Underground mining Methods

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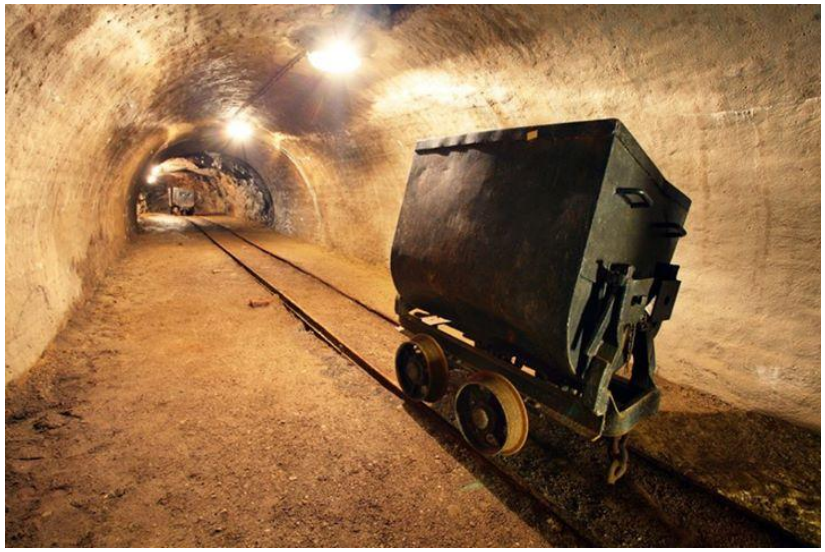

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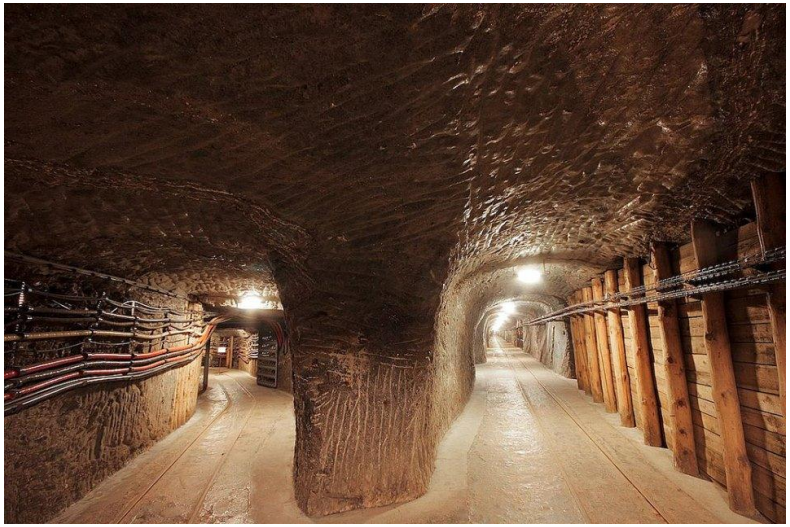
Underground Mining



Choice of mining method

Underground Mining Methods

Soft rock Mining Methods

- ***Blast mining***
- ***Shortwall mining***
- ***Coal Skimming (or Sink and Float) method***

Hard rock Mining Methods

Stoping

1) *Room and pillar*
2) *Bench and Fill (B & F) stoping*
3) *Cut and Fill (C & F) stoping*
4) *Stull stoping*
5) *Square-set stoping*
6) *Shrinkage stoping*
7) *Long-hole Open stoping*
8) *Vertical Crater Retreat (VCR) stoping*
9) *Longwall stoping*
10) *Caving methods*
    i) *Sublevel caving*.
    ii) *Block caving*

Stope and Retreat vs. Stope and Fill

Ore Removal

Unit Operations of Mining

We will explore all of the above in Part 9.

When do we mine underground?

- The ore deposit is deep
- Ore body is steep
- Grade is high enough to exceed costs

Underground Mining Methods

- The mining method used will depend on the characteristics of the orebody, particularly thickness and dip, and the competency of the surrounding rock.
- Different methods can be used in different parts of a mine (e.g., *as this plan from the Black Swan nickel mine exemplifies*).
- This type of planning is done continuously as mining proceeds and more data are acquired on the orebody configuration through underground drilling.

❑***Underground mining methods are usually classified in two categories of methods:***

UNDERGROUND MINING METHODS	
Soft rock Mining Methods	***Hard rock Mining Methods***
Mining can be done by any one of the following methods:- ***1) Longwall mining.*** ***2) Room-and-pillar mining.*** ***3) Blast mining.*** ***4) Shortwall mining.*** ***5) Coal Skimming.***	Mining can be done by the following methods:- ***a) Short-hole and Long-hole mining methods*** ***b) Selective and unselective mining methods*** ***c) Supported and Unsupported underground mining methods***

Choice of mining method :

The choice of mining method is an extremely important decision affecting the entire mining project;

The definition of the method permits:

- establish the configuration of the mine;
- choose mining equipment;
- perform an economic evaluation of the project.

Examples of factors in the choice of mining method:

Form of deposit

- Dimensions of deposit
- Strength of the ore and host rocks Depth
- Geological conditioning
- Content and distribution of the ore deposit.

Soft rock Mining Methods

Blast mining

- *An older practice of coal mining* that uses explosives such as dynamite to break up the coal seam, after which the coal is gathered and loaded onto shuttle cars or conveyors for removal to a central loading area.
- This process consists of a series of operations that begins with "***cutting***" the coal bed *so it will break easily when blasted with explosives*.
- This type of mining accounts for less than 5% of total underground production in the U.S. today.

Shortwall mining

- A coal mining method that accounts for less than 1% of deep coal production,
- Shortwall involves the use of a continuous mining machine with moveable roof supports, ***similar to longwall***.
- The continuous miner shears coal panels 150–200 feet wide and more than a half-mile long, depending on other things like the strata of the Earth and the transverse waves.

Coal Skimming (or Sink and Float) method

- method to separate the lighter coal from slate, by using large amounts of water to sink slate and float coal.
- No longer in general use, because of the massive amount of water needed and environmental damage
- Much faster and less labour intensive.

Hard rock Mining Methods

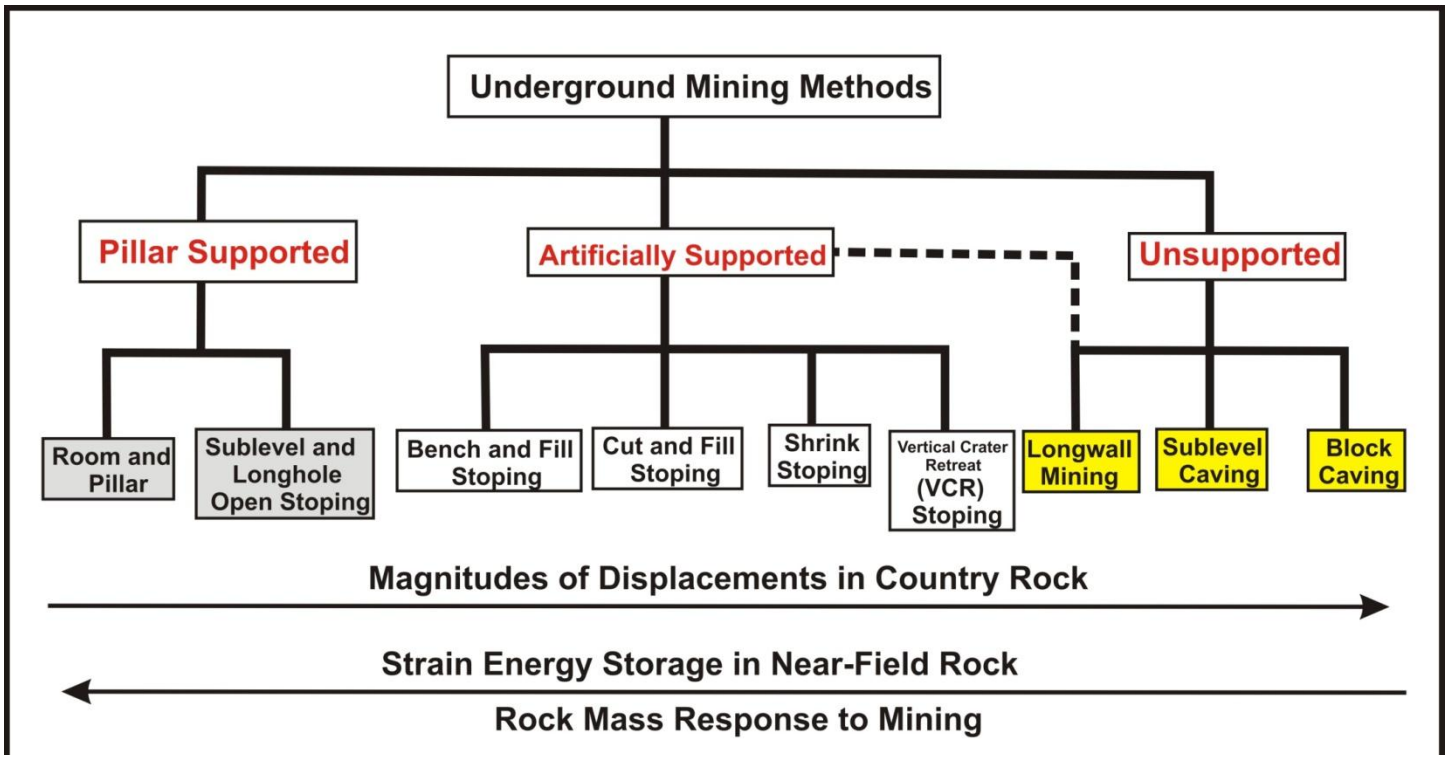
Hard rock underground mining methods can be classified as the following:-

a) ***Short-hole and Long-hole mining methods;***
b) ***Selective and unselective mining methods; and***
c) ***Unsupported , supported and caving underground mining methods***

Selective Mining Methods	Unselective Mining Methods
1) *Narrow vein* 2) *Long-hole Open stoping* 3) *Sublevel Open stoping* 4) *Cut and Fill (C & F) stoping* 5) *Bench and Fill (B & F) stoping* 6) *Stull stoping* 7) *Shrinkage stoping* 8) *Room and pillar* 9) *Square-set stoping* 10) *Longwall stoping*	1) *Caving methods* i) *Sublevel caving.* ii) *Block caving* 2) *Vertical Crater Retreat (VCR) stoping*

c) Supported and Unsupported underground mining methods

Unsupported Methods	***Supported Methods***	***Caving Methods***
Unsupported methods of mining are used to extract mineral deposits that are roughly tabular (plus flat or steeply dipping) and are generally associated with strong ore and surrounding rock. These methods are termed unsupported because they do not use any artificial pillars to assist in the support of the openings. However, generous amounts of roof bolting and localized support measures are often used. *1) Narrow vein* *2) Room and Pillar (R & P)* *3) Stope and Pillar* *4) Long-hole Open stoping* *5) Sublevel Open stoping*	This methods are often used in mines with weak rock structure. In ***"Artificially supported"*** mining, the mine-workings are supported temporarily only for as long as needed to keep the active face open to mining. ***After mining, the support*** (e.g. hydraulic props or wood packs) is removed (or becomes crushed), and the mining cavities close up under the pressure of the overburden material. *1)Bench and Fill (B & F) stoping* *2)Cut and Fill (C & F) stoping* *3)Stull stoping* *4)Square-set stoping* *5)Shrinkage stoping* *6)Vertical Crater Retreat (VCR) stoping*	Caving mining is advantageous in that it ***maximizes ore recovery*** (as little ore as possible is left behind) the method comes with ***significant problems***: ➢ Surface subsidence in the case of shallow mines. ➢ Rock-bursts underground, causing injury and death in deep level mines. ***The cavity closure is either partial, for shallow mining, or complete, for deep level mining***. *1) Longwall mining* *2) Caving methods* *i) Sublevel caving.* *ii) Block caving*



Method	T / Manshift	Avg. T / Day	Relative Operating Cost per tonne
Resuing	0.2 - 0.5	50 - 100+	70+
Cut and Fill	12 - 48	500 – 1,500	20 to 70
Shrinkage	20 - 28	200 - 800	20 to 50
Room and Pillar	15 - 150	1,500 – 10,000	7 to 20
Open Stoping	20 - 115	1,500 – 25,000	7 to 25
Sub-level Caving	65 - 180	1,500 – 50,000	7 to 17
Block Caving	300 - 2000	10,000 – 100,000	1 to 2.5

BMO Capital Markets 2011 Global Metals & Mining Conference

Underground Mining Methods Flow Chart (modified from Brown, 2003)

Note:

- They are differentiated by the type of wall and roof supports used, the configuration and size of production openings, and the direction in which mining operations progress.
- **The major distinction between the different underground mining methods is whether *the mined out areas remain supported after mining, or if they are allowed to collapse.***

Table Methods for underground mining

Underground methods	Unsupported				Supported		Caving		
Factor	***Room and Pillar***	***Stope and Pillar***	***Shrinkage Stoping***	***Sublevel Stoping***	***Cut and Fill Stoping***	***Square Set Stoping***	***Longwall Stoping***	***Sublevel Caving***	***Block Caving***
Ore strength	Weak / Moderate	Moderate/ Strong	Strong	Moderate/ Strong	Moderate/ Strong	Weak	Any	Moderate/ Strong	Weak/ Moderate
Rock strength	Moderate / Strong	Moderate/ Strong	Strong	Fairly Strong	Weak	Weak	Weak / Moderate	Weak	Weak / Moderate
Deposit shape	Tabular	Tabular / Lenticular	Tabular / Lenticular	Tabular / Lenticular	Tabular / Irregular	Any	Tabular	Tabular / Massive	Massive / Thick
Deposit dip	Low / Flat	Low / Moderate	Fairly Steep	Fairly Steep	Fairly Steep	Any	Low / Flat	Fairly Steep	Fairly Steep
Deposit size	Large / Thin	Any	Thin / Moderate.	Thick / Moderate	Thin / Moderate	Usually Small	Thin / Wide	Large Thick	Very Thick
Ore grade	Moderate	Low / Moderate	Fairly High	Moderate	Fairly high	High	Moderate	Moderate	Low
Ore uniformity	Uniform	Variable	Uniform	Uniform	Variable	Variable	Uniform	Moderate	Uniform
Depth	Shallow / Moderate	Shallow / Moderate	Shallow / Moderate	Moderate	Moderate / Deep	Deep	Moderate / Deep	Moderate	Moderate

STOPING

Sketch painting of miners stoping at the Burra Burra Mine, Burra, Australia, 1847.

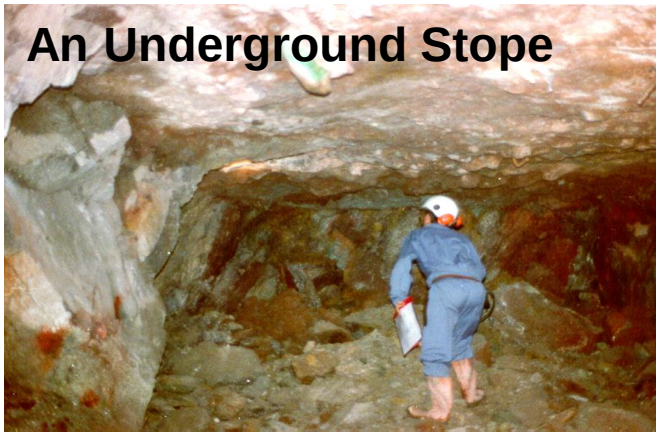
Stoping with an air drill in an American iron mine in the 20th century (museum exhibit)

Overview

- **Stoping** is the process of extracting the desired ore or other mineral from an underground mine, leaving behind an open space known as a **stope**.[1]
- Stoping is the removal of the orebody from the surrounding rock.
- Stoping is used when the country rock is sufficiently strong *not to cave into the stope, although in most cases artificial support is also provided.*
- The earliest forms of stoping were conducted with hand tools or by fire-setting; later gunpowder was introduced. From the 19th century onward, various other explosives, power-tools, and machines came into use. As mining progresses the stope is often backfilled with tailings, or when needed for strength, a mixture of tailings and cement. In old mines, stopes frequently collapse at a later time, leaving craters at the surface. They are an unexpected danger when records of underground mining have been lost with the passage of time.
- Stoping is considered "***Productive work***", and is contrasted with "***Deadwork***", the work required merely to access the mineral deposit, such as **sinking shafts and winzes, carving adits, tunnels, and levels, and establishing ventilation and transportation**.[2]

- A stope can be created in a variety of ways → The specific method of stoping depends on a number of considerations, both technical and economical, based largely on the geology of the ore body being mined. These include the incline of the deposit (whether it is flat, tilted or vertical), the width of the deposit, the grade of the ore, the hardness and strength of the surrounding rock, and the cost of materials for supports[3] (i.e., The methods used may vary throughout each mine, depending on the changing characteristics of the orebody and mine planning techniques).

MPI Mines



IAEA

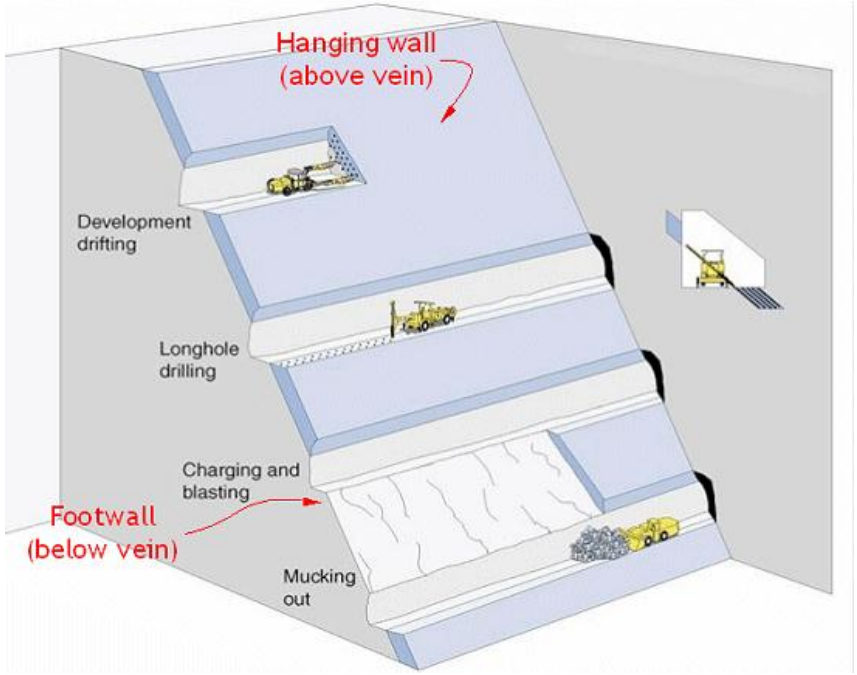
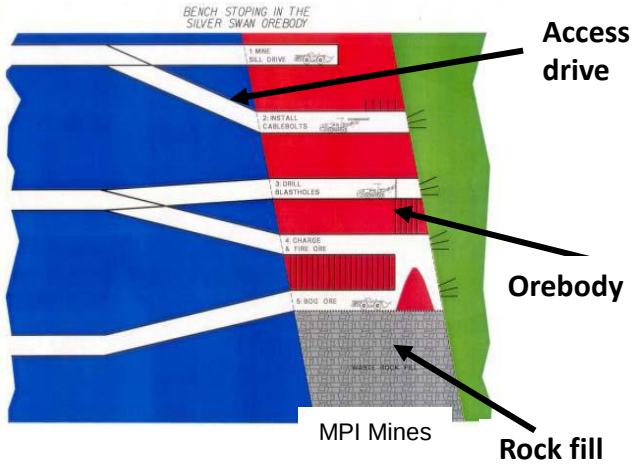


Figure shows stoping a narrow vein mining orebodies may be only half a meter wide

Fig.12: A narrow vein stope at Gymbie Eldorado Mine, Queensland-Australia.

Overview (Cont.)

- It is common to dig shafts vertically downwards to reach the ore body and then drive horizontal levels through it. **Stoping then takes place from these levels.**
- When the ore body is **more or less horizontal**, various forms of ***room and pillar stoping, cut and fill,*** [4] ***or longwall mining*** can take place.
- ***In steeply-dipping ore bodies***, such as lodes of tin, the stopes become long narrow near-vertical spaces, which, if one reaches the surface is known as a *Gunnis* or *Coffen*.[1] A common method of mining such vertical ore bodies is ***stull stoping***.
- The development of the infrastructure for the stoping methods is time-consuming, costly, and complex.
- All methods involve:
  - drilling a pattern of holes into the rock
  - charging (filling) the holes with explosive
  - blasting the rock
  - bogging (digging) it out
  - transporting it to the surface.



- The general approach is to access the orebody at regular intervals (generally between 15 and 40 vertical meters) and then stope between these.

1) Open-Stope Systems

- Open stoping is generally divided into two basic forms based on direction: ***overhand and underhand stoping***, which refer to the removal of ore from above or below the level, respectively.
- It is also *possible to combine the two in a single operation*.

1.1) Underhand stoping

- Underhand stoping, also known as *horizontal-cut underhand or underbreaking stoping*, is the working of an ore deposit from the top downwards.
- Like shrinkage stoping, underhand stoping is most suitable for steeply dipping ore bodies.[5] Because of the mechanical advantage it offers hand tools being struck downward (*rather than upward, against gravity*), this method was dominant prior to the invention of rock blasting and powered tools.[6]

1.2) Overhand stoping

- In overhand stoping, the deposit is worked from the bottom upward, the reverse of underhand stoping.
- With the advent of rock blasting and power drills, it became the predominant direction of stoping.[3]

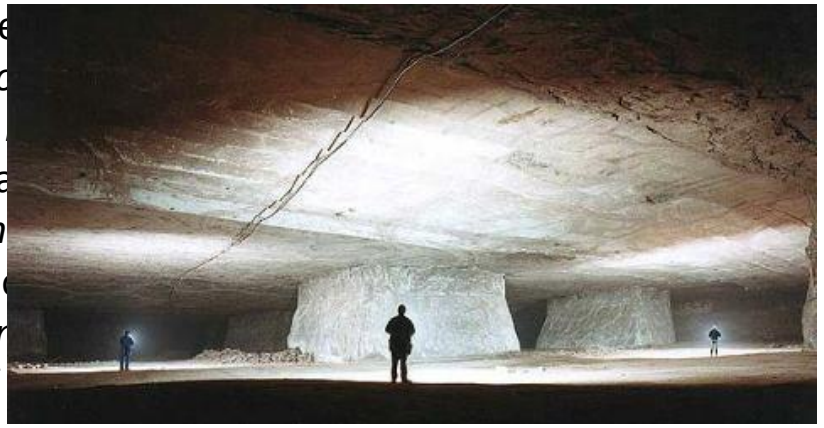
1.3) Combined stoping

- In combined stoping, the deposit is simultaneously worked from the bottom upward and the top downward, combining the techniques of overhand and underhand stoping into a single approach.

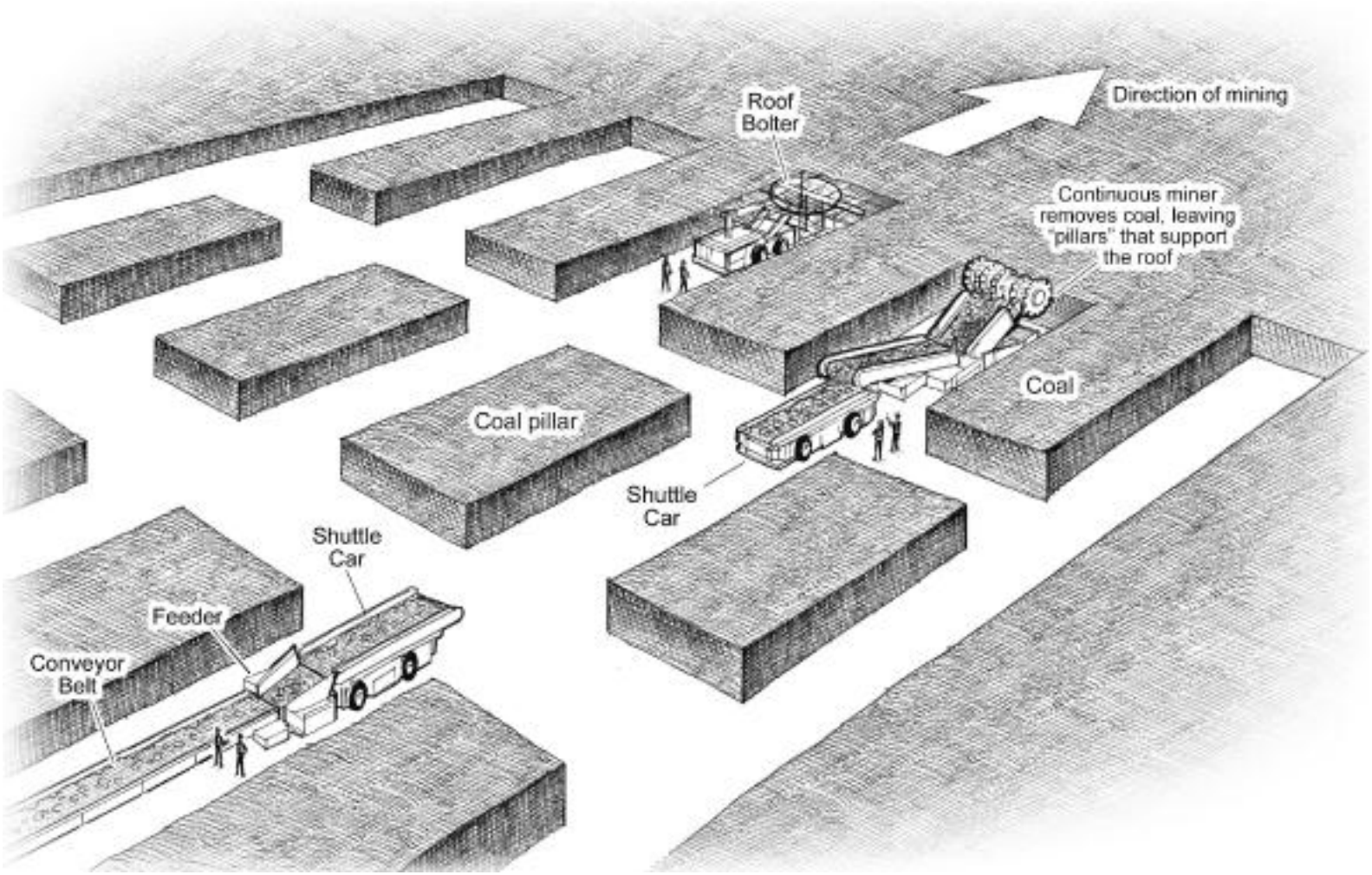
1.4) Breast stoping

- Breast stoping is a method used in ***horizontal or near-horizontal ore bodies***, **where gravity is not usable to move the ore around**.[7]
- Breast stoping lacks the characteristic ***"steps"*** of either underhand or overhand stoping, being mined in a singular cut.
- *Room and pillar is a type of breast stoping*.

2) Room (Bord)-and-Pillar mining (or continuous mining) method



- It is the most common supported pillar method, designe
  seams, or tabular orebodies, *or gently dipping bedded d*
  oil shale, limestone, *phosphate, salt,* trona, *potash, and*
- Room and pillar methods are well adapted to mecha
  sedimentary deposits (such as *shales, limestone, dolom*
  coal seams, phosphate layers, and evaporate (salt and p
- Pillars are left in place in a regular pattern *while the roor*
- Support of the roof is provided by natural pillars of
  systematic pattern.
- The mining cavity is supported (kept open) by the strength of r
  that are left un-mined.
- Room-and-pillar mining method has a low recovery rate (*a lar*
  place underground).
- In many room and pillar mines, the pillars are taken out startin
  stope access, allowing the roof to collapse and fill in the stope. *T*
  less ore is left behind in pillars.
- It is an advantageous mining method for ***shallow*** orebodies –as a means of preventing surface subsidence. Historic, ultra-shallow underground coal mines (<30 m) nevertheless ***are*** characterized by surface subsidence in the areas between pillars (e.g., Witbank coal field, South Africa).
- Pillars are sometimes mined on ***retreat*** from a working area, inducing closure and caving of these working panels, and raising the risk of surface subsidence.



Room and Pillar Mining

Room (Bord)-and-Pillar Layout

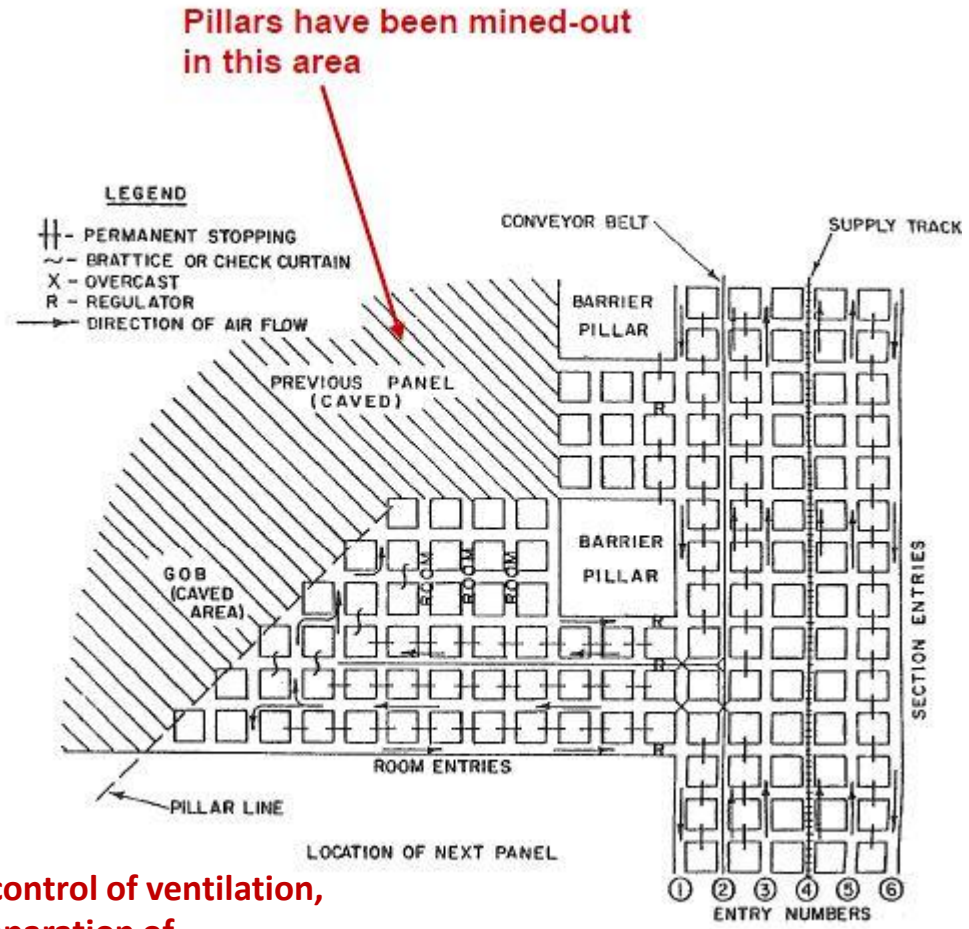


Figure from Hartman and Mutmansky, 2002.

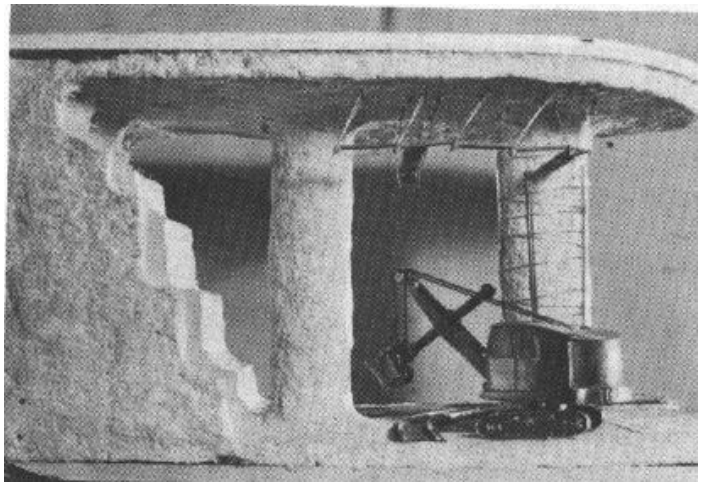
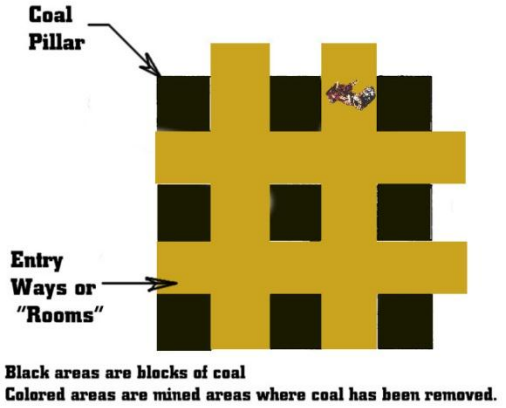
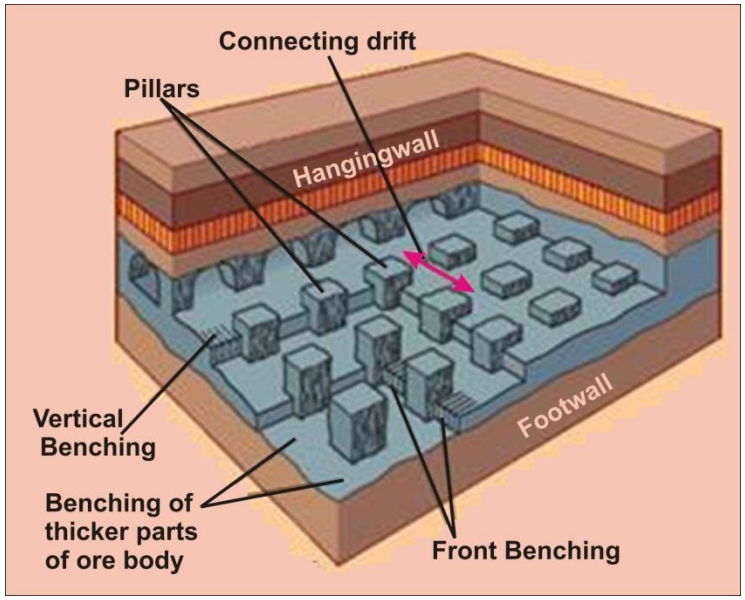


Figure shows Room and Pillar Mining



Note the control of ventilation, i.e., the separation of contaminated (used) and uncontaminated (fresh) air using a variety of devices.

Underground mining: room-and-pillar mining of thick seams –"Benching"



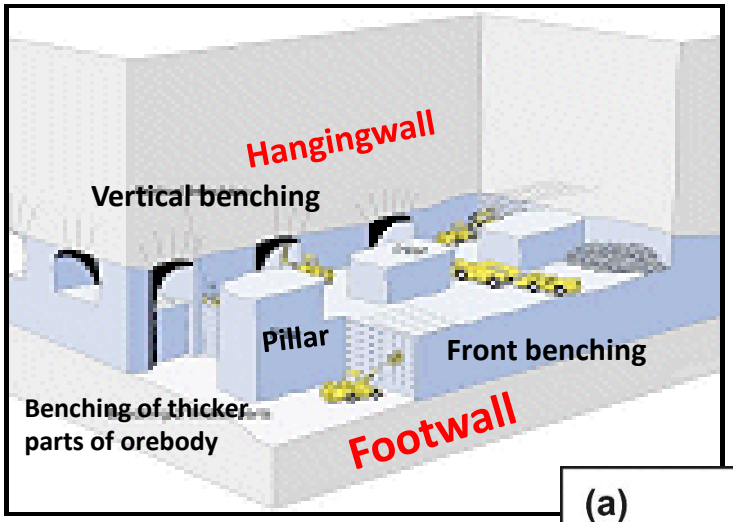
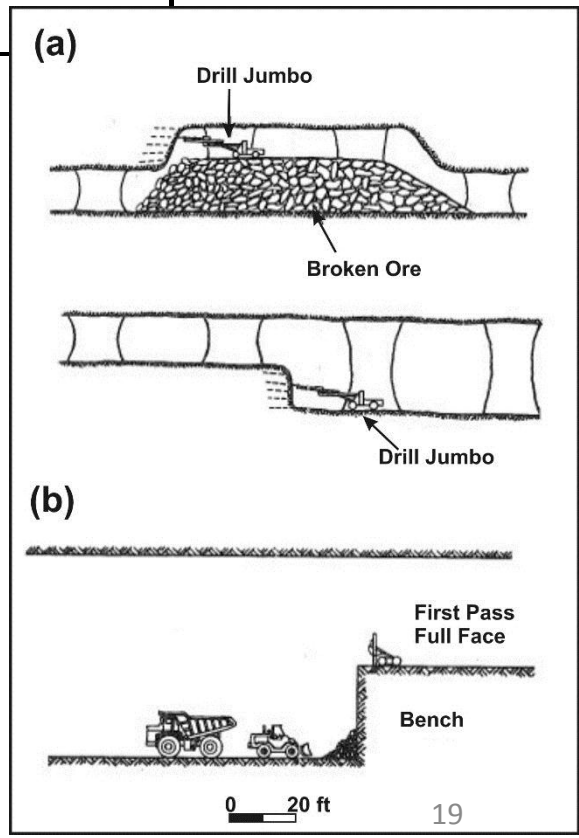


Figure shows Room and Pillar is designed for mining flat, bedded deposits of limited thickness.

Different approaches allow either the top or bottom part of the seam to be mined out first.

Note: the ***"hangingwall"*** is above the mining cavity, and the ***"footwall"*** is below it.



Figures from Hartman and Mutmansky, 2002.

3) Cut and Fill (C & F) Stoping

- It is one of the more popular methods used for vein deposits and has recently grown in use.
- It is an expensive but selective mining method, with low ore loss and dilution.[3] (i.e., allows selective mining and avoid mining of waste or low grade ore).
- Is relatively expensive and therefore is done only in high grade mineralization (Because the method involves moving fill material as well as a significant amount of drilling and blasting).
- It is a method of ***shorthole mining*** used in **steeply dipping or** It is preferred for orebodies with **irregular ore zones and scattered mineralization**.
- It requires **working at face** (*which is less safe than longhole stoping*).
- It is used:-
  - in mining steeply dipping orebodies in stable rock masses (primarily in steeply dipping metal deposits),
  - in strata with good to moderate stability, and comparatively high grade mineralization.
  - either fill option may be consolidated with concrete, or left unconsolidated.
  - Generally uses no cement
  - Bottom up mining method: Remove ore in horizontal slices, *starting from a bottom undercut and advancing upward*.
  - Moderate production rates.
  - Good resource usage.
  - Not stress friendly.
  - Moderate ground support
- Ore is drilled, blasted and removed from stope.
- The ore is mined in slices: As each horizontal or slightly inclined slice is taken, the **voids (Opens)** are ***backfilled with a variety of fill types to support the walls*** (i.e., the fill can be rock waste, tailings, cemented tailings, or other suitable materials).

  {(**note**: *The fill serves both to support the stope walls and provide a working platform for equipment when the next slice is mined*)}.

3) Cut and Fill (C & F) Stoping (Cont.)

Ore is drilled, blasted and removed from stope

Stopes

"Fill" is some combination of tailings and cement

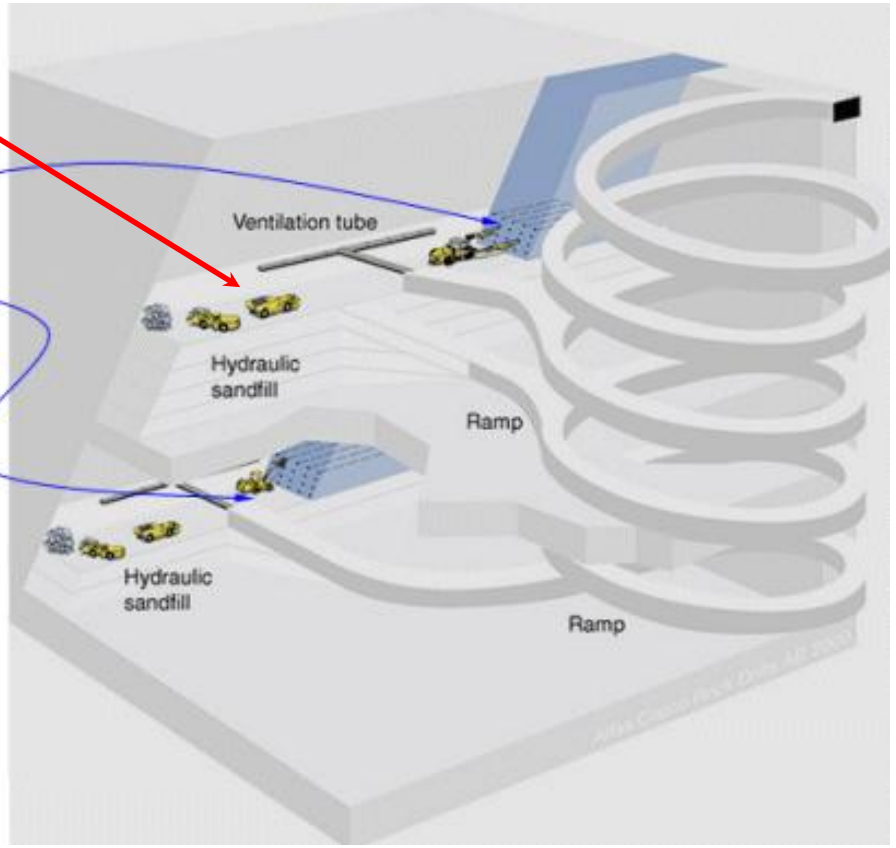


Figure showing cut and fill mining method.

Remove ore in horizontal slices, *starting from a bottom undercut and advancing upward*.

As each horizontal slice is taken, the **voids (Opens)** are *filled with a variety of fill types to support the walls.* (i.e., the fill can be rock waste, tailings, cemented tailings, or other suitable materials).

3) Cut and Fill (C & F) Stoping (Cont.)

- Because the method involves moving fill material as well as a significant amount of drilling and blasting, *it is relatively expensive and therefore is done only in high grade mineralization* where there is a need to be selective and avoid mining of waste or low grade ore.
- It is practiced both in the ***overhand (upward) and in the underhand (downward) directions***.

i) Overhand (upward) cut and fill

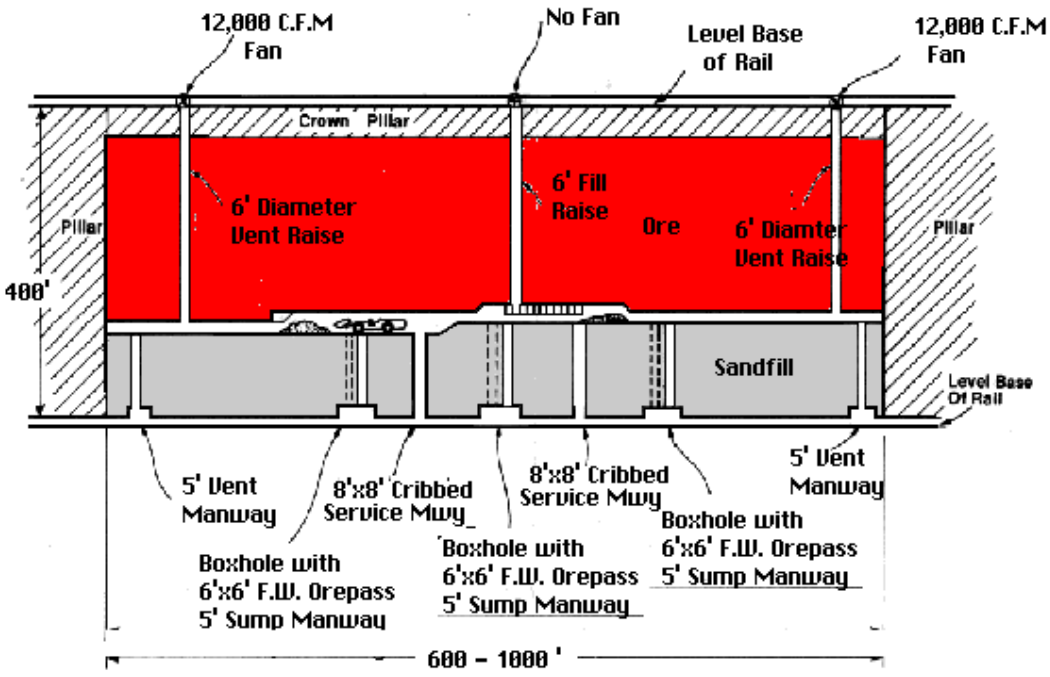
- is applied to ore lies underneath the working area and the roof is backfill.
- involves a work area of cemented backfill while mining ore from the roof.

ii) Underhand (Downward) cut and fill ore

- is applied to ore lies beneath the working area and the roof is cemented backfill.
- ore overlies the working area and the machines work on backfill.

Note:

Drift and Fill is similar to cut and fill, except it is used in ore zones which are wider than the method of drifting will allow to be mined. In this case the first drift is developed in the ore, and is backfilled using consolidated fill. The second drift is driven adjacent to the first drift. This carries on until the ore zone is mined out to its full width, at which time the second cut is started atop of the first cut.



3) Stull stoping

- ***Stull stoping*** is a common method of to mine vertical ore bodies or *steeply-dipping ore bodies (because the stopes become long narrow near-vertical spaces, which, if one reaches the surface is known as a Gunnis or Coffen[1]).*
- Stull stoping is a form of stoping used in *hardrock mining* that uses *systematic or random timbering* ("***stulls***") placed between the foot and hangingwall of the vein.
- *Stull stoping* is a supported mining method using timber or rock bolts in tabular, pitching ore bodies.
- It is one of the methods that can be applied to ore bodies that have dips between 10^{o} and 45^{o}.
- The method requires that the hangingwall and often the footwall be of competent rock as the stulls provide the only artificial support.
- It often utilizes artificial pillars of waste to support the roof.
- This type of stope has been used up to a depth of 3,500 feet (1,077 m) and at intervals up to 12 feet (3.7 m) wide.[8]

4) Square-set stoping

- Square-set stoping is a method relying on square-set timbering.
- The square-set stoping method (Fig. 9) is used where the ore is weak, and the walls are not strong enough to support themselves.
- This is a highly specialized method of stoping requiring expert input.
- The value of the ore must be relatively high, for square-setting is slow, expensive, and requires highly skilled miners and supervisors.
- In square-set stoping, one small block of ore is removed and replaced by a ***"set" or cubic frame of timber which is immediately set into place.***
- The timber sets interlock and are filled with broken waste rock or sand fill, for they are not strong enough to support the stope walls.
- The waste rock or sand fill is usually added after one tier of sets, or stope cut, is made.
- Square-set timbers are set into place as support and are then filled with cement.
- The cement commonly uses fine tailings.
- Square-set stoping also involves backfilling mine voids; however, it relies mainly on timber sets to support the walls during mining.
- This mining method is still finds occasional use in mining high-grade ores or in countries where labour costs are low.

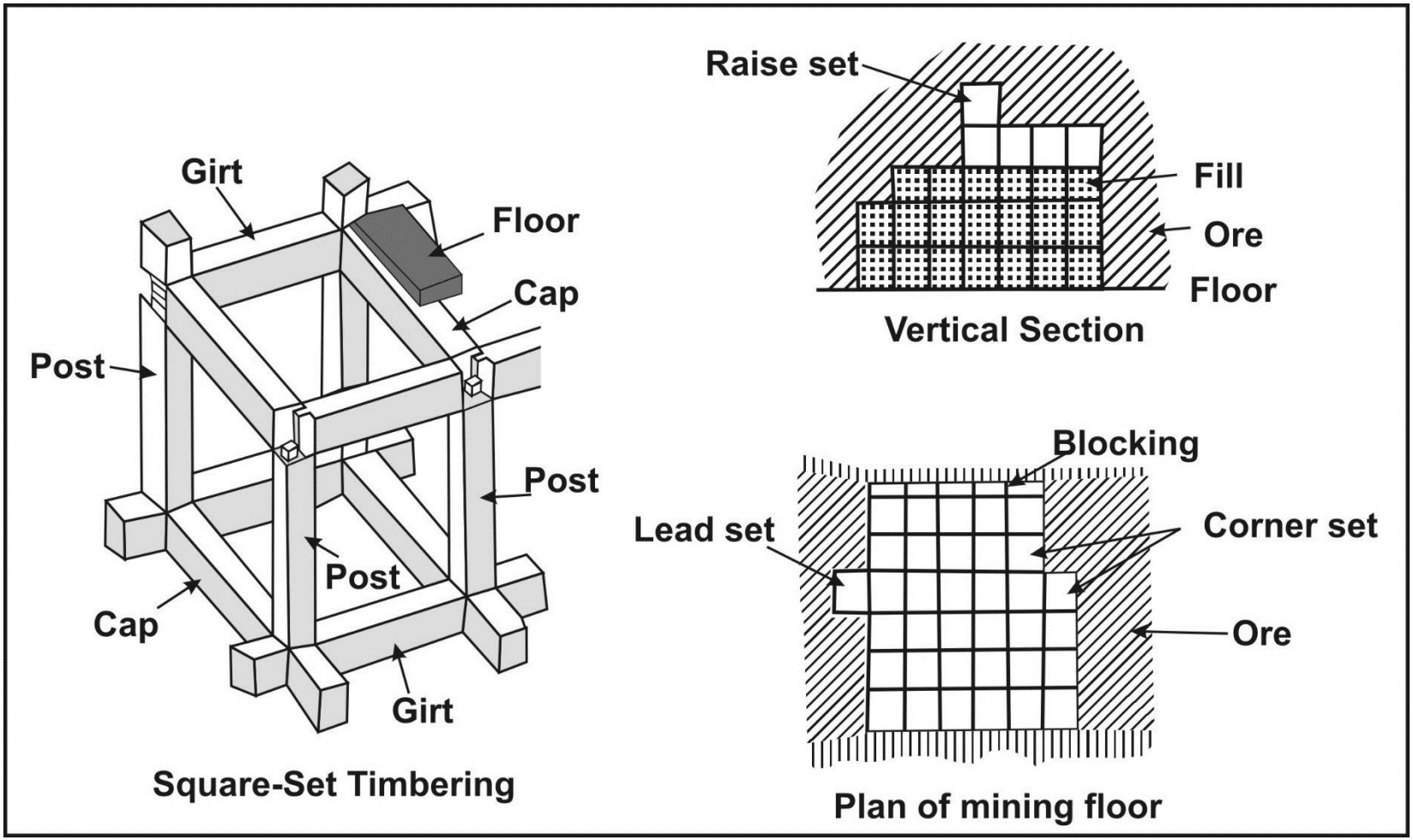


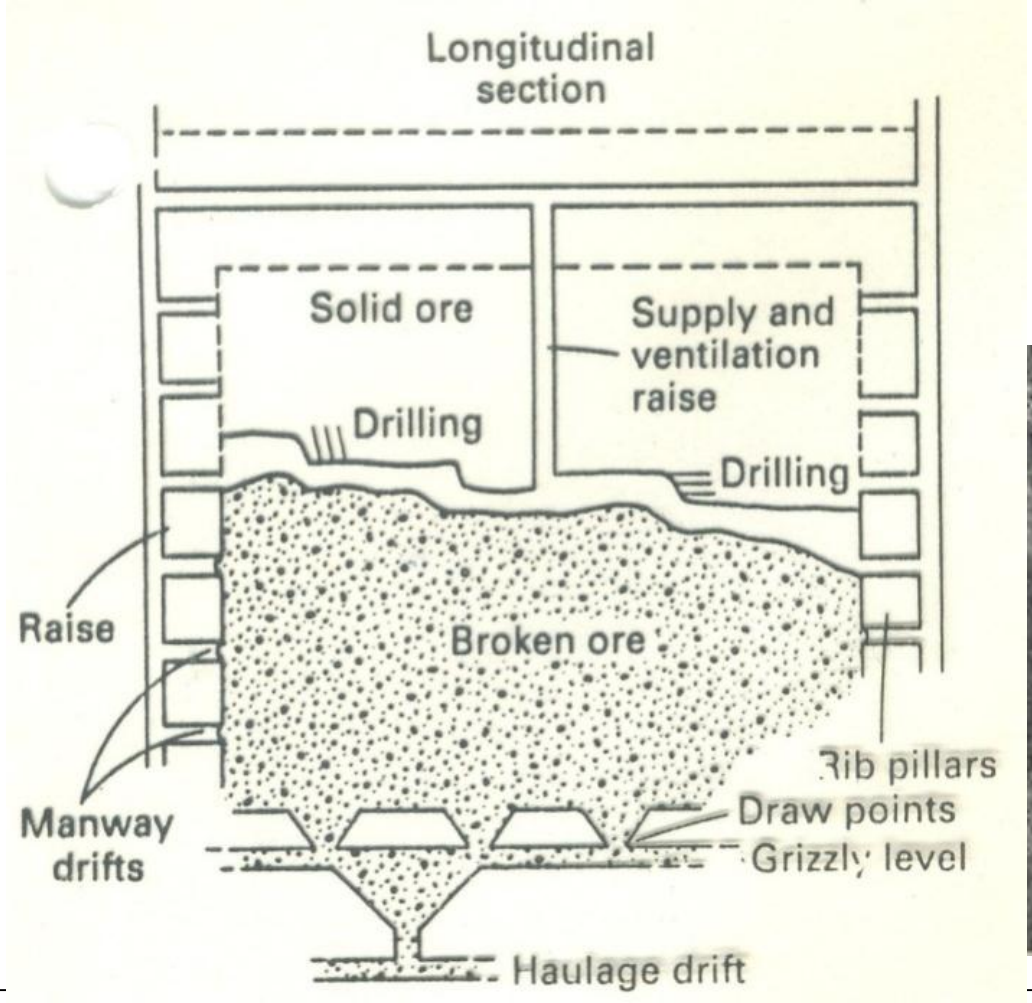
Figure 9: shows Square-set stoping

5) Shrinkage Stoping

Shrinkage stoping may be termed a "classic" mining method, having been perhaps the most popular mining method for most of the past century. It has largely been replaced by mechanized methods but is still used in many small mines around the world.

- Shrinkage stoping is a ***short-hole mining*** *method* which is most *suitable for* ***steeply dipping orebodies*** **(70°- 90°).**
- Also, the blasted ore must not be affected by storage in the slopes (e.g., sulfide ores have a tendency to oxidize and decompose when exposed to air).
- Its most prominent feature is the use of gravity flow for ore handling: *ore from stopes drops directly into rail cars via chutes obviating manual loading, traditionally the most common and least liked job in mining.*
- Mining progresses upward (*i.e., proceeds from the bottom upwards*), with horizontal slices (*similar to cut and fill mining*) of ore being blasted along the length of the stope. A portion of the broken ore is allowed to accumulate in the stope to provide a working plat form for the miners and is there after withdrawn from the stope through chutes.
- The method is ***similar*** to cut and fill mining with the *exception that after being blasted, broken ore is left in the stope where it is used to support the surrounding rock and as a platform from which to work.*
- Because blasted rock takes up a greater volume than in situ rock (*due to swell factor*), some of the blasted ore (~40%) must be removed to provide working space for the next ore slice.
- Only enough ore is removed from the stope to allow for drilling and blasting the next slice.
- Once the top of the stope is reached all the ore is removed from the stope.
- The stope is emptied when all of the ore has been blasted.
- The stope may be backfilled or left empty, depending on the rock conditions.[10]
- Although it is very selective and allows for low dilution, since the most of the ore stays in the stope until mining is completed there is a delayed return on capital investments.[3]
- Shrinkage stoping is more suitable than sublevel stoping for stronger ore and weaker wallrock.

5) Shrinkage Stoping (Cont.)



A large stope in the Treadwell gold mine, Alaska, USA 1908; an example of shrinkage stoping

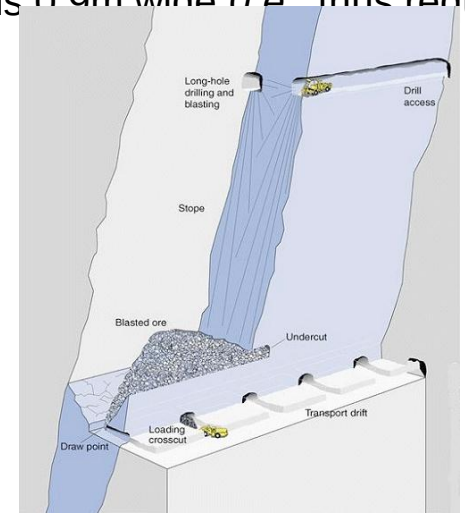
Note: *Sublevel stoping* differs from shrinkage stoping by providing sublevels from which vertical slices are blasted. In this manner, the stope is mined horizontally from one end to the other.

6) Long-hole Stoping

6.1) Introduction

Long-hole stoping as the name suggests *uses holes drilled by a production drill to a predetermined pattern as designed by a Mining Engineer*.

- Long-hole stoping is a ***highly selective and productive method*** of mining
- Long-hole stoping can cater for varying ore thicknesses and dips (0 - 90º).
- It differs from manual methods such as timbered and shrinkage as once the stope has begun blasting phase it cannot be accessed by personnel. For this reason the blasted dirt is designed to fall into a supported drawpoint or removed with Tele Remote Control LHD. The biggest limitation with this method is the length of holes that can be accurately drilled by the production drill, larger diameter holes using ITH (In the Hole Hammer) drills can be accurate to over 100m in length while floating boom top hammer rigs are limited to ~30m.
- Applied to loner (~100 m) and longer diameter blastholes
- Long-hole stoping blastholes can be as deep as 100 m, (Figure 6).
- Greater drilling accuracy is required.
- The drive is 2.5m wide and the stope is 0.9m wide (*i.e.*, thus requiring less drilling than sublevel stoping).
- Traditionally high production rates
- Large openings with long open times
- Bottom up mining method
- High ground support cost
- Uses some cement
- Not stress friendly
- Many equipment types



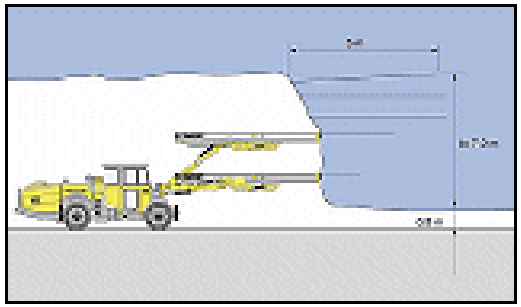


Fig.6: Long-hole stoping and removing ore after blasting.

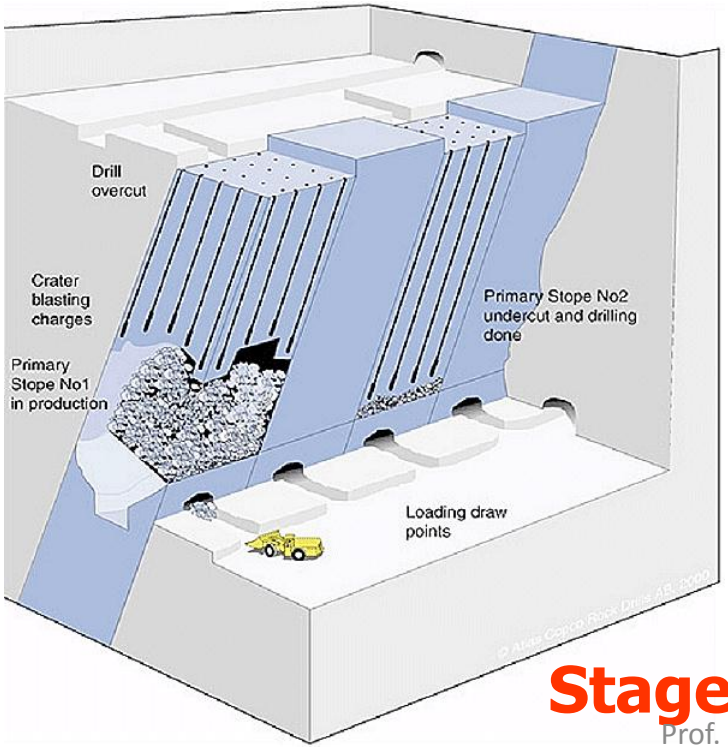
6) Long-hole Stoping (Cont.)

6.2) Slot - Initial Void

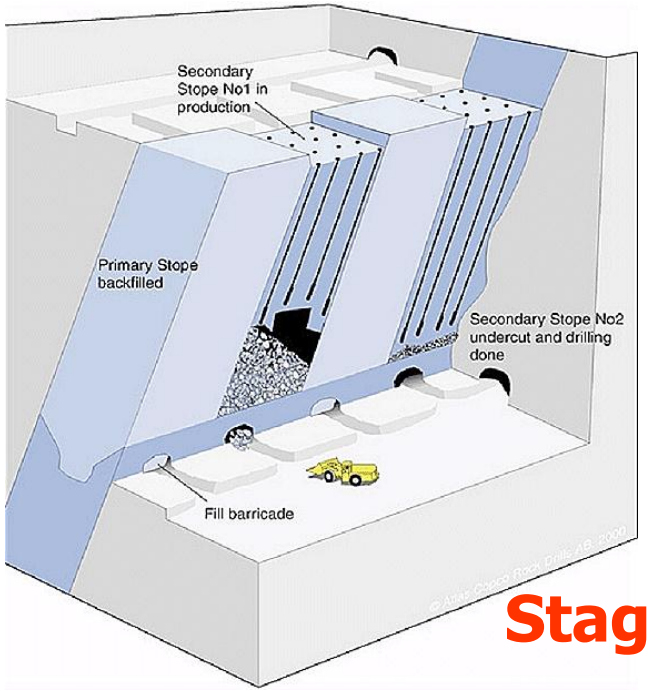
- Holes drilled underground are generally drilled perpendicular, in a radial pattern around the drive. For the blastholes to successfully extract the ore material they must be able to fire into a void in front.
- A slot is required in every stope to provide the initial void.
- The slot is often the most difficult, costly and highest risk component of mining a stope.
- Depending on the shape, height and other factors, different methods to create a slot can be used such as:
  - ***Raise bore***, a circular shaft mined bottom up using mechanical rollers to achieve shaft profile. This method works well in larger stopes however requires both access to top and bottom of stoping block, raise bore's work most effectively between 45^{o} and 90^{o}.
  - ***Longhole rise***, a pattern of tightly spaced blastholes and reamers (empty holes with no charge), similar to a burn cut in a development round. Can be done as downhole and fired in multiple lifts (15m rise in 3 lifts of 5m to minimise chance of blast failing) or as uphole in one single firing. This method works well for shorter raises between 45^{o} - 90^{o}, however is prone to freezing and remedial drilling is possibly required to extract slot to full height.
  - ***Airleg Raise***, using an airleg (jackleg) machine to develop a sub vertical raise into the stoping block. This method has the advantage of giving geological and geotechnical teams further analysis of the stoping block prior to mining.
  - ***Boxhole Boring***, similar to raise boring however less productive as broken material is extracted from the same location as the drill, is used to bore vertically with no top level access required.

7) Vertical Crater Retreat (VCR) Stoping

- **Vertical longholes are drilled** from drives developed in the ore between two levels.
- **Ore is then blasted** using a charge that occupies a relatively short length of the hole, some distance from the bottom face.
- The method has a **low explosive consumption**.
- The blast creates downward facing craters and the broken ore is drawn from the stope at the lower level.
- **The stope is then backfilled**.



Stage 1



Stage 2

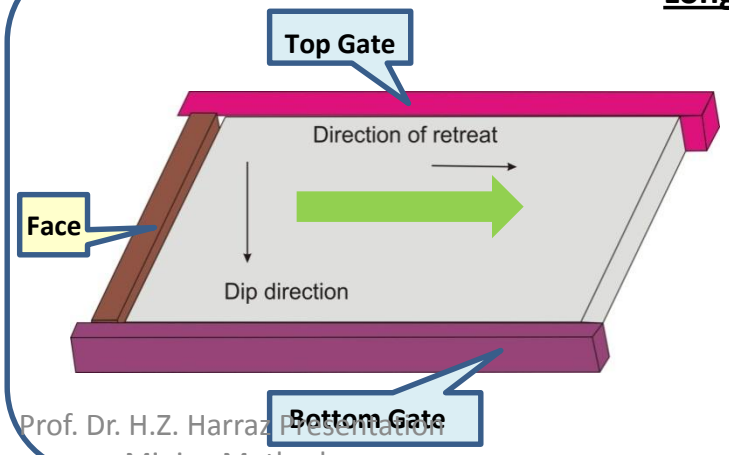
7) Vertical Crater Retreat (VCR) Stoping (Cont.)

- Vertical Long-holes are drilled from drives developed in the ore between two levels.
- Ore is then blasted using a charge that occupies a relatively short length of the hole, some distance from the bottom face.
- The blast creates downward facing craters and the broken ore is drawn from the stope at the lower level.
- The stope is then backfilled.
- The method has a low explosive consumption.
- It uses a different blasting technique breaking the rock with heavy, concentrated charges placed in holes ("craters") with very large diameter (~165 mm) about 3 m away from a free rock surface.
- Blasting breaks a cone-shaped opening in the rock mass around the hole and allows the blasted material to remain in the stope during the production phase so that the rock fill can assist in supporting the stope walls.
- The need for rock stability is less than in sublevel stoping.
- VCR stoping is applicable to mineralization in steeply dipping strata.
- The development for VCR mining is requiring both over-cut and under-cut excavations.
- The ***over-cut is needed in the first stage*** to accommodate the rig drilling the large-diameter (~165 mm) blast holes and for access while charging the holes and blasting.
- The *under-cut excavation* provided the free surface necessary for VCR blasting.
- It may also provide access for a LHD vehicle (operated by remote control with the operator remaining outside the stope) to recover the blasted ore from the draw-points beneath the stope.
- The usual VCR blast uses holes in a 4 m x 4 m pattern directed vertically or steeply inclined with charges carefully placed at calculated distances to free the surface beneath.
- The charges cooperate to break off a horizontal ore slice ~3 m thick.
- The blasted rock falls into the stope underneath.
- By controlling the rate of mucking out, the stope remains partly filled so that the rock fill assists in stabilizing the stope walls during the production phase.
- The last blast breaks the over-cut into the stope, after which the stope is mucked clean and prepared for back filling.
- VCR mines often uses a system of primary and secondary stopes to the orebody.
- Primary stopes are mined in the first stage, then backfilled with cemented fill.
- The stope is left for the fill to consolidate.
- Miners then return and recover the ore in the pillars between the primary stopes, the secondary stopes.
- This system, in combination with the cemented backfill, results in close to a 100% recovery of the ore reserves.

8) Longwall Stoping

- Longwall stoping is applicable to bedded deposits of uniform shape, limited thickness and large horizontal extension (*e.g., a coal seam, a potash layer or the reef, the bed of quartz pebbles exploited by gold mines in South Africa*).
- It is a caving method particularly well adapted to relatively flat-lying, thin, planar deposits or horizontal seams, usually ***coal,*** at some depth.
- It is suitable *for tabular orebodies, with moderate dip* (e.g., coal and stratiform hard-rock ores like diamond deposits).
- It is one of the main methods for mining coal. It recovers the mineral in slices along a straight line that are repeated to recover materials over a larger area.
- Need to divide orebody to "face" or the "working face".
- The collection of cuts, cross-cuts, and pillars all together make up a "panel" and all the equipment that goes together to operate in that panel is a "unit or Longwall units".
- In this method, a face of considerable length (a long face or wall) is maintained, and as the mining progresses, the overlying strata are caved, thus promoting the breakage of the coal itself.
- Applied to longer (~100 m) and longer diameter blastholes (i.e., *thus requiring less drilling than sublevel stoping*).
- Greater drilling accuracy is required.
- Need to a ***longwall machine*** (*It's designed to let the roof fall behind it, and mines out big rooms in which the roof almost immediately collapses, leaving only a small entryway and the metal barrier that protects the longwall unit*).
- The space closest to the face in kept open while the hanging wall is allowed to collapse at a safe distance behind the miners and their equipment.
- Preparation for longwall mining involves the network of drifts required for access to the mining area and transport of the mined product to the shaft. Since the mineralization is in the form of a sheet that extends over a wide area, the drifts can usually be arranged in a schematic network pattern. The haulage drifts are prepared in the seam itself. The distance between two adjacent haulage drifts determines the length of the longwall face.
- Continuous miner operations, and longwall units.
- Traditionally high production rates.
- Large openings with long open times.
- High ground support cost .
- *Bottom up mining method.*
- *Non-selective mining*.
- Not stress friendly.
- Many equipment types.

Longwall General Layout



Longwall mining method includes drivage of two long roadways in coal and joining them at the end by a perpendicular drivage forming a face.

- Longwall (subsurface mining)

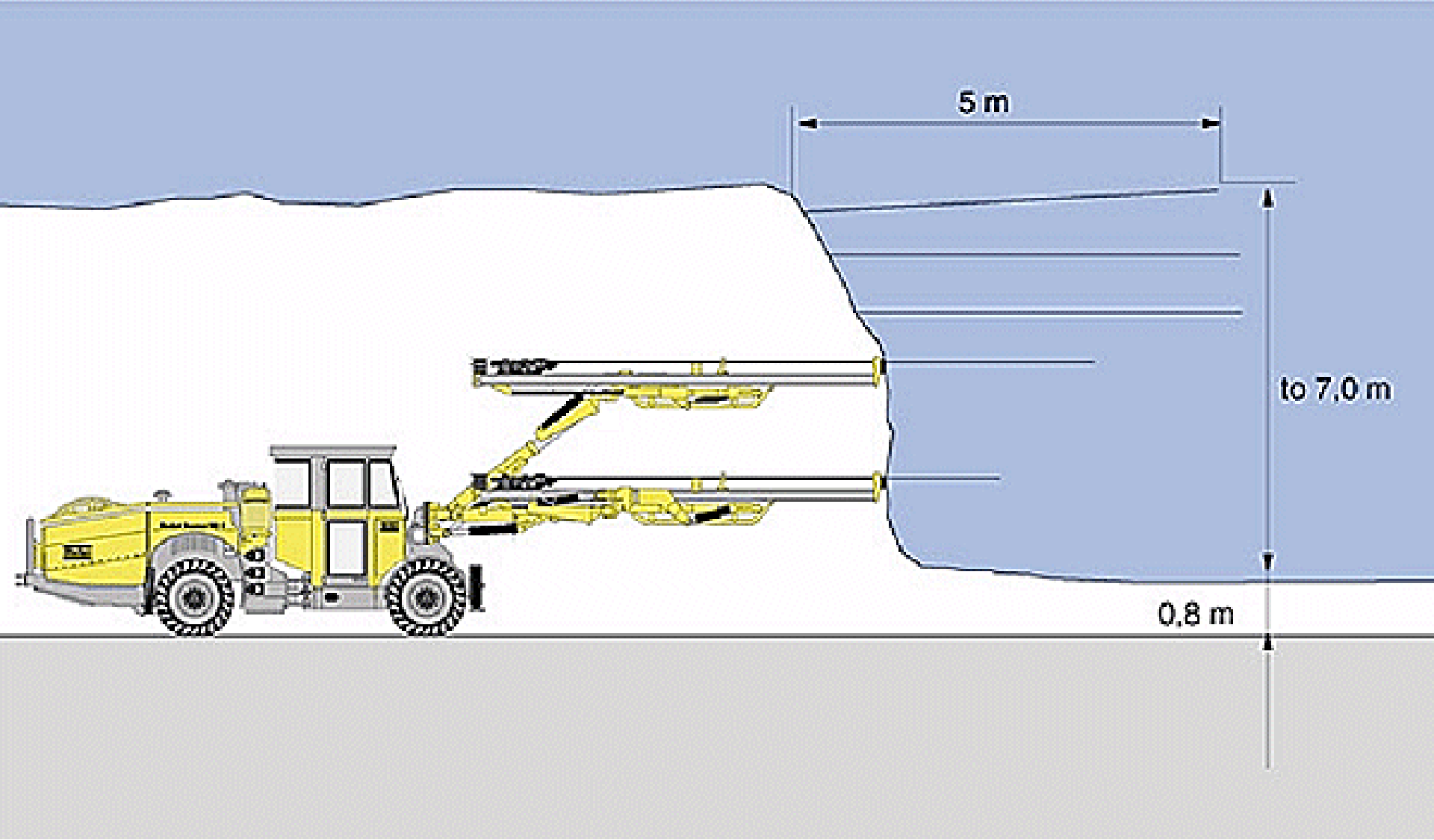


Figure shows "Slim-size" machines including drill rigs, jumbos, and 2 m^3 bucket **LHDs**, are available for working in drifts as narrow as 2 m.

Longwall Mining

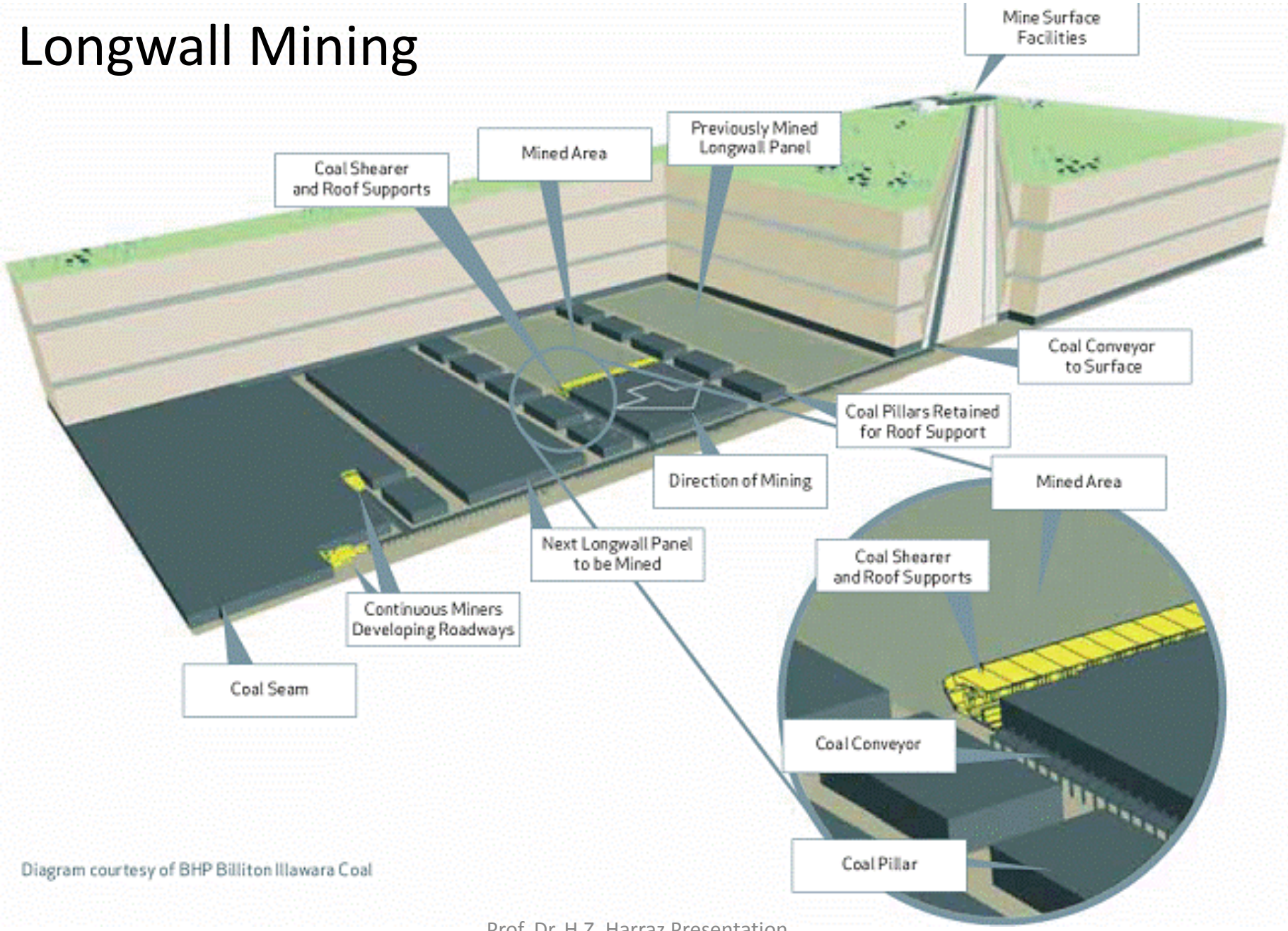
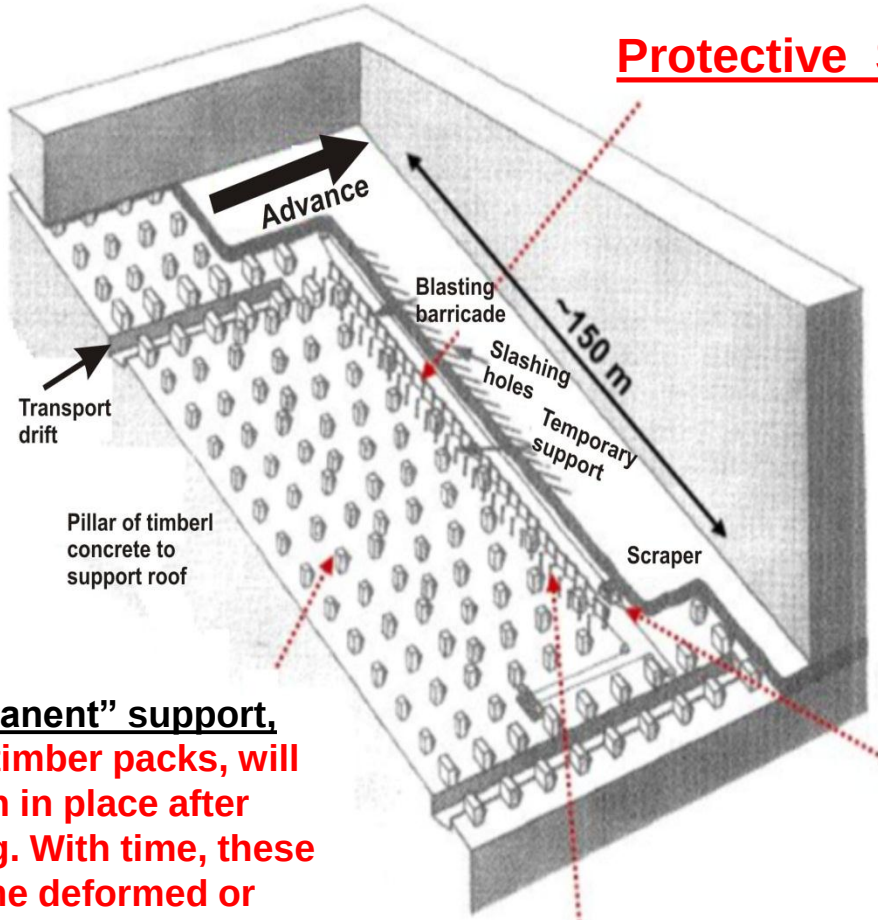


Diagram courtesy of BHP Billiton Illawara Coal

Schematic of Longwall Panel
(Hangingwall Stripped Away For Illustrative Purposes)



"Permanent" support, often timber packs, will remain in place after mining. With time, these become deformed or completely crushed –as part of the "controlled" closure of the panel.

Temporary support near the working face: often hydraulic props.

In hard-rock minerals mining a "*scraper*" is pulled down the length of the stope face after drilling and blasting, to collect the fragmented ore rock.

In coal mining, a mechanized cutting device is run along the length of the coal face.

Figure from Hartman and Mutmansky, 2002.

Example: Longwall Mining of Coal

- Longwall mining is a highly mechanized underground mining system for mining coal.
- It set of longwall mining equipment consists of a coal shearer mounted on conveyor operating underneath a series of self-advancing hydraulic roof supports.
- Almost the entire process can be automated.
- **Longwall mining machines are typically 150-250 meters in width and 1.5 to 3 meters high**.
- Longwall miners extract "***panels***" - rectangular blocks of coal as wide as the face the equipment is installed in, and as long as several kilometers.
- A layer of coal is selected and blocked out into an area known as a ***panel*** **(A typical panel might be 3000 m long X 250 m wide).**
- ***Passageways*** would be excavated along the length of the panel to provide access and to place a conveying system to transport material out of the mine.
- Entry tunnels would be constructed from the passageways along the width of the panel.
- **Extraction is an almost continuous operation involving the use of:** self-advancing hydraulic roof supports sometimes called ***shields***, ***a shearing machine***, and *a* ***conveyor which runs parallel to the face being mined***.
- Powerful mechanical coal cutters (***Shearers***) cut coal from the face, which falls onto an armoured face conveyor for removal.
- The longwall system would mine between entry tunnels.
- Longwalls can ***advance*** *into an area of coal, or more commonly, retreat back between development tunnels* (called "***Gate roads***")
- As a longwall miner ***retreats back along a panel****, the roof behind the supports is allowed to collapse in a planned and controlled manner.*

Longwall Mining Machine

It's *designed* to let the roof fall behind it, and mines out big rooms in which the roof almost immediately collapses, leaving only a small entryway and the metal barrier that protects the longwall unit.

http://upload.wikimedia.org/wikipedia/commons/thumb/5/5d/Schildausbau.jpg/220px-Schildausbau.jpg

Figure shows Hydraulic chocks

Figure shows Hydraulic chocks, conveyor and shearer

http://upload.wikimedia.org/wikipedia/commons/thumb/9/91/Longwall_with_hydraulic_chocks%2C_conveyor_and_shearer.jpg/220px-Longwall_with_hydraulic_chocks%2C_conveyor_and_shearer.jpg

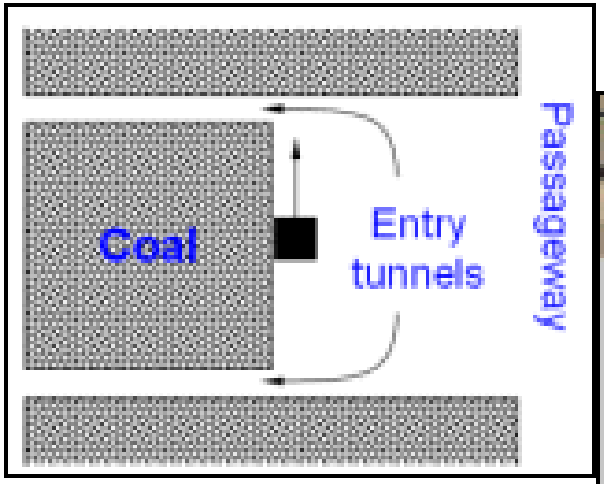


Fig 12a: Passageway

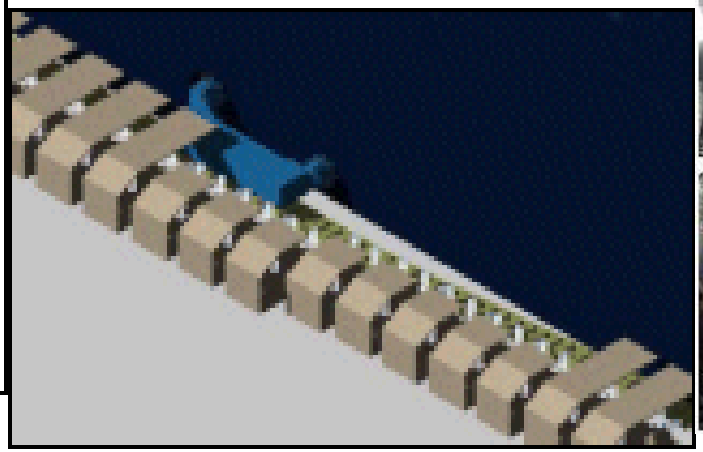


Figure 12b: A typical panel is 3000 m long by 250 m wide

Figure 12c: Longwall system in place.

Mechanized cutting machineon a longwall coal-mining face.

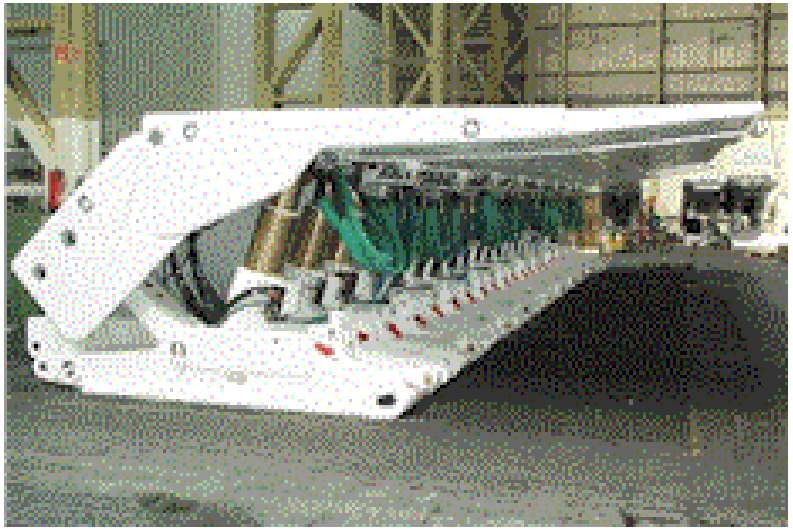
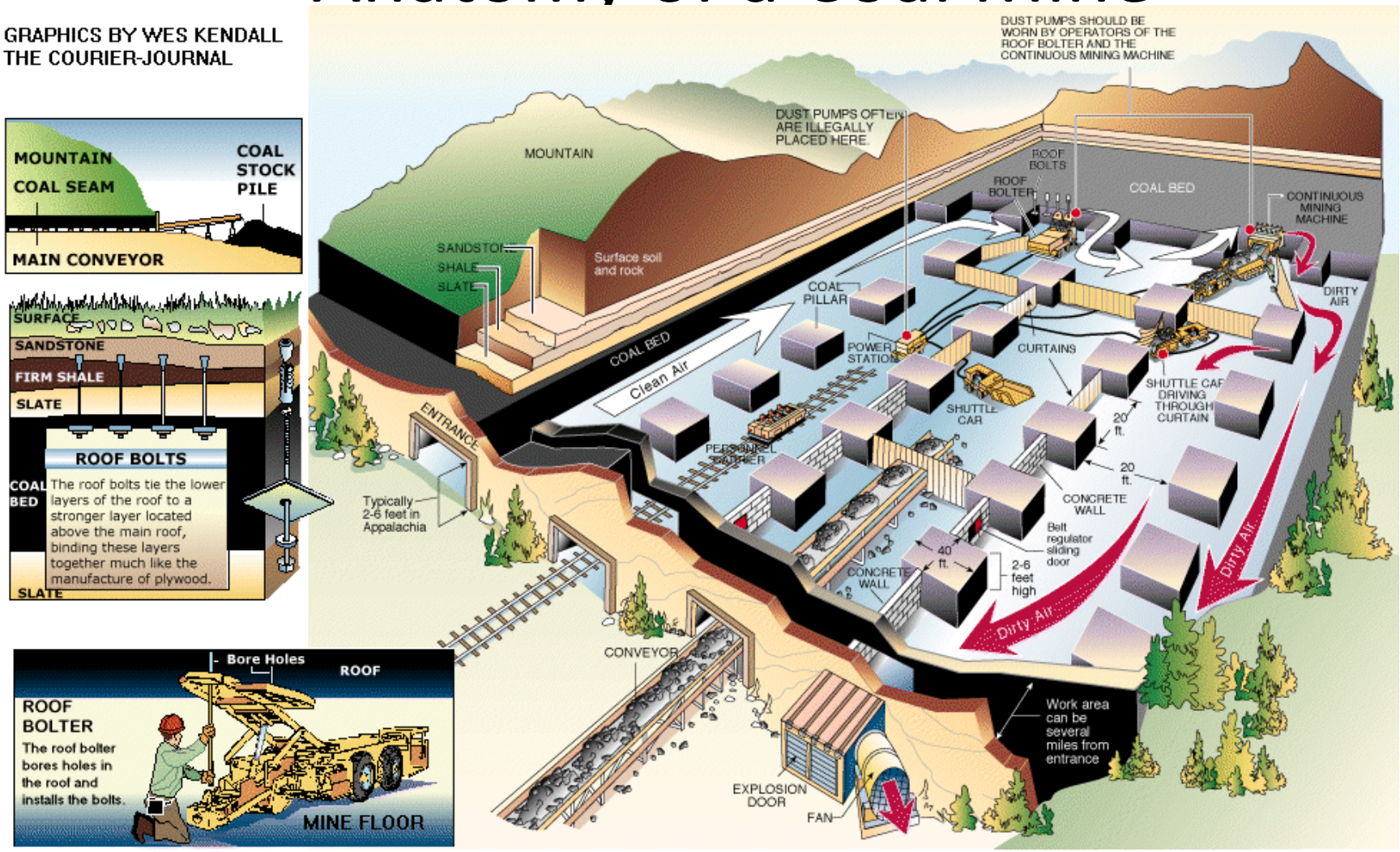


Figure shows another continuous miner in an underground coal mine.

Anatomy of a Coal Mine



Pennsylvania Department of Environmental Protection
Bureau of Deep Mine Safety

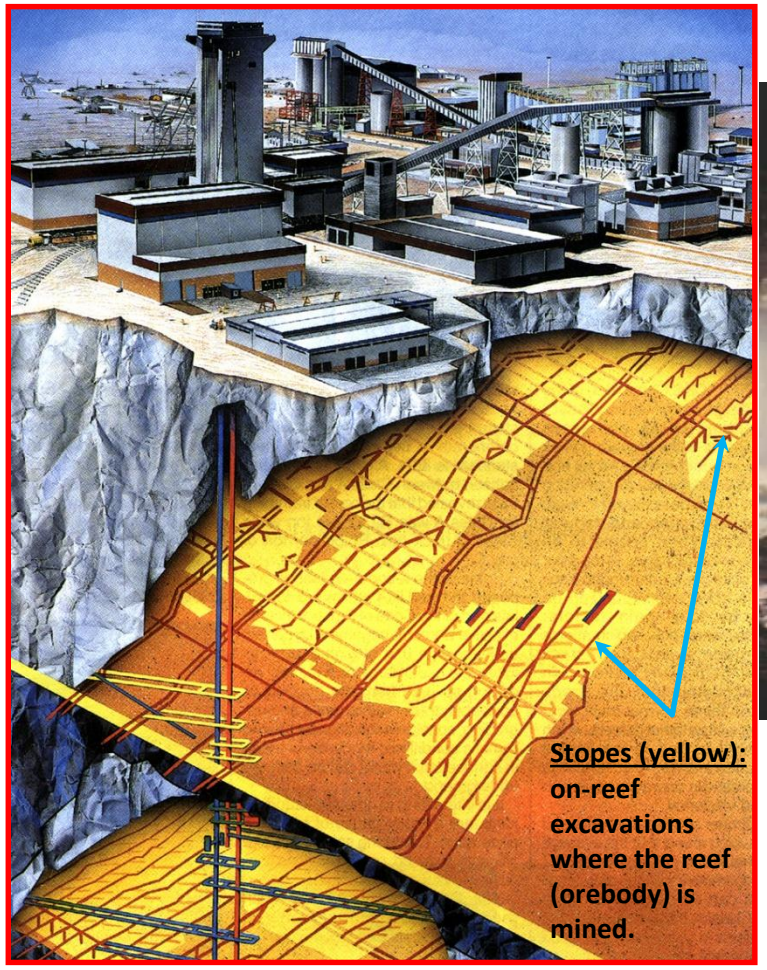
Coal Mine

Then → And Now

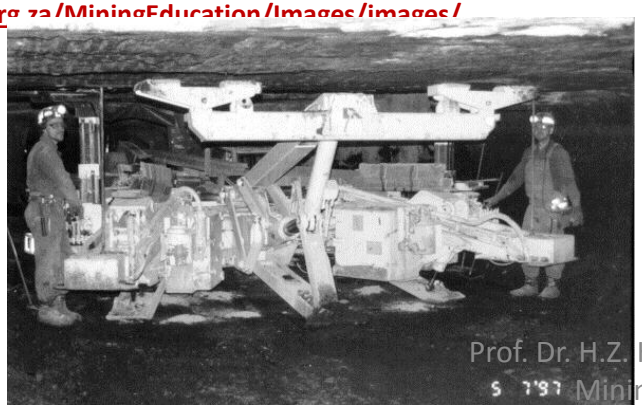
Pennsylvania Department of Environmental Protection
Bureau of Deep Mine Safety

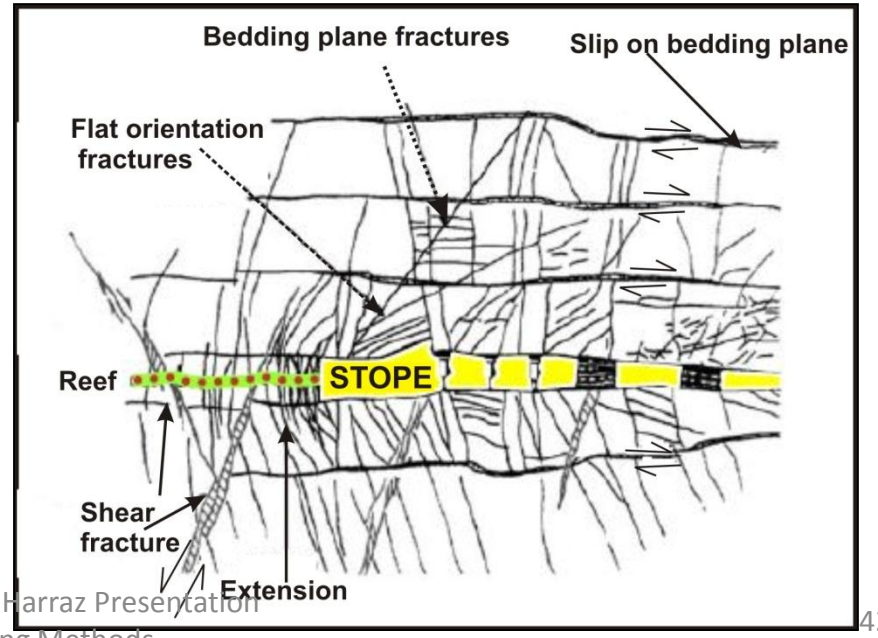
Mechanized cutting machine on a longwall coal-mining face:
Shearer Working at Longwall Face.

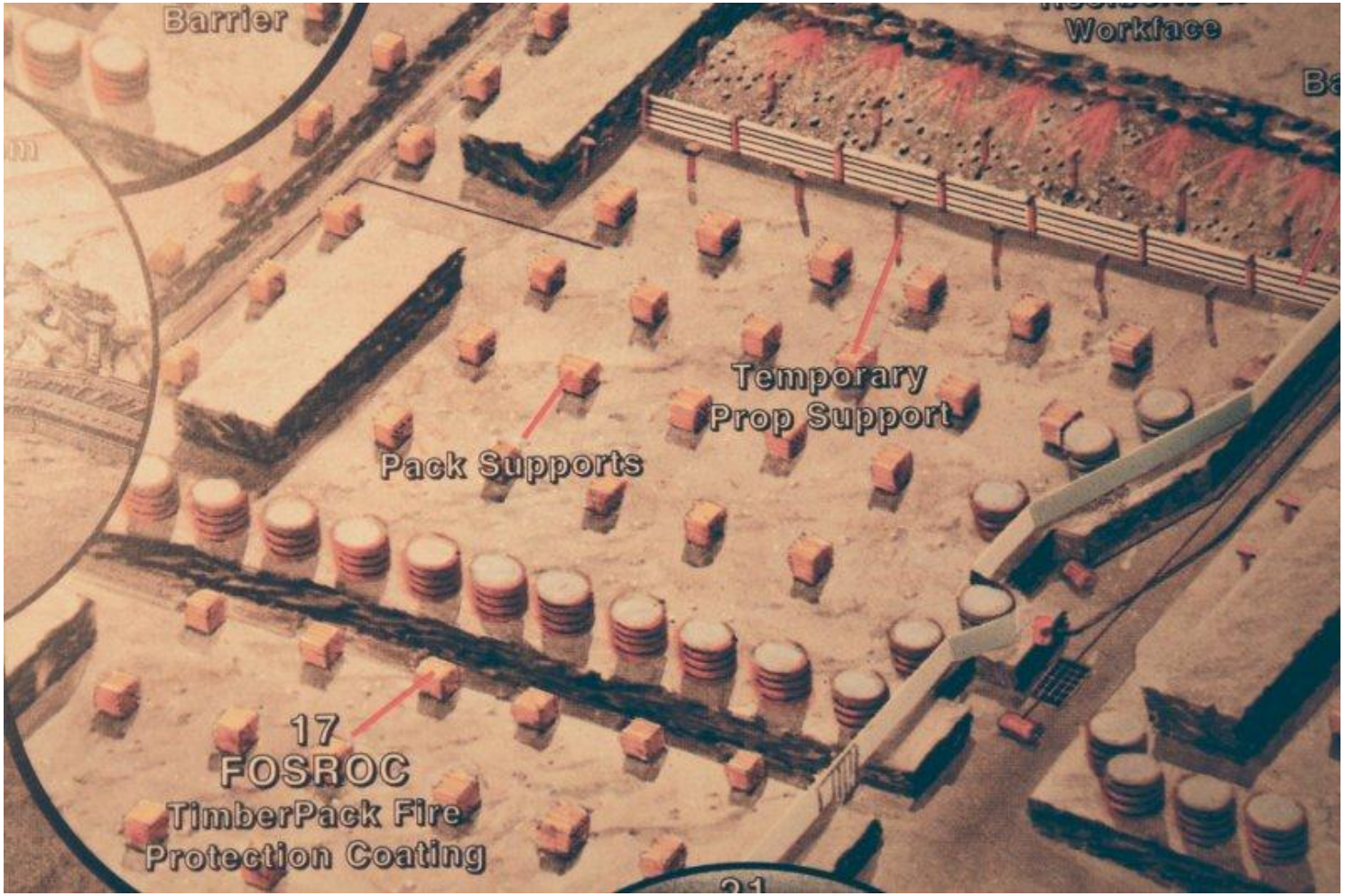
Deep level gold mining, South Africa



http://www.bullion.org.za/MiningEducation/Images/images/CrossSectMine.jpg







Work Face at South African Gold Mine

9) Caving Mining Methods:

Caving *(i.e., Sublevel and Block) mining* methods are varied and versatile and involve caving the ore and/or the overlying rock. Subsidence of the surface normally occurs afterward.

Caving methods are varied and involve caving the ore and/or the overlying rock.

Caving mining is advantageous in that it ***maximizes ore recovery*** (as little ore as possible is left behind) the method comes with ***significant problems***:

- Surface subsidence in the case of shallow mines.
- Rock-bursts underground, causing injury and death in deep level mines

Subsidence of the surface normally occurs afterward

Figure shows Continued mining results in subsidence of the surface, causing sink holes to appear.

Ultimately, the ground surface on top of the orebody subsides.

Rockbursts underground, causing injury and death in deep level mines.

After math of a rockburst in a deep-level tunnel showing complete tunnel closure. The energy released by this event is ***equivalent to magnitude M = 3.4 earthquake***.

9.1) Sublevel Caving

- It is used to mine large orebodies with steep dip tabular or massive deposit and continuation at depth (Fig.17).
- The ore is extracted via sublevels which are developed in the orebody at regular vertical spacing.
- Each sublevel has a systematic layout of parallel drifts, along or across the orebody.
- **Sublevel stoping** recovers the ore from open stopes separated by access drifts each connected to a ramp.
- The orebody is divided into sections about 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 above. The bottom is V-shaped to funnel the blasted material into the draw-points.
- *Short blastholes are drilled from the access drifts in a ring configuration*. The ore in the stope is blasted, collected in the draw-points, and hauled away.
- Blasting on each sublevel *starts at the hangingwall and mining then proceeds toward the footwall*.
- **Blasting removes support for the hangingwall, *which collapses into the drift.***
- As mining progresses *downward,* each new level is caved into the mine openings, with the ore materials being recovered while the rock remains behind.
- Loading continues until it is decided that waste dilution is too high → *Work then begins on a nearby drift heading with a fresh cave*.
- As mining removes rock ***without backfilling***, *the hangingwall keeps caving into the void.* Continued mining results in subsidence of the surface, ***causing sink holes to appear.*** Ultimately, the ground surface on top of the orebody subsides (Fig.18).
- However, the stopes are ***normally backfilled*** with consolidated mill tailings after being mined out (*This allows for recovery of the pillars of unmined ore between the stopes, enabling a very high recovery of the orebody*).

Sublevel Stoping

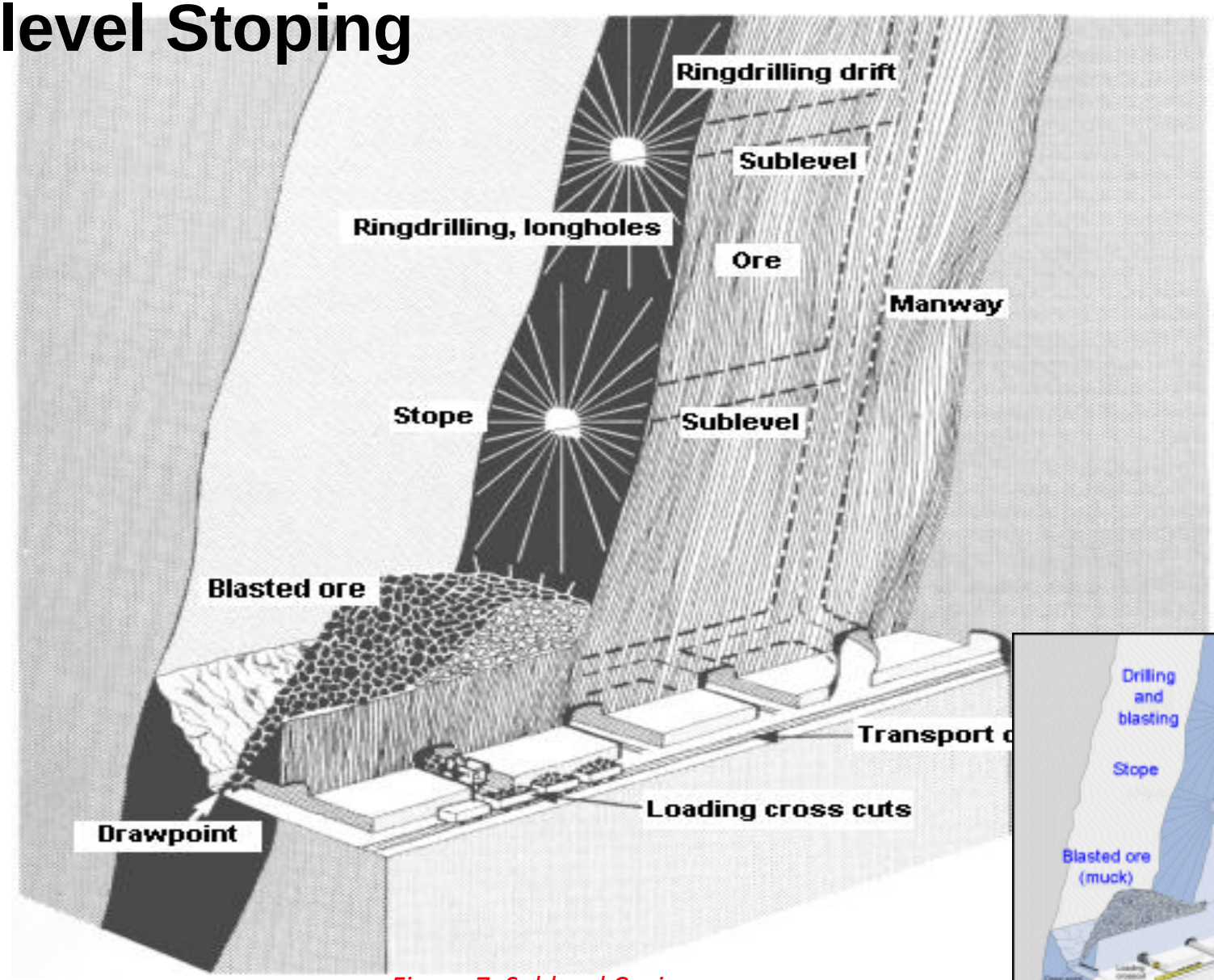


Figure 7: Sublevel Caving

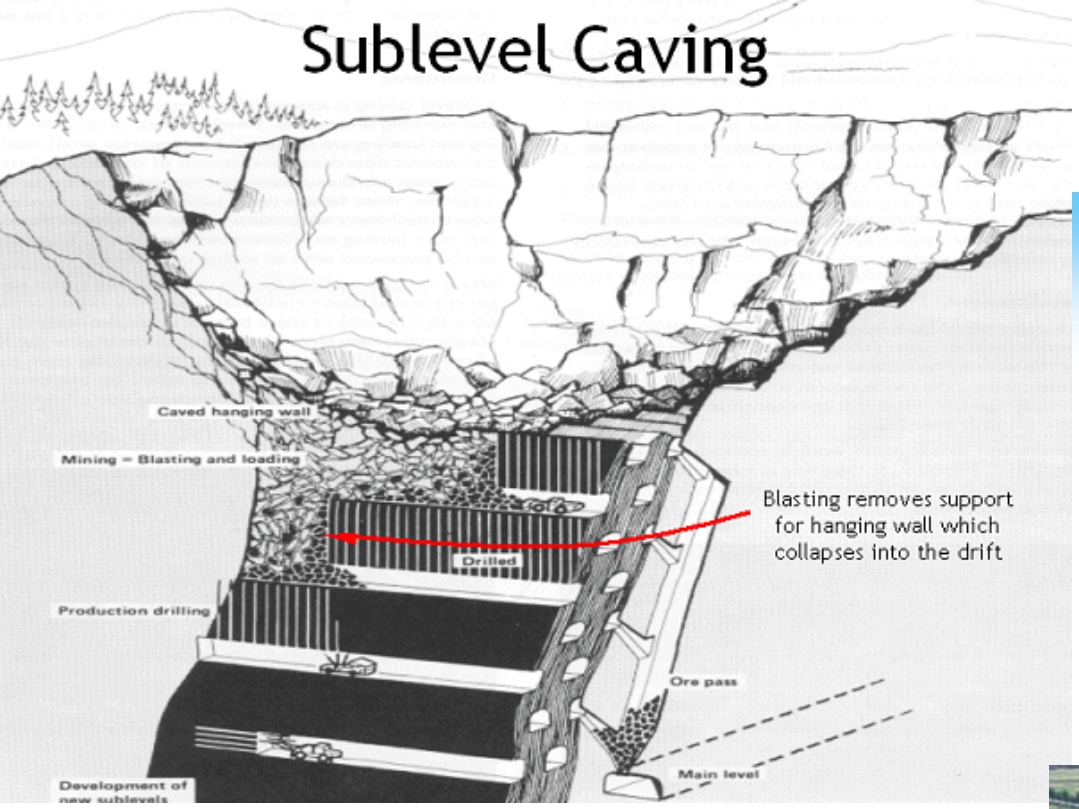


Figure shows sublevel caving is used to mine large orebodies with steep dip and continuation at depth.

Figure shows Continued mining results in subsidence of the surface, causing sink holes to appear.

Ultimately, the ground surface on top of the orebody subsides.

9.2) Block Caving

- Block-caving method ***is employed generally for steeply dipping ores, and thick sub-horizontal seams of ore.*** The method has application, for example in sulfide deposits and underground kimberlite (diamond) mining.
- It is most applicable to :-
    - A large-scale or bulk mining method that is highly productive, low in cost, and used primarily on massive steeply dipping orebodies that must be mined underground.
    - Weak or moderately strong orebodies that readily break up when caved.
    - Large, deep (>2 km deep), low-grade deposits with high friability (Fig.19).
- It is often done to continue mining *after open pit mining becomes uneconomic or impossible*. However, some mines start as block cave operations (e.g., *There are several of these in Chile. Rio Tinto is considering a deep at the Resolution deposit to the east of Phoenix).*
- A grid of tunnels is driven under the orebody ⟶ ***The rock mass is then undercut by blasting***.
- Ideally the rock will break under its own weight ⟶ Broken ore is then taken from draw points.
- There may be hundreds of draw points in a large block cave operation (Fig.20).

- An ***undercut with haulage access is driven under the orebody***, with "***drawbells***" excavated between the top of the haulage level and the bottom of the undercut. *The drawbells serve as a place for caving rock to fall into.*
- The orebody is drilled and blasted *above* the undercut, and the ore is removed via the haulage access.
- Due to the friability of the orebody the ore above the first blast caves and falls into the drawbells. As ore is removed from the drawbells *the orebody caves in providing a steady stream of ore*[3].
- If caving stops and removal of ore from the drawbells continues, *a large void may form*, *resulting in the potential for a sudden and massive collapse and potentially catastrophic windblast throughout the mine*.[4]
- Where caving does continue, the ground surface may collapse into a surface depression (such as those at the Climax and Henderson molybdenum mines in Colorado. Such a configuration is one of several to which miners apply the term "***glory hole***").
- Orebodies that do not cave readily are sometimes preconditioned by *hydraulic fracturing, blasting, or by a combination of both*. Hydraulic fracturing has been applied to preconditioning strong roof rock over coal longwall panels, and to inducing caving in both coal and hard rock mines.
- Essentially block caving creates an underground *'inverted open pit'*. **Surface subsidence can be a problem….???.**

Figure shows application of the Block caving to large, deep, low-grade deposits

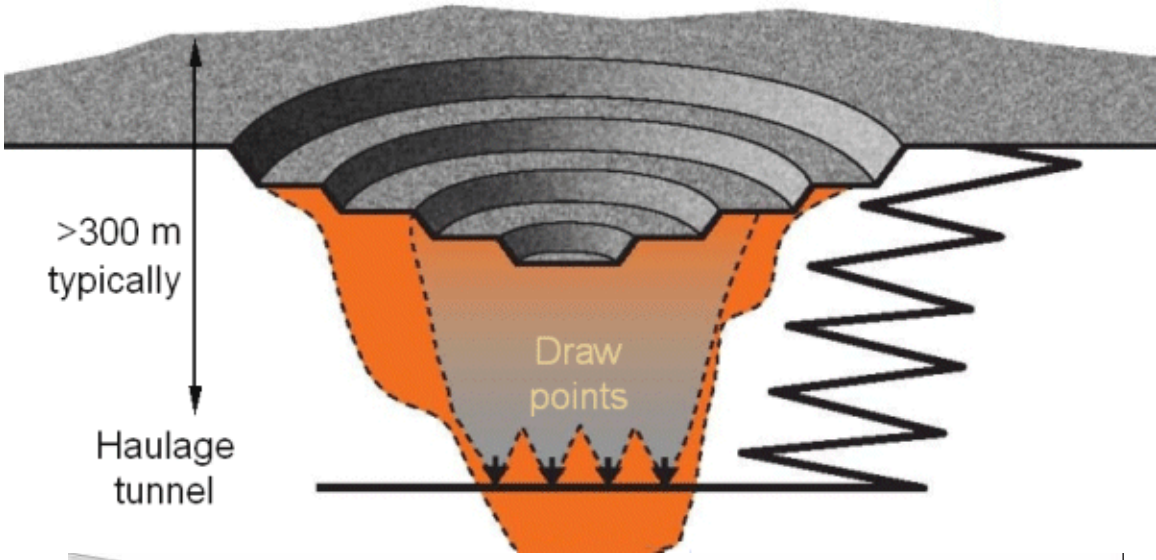


Figure shows hundreds of draw points to take broken ore in a large block cave operation

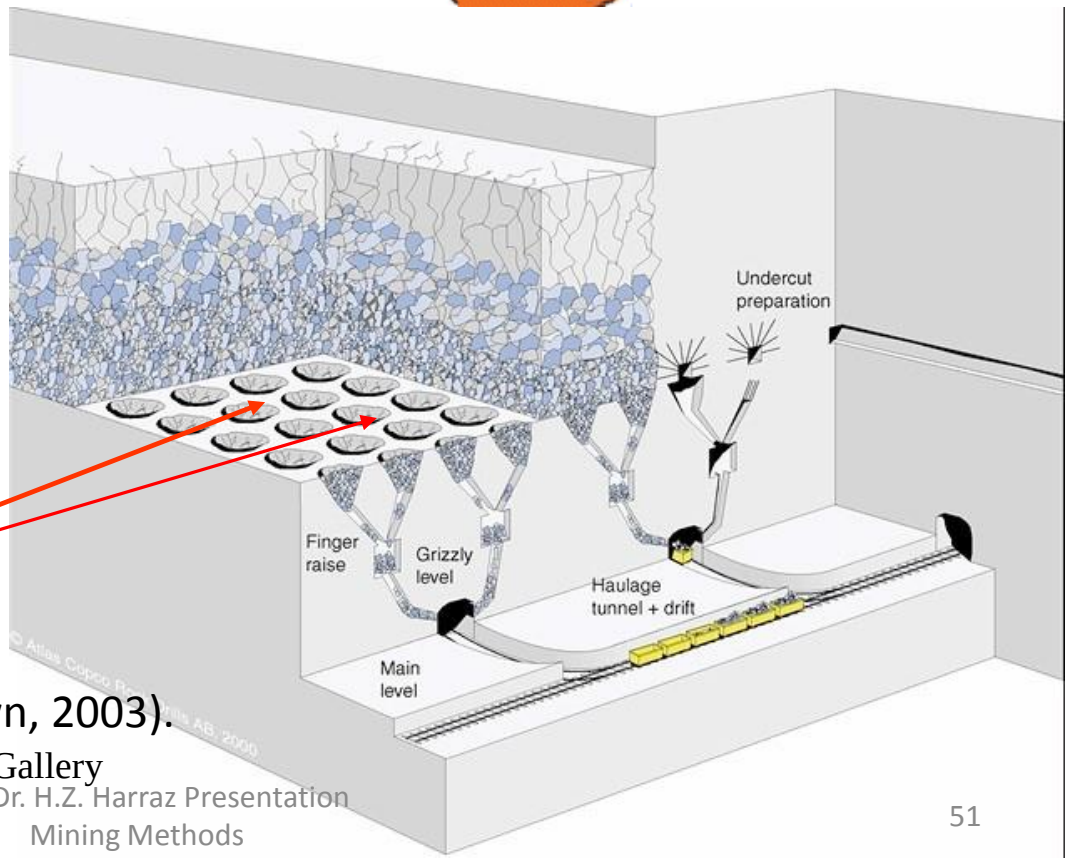


Figure: Models of block caving (Brown, 2003).

www.ivanhoe-mines.com/s/Mongolia_ImageGallery

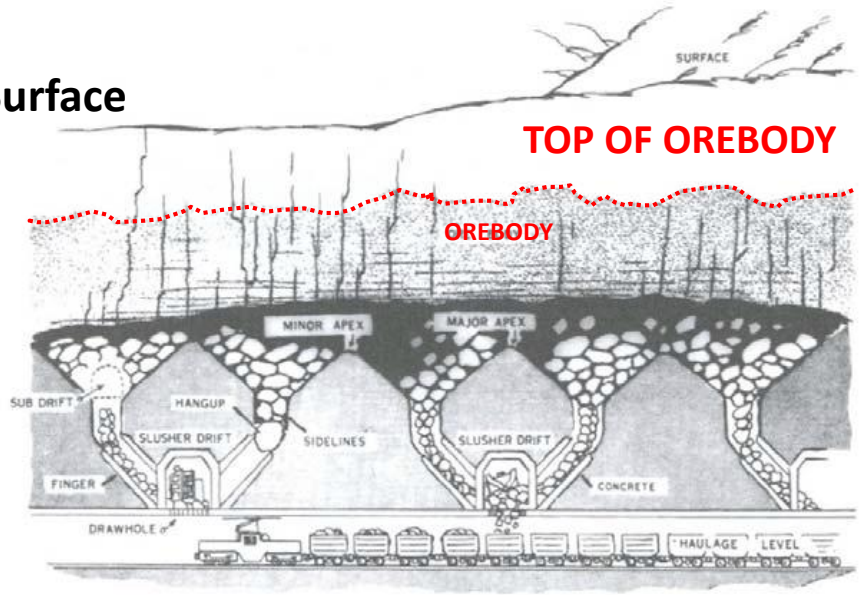
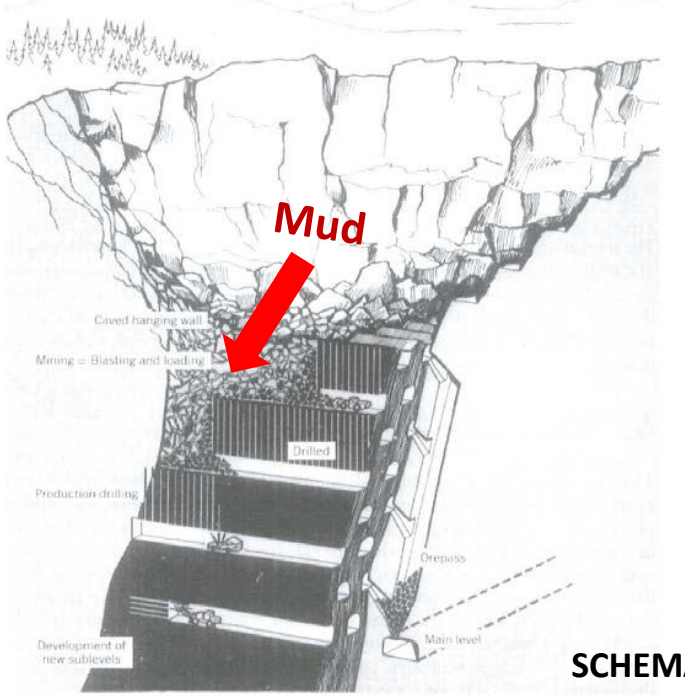


Figure from Hartman and Mutmansky, 2002.

An undercut tunnel is driven under the orebody, with ***"drawbells"*** excavated above. Caving rock falls into the drawbells. The orebody is drilled and blasted above the undercut to initiate the "caving" process. As ore is continuously removed from the drawbells, ***the orebody continues to cave spontaneously***, providing a steady stream of ore. If spontaneous caving stops, and removal of ore from the drawbells continues, a large void may form, resulting in the ***potential for a sudden and massive collapse and a potentially catastrophic windblast throughout the mine*** (***e.g., the Northparks Mine disaster, Australia***).

Block-cave mining: Mud-rushes –an under-reported hazard

Mud-rushes are sudden inflows of mud from ore drawpoints (or other underground openings), in block-cave mines that are ***open to the surface***. ***Considerable violence, in the form of an airblast, is often associated with mud-rushes***. Mud-rushes are (under-reported) hazardous occurrences that have occurred frequently in mines in South Africa, as well as in Chile and Western Australia, and have caused fatalities (Butcher *et al*., 2005).



Mud is produced by the breakdown of rock in the near-surface muckpile in the presence of rainwater.

Kimberlite rock on diamond mines is particularly susceptible to weathering by rainwater.

SCHEMATIC CUT-AWAY VIEW OF SUB-LEVEL BLOCK-CAVE MINE

Figure from Hartman and Mutmansky, 2002.

Effect of Mineral extraction upon displacement of country rock and surface

Workings and voids formed after extraction of mineral gets filled with time by the caving rock so that the rock over the deposit may deformed and subside.

This phenomenon is called "***Displacement of rock***". Displacement causes smooth subsidence of the earth's surface without ruptures, or abrupt subsidence with considerable movements, caving and collapses.

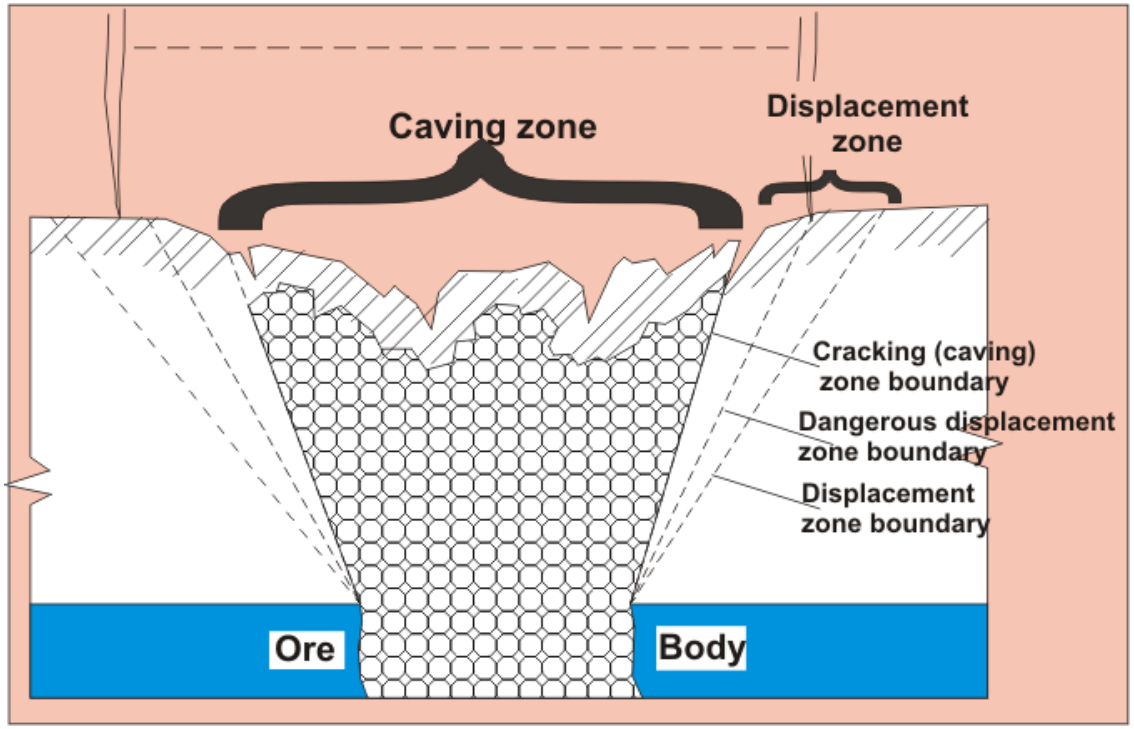


Figure shows Effect of Mineral extraction upon displacement of country rock and surface as well as rock displacement in mining.

The rock displacement zone include:- "***a caving zone***" within which the displacement is accompanied by the fault and destruction of layers and the separation of lumps and blocks from the solid;
"***a cracking zone***" which is an area of rock discontinuity and cracks;
"***a smooth-displacement zone***" wherein rock features plastics deformation without discontinuities.

The earth's surface area which experienced displacement is called a "***trough***".

Stope and Retreat vs. Stope and Fill

Retreat

- Retreat is a term used to *reference the final phase of an underground mining technique*.
- This involves excavating supporting pillars
- Once a deposit has been exhausted using this method, the pillars that were left behind initially are removed (or **'pulled')** retreating back towards the mine's entrance.
- After the pillars are removed, the roof (or back) is allowed to *collapse behind the mining area.*
- Pillar removal must occur in a very precise order in order to *reduce the risks to workers, due to the high stresses placed on the remaining pillars by the abutment stresses of the caving ground.*

Stope and Retreat	***Stope and Fill***
➢ Using this method, mining is planned to extract rock from the stopes without filling the voids; this allows the wall rocks to cave in to the extracted stope after all the ore has been removed. ➢ The stope is then sealed to prevent access.	➢ Where large bulk ore bodies are to be mined at great depth, or where leaving pillars of ore is uneconomical, the open stope is filled with backfill, which can be a cement and rock mixture, a cement and sand mixture or a cement and tailings mixture. ➢ This method is popular as the refilled stopes provide support for the adjacent stopes, allowing total extraction of economic resources.

Example for Block Caving Production

Figure shows large fragments of ore are a **problem** because they cannot be easily transported?

Usually they have to be broken up by secondary blasting, which costs money and time.

Ore Removal

- In mines which use rubber tired equipment for coarse ore removal, the ore (or "muck") is removed from the stope (referred to as "mucked out" or "bogged") using center articulated vehicles (referred to as **boggers or LHD [i.e., Load, Haul, Dump]**). These pieces of equipment may operate using diesel or electric engines and resemble a low-profile front end loader.
- *In shallower mines ,* the ore is then *dumped into a truck to be hauled to the surface*.
- In deeper mines the ore is *dumped down an ore pass* (a vertical or near vertical excavation) where it falls to a collection level. On the collection level, it may receive primary crushing via jaw or cone crusher. The ore is then moved by conveyor belts, trucks or occasionally trains to the shaft to be hoisted to the surface in buckets or skips and emptied into bins beneath the surface headframe for transport to the mill.
    - In some cases the underground primary crusher feeds an inclined conveyor belt which delivers ore via an incline shaft direct to the surface. The ore is fed down ore passes, with mining equipment accessing the ore body via a decline from surface.

UNIT OPERATIONS OF MINING

Ore extraction and underground development is achieved by precise drilling and blasting techniques.

- Drilling a pattern of holes into the rock.
- Charging (filling) the holes with explosive.
- Blasting the rocks.
- Bogging (digging) it out.
- Ground support.
- Transporting it to the surface.

During the development and exploitation stages of mining when natural materials are extracted from the earth, remarkably similar unit operations are normally employed.

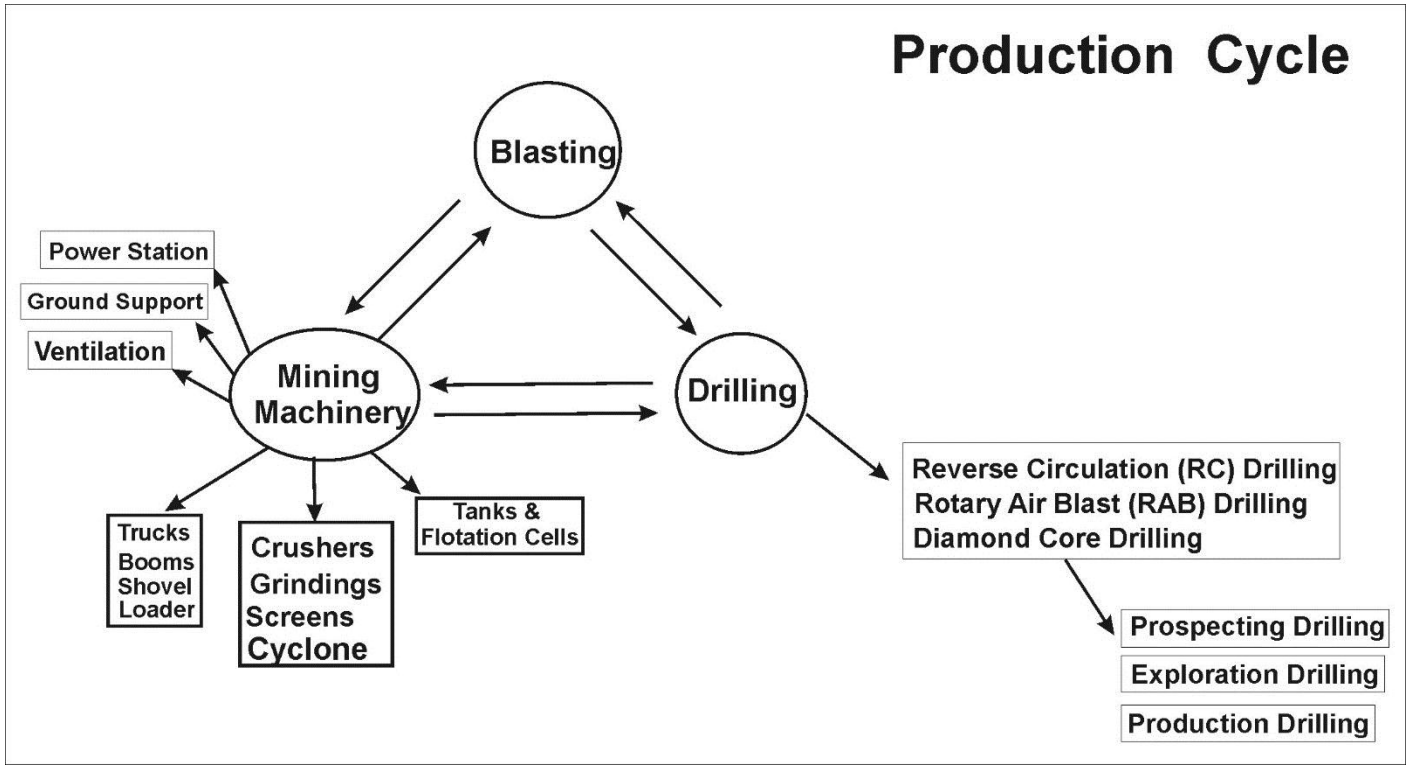
The *unit operations of mining* are the basic steps used to produce mineral from the deposit, and the auxiliary operations that are used to support them. The steps contributing directly to mineral extraction are production operations, which constitute the production cycle of operations.

The production cycle employs unit operations that are normally grouped into rock breakage and materials handling. Breakage generally consists of drilling and blasting and materials handling encompasses loading or excavation and haulage (horizontal transport) and sometimes hoisting (vertical or inclined transport).

The Mining Production Cycle includes the following steps:-

- Drill holes.
- Blast.
- Mining machinery.
- Load .
- Haulage.
- Repeat until orebody is depleted.

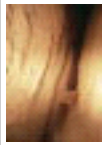
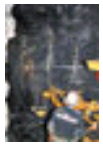
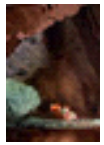
Production Cycle =
Drill + Blast + Load + Haulage



Underground Mine Development and Production

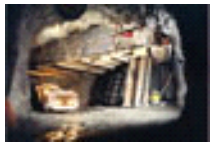




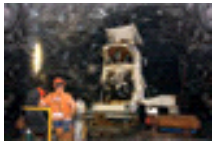




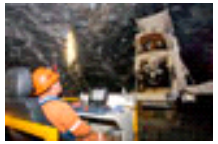
Alimak Raising



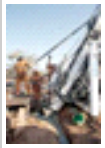
Raise Boring





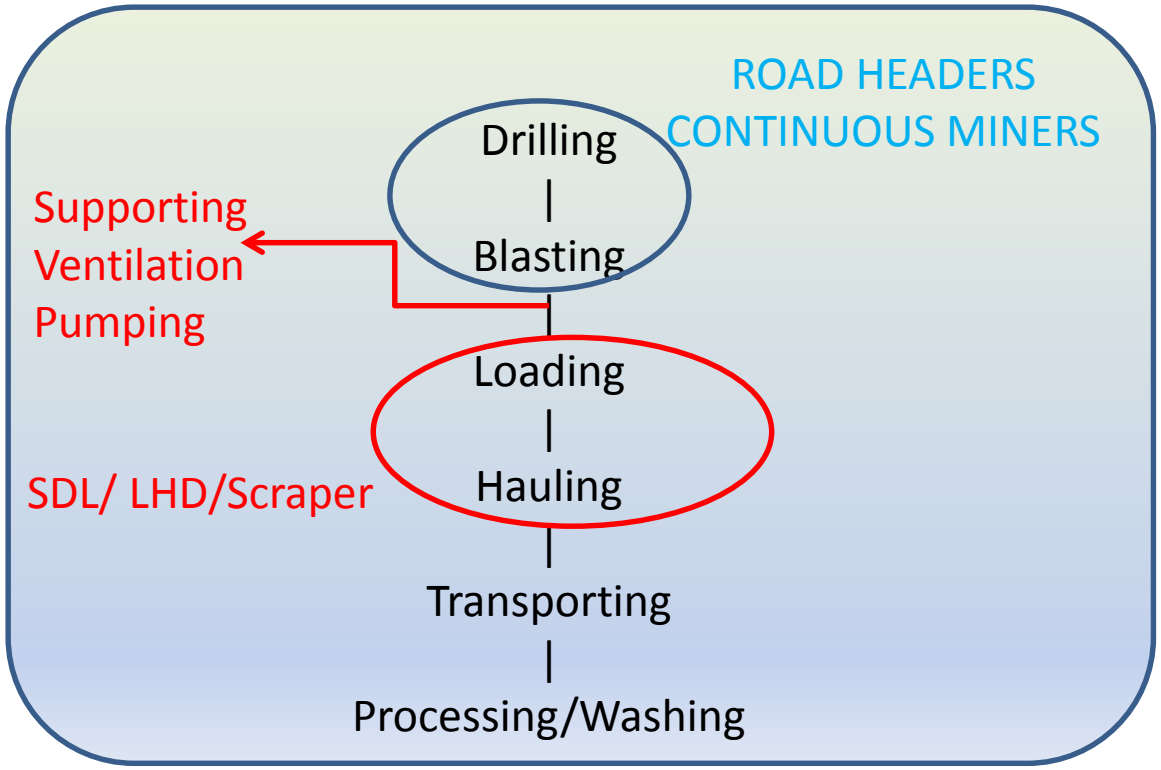
Surface Diamond Drilling



Underground Diamond Drilling

Mining Process used in Underground Mining methods



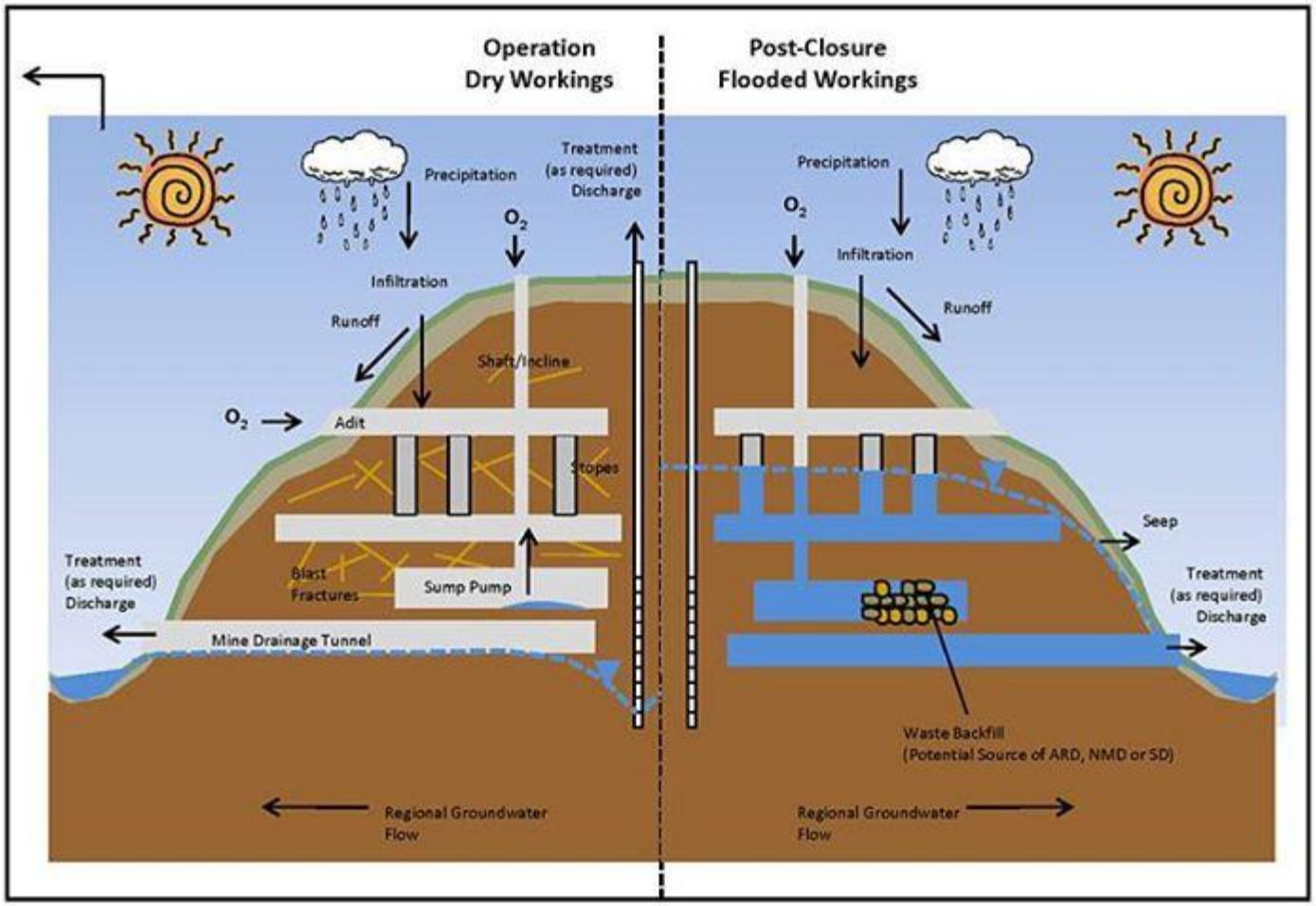
Drill
|
Permitted explosives
|
Manual/ SDL/ LHD/Scraper
|
Manual/ SDL/ LHD/Scraper
|
Tubs, Conveyors, ..etc
|
Washeries

Underground LHD

Campbell Mine, Ontario

Remote-LHD

Olympic Dam Mine, Australia



Underground Workings During Operation and Closure...

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