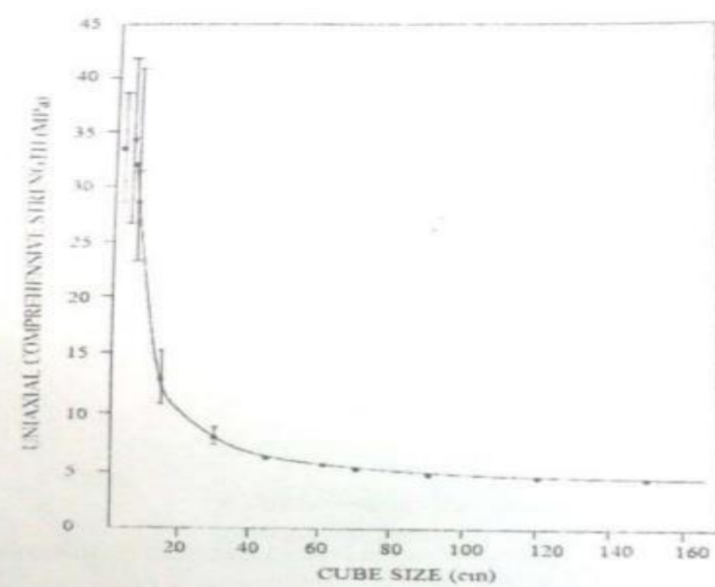


Figure 8.6: The relationship between the size and the strength of the specim
(Bieniawski, 1968)

SHAPE EFFECT

- In addition to the size effect coal strength is also found to depend on specimen geometry or shape effect . It is the ratio of diameter or width to height of specimen (Evans et al obert Duvall 1967). The shape effect was said to be a result if constraints imposed in pillar through friction or cohension by the roof and floor which ib turn to increse the confinement to the core of the pillar . Thus strength of pillar will increses . Das (1981) has conducted laboratory investigation on various coal specimen having different width & heightratioo. And it is concluded from the investigationthat pillar strenght increases with increasing w/h ratioof specimen as shown in fig

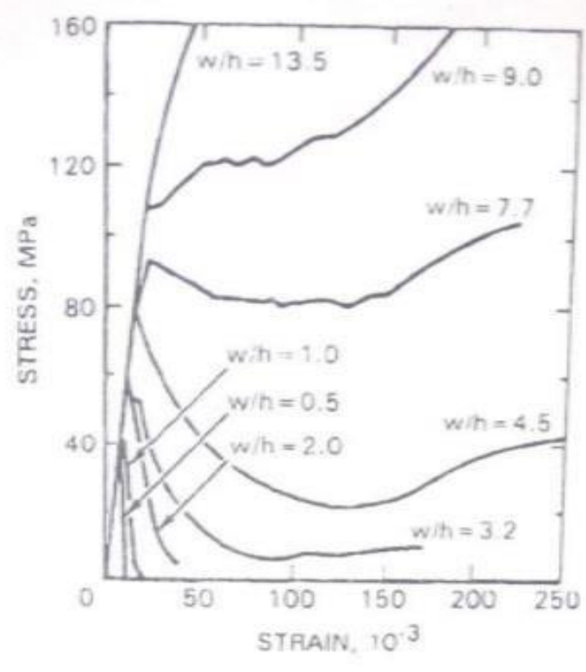


Figure 8.7 Complete stress strain curve for Indian coal specimen (Das, 1986)

Pillar strength formulae

- Over a year many pillar strength formulae are developed these are as follows –
- Holland –gaddy Formula – Holland (1964)extended gaddy's work (1956) and proposed a formulafor pillar strength as below

$$S_p = \frac{K\sqrt{w_p}}{h}$$

- K is gaddy constant and the unit of wp & h is expressed in inch.
- This formula well being work for a coal pillar safety factor with a wp/h ratio 2 to 8.

- **Holland formula –**

In 1973 holland provide a formula –

$$S_p = \frac{K\sqrt{w_p}}{h}$$

Recommaded safety factor 2 to 8

Salamon – munro formula (1960)- after coalbrook disaster salamon and munro analysed 125 case histories involving coal pillar collapse in south african coalfields and proposed that the coal pillar strength could be adequately determined using the power formula using back calculation approach

$$S_p = 1320\frac{w_p^{0.46}}{h^{0.66}} \text{ (English units) or } \quad S_p = 7.2\frac{w_p^{0.46}}{h^{0.66}} \text{ (SI units)}$$

The safety factor using this formula is 1.6 ranging b/w 1.31 to 1.88

- Bieniawski Formula – This formula is based on large scale testing of in situ coal samples in south africa ans in USA ans is expressed as –

$$S_p = S_1\left(0.64 + 0.36\frac{w_p}{h}\right)$$

Recommanded safety factor 1.5 to 2.0

- CMRI Formula

$$S = 0.27\sigma_c h^{-0.36} + \frac{H}{160}\left(\frac{W}{h} - 1\right) \text{ MPa}$$

Where:

S = Strength of pillar

σ_c = Uniaxial compressive strength of coal

W = Width of pillar

h = height of gallery

H = Depth of seam

Long wall Mining

Long wall mining accounts for about 50 percent of underground production. The longwall shearer has a face of 1,000 feet (300 m) or more.

- It is a sophisticated machine with a rotating drum that moves mechanically back and forth across a wide coal seam. The loosened coal falls onto an armored chain conveyor or pan line that takes the coal to the conveyor belt for removal from the work area.
- Longwall systems have their own hydraulic roof supports which advance with the machine as mining progresses. As the longwall mining equipment moves forward, overlying rock that is no longer supported by coal is allowed to fall behind the operation in a controlled manner.
- The supports make possible high levels of production and safety. Sensors detect how much coal remains in the seam while robotic controls enhance efficiency.
- Longwall systems allow a 60-to-100 percent coal recovery rate when surrounding geology allows their use. Once the coal is removed, usually 75 percent of the section, the roof is allowed to collapse in a safe manner

Continuous mining

- It utilizes a Continuous Miner Machine with a large rotating steel drum equipped with tungsten carbide picks that scrape coal from the seam.

- Operating in a "room and pillar" (also known as "bord and pillar") system—where the mine is divided into a series of 20-to-30-foot (5–10 m) "rooms" or work areas cut into the coalbed—it can mine as much as 14 tons of coal a minute, more than a non-mechanised mine of the 1920s would produce in an entire day. Continuous miners account for about 45 percent of underground coal production.

Conveyors

- Transport the removed coal from the seam. Remote-controlled continuous miners are used to work in a variety of difficult seams and conditions, and robotic versions controlled by computers are becoming increasingly common.

- Continuous mining is a misnomer, as room and pillar coal mining is very cyclical. In the US, one can generally cut 20 feet (6 meters) (or a bit more with MSHA permission) (12 meters or roughly 40 ft in

South Africa before the Continuous Miner goes out and the roof is supported by the Roof Bolter), after which, the face has to be serviced, before it can be advanced again.

- During servicing, the "continuous" miner moves to another face. Some continuous miners can bolt and rock dust the face (two major components of servicing) while cutting coal, while a trained crew may be able to advance ventilation, to truly earn the "continuous" label.

- However, very few mines are able to achieve it. Most continuous mining machines in use in the US lack the ability to bolt and dust. This may partly be because incorporation of bolting makes the machines wider, and therefore, less maneuverable.[

Room and pillar mining

- Consists of coal deposits that are mined by cutting a network of rooms into the coal seam. Pillars of coal are left behind in order to keep up the roof. The pillars can make up to forty percent of the total coal in the seam,

- There was space to leave head and floor coal there is evidence from recent open cast excavations that 18th-century operators used a variety of room and pillar techniques to remove 92 percent of the *in situ* coal. However, this can be extracted at a later stage (*see* retreat mining).

Blast mining or conventional mining

- It is an older practice that uses explosives such as dynamite to break up the coal seam, after which the coal is gathered and loaded onto shuttle cars orconveyors for removal to a central loading area.
- This process consists of a series of operations that begins with "cutting" the coalbed so it will break easily when blasted with explosives. This type of mining accounts for less than 5 percent of total underground production in the US today.[

Shortwall mining

- It is a method currently accounting for less than 1 percent of deep coal production, involves the use of a continuous mining machine with movable roof supports, similar to longwall. The continuous miner shears coal panels 150 to 200 feet (45 to 60 metres) wide and more than a half-mile (1 km) long, having regard to factors such as geological strata.

Retreat mining

- Thbis a method in which the pillars or coal ribs used to hold up the mine roof are extracted; allowing the mine roof to collapse as the mining works back towards the entrance.

- This is one of the most dangerous forms of mining, owing to imperfect predictability of when the roof will collapse and possibly crush or trap workers in the mine.

Ore Formation

Magma is the principal material of the lithosphere responsible for formation of rocks as well as various ore deposits of all kinds. The formation of valuable ore deposits which are the potential source of metal and minerals have been deposited by various geologic processes. Geological processes leading the following ore deposits : Hydrothermal; magma crystallization; pegmatitic ;contact metamorphic deposits; metamorphic deposits; placer deposits.

Majority of ore formations are based on hydrothermal process

Cavity Filling The process of cavity filling has given rise to a vast number of mineral deposits of diverse form and size. The Vein deposits resulting from cavity filling may be grouped as follows: fissure veins, (it is a tabular ore body that occupies one or more fissures: two of its dimensions areθ much greater than the third) shear zone deposits, (thin sheet like connecting openings of a shear zone)θ.

Stock-works, (interlacing network of small ore bearing veinlets traversing a mass of rock.θ saddle reefs,θ ladder veins, andθ replacement veins or veinlet'sθ Characteristics Vein deposits include gold, silver, copper and lead-zinc. Veins range in thickness from a few centimeters to 4 meters. They can be several hundreds of meters long and extend to depths in excess of 1,500 meters.

Morphology and Relationship with Host Rocks

Mode of occurrence of an ore deposit is important from the mining point of view. Sedimentary ore deposits are roughly tabular, most others occur in a variety of forms.

In replacement deposits knowledge of the form, as also of the internal structure and its relationship with the enclosing rock is important.

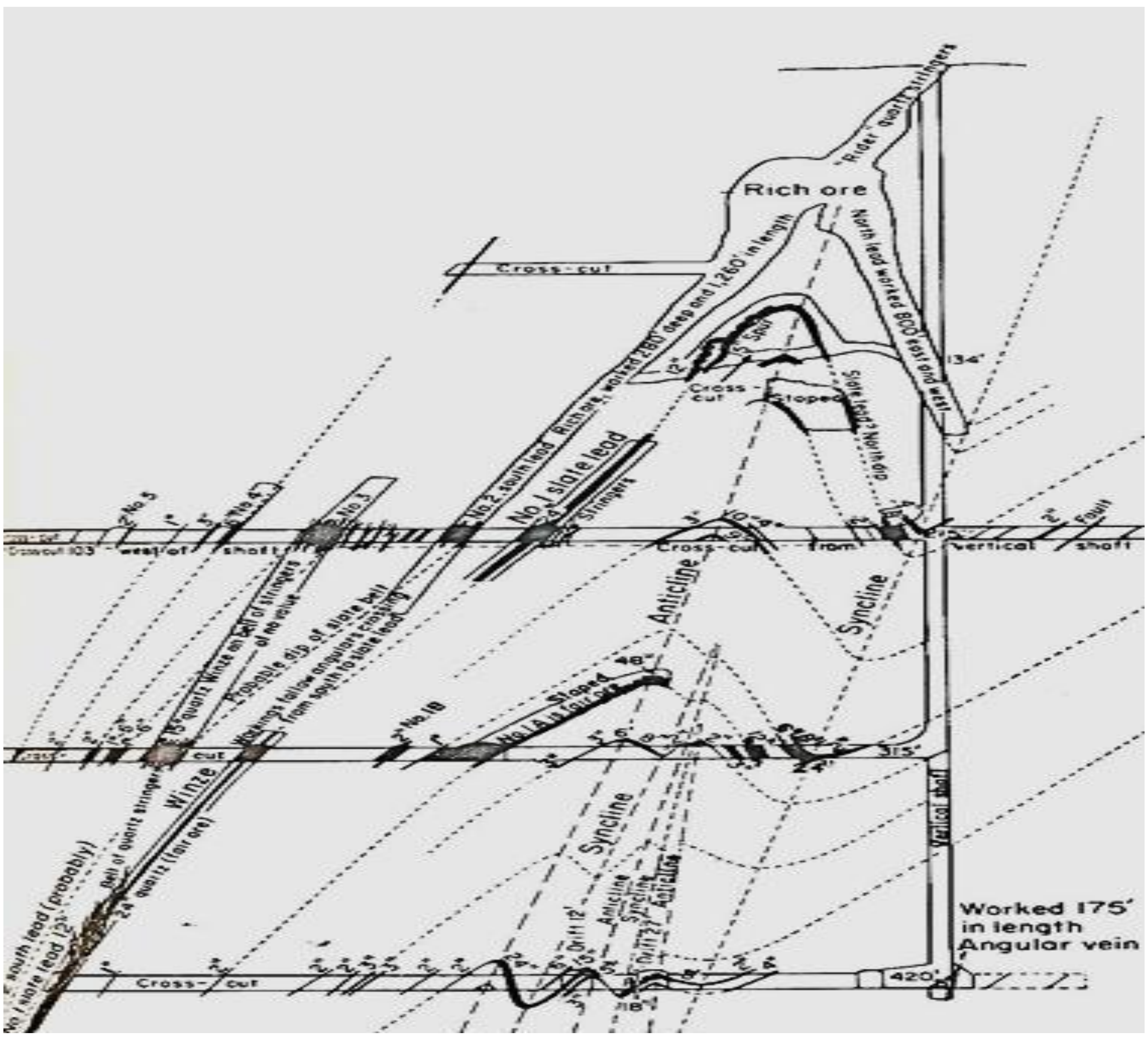
Form the point of view of form & structure, ore deposits may be classified into two broad groups:

Syngenetic deposits

Which have formed at the same time as the rock in which they occur. They are sometimes part of the succession like an iron-rich sedimentary horizon.

They have formed by the same process and at the same time as the enclosing rock, and Epigenetic deposits - which are believed to have come into being after the host rock in which they occur, e.g. a vein or a dyke.

They have been introduced into pre-existing country rock after its formation



Morphology and Relationship with Host Rocks

Regularly shaped ore bodies

Regularly shaped ore-bodies are of two types – **tabular and non-tabular.**

a) Tabular ore-bodies: These are extensive in two dimensions but have a restricted third dimension. To this category belong the veins and lodes. Veins are considered to have resulted mainly from the filling of open spaces, whilst the formation of
lodes was due to extensive replacement of pre-existing rock. Since such a genetic distinction is often ambiguous, all tabular ore-bodies are generally referred to as veins.
Veins are often inclined, and in such cases one can speak of hanging walls and foot walls.

b) These are relatively short in two dimensions but extensive in the third. When vertical to sub-vertical, they are called **pipes** or **chimneys**. When horizontal or sub-horizontal they are called **mantos**.

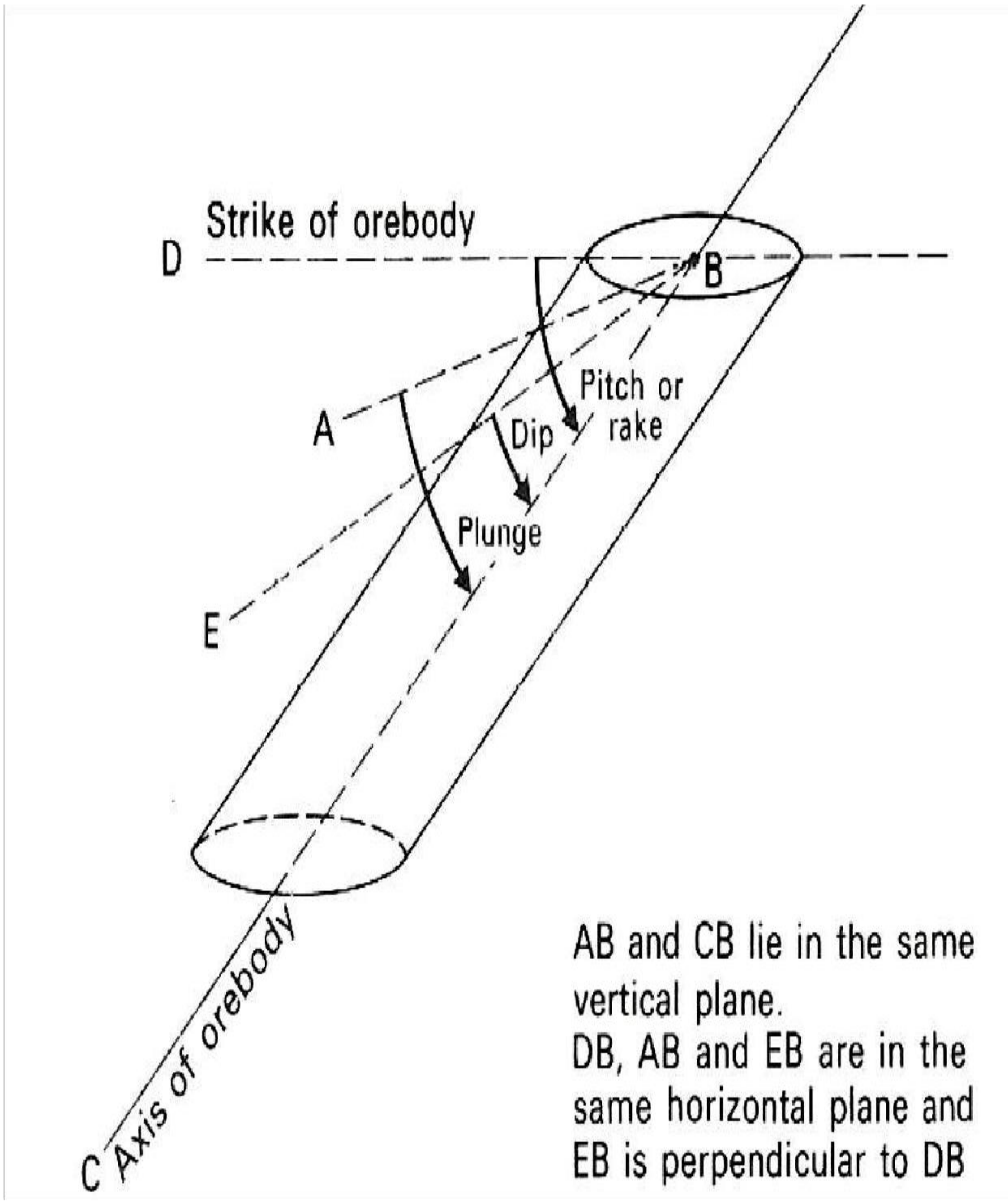
Irregularly shaped ore-bodies:

Irregularly shaped ore-bodies are of two types – disseminated deposits and irregular replacement deposits. Disseminated deposits: In these deposits, the ore minerals are dispersed throughout the body of the host rock e.g. diamonds in kimberlite.

In other deposits, the disseminations may be mainly along close-spaced veinlets cutting the host rock and forming an intercalated network called a stockwork.

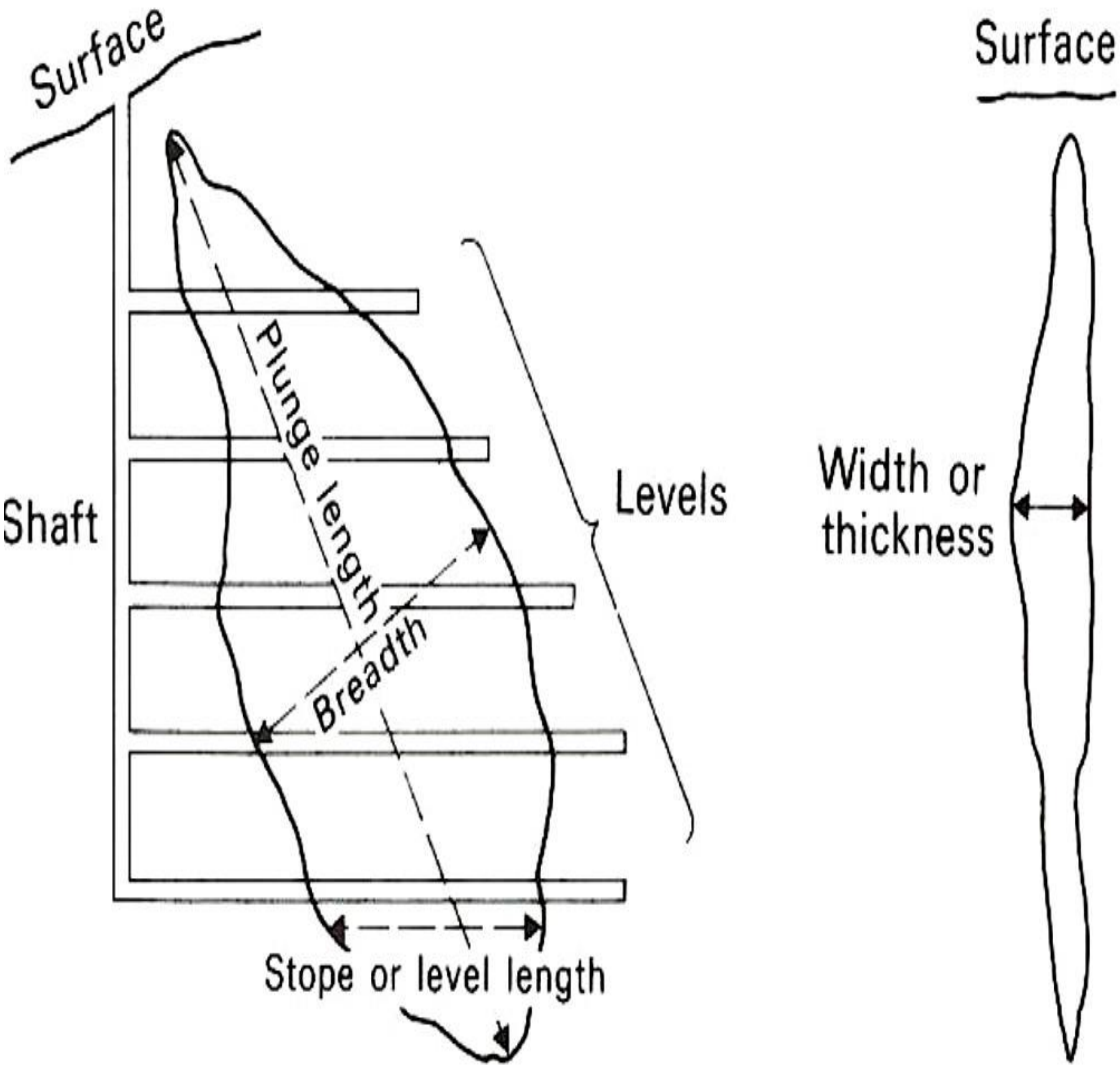
Geometric Measures of an Ore body Axis of ore body:

Line that parallels the longest dimension of the ore body.
Pitch (Rake) of ore body: angle between the axis and the strike of the ore body.


Strike of orebody
D
B
A
Dip
Pitch or
rake
Plunge
E
C
Axis of orebody
AB and CB lie in the same vertical plane.
DB, AB and EB are in the same horizontal plane and EB is perpendicular to DB

Longitudinal section of an orebody

Cross section of the same orebody



Mine Development

Levels and Level Interval

Level is an opening developed along the strike direction of an ore deposit and is driven with zero to near zero (1 in 200) gradient. It is considered as the secondary mine development operation of an underground metal mine.

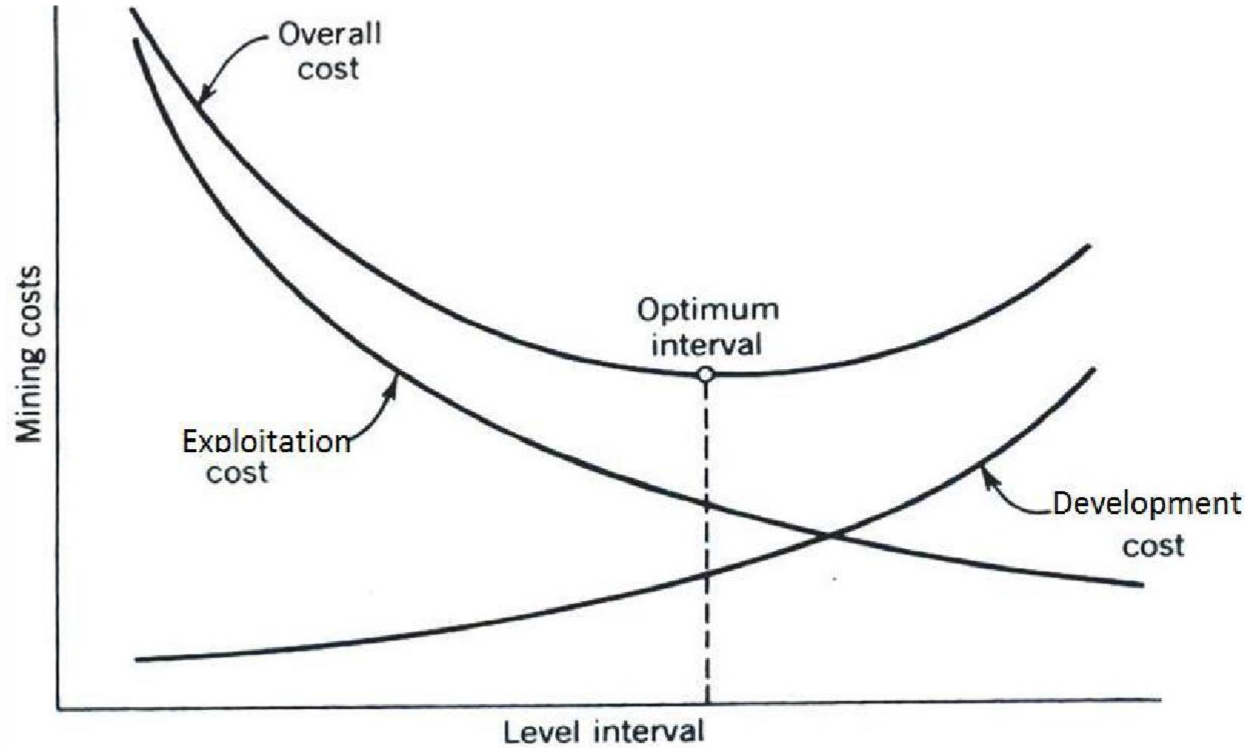
Every single underground mine developmental operation is a capital intensive and there is a significant degree of risk, because any increase in the length of development openings could augment high capital expenditures. The levels also offer the service of transportation, for men and material, from the shaft to the production site. Of the many factors influencing the selection of a suitable level interval, the important factor is to facilitate quick disposal of broken ore from the workings

Level Intervals

Underground mining of ore deposits is necessarily worked with multiple levels. A level interval is selected which lead to lowest overall mining cost for the mine development and exploitation plan chosen. Number of factors affects these costs and some of them are following:

- Geological and natural conditions of the deposit and country rock
- Method of mining
- Development layout
- Method of drivages of openings
- Life of openings, mine life
- Other financial considerations

The current trend with mechanized high production method is to have fewer levels with large level intervals and supplemented by less cost sublevels as required by the stoping method adopted.

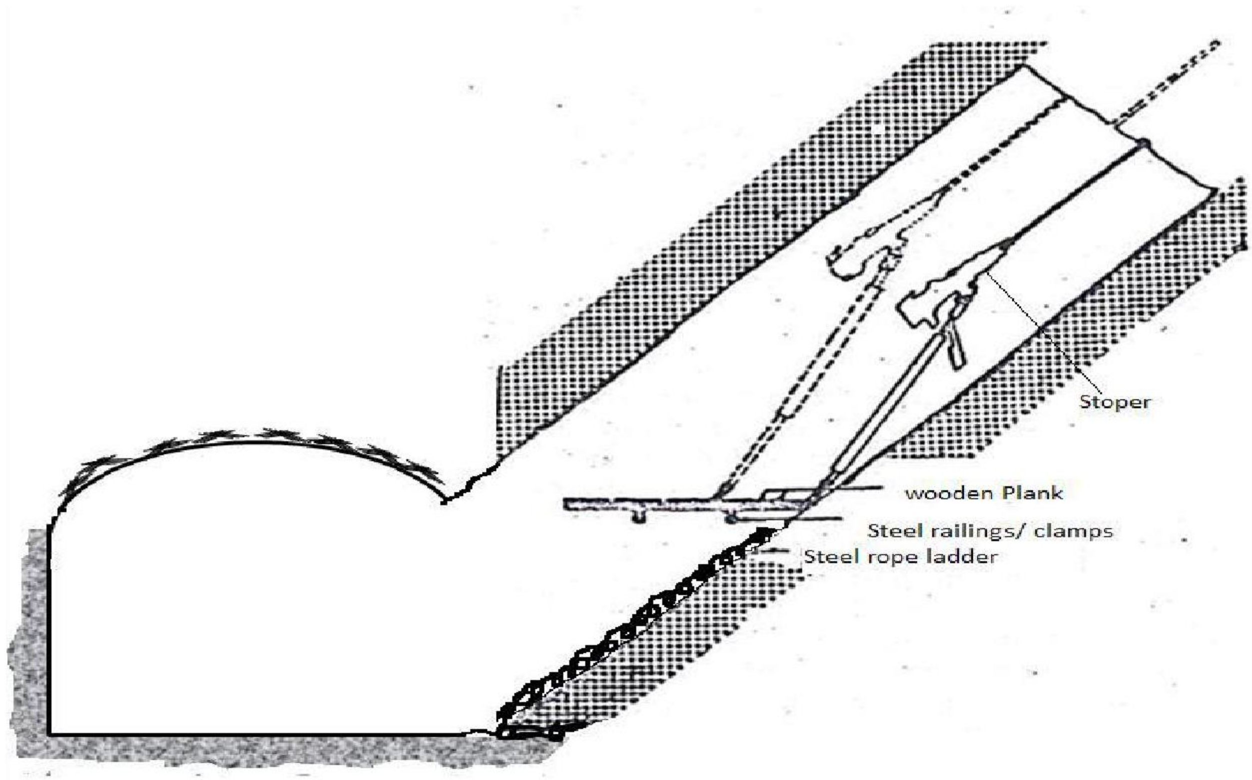


Raising Methods

1.Manual raising method
2.Two compartment method
3. Mechanized Raising
4. Jora raising method
5. Alimak Raising
6. RAISE BORING METHODS

Manual Raising Method

This is a simple and most common method adopted in majority of the metal mines. The unit operations followed in the construction of a manual raise are:
Drilling and blasting
Mucking and transportation
Erection / construction of a manual platform or also known as scaffold The workers stand on a platform or scaffold made of timber planks supported in stulls or iron bars fitted into the footwall.
The clamps used for supporting the platform are made in standard lengths out of old rails.



Manual Raising Method

LIMITATIONS:

A simple but a very tedious method and has a limitation of comfortable raising operations upto 15m. Careful checking and dressing down of the loose rock by skilled workers before allowing workers to go up is essential. At Jaduguda mine of UCIL where this method of open raising was adopted for a number of stopes, the longest raise driven was 90 m at 450 inclination.

Two Compartment Method

The raising cycle comprises the following operations:

1. Inspection and dressing down of loose rocks,
2. Timbering extending the ladder way,
3. Construction of the working stage and drilling,
4. Removing the working stage,
5. Charging and firing of the blast holes, and
6. Clearing the smoke.

Mechanized Raising

In mechanical raise climber most of these difficulties are avoided and the most popular to this kind are:

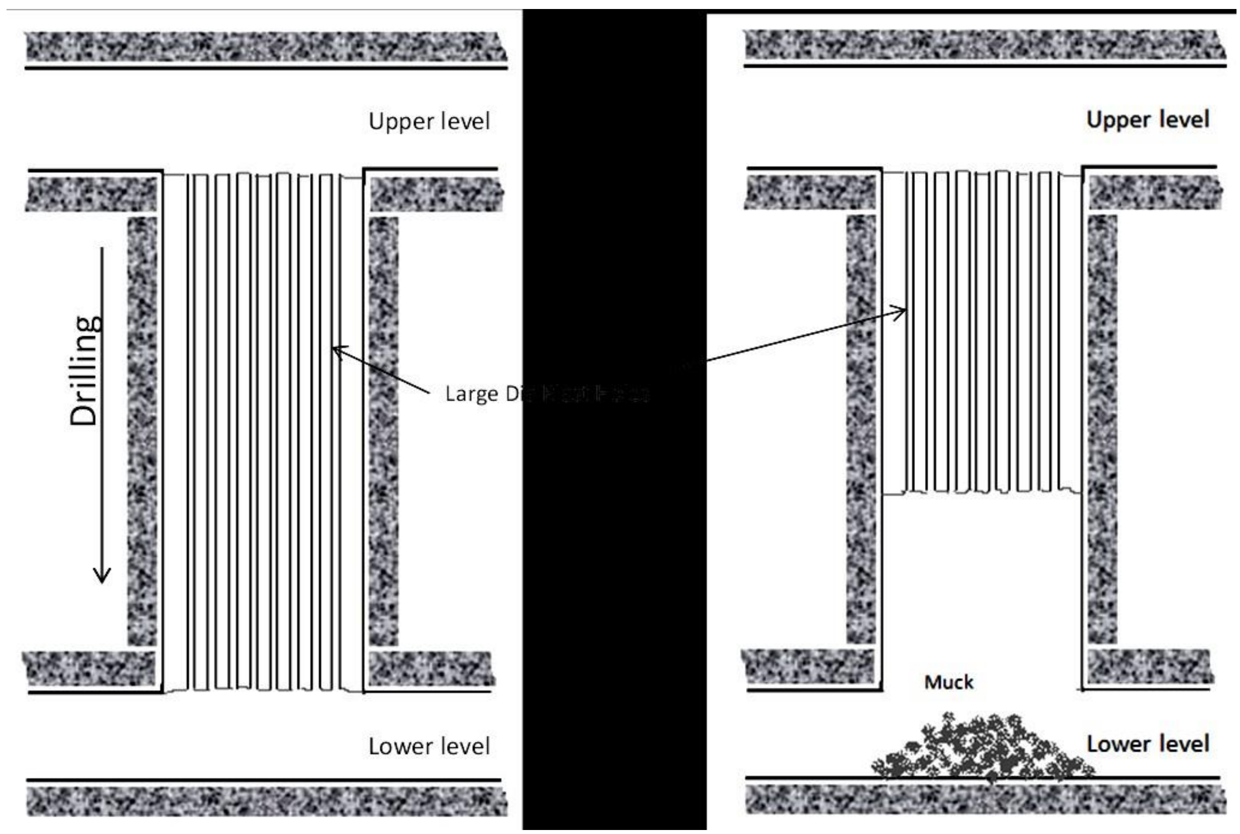
- Jora raising method
- Alimak raise climber.
- Raising by long hole drilling
- Raise borers

Jora Raising Method

Jora raising method is suitable only for the condition when two levels are available for connectivity by a raise. The method consists of drilling a large diameter hole at the centre of the intended raise to get through into the lower level (Fig. below).

The upper level a cage is suspended using a flexible steel rope that can be hoisted up and down using a winch. There is a working cabin also known as Jora cabin. The Jora cabin is provided with a sturdy working platform on top of it, it is from this platform that the drill operators make the drill holes

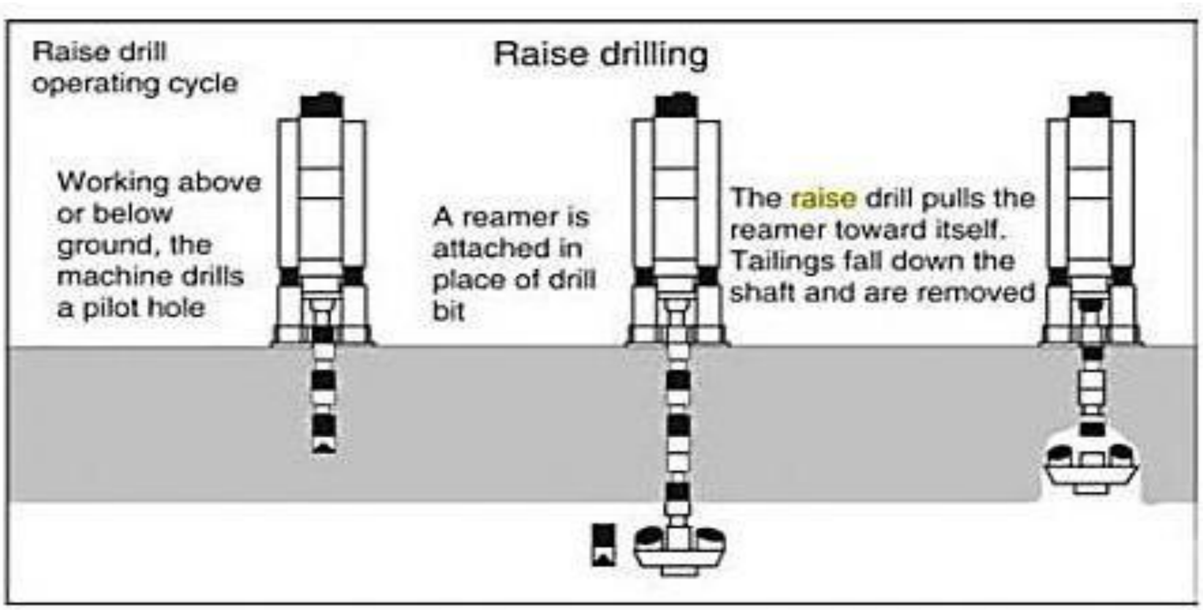
Raising by Large Diameter Blast Holes



RAISING BY LARGE DIAMETER BLAST HOLES

RAISE BORING METHODS

RAISE BORING IN THIS SYSTEM, THE PILOT HOLE IS DRILLED DOWN TO A LOWER LEVEL IN THE MINE DRIVE. ONCE THE PILOT HOLE CONNECTS TO THE LOWER ACCESS LEVEL, THE DRILL BIT IS REMOVED AND A REAMER OR RAISE HEAD IS ATTACHED AND THE REAMER IS ROTATED AND PULLED UPWARDS. THE BROKEN ROCK FALLS TO THE LOWER LEVEL BY GRAVITY. THIS SYSTEM OPERATES WITH THE DRILL STRING IN TENSION AND THIS PROVIDES THE MOST STABLE PLATFORM.

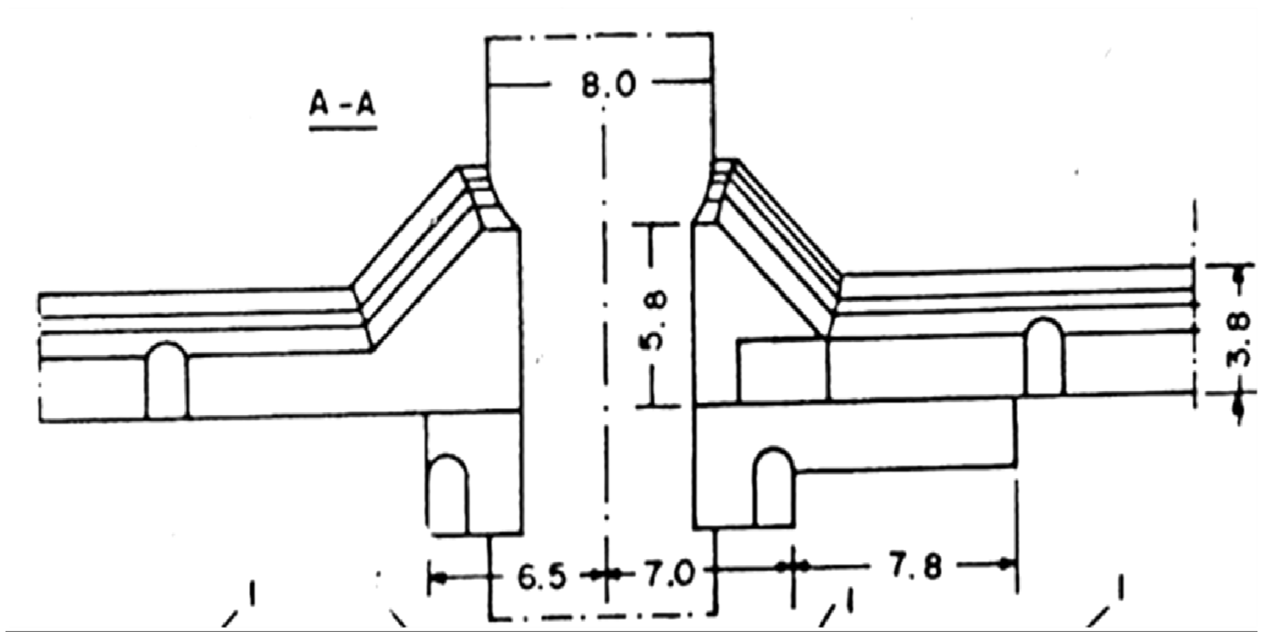


DRIVING VERTICAL RAISES WITH RAISE BORERS

ADVANTAGES OF BORED RAISES

THE MOST IMPORTANT ARE SAFETY, SPEED, PHYSICAL CHARACTERISTICS OF THE COMPLETED HOLE, LABOUR REDUCTION AND COST REDUCTION. THE SAFETY FACTOR IN RAISE DRILLING CANNOT BE OVER EMPHASIZED. NO MEN ARE EXPOSED TO THE DANGER OF ROCK FALL FROM FRESHLY BLASTED GROUND OR TO THE CONTINUAL USE OF EXPLOSIVES, WITH THEIR FUMES AND INHERENT DANGER OF MISFIRESA HOLE DRILLED BY RAISE BORING MACHINE CAN GENERALLY BE COMPLETED IN A FRACTION OF THE TIME REQUIRED FOR CONVENTIONAL METHODS. THE BORED RAISE, WITH ITS FIRM UNDISTURBED WALLS, IS MORE ADAPTABLE TO USE AS VENTILATION AND ROCK PASSES. AS CONVENTIONAL METHODS REQUIRE A RELATIVELY LARGE OPENING, IT HAS BECOME CUSTOMARY TO DRIVE RAISES

SHAFT STATION IN METAL MINE



1- Access drift to waiting room; 2- basement for two-level traffic and swinging platforms; 3- Basements for pushers and barrages (blocking cars); 4- a slot for control equipment

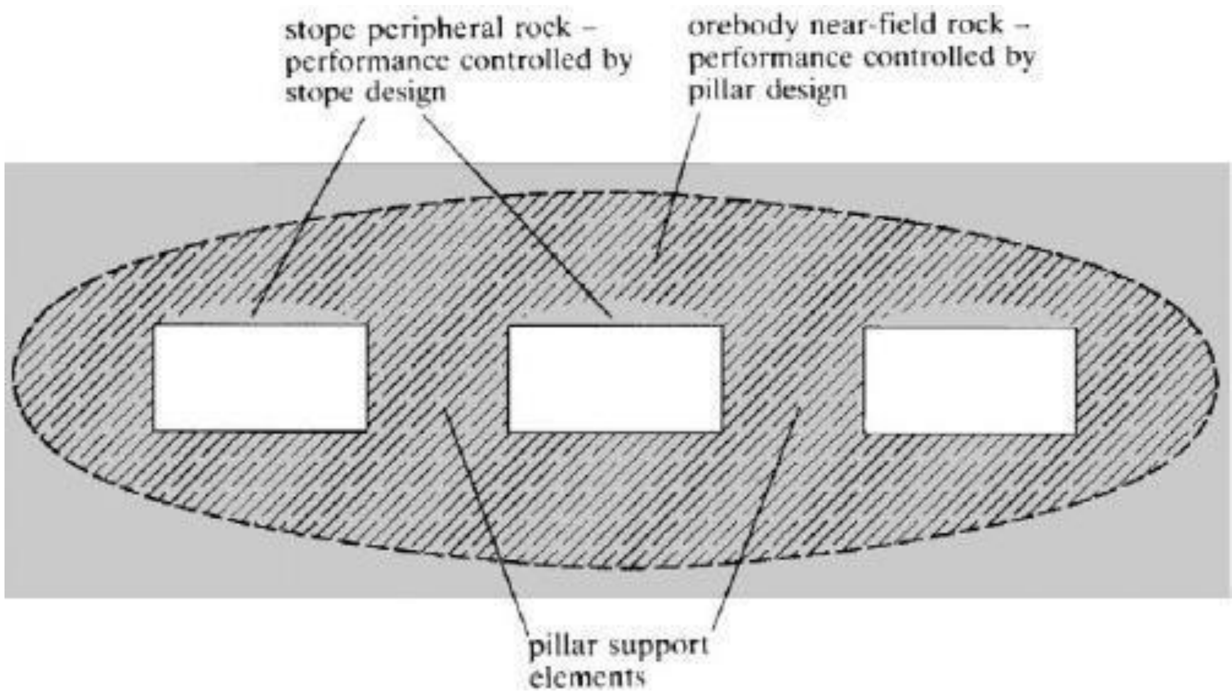
Some terms used in underground mining

- **Back** or **Roof** - ceiling or inner surface of an underground excavation (synonymous with roc
- **Bell** - shaped excavation funnel formed in the top of a raised comminuted material to mov by gravity into a stope of a drawPoint;
- **Capping** - waste material overlying the mineral deposit;
- **Crosscut** - gallery oriented perpendicular to the strike of a deposit that has inclination to th horizontal;
- **Pillar** - not mined portion of a deposit that serves as support for the roof or hood;
- **Crown pillar** - an overlying portion of an excavation and left intact in the form of pillar deposit. Can also be the mainstay of the above drawPoint;
- **Sill pillar** - behind an excavation and left intact in the form of pillar support portion;
- **Dip** - tilt angle of a deposit measured from the horizontal (synonymous with attitude);
- **Slope** - inclined plane, connecting the surface to the underground workings;
- **DrawPoint** - point loading fragmented ore located at the bottom of the stope and uses gravity to drain fragmented material for a kick or loading equipment;
- **Drift** - gallery oriented parallel to the strike of a deposit that has diving;
- **Finger** raise - approximately vertical opening used to transfer ore from a stope for drawPoi (point of load);
- **Floor** - floor or bottom surface of an underground excavation;
- **Footwall** - footwall of a deposit;
- **Hanging wall** - cover a deposit;

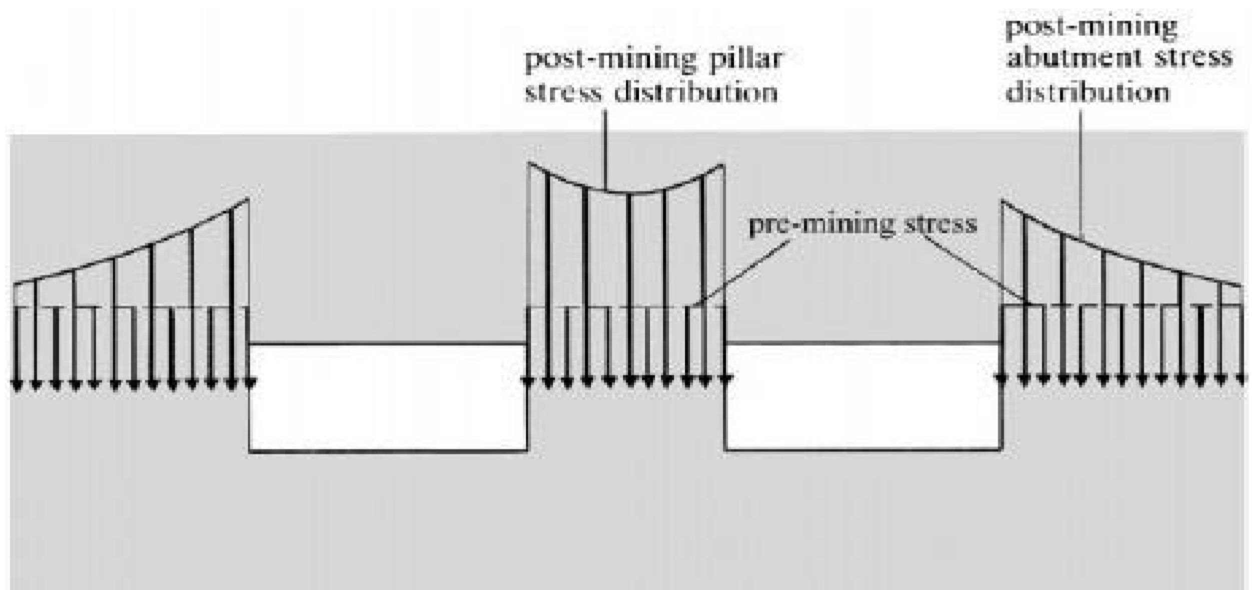
Analysis of Pillar support system in Room-and –Pillar stoping

A mining method based on pillar support is intended to control rock mass displacements throughout the zone of influence of mining. Stopes may be excavated to be locally self-supporting. Near-field ground control is achieved by the development of load-bearing elements, or pillars, between the production excavations.

Effective performance of a pillar support system can be expected to be related to both the dimensions of the individual pillars and their geometric location in the orebody. An economic design of a support system implies that ore committed to pillar support be a minimum.



Schematic illustration of problems of mine near-field stability and stope local stability, affected by different aspects of mine design



Redistribution of stress in the axial direction of a pillar

Drilling and blasting in Room-and-pillar stoping

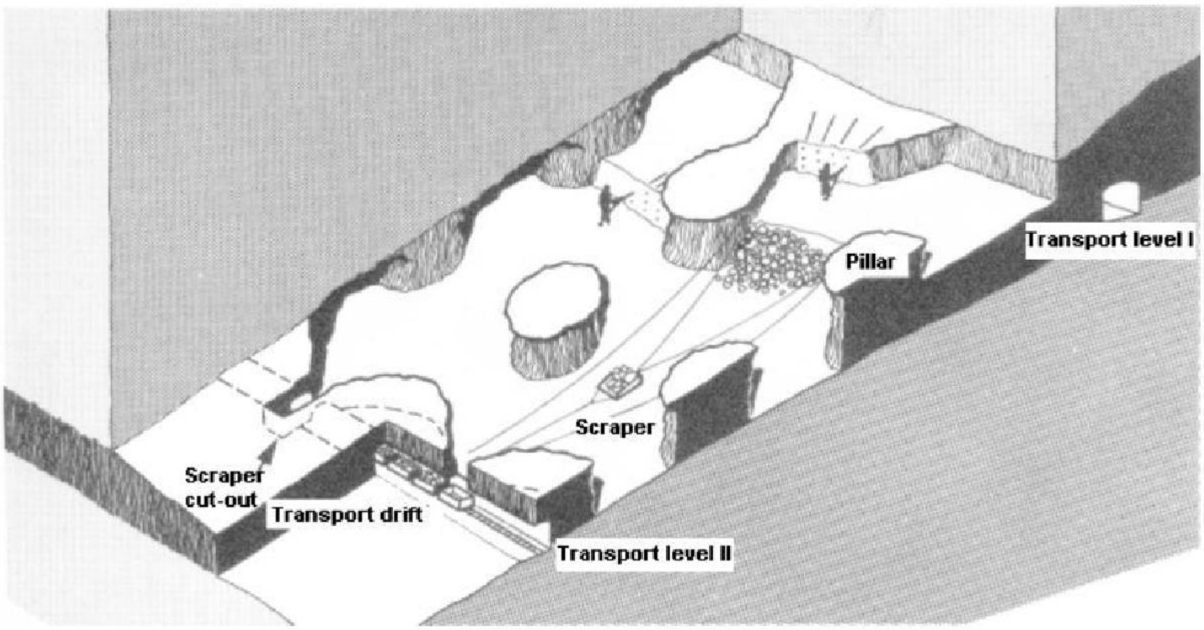
The initial advance in room and pillar mining uses a cut pattern when there is only one free face open. The burn cut is the most common drilling pattern in metal mines(drives). The next type of blasting used in room and pillar is known as slabbing.

This type of round is used once a free face has been established so that there is a group of drill holes parallel to an open face. This free face allows the fragmentation of the rock to be the same as a swing with less explosives which leads to lower costs.

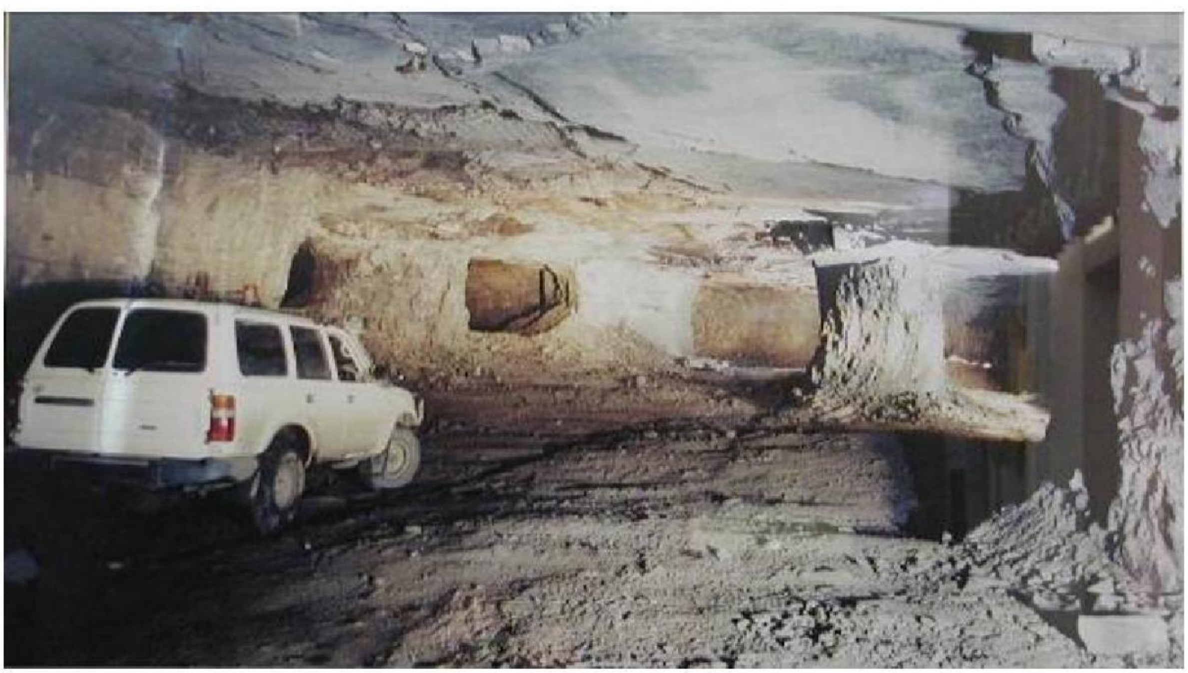
Jumbo Drill Machine

A drilling jumbo consists of one, two or three rock drill carriages, sometimes a platform, which the miner stands on to load the holes with explosives, clear the face of the tunnel or else. The carriages are bolted onto the chassis, which supports also the miners cabin and of course the engine.

Inclined Room and Pillar



Room and Pillar



Room and Pillar Features

- Summary of Applications
  - relatively flat orebodies
  - limited thickness
  - competent hanging wall and ore
- Advantages ...
  - good productivity
  - moderate cost
  - flexible method, amenable to mechanization
  - Selective
  - minimal early development
  - No backfill required
- Disadvantages ...
  - possible ground control problems
  - Medium to low recovery, ore lost in pillars

Modes of Pillar Failure

Different modes of failure as seen in the field observations are:

Fretting or or necking of the pillar: Fretting occurs in relatively massive rock with moderately strong H/W, F/W, and ore body.

One of the main causes for necking is the development of tri-axial stress condition at the wall contacts (H/W and F/W), which result in the development of shear stresses at the contact zones and the failure is localised in the central part of the pillar.

The failure is due to tensile stress concentration. The most obvious sign of pillar stressing involves spalling from the pillar surfaces, which consequently leads into the development of hour-glass shaped pillar.

Sublevel Stoping Methods

- Sublevel stoping is also known as "blasthole stoping" or "longhole stoping".
- vertical or steeply dipping ore bodies with regular boundaries
- mined from levels at predetermined vertical intervals
- drilling/blasting from sublevels (overcut or undercut), mucking from undercut
- ore pillars between stopes for support, may be recovered later
- The orebody is divided into sections up to 100 m high and further divided laterally into alternating stopes and pillars. A main haulage drive is created in the footwall at the bottom, with cut-outs for draw-points connected to the stopes.
- Long hole blasthole and stoping uses longer and larger diameter blastholes than sublevel stoping, thus requiring less drilling than sublevel stoping. Greater drilling accuracy is required

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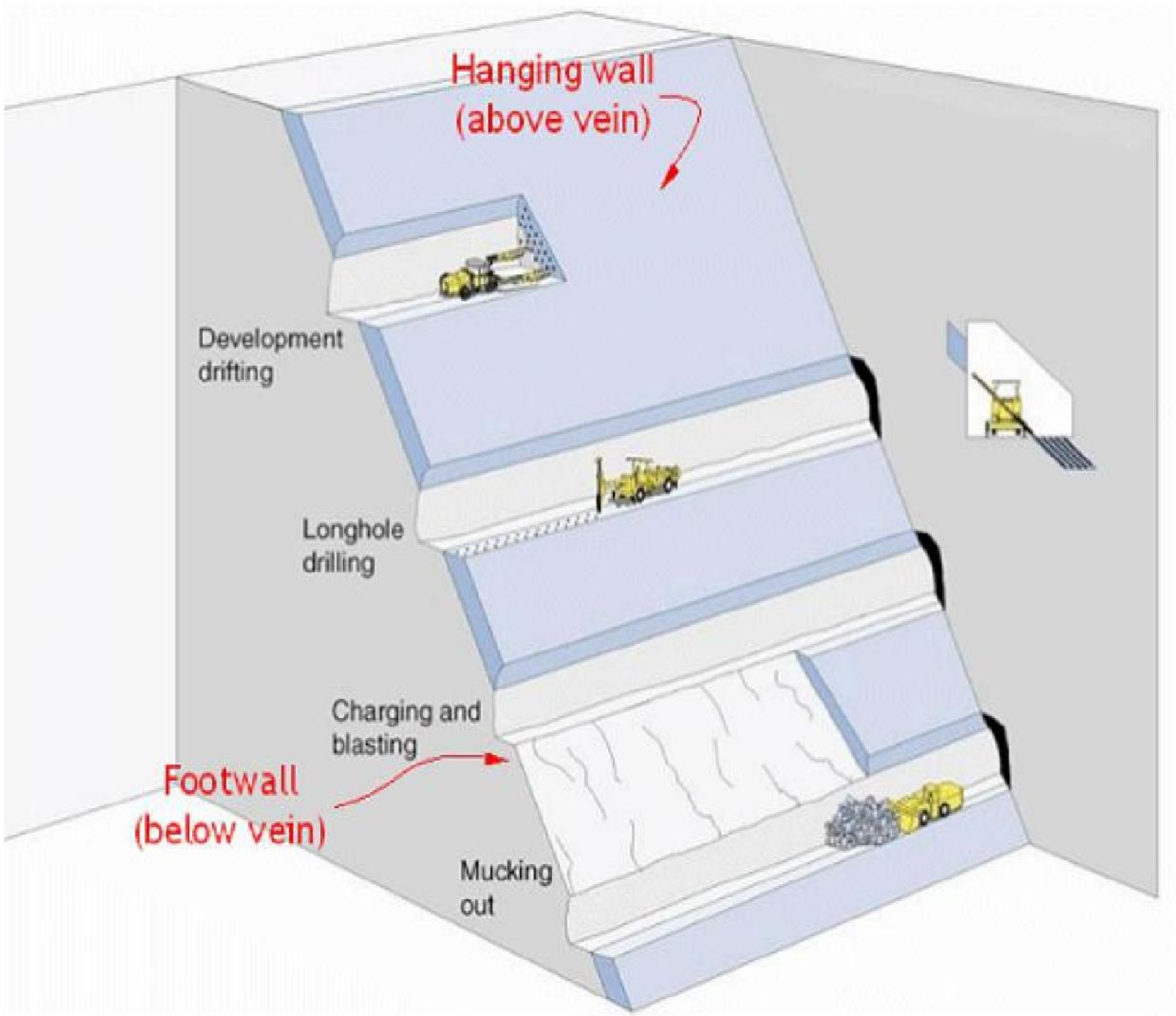
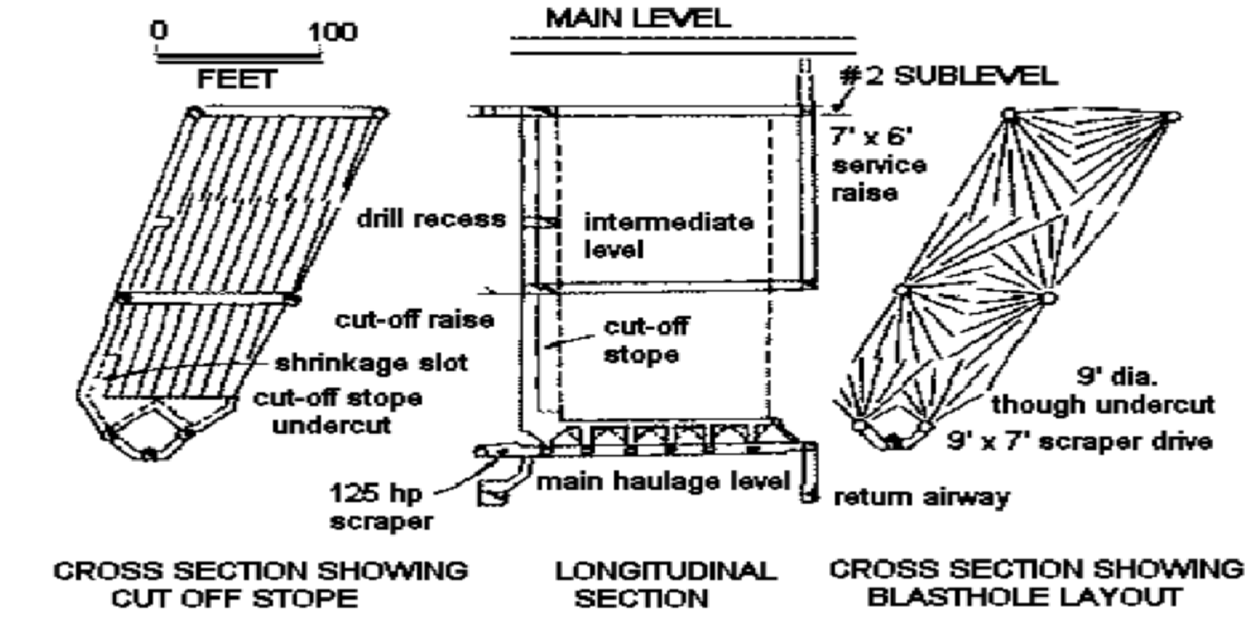
Sublevel Stoping Methods

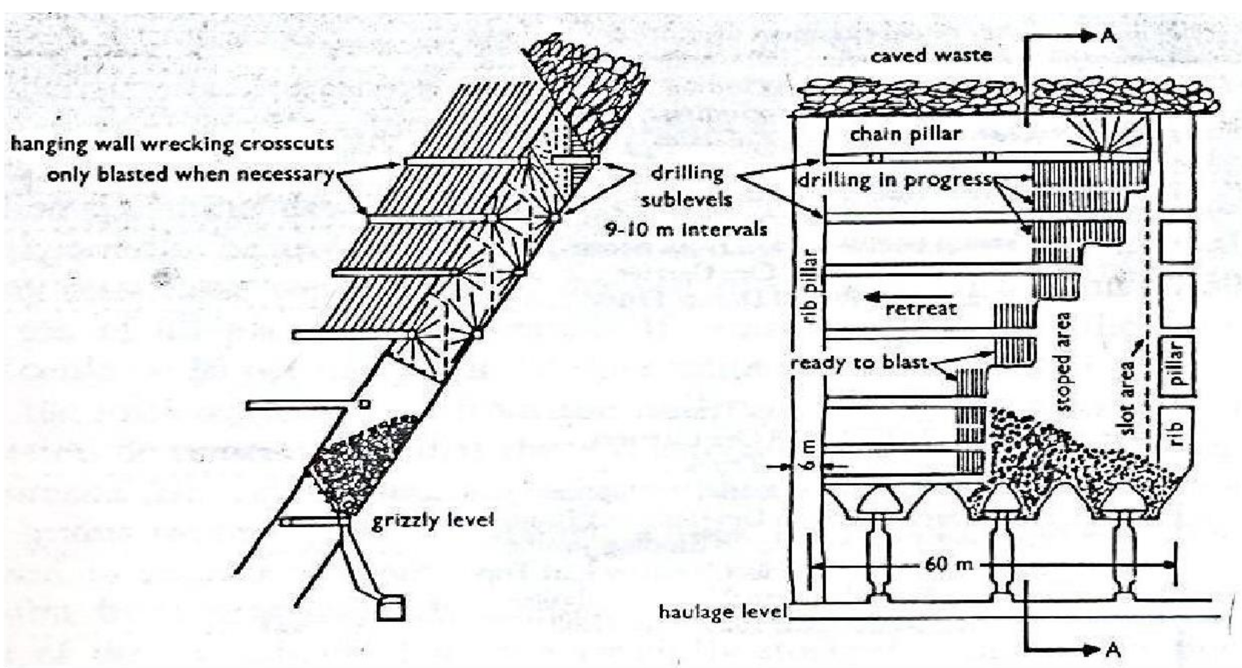
- minimum orebody width 2m
- tabular or massive shape
- Can be mined transverse or longitudinal
- dip >50°
- large stopes (non-entry)
- limited selectivity, orebody should be regular
- No Backfill
  - pillar size considerations similar to room and pillar
  - competent footwall, ore zone and hanging wall
  - dilution a potential problem
- With Backfill
  - pillar size must be suitable for recovery
  - stress on pillars should be low
  - fill material must allow recovery of pillars with minimum dilution

Sublevel Stoping Methods



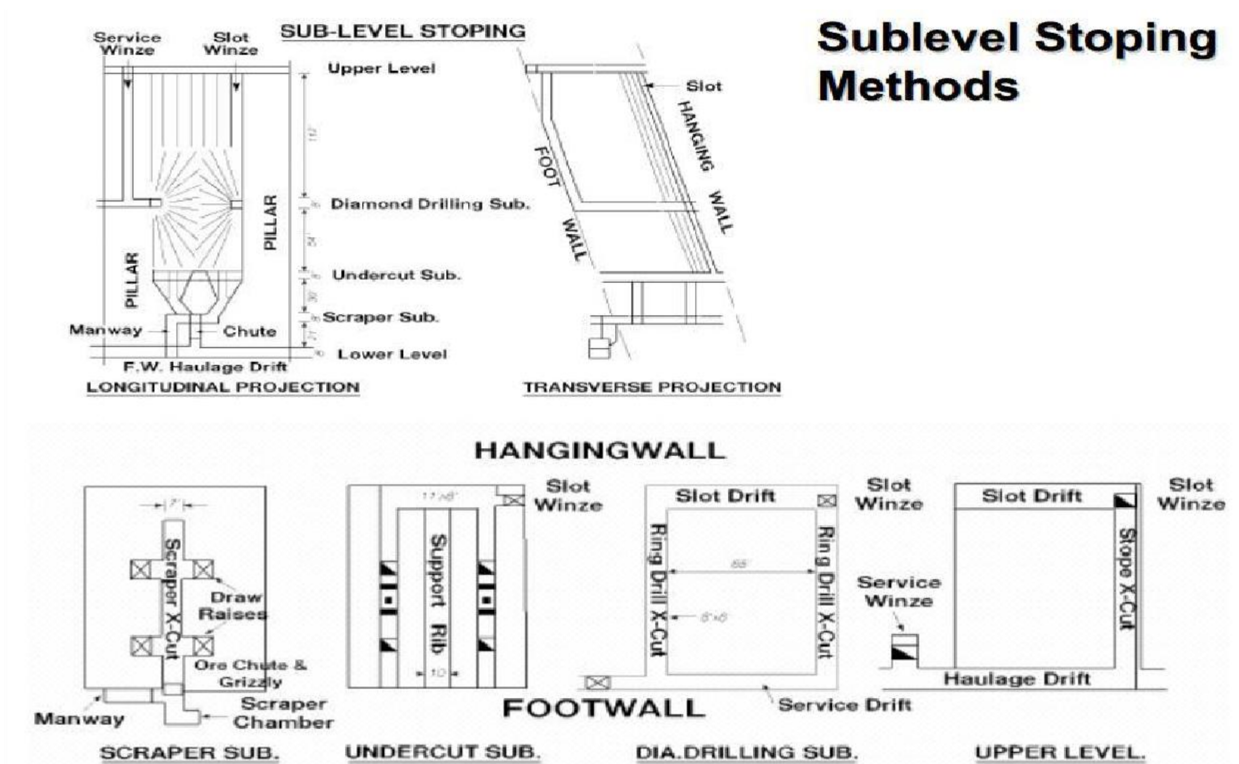


Drilling and Blasting in Sub-level Stoping Method



Transverse and longitudinal sections of sub-level Stoping Method

Sub-level Stope



The following disadvantages

- rate of penetration slows down with longer holes due to energy attenuation at a larger number of steel junctions (with the commonly used drifters and prevalent air pressure a maximum hole length of 30 m is desirable)

- hole deviation may become significant .

- with a larger sublevel interval the number of holes in a ring increase in order to maintain the required toe burden which results in crowding of the holds at the cellar.

- open space required at the undercut level to accommodate the swell of blasted ore increases with increased sublevel spacing.

- Length of stope ranges from as small as 20m to as large as 150m depending on ground pressure and rock characteristics. Rib pillars vary from 6 to 10 m length.

SLOS Stopping

Stoping starts from a slot at one end of the stope sometimes a slot is made at the centre of the stope, but this is desirable in relatively long stopes which is possible in relatively strong ground.

The slot is made by stripping a slot raise from wall to wall by parallel long holes drill from cross-cuts it the ends of the upper sublevels. Rings of long holes are then drilled from the sublevels and blasted into the slot.

Rings of 45 to 65 holes (52 & 57 mm holes are most prevalent) are usually drilled. Burden on rings is generally kept at 30 times hole diameter while a larger toe spacing 50 times hole diameter is adopted between holes in a ring.

This should however, be varied depending on rock structure and strength and fragmentation desired based on experimental stope blasts. Blasting efficiency requires a correct maintenance of the drilling pattern through rigorous control of hole direction and deviation.

Charging of holes also needs careful planning to ensure efficiency in blasting and good fragmentation. Holes should be charged to different distances from the collar in order to maintain a uniform charge spacing as far as practicable.

Charging pattern must be worked out in the planning office and supplied to the face.

Shrinkage Stopping Method

Shrinkage

- Ore is broken in horizontal slices working upwards.
- Sufficient ore withdrawn at the bottom after each slice to accommodate swell (30% - 40%)
- Remainder stays in the stope to provide a working platform ... removed at the end.
- Stopes separated by intermediate (recoverable) pillars

Shrinkage

- orebody width 1.2m - 30m
- tabular orebody; regular boundaries
- dip >50°
- stable hanging wall and footwall
- uniform draw down important
- dilution generally low
- Ore must be unaffected by storage in stope
- Labour intensive method, limited scope for mechanization

Shrinkage

- Summary of Application…
  - Shrinkage not a common method ... too labour intensive
  - Employed only where mechanization not possible.
  - Maintaining stope full of muck increases possible stope spans and minimizes dilution .. support and development costs reduced.
  - Limited production capacity and bulk of ore tied up for a long time.

- Advantages…
  - moderate production rate.
  - draw down by gravity
  - conceptually simple (small mine usage)
  - low capital investment
  - minimal support in stope
  - moderate development
  - good recovery, low dilution

- Disadvantages…
  - low productivity
  - moderate to high mining cost.
  - labor-intensive
  - dangerous working conditions
  - ore tied up in stope
  - ore subject to oxidation, packing in stope

Cut-and-Fill Stopping

In this method the ore is excavated in horizontal slices starting from the bottom of the stope and advancing upwards. The broken ore is loaded and completely removed from the stope.

When ore slice of the ore has been excavated the corresponding volume is filled with waste material. The filling is conducted integrally with the mining cycle and not after the completion of the entire mining operation.

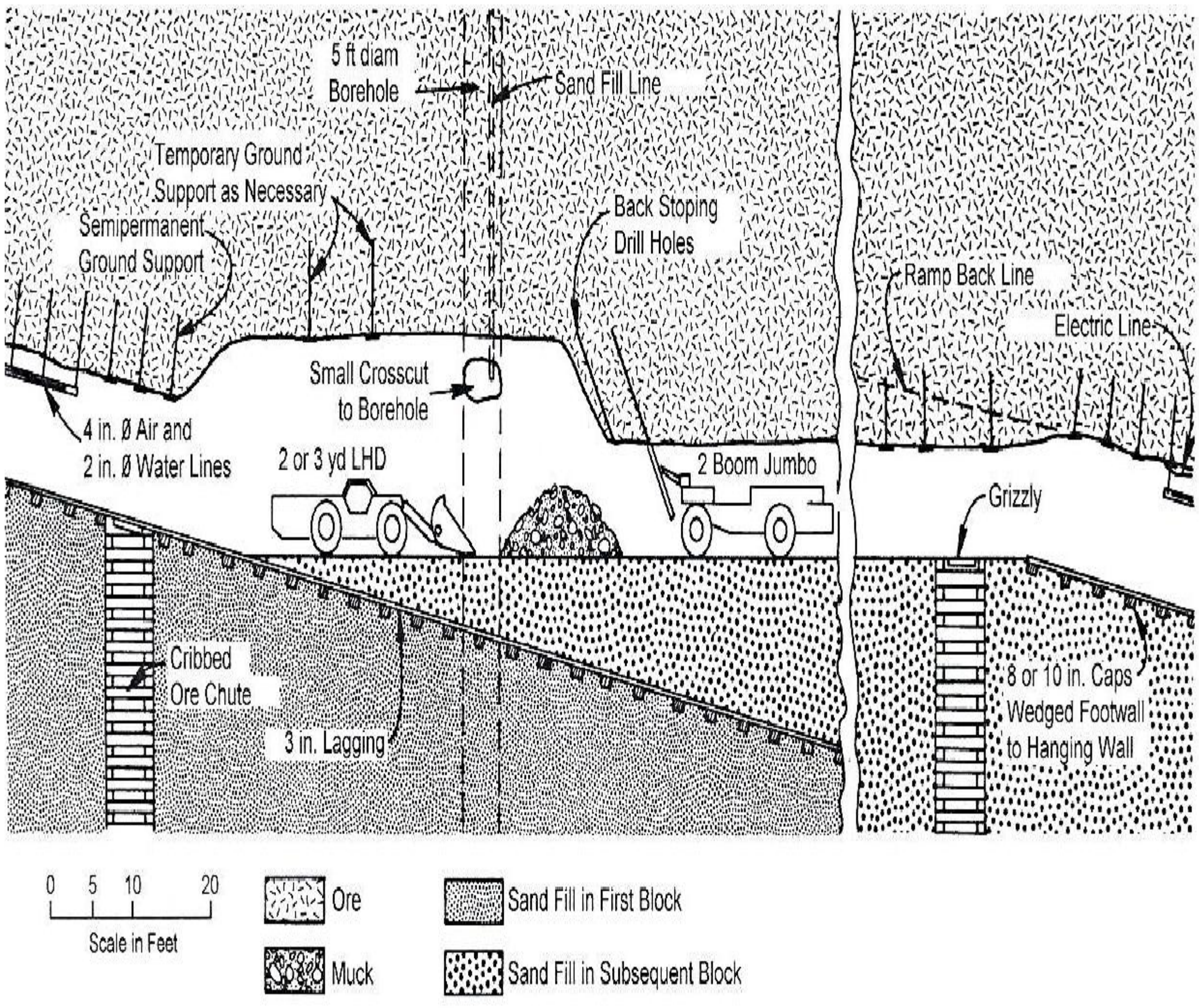


Figure: Cut-and-Fill Stoping Operation

Cut and Fill

- Summary of application
  - **orebody width 2m - 30m**
  - **tabular shape ... good for irregular orebodies**
  - **orebody dip 35° - 90°**
  - **good for low strength / high stress regions**
  - **requires safe, stable back for man entry**
  - **Expensive, generally high grade ore required for this method to be economic**

•Selective mining and minimum dilution

Application :

This method can be used with steeply dipping ore bodies with reasonably firm ore. The condition can be stated as: Ore strength: Moderate to strong, maybe less competent than with un-supported method.

Rock Strength: Weak Deposit Shape: Tabular, can be irregular Dip: Moderate to fairly steep can accommodate flatter deposit if ore passes are steeper than angle of repose Deposit Size: Narrow to moderate width Ore grade: Fairly high Depth: Moderate to deep.

Cut and Fill

Type of Stope	Drilling Equipment	Mucking Equipment
Breast (Narrow Vein)	Jackleg	Slusher
		0.4 m^3 LHD
Breast (Wide Vein)	Jackleg	Slusher
	2-boom Jumbo	0.8-3.8 m^3 LHD
		Rubber tired overshot mucker
Post-Pillar	Jackleg	0.8-3.8 m^3 LHD
Drift and Fill	2-boom Jumbo	0.8-3.8 m^3 LHD
Back	Stoper	Slusher
	Stope Jumbo	0.8-3.8 m^3 LHD
	2- or 3-boom Jumbo	
	Crawler	
	Mounted Drifter	
Undercut	Jackleg	Slusher
	2-boom Jumbo	0.8-3.8 m^3 LHD

Cut and Fill

- Advantage…
  - **moderate production and scale**
  - **good selectivity**
  - **low development cost**
  - **adaptable to mechanization**
  - **flexible method**
  - **excellent recovery with low dilution**
  - **tailings can be disposed of as fill**
- **Disadvantage…**
  - **high production cost**
  - **fill complicates cycle**
  - **requires stope access for mechanized equipment**
  - **labour intensive**
  - **ground settlement/instability risk**

Cut and Fill Variations

- Underhand Cut and Fill or Undercut and Fill
  - **Developed to recover pillars or to mine low strength ore bodies**
  - **Mining top down and placing a cemented/reinforced mat over the working area … enabling mining below.**
- Drift and Fill
  - **Used to mine wide, flat, thin (<6m) orebodies with poor hanging wall conditions.**
    Mining involves a series of parallel drifts with an access heading driven along the hanging wall contact. Each mined drift is filled with cemented sand fill … providing back support for the next drift.
- Post Pillar
  - **Hybrid between room and pillar and cut and fill**
  - **moderately thick, flat, tabular ore bodies**
  - **moderate to low strength back**

Vertical Crater Retreat Method

VCR Stopping

VCR stoping is applicable in many cases where conventional shrink stoping is feasible, although narrow ore body widths (less than about 3 m) may not be tractable.

The method is also particularly suitable for mining configurations in which sublevel development is difficult or impossible.

These geometric conditions arise frequently in pillar recovery operations in massive ore bodies.

Mechanics of Crater Formation

The method of VCR mining utilizes concentrated or spherical charges as opposed to conventional cylindrical charges.

A charge is considered to be spherical if its length-to-diameter ratio does not exceed 6 to 1. Thus for a hole of 165 mm diameter, a slurry package of 165 mm diameter and 990 mm length would form a spherical charge.

The geometrical configuration of a spherical charge limits its weight to approximately 35 kg in a 165 mm hole.

These spherical charges are placed in vertical or near-vertical parallel blast-holes at an optimum distance from the bottom of the hole.

Mechanics of Crater Formation

The optimum distance (also called the depth of burial) is defined as the distance from the free surface to the centre of gravity of the charge and is so chosen that the maximum volume of rock is broken to an excellent fragmentation size. When the charge is detonated, it produces a crater (surface cavity) in the surrounding rock.

As gravity works with the explosives breakage process and as the explosive energy in spherical charges is used at optimum confinement conditions, the resultant crater depths normally exceed the top of the explosives charge location and the muck produced is very – well fragmented for an efficient handling.

Stopping Method

The VCR method requires large diameter holes, usually of 165 mm diameter, to be drilled in a parallel pattern from a top drilling drive in the roe (called an over cut) down to an undercut on the level below.

The bottom of each hole is blocked off and charged with 'spherical' slurry bags placed in the hole at an optimum depth of burial. Horizontal slices of ore up to about 5 m thick, are then blasted into the undercut.

The 'swell' of broken ore is then drawn off (as in shrinkage stoping) from draw points by LHD equipment, prior to the next blast being taken.

After each blast has been drawn off, the space between the top of the broken ore which forms the basis for determining the thickness of the next slice to be blasted.

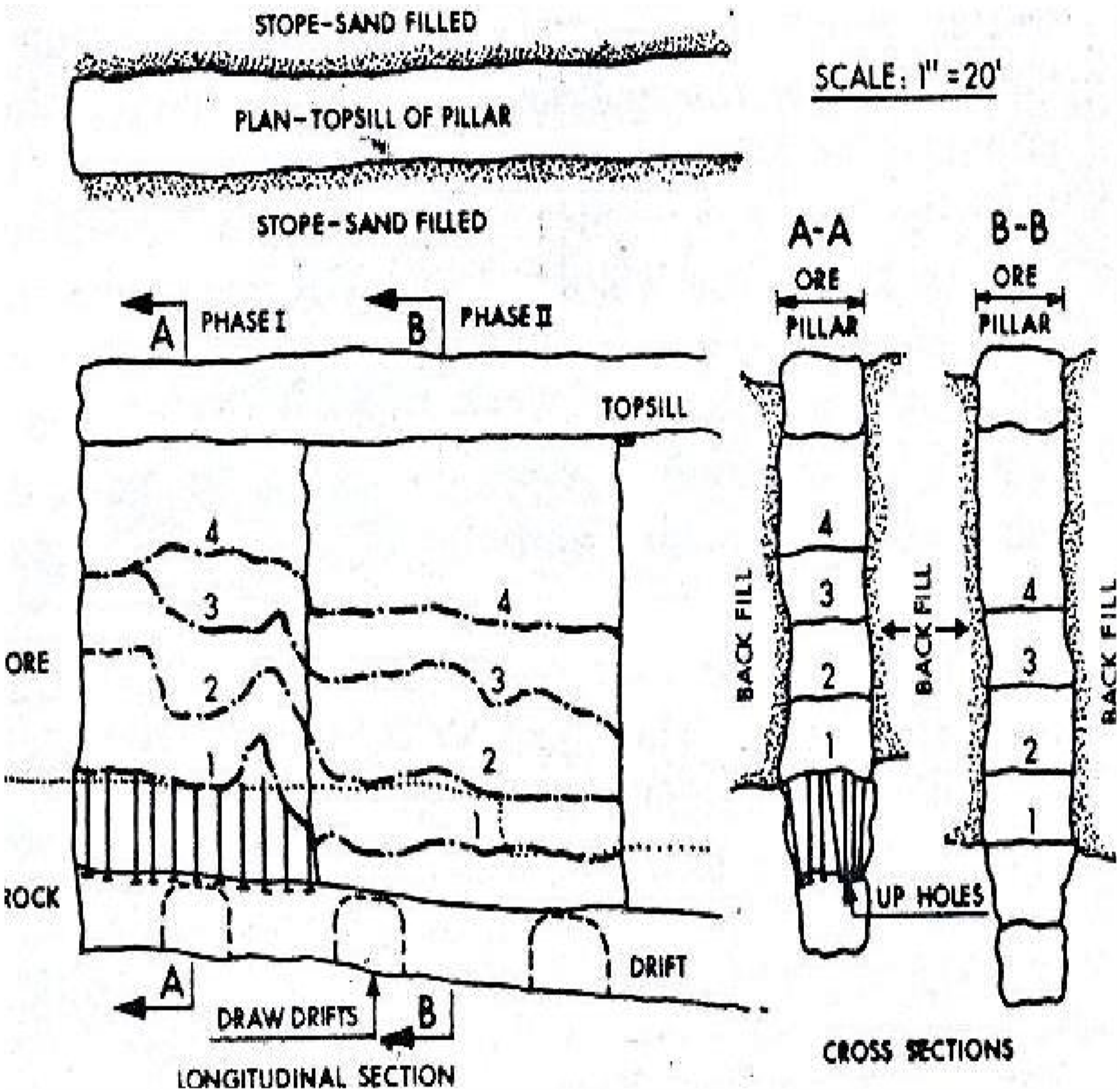
Repeating this loading and blasting procedure, mining of the stone or pillar retreats in the form of horizontal slices in a vertical upwards direction until the entire block is crater-blasted.

The VCR method necessitates the use of water jel or aluminized slurry explosive having high densities, high detonation velocities and high bulk strengths. ANFO, because of its low density has not been used in VCR blasting, despite its attractive cost and safety characteristics.

patterns of millisecond delays for blasting the slices of the ore body are used but the preferred method isto first blast a burn cut out of the centre of the pattern while the remaining holes are then blasted concentrically around the burn.

This method gives each hole two free faces into which it can break, laterally into the burn and downwards into the horizontal stope back.

VCR STOPING


STOPE-SAND FILLED
PLAN-TOPSILL OF PILLAR
STOPE-SAND FILLED
SCALE: 1" = 20'
A PHASE I
B PHASE II
TOPSILL
4
3
2
1
ORE
ROCK
DRIFT
A
DRAW DRIFTS
B
LONGITUDINAL SECTION
A-A
ORE
PILLAR
BACK FILL
UP HOLES
B-B
ORE
PILLAR
BACK FILL
CROSS SECTIONS

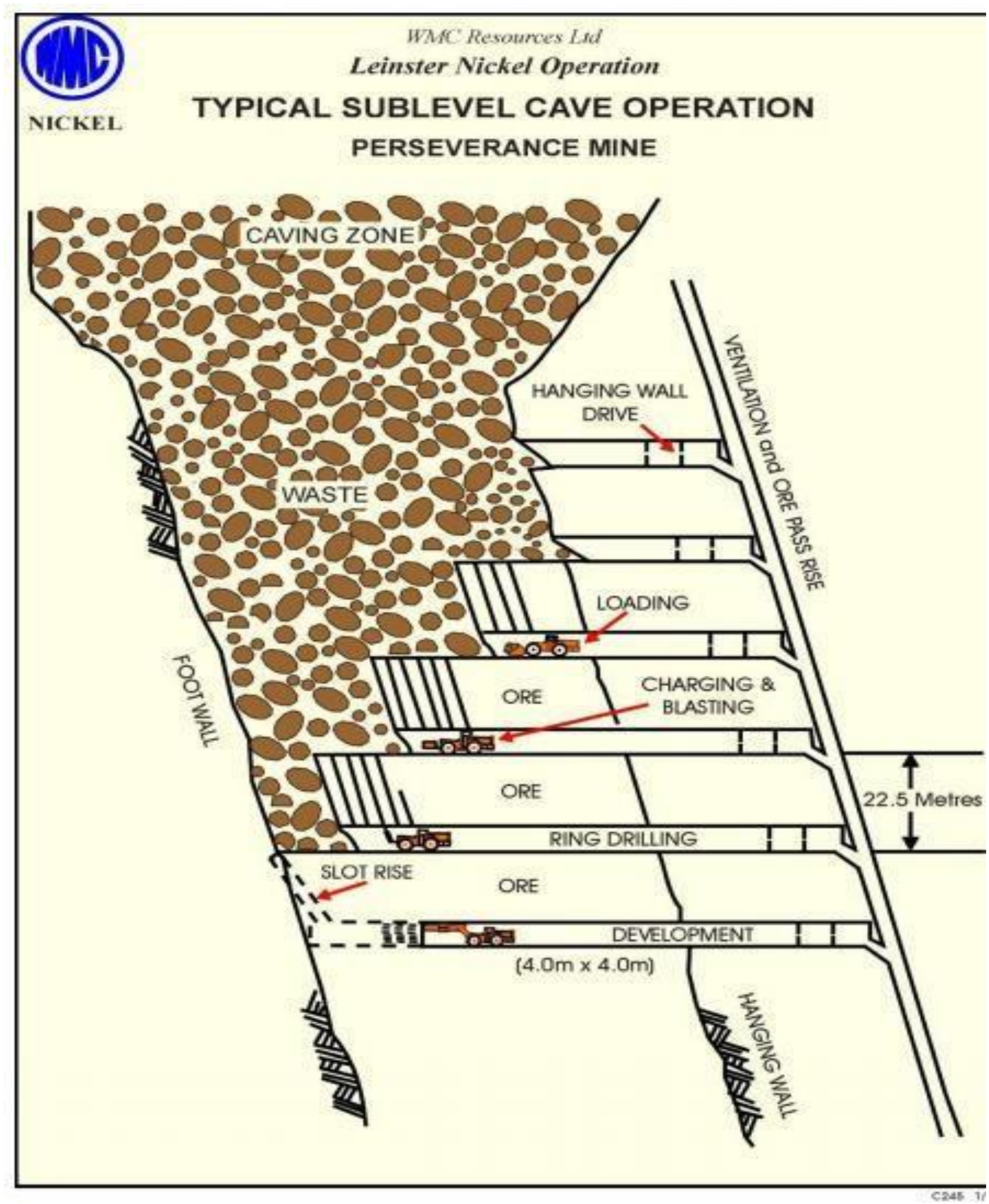
Advantages

VCR method has gained popularity both as a stoping method and for pillar extraction, in conditions where suitable ore blocks are available and the rock mechanics aspects are favourable.
The VCR stopes have been used both as sublevel and shrinkage stopes. The method has also been used in drop raising.

The main advantages of this method include:
(i) Higher tonnage per day and lower stoping cost.
(ii) Lower development cost since it eliminates raise boring and slot-cutting.
(iii)Increased safety of operations because drilling and blasting are
carried out from above and there is no need for the miner to enter the actual stope.
(iv)Improvement in fragmentation (the method yields lowest powder
factor).
(v) Reduced labour requirements and drilling and charging time.
(vi) Reduced dilution and over break.
(vii) Elimination of up-hole drilling and up-hole loading of explosives.

The term cratering is applied to the formation of a surface cavity in a material through the action of detonating an explosive charge within the material. A crater blast is a blast when a spherical charge is detonated beneath a surface that extends laterally in all directions beyond the point where the surrounding material would be affected by the blast.

Sub-level Caving Method



Sublevel Caving

Sub level caving is a productive mining **method** where all of the ore is fragmented by blasting and the host rock in the hanging wall of the ore body caves. ... Activities in the parallel production drifts are performed simultaneously in order to maintain a good process in the mine.

Sublevel Caving is one of the most advanced mining methods. This method is usually undertaken when mining the orebody through an open pit is no longer economically viable.

In Sublevel Caving, mining starts at the top of the orebody and develops downwards.

Ore is mined from sublevels spaced at regular intervals throughout the deposit. A series of ring patterns is drilled and blasted from each sublevel, and broken ore is mucked out after each blast.

Sublevel Caving can be used in orebodies with very different properties and is an easy method to mechanize.

This method is normally used in massive, steeply-dipping orebodies with considerable strike length, and usually has a high amount of dilution and low recoveries.

Thus Sublevel Caving is usually used to mine low-grade, low-value orebodies.

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