Surface Mining-Planning and Design of Open Pit Mining

2017 - 2018

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1.2) Open pit Mining method

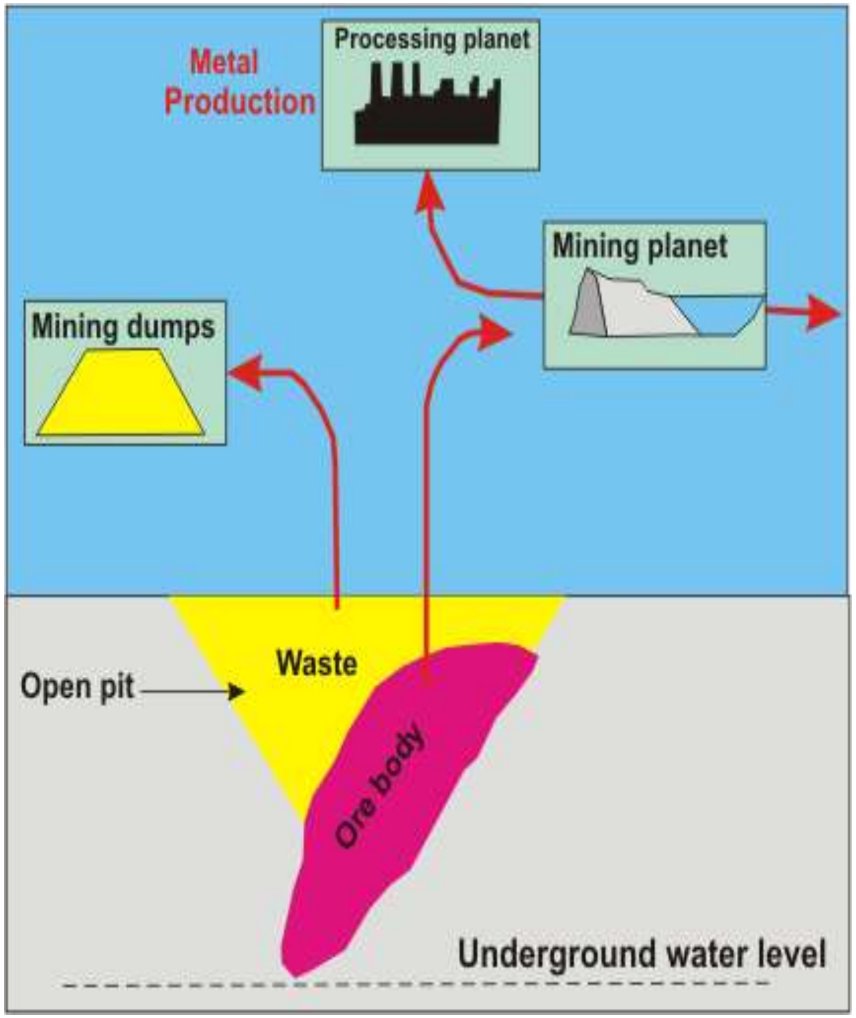
- Mine working open to the surface.
- It is usually employed to exploit a near-surface deposit or one that has a low stripping ratio.
- Operation designed to extract mineral deposits that lie close to the surface.
- It is used when the orebody is near the surface and little overburden (waste rock) needs to be removed.
- Large hole exposes the ore body.
- Waste rock (overburden) is removed.
- It often necessitates a ***large capital investment*** but generally results in high productivity, ***low operating cost, and good safety conditions.***
- 2nd cheapest method, but has the largest environmental impact. Why?

- Funnel shaped hole in ground, with ramp spiraling down along sides, allows moderately deep ore to be reached.
- 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).
- Design issues:
  - Stripping overburden
  - Location of haul roads
  - Equipment → size of trucks and fleet
  - Pit slope angle and stability

Classic Open Pits Characterized by Oval Shape, Benches, spiraling roads

- ❑ Characterized by a series of stair-step like benches that each act as a working area
- ❑ Pit shapes tend to be more configured to geology of the deposit more than equipment needs/convenience
  - ➢ Many pits are ovals
    - ✓ Fits the geometry of disseminated metal deposits
  - ➢ Pits tend to be wider relative to length
  - ➢ Pits tend not to move like strip mine – pit develops in place

These pits expand without
Moving and generally
Target a vein or steeply
Dipping stock on ore



Surface Mining methods (Open pit Mining method)

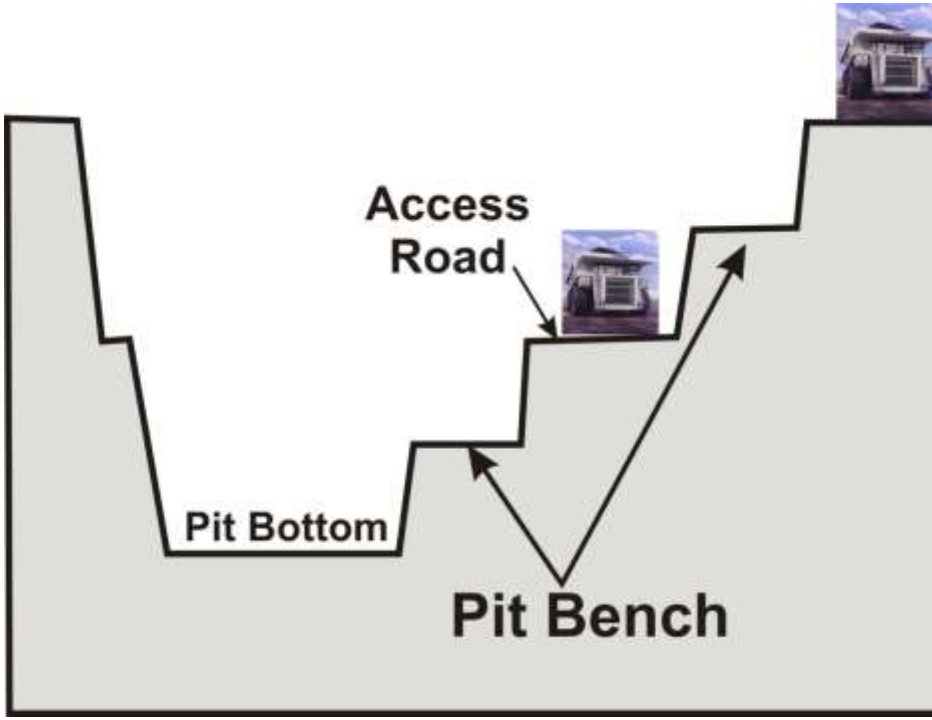


Figure shows Open pit Mining method

open pit mining: funnel shaped hole in ground, with ramp spiraling down along sides, allows moderately deep ore to be reached.

Initial mining for zinc at Franklin and Ogdensburg, New Jersey-USA.

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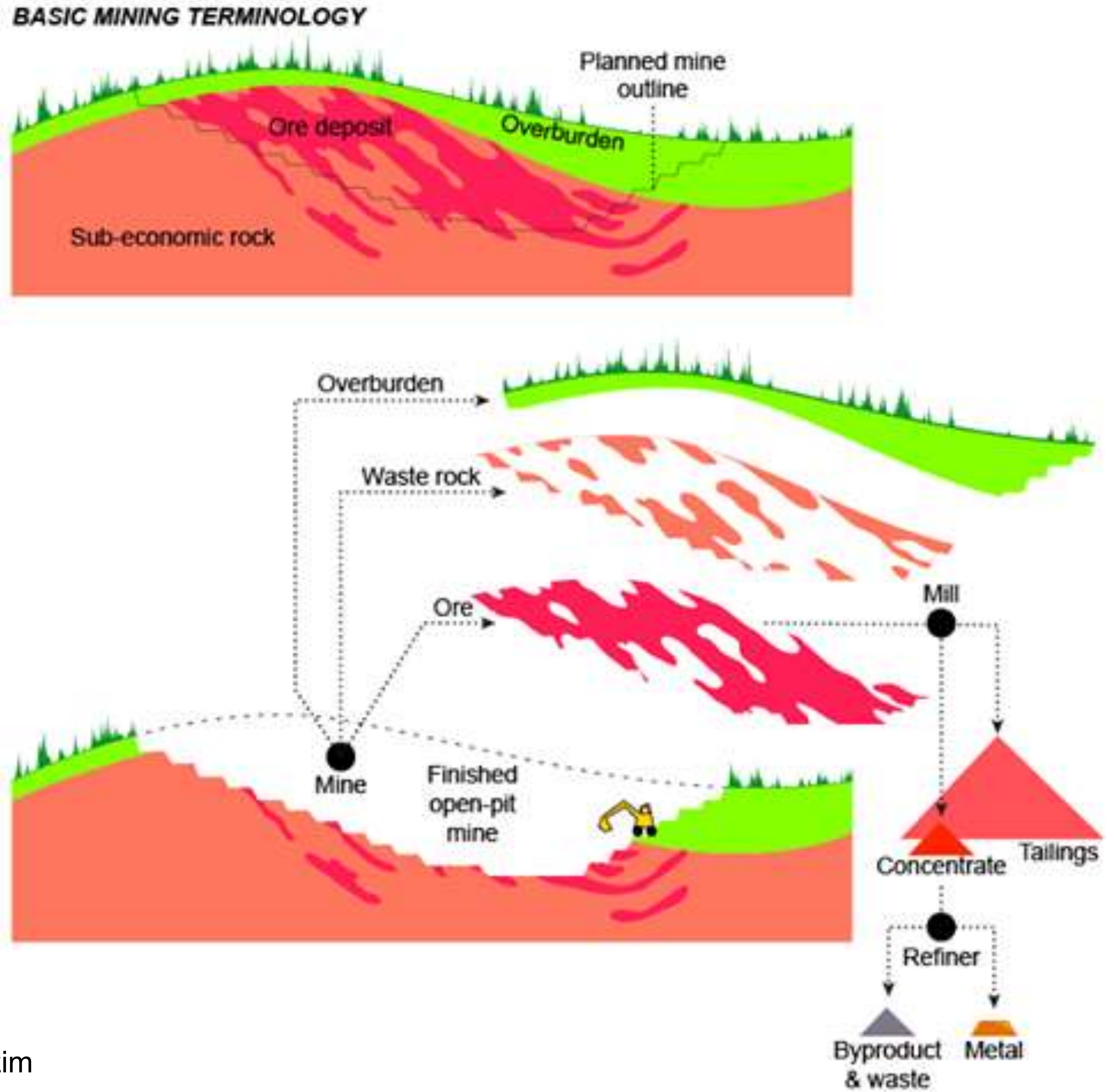
Photo I took at Bingham. 4 km in diameter 1 km in depth, at its zenith 400000 tons of rock per day



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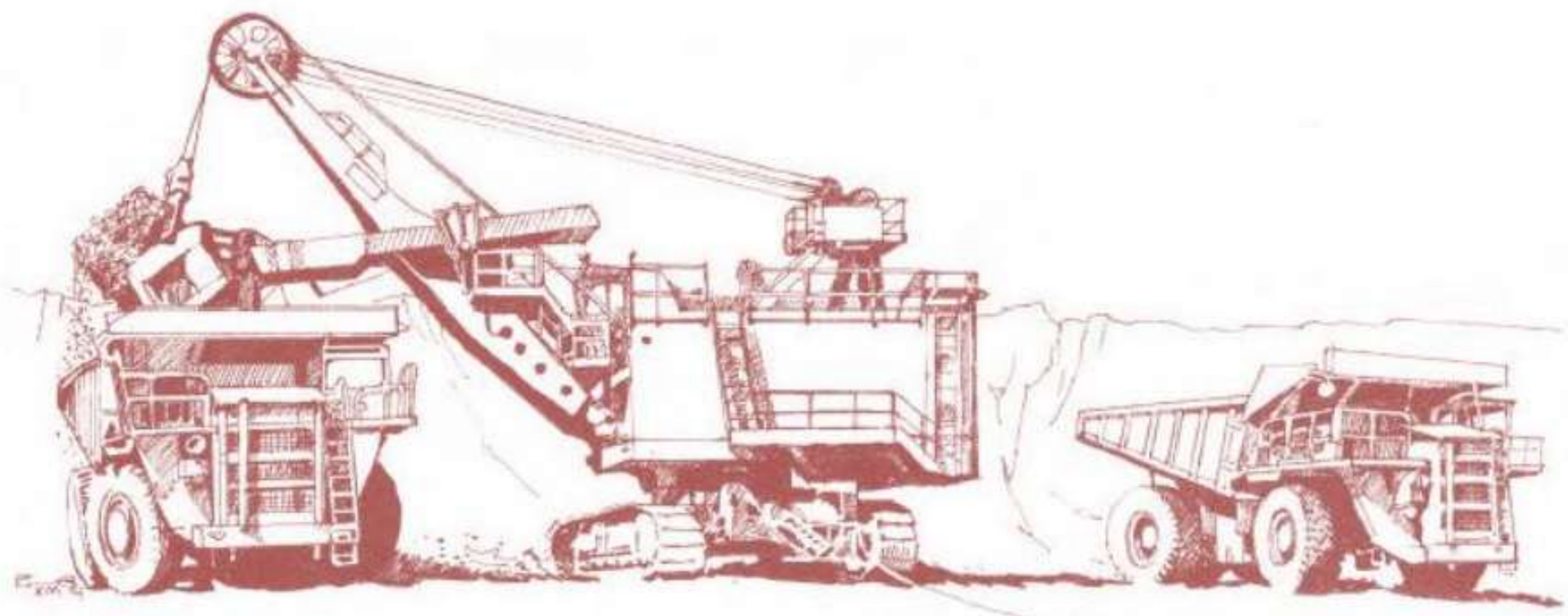
Open Pit Mining Fundamentals



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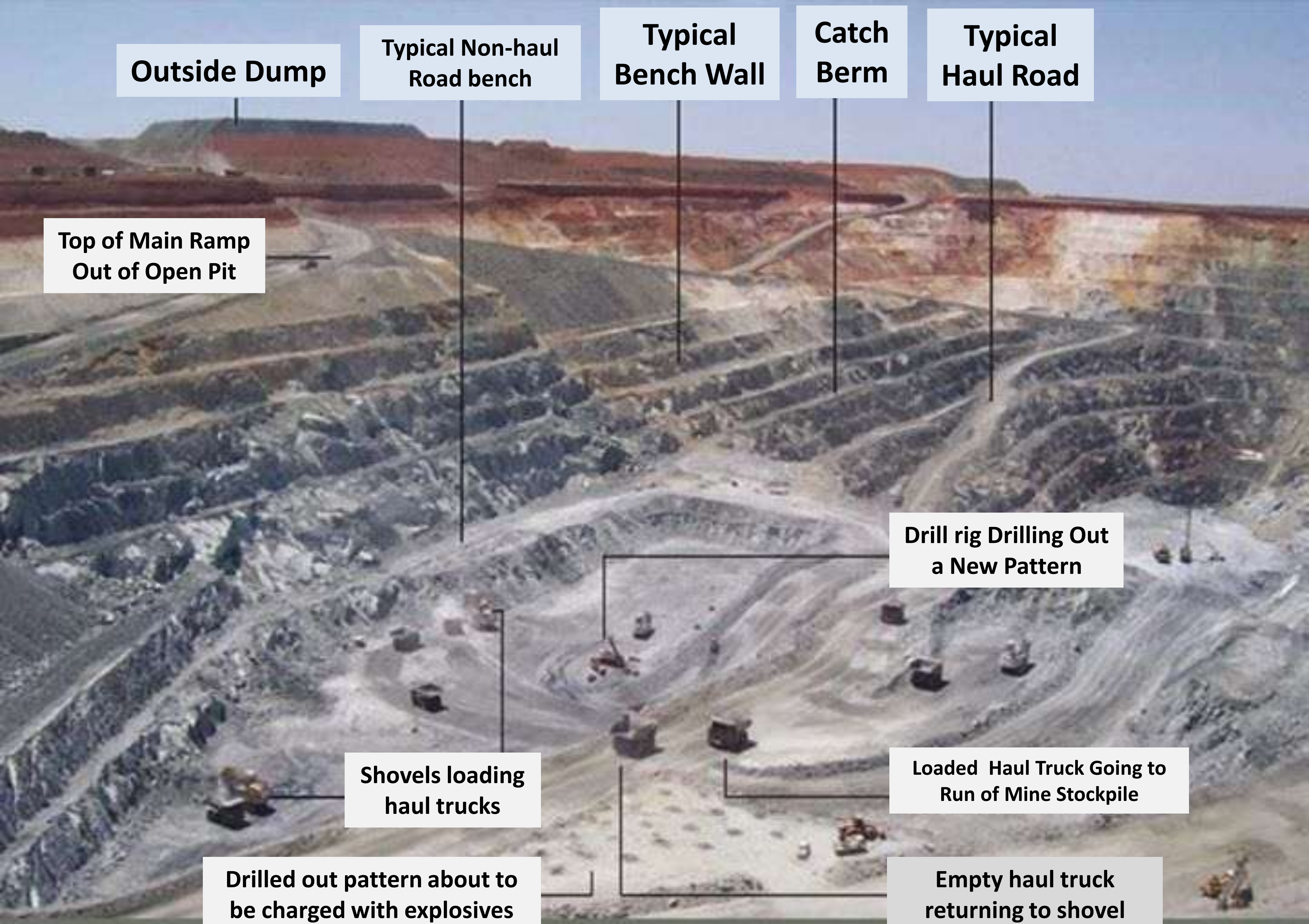

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Typical Open Pit Mine

Pit	Bench	Beam
Floor	Weight	Weight
Angle	Width	Width
Overall slope	Slope	Slope
	crest	Interval
	Top	

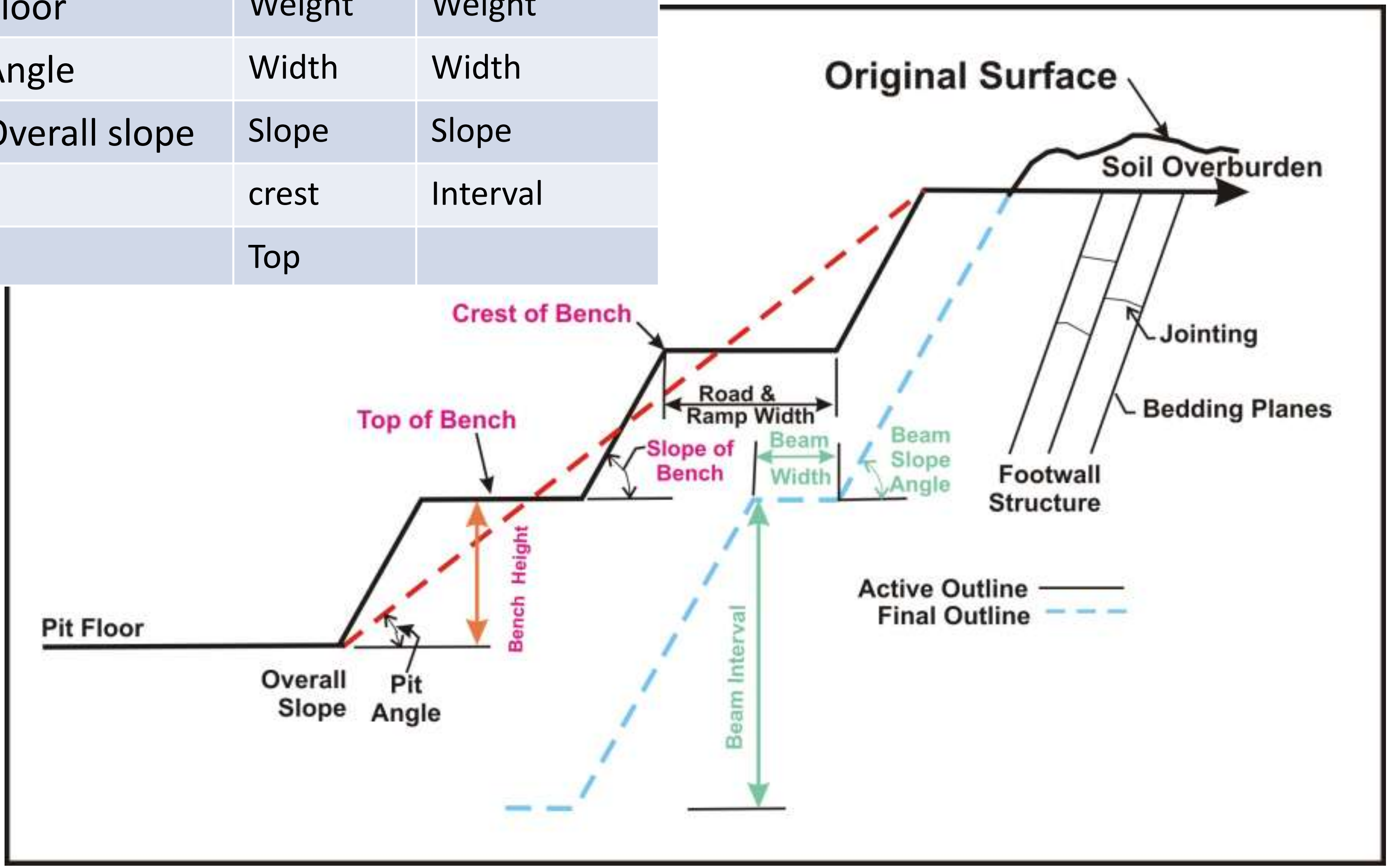
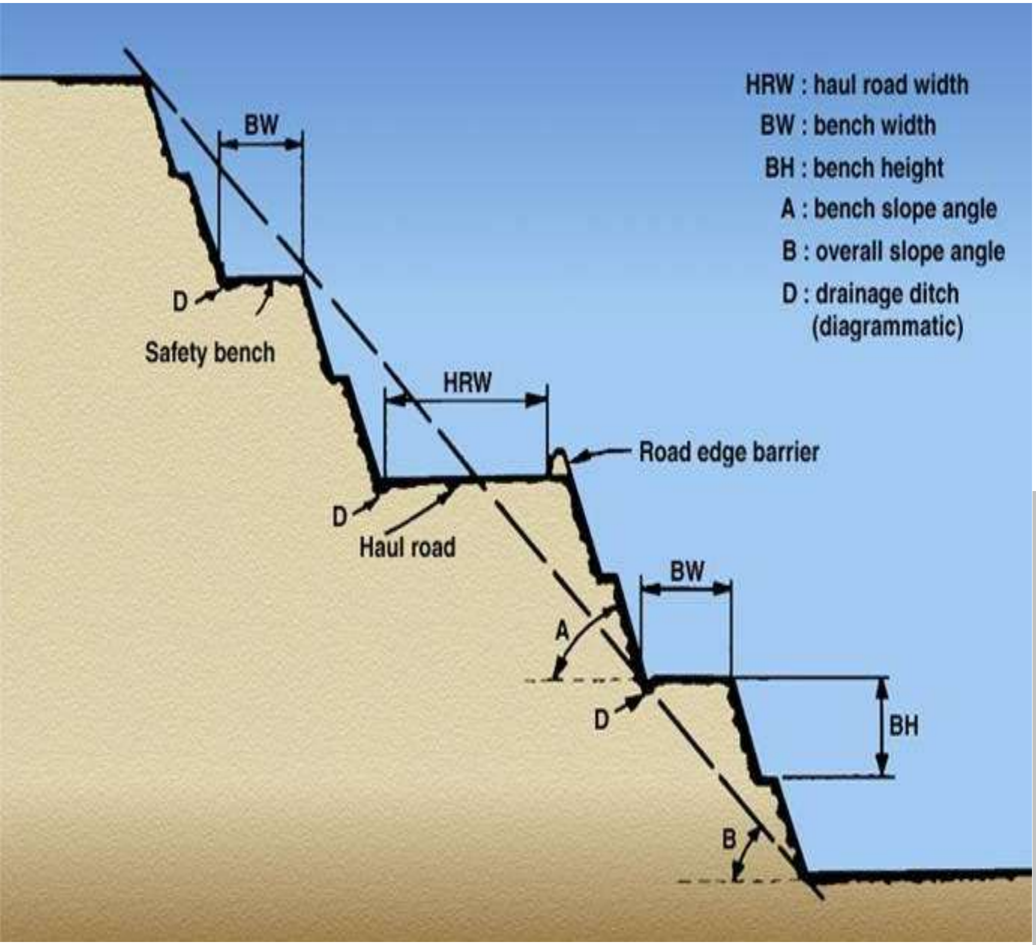
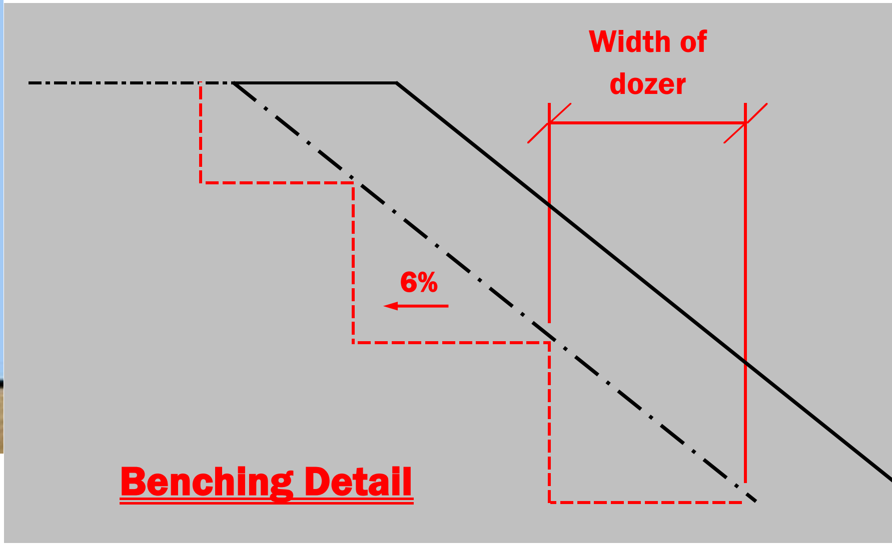


Figure showing typical open-pit bench terminology

1.3) Benching

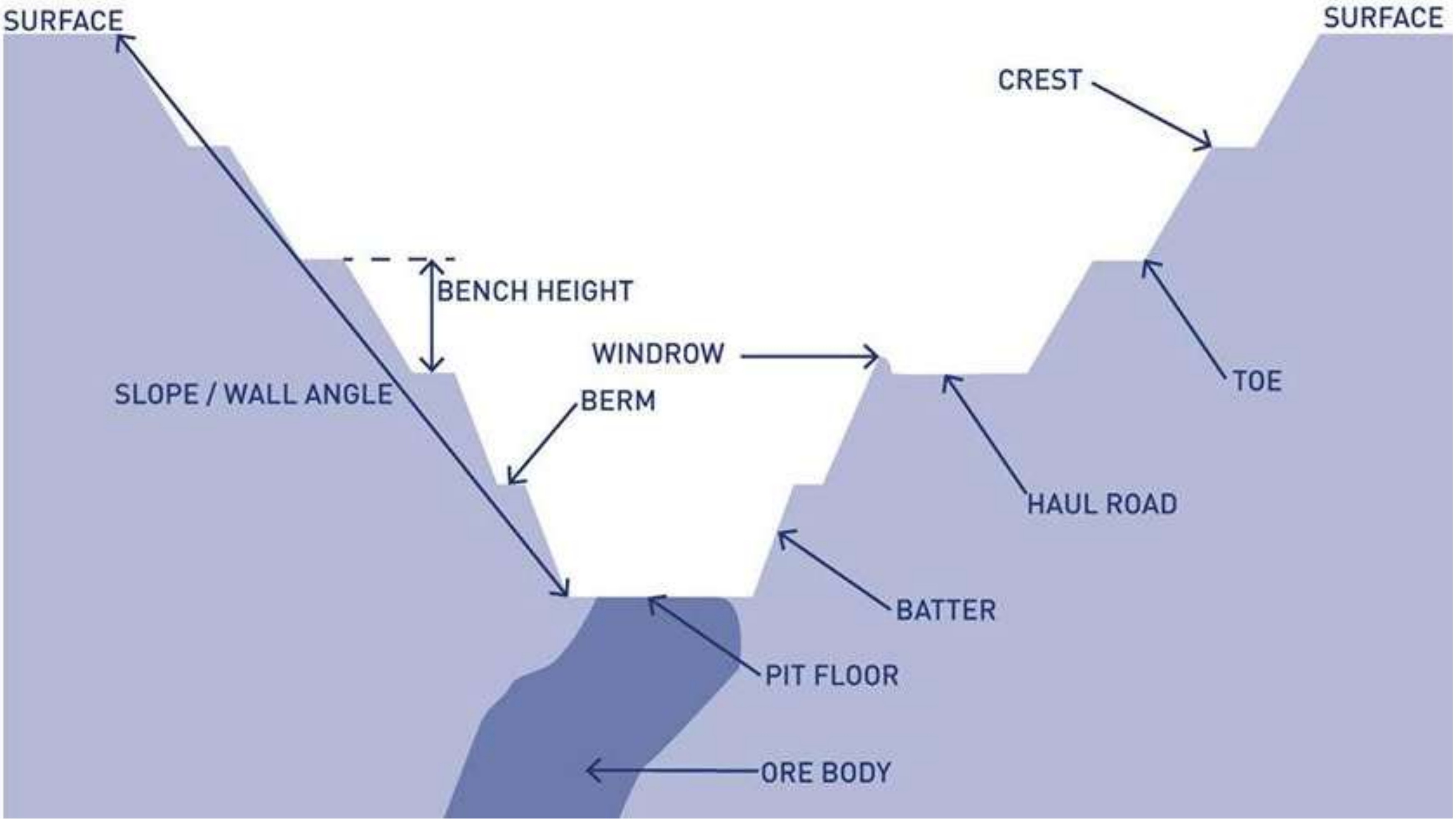


- BENCH: Ledge that forms a single level of operation above which mineral or waste materials are mined from the bench face.
- Benching is used to properly patch or extend a slope
- Benching is also used to temporarily support equipment for other work elements
- Bench detail must be wide enough to support a dozer % slope in towards the roadway to resist sliding



Bench level intervals are to a large measure determined by the type of shovel or loader used, and 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.

1.4) Open Pit Bench Terminology



1.5) Bench height

- The bench height is the vertical distance between each horizontal level of the pit.
- Vertical distance between the highest point on the bench (crest) and the lowest point or the bench (toe).
- It is influenced by size of the equipment, mining selectivity, government regulations and safety .
- The elements of a bench are illustrated in Fig. 1.
- Unless geological conditions dictate otherwise, all benches should have the same height.

The height will depend on :

i) The physical characteristics of the deposit;

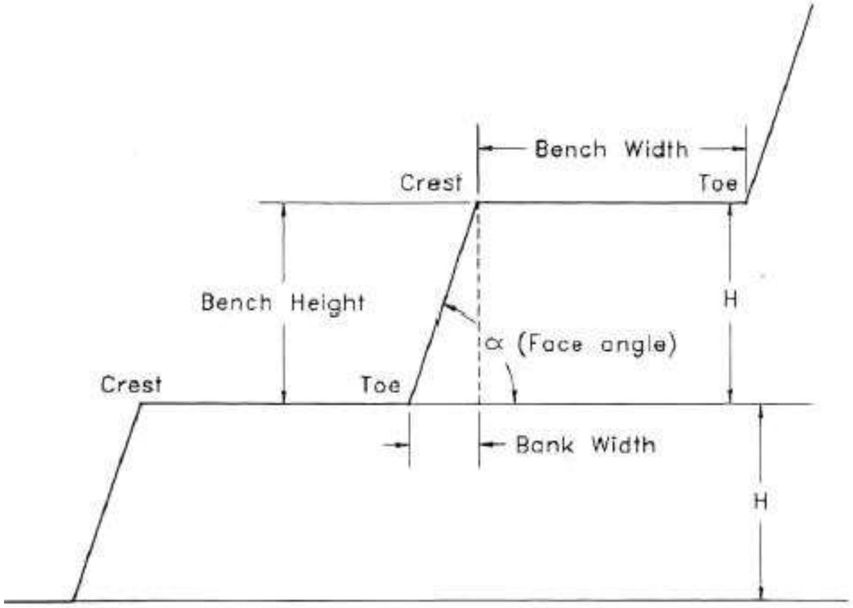
ii) The degree of selectivity required in separating the ore and waste with the loading equipment; the rate of production;

iii) The size and type of equipment to meet the production requirements; and

iv) The climatic conditions.

- The bench height should be set as high as possible within the limits of the size and type of equipment selected for the desired production.
- The bench should not be so high that it will present safety problems of towering banks of blasted or un-blasted material.
- The bench height in open pit mines will normally range from 15m in large copper mines to as little as *1 m in uranium mines.*

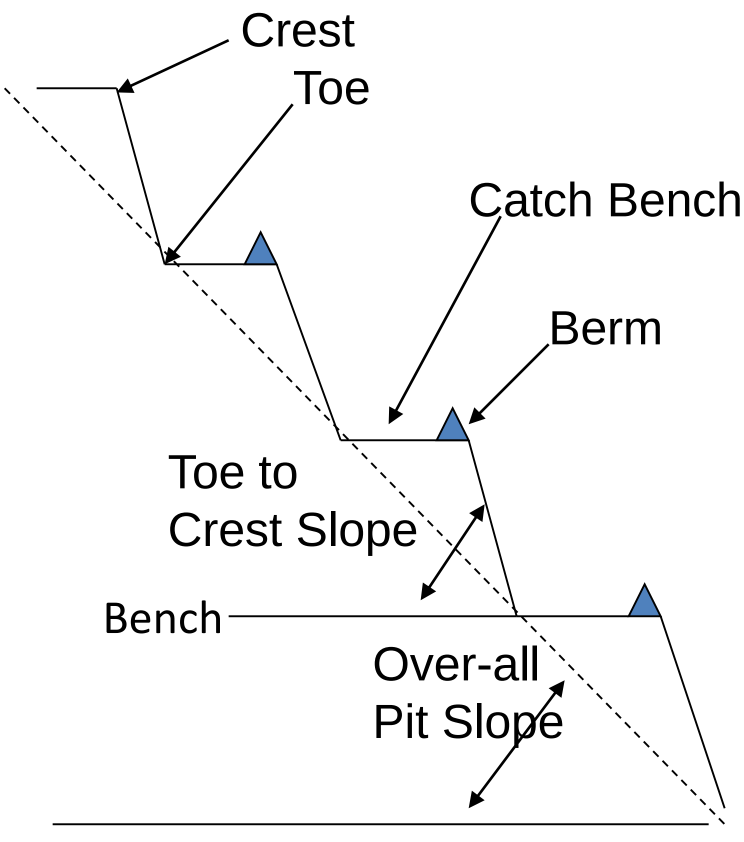
Trucks parked awaiting the call for their next loads of ore...!!!



Parts of a bench

Terms in Open Pit Benches

- Quarries in strong rock can sustain about 80 to 85º toe to crest slopes.
- Geology determines limits but about 58 to 72º is a common range for toe to crest in open pit metal.
- Over-all slopes often more conservative
  - Frequently less than 45º.
    - Cannanea Mexico is nearly 60º



Final Pits Slopes allow Benches to be wide enough to Catch rocks and accommodate A berm. (This is often less than Than 10 m).

Note: *that the toe to Crest slope is much Steeper than the over-all*

Localized single bench failures from a steep toe to crest slope are much more Tolerable than an over-all pit slope failure over the entire side of a pit.

- **BENCH SLOPE (or BANK ANGLE):** Horizontal angle of the line connecting bench toe to the bench crest.
- **BERM:** Horizontal shelf or ledge within the ultimate pit wall slope left to enhance the stability of the a slope within the pit and improve the safety . Berm interval, berm width and berm slope angle are determined by the geotechnical investigation.
- **OVERALL PIT SLOPE ANGLE:**
  - ➢ The angle measured from the bottom bench toe to the top bench crest.
  - ➢ It is the angle at which the wall of an open pit stands and it is determined by rock strength, geologic structures and water conditions.
  - ➢ It is affected by the width and grade of the haul road.

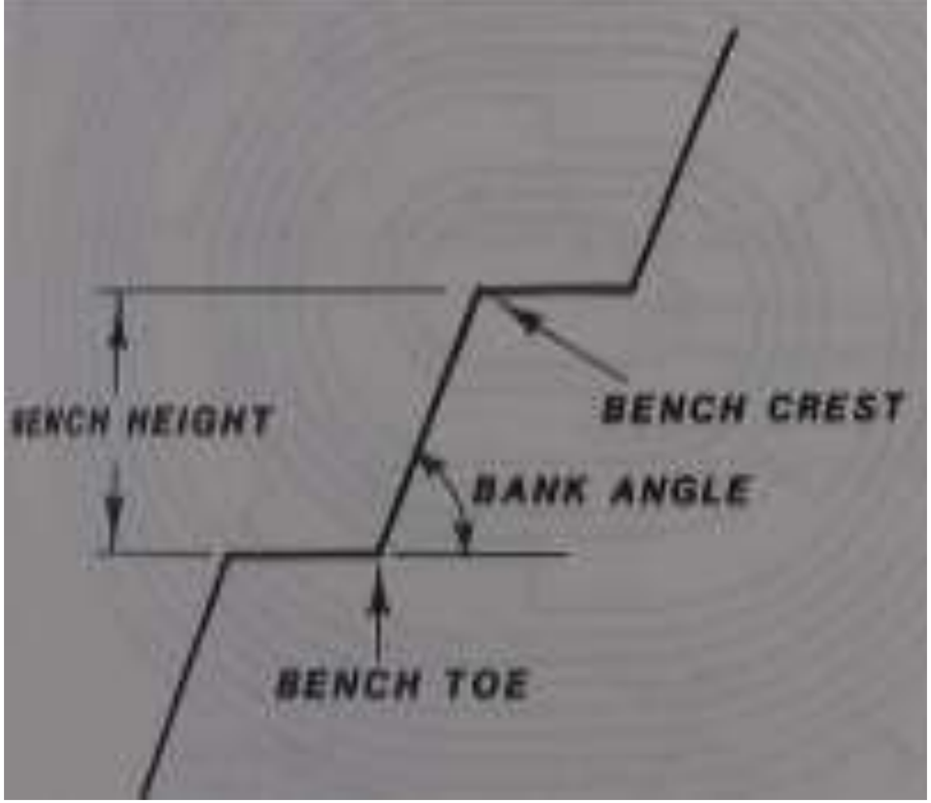


Fig.1: Bench cross sections

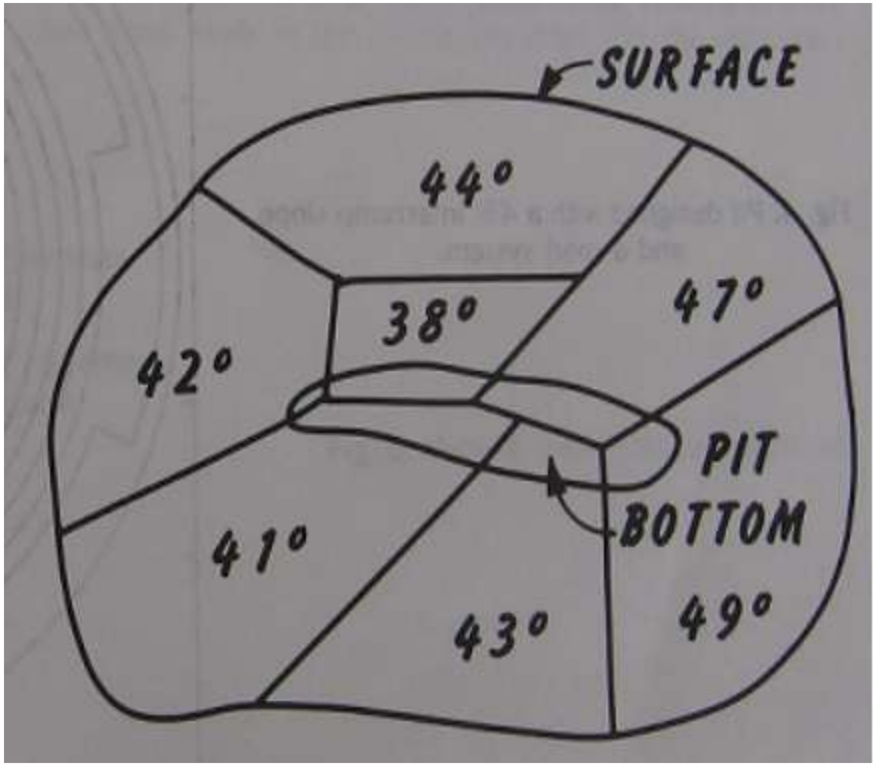
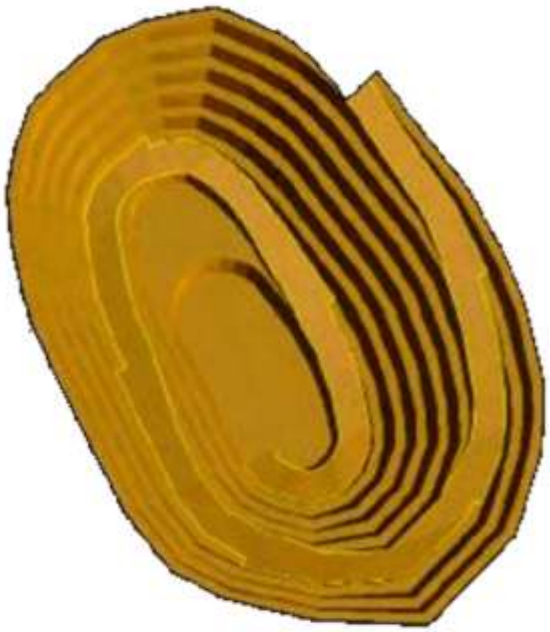


Fig.2: Example of pit slopes varying in a deposit

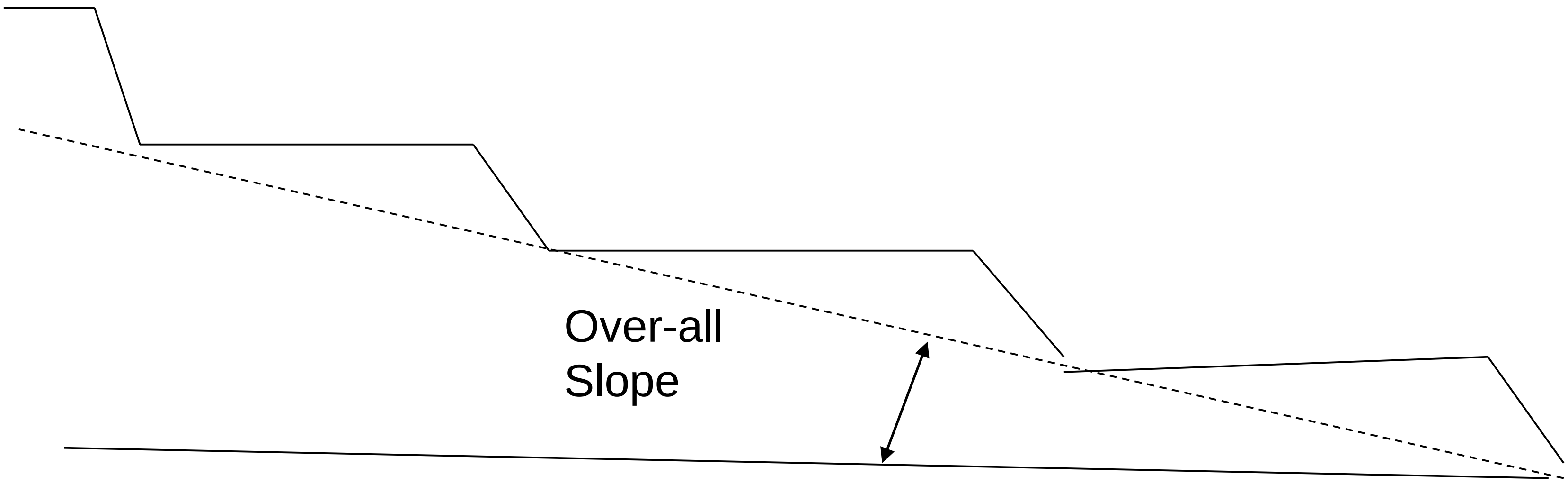
- **HAUL ROADS:** During the life of the pit a haul road must be maintained for access.
- **HAUL ROAD – SPIRAL SYSTEM**: Haul road is arranged spirally along the perimeter walls of the pit.



- **HAUL ROAD – SWITCH BACK SYSTEM:** Zigzag pattern on one side of the pit.
- **HAUL ROAD WIDTH:** Function of capacity of the road and the size of the equipment. Haul road width must be considered in the overall pit design.

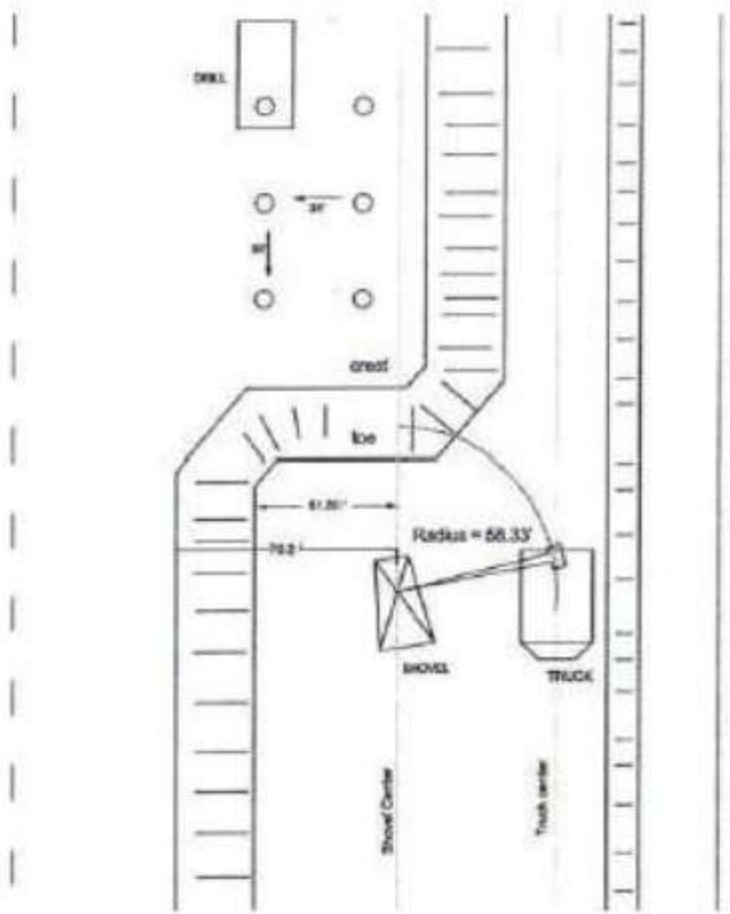
- **STRIPPING RATIO:** Expressed in tons of waste to tons of ore in hard rock open pit operations. Critical and important parameter in pit design and scheduling.
- **AVERAGE STRIP RATIO:** Total waste divided by total ore within the ultimate pit.
- **CUTOFF STRIPPING RATIO:** Costs of mining a ton of ore and associated waste equals to net revenue from the ton of Ore.

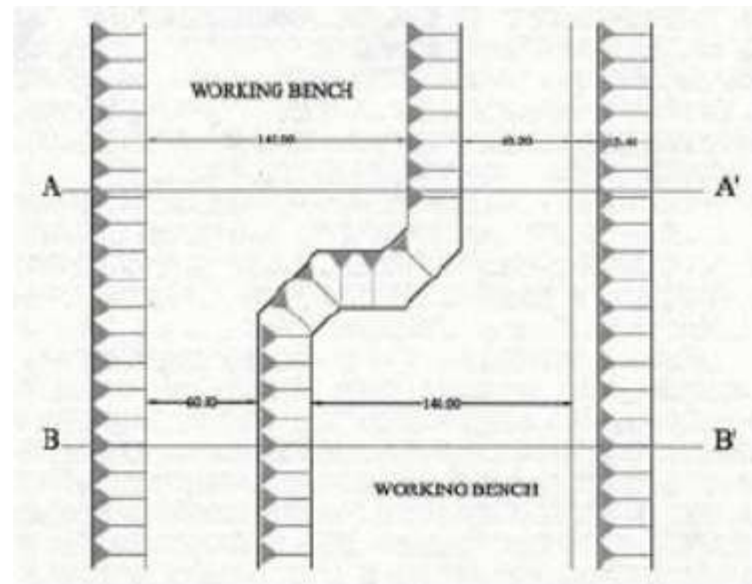
Impact of a Working Bench

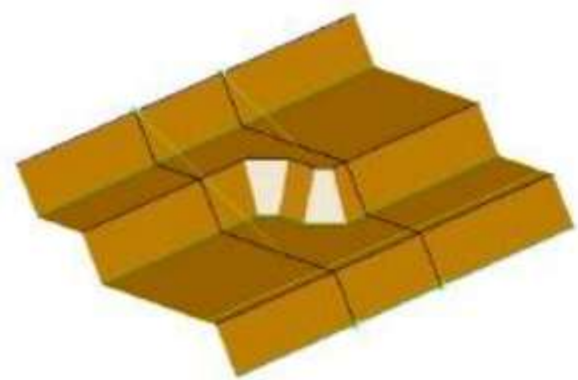


The over-all slope of the pit is drastically
Reduced if one must accommodate wide
Working benches.

Single Working Bench







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Shovel in Working Bench

Assumptions:

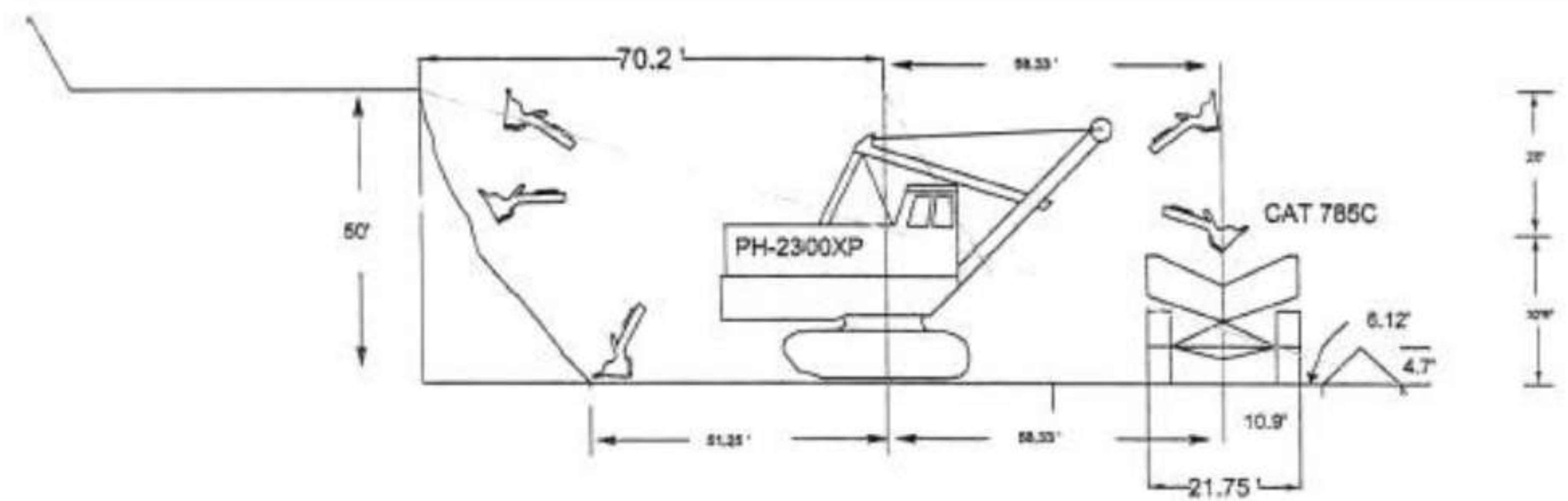
Shovel: PH-2300XP & CAT 785C

Tire type:33.00x51 (From Cat Handbook)

Axle height = (51 + 2x0.95x33)/2 /12 = 4.70' (formula)

D = 51.25 (Radius at level floor)

Width of cut = 0.90x2xD (Aprox. 90')



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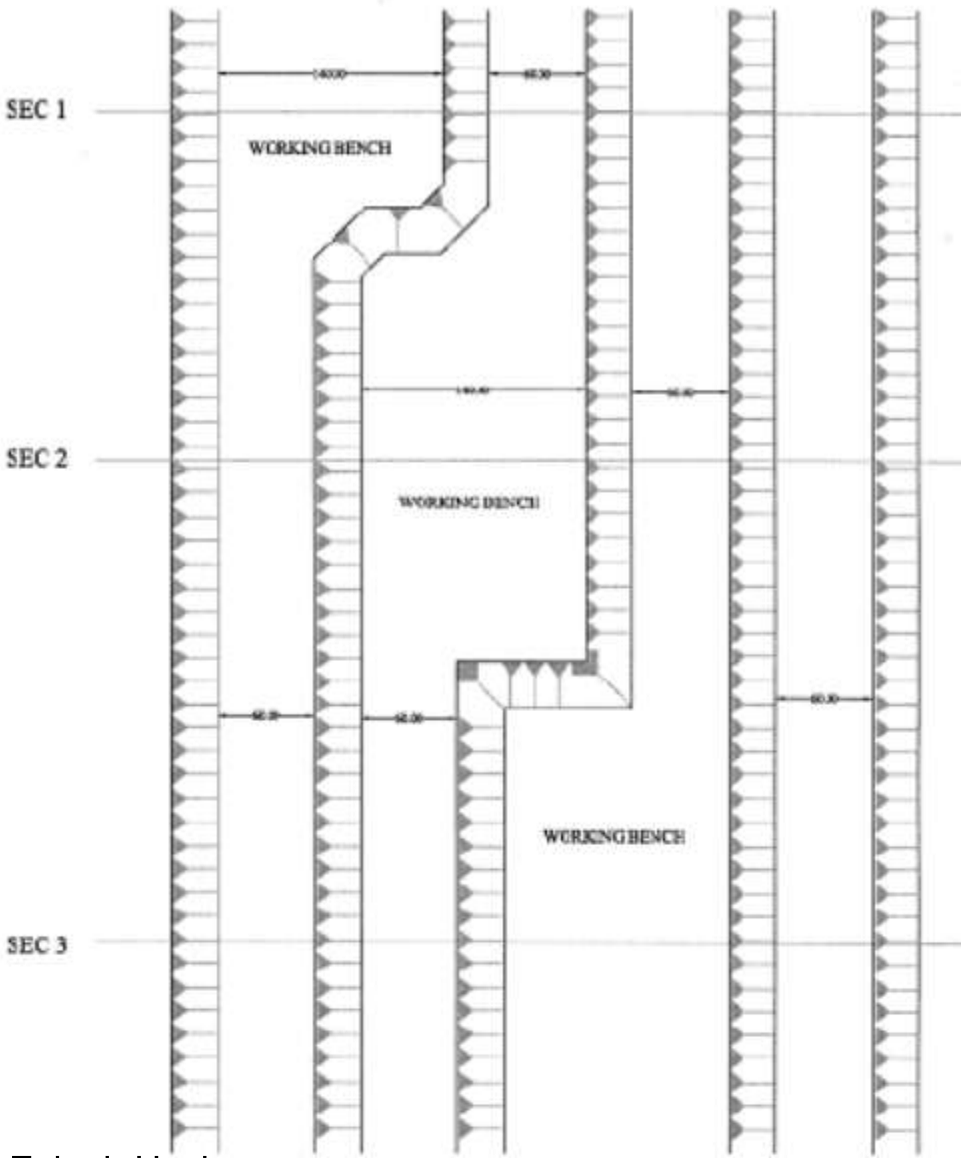
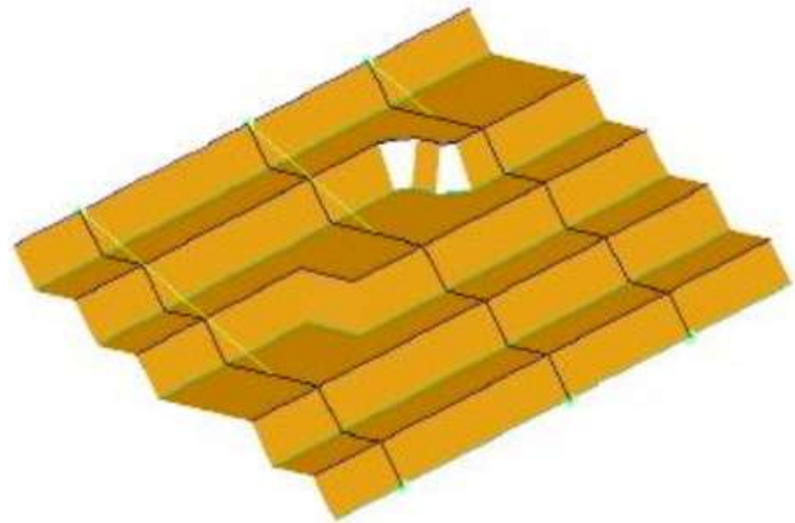
Two Working Benches





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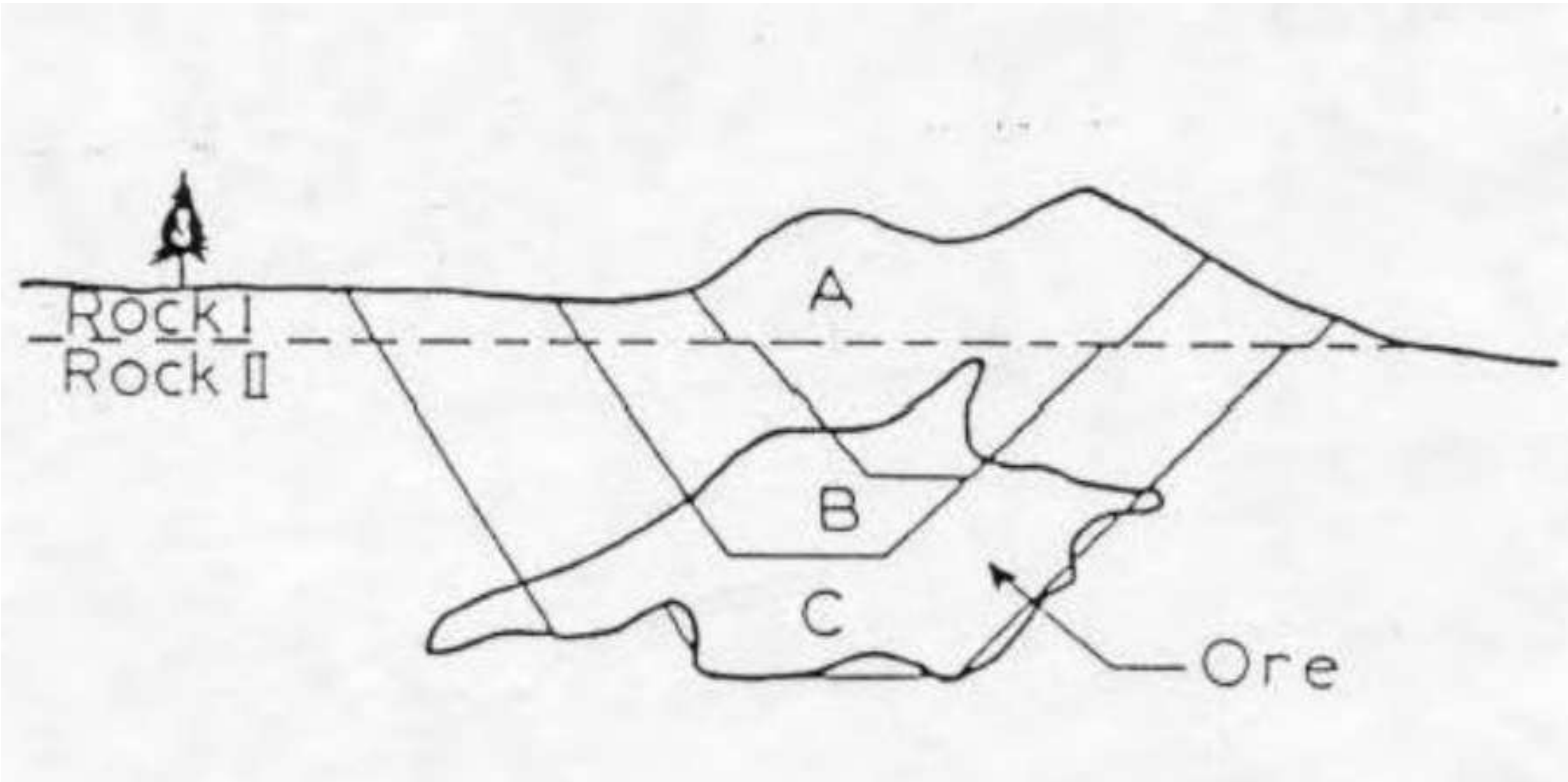
Section of Pit Sequence



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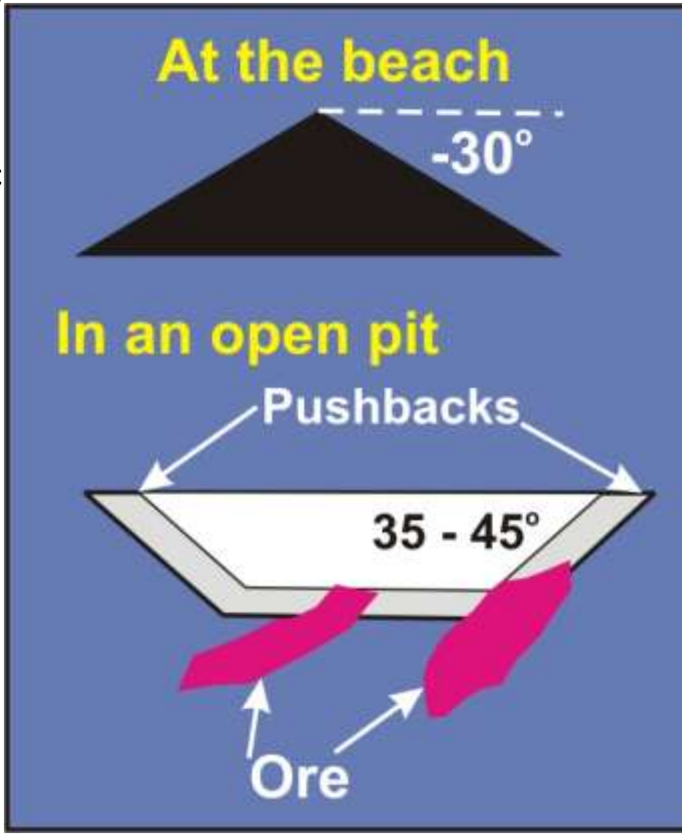
1.7) Open Pit Stability

- The following are the key items affecting the Open Pit Stability:
  - i) Pit slope
  - ii) Pit wall stability
  - iii) Rock strength
  - iv) Pit Depth
  - v) Pit diameter
  - vi) Water Damage
  - vii) Strip Ratio (SR)

i) Pit Slopes

- ❑ The slope of the pit wall is one of the major elements affecting the size and shape of the pit.
- ❑ The pit slope helps determine the amount of waste that must be moved to mine ore.
- ❑ The pit wall needs to remain stable as long as mining activity is in that area.
- ❑ The stability of the pit walls should be analyzed as carefully as possible.
- ❑ Rock strength, faults, joints, presence of water, and other geologic information are key factors in the evaluation of the proper slope angle.
- ❑ The physical characteristics of the deposit cause the pit slope to change with rock type, sector location, elevation, or orientation within the pit.
- ❑ Pit slopes are cut into benches to aid stability and contain any slope failures.
- ❑ Rock most be ***stronger than sand*** so the angle of repose can be larger.
    - ➢ 45° is usually the maximum slope.
    - ➢ Pit slopes are benched.



- The revenue from ore must pay for the cost of excavating waste from the pushback and for excavating the ore.
- The ***slope cannot exceed 45°*** and remain stable,→ so at some point it becomes impossible and/or uneconomic to continue mining.

Pit slopes

- Fig. 2 illustrates how the pit slopes may vary in the deposit.
- A proper slope evaluation will give the slope that allows the pit walls to remain stable.
- The pit walls should be set as steep as possible to minimize the strip ratio.
- The pit slope analysis determines the angle to be used between the roads in the pit.
- The overall pit slope used for design must be flatter to allow for the road system in the ultimate pit.
- Fig 3 and Fig 4 show the need to design the pit with a lesser slope to allow for roads:
  - Fig. 3 has been designed with a 45^0 angle for the pit walls.
  - The pit in Fig. 4 uses the same pit bottom and the 45^0 inter-ramp slope between the roads, but, a road has been added. So the overall pit slope is lesser the inter-ramp slope.
- In the example, almost 50% more tonnage must be moved to mine the same pit bottom.
- In the early design of a pit a lesser pit slope can be used to allow for the road system.
- The pit in Fig. 5 was designed with an overall slope of 38^0.
- The overall slope to use will depend on the width, grade, and anticipated placement of the road.
- Fig. 6 shows a vertical section of a pit wall from Fig.4.
- The inter-ramp angle is projected from the pit bottom upward to the original ground surface at point B.
- The overall pit slope angle is the angle from the toe of the bottom bench to the crest of the top bench.
- Point A shows the intercept of the overall pit slope angle with the original ground surface.

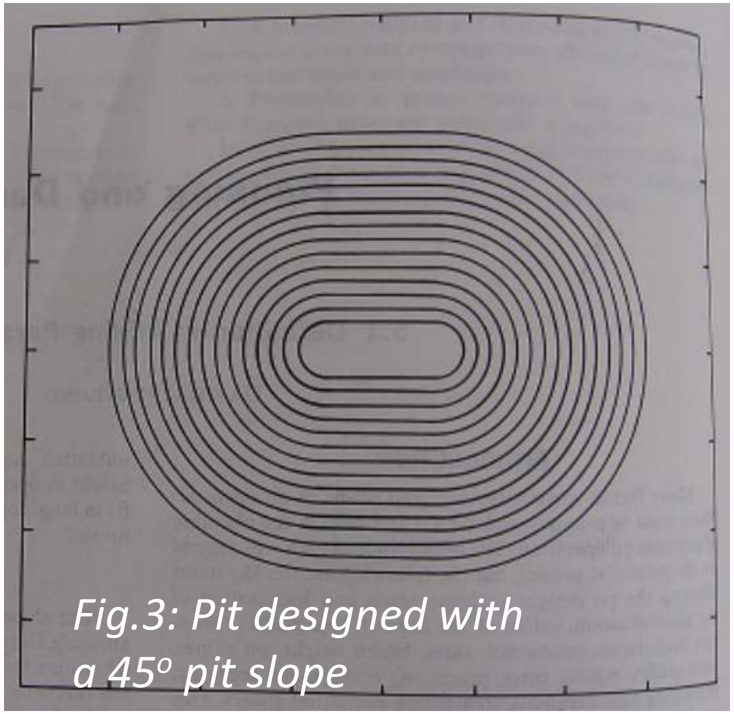


Fig.3: Pit designed with a 45^o pit slope

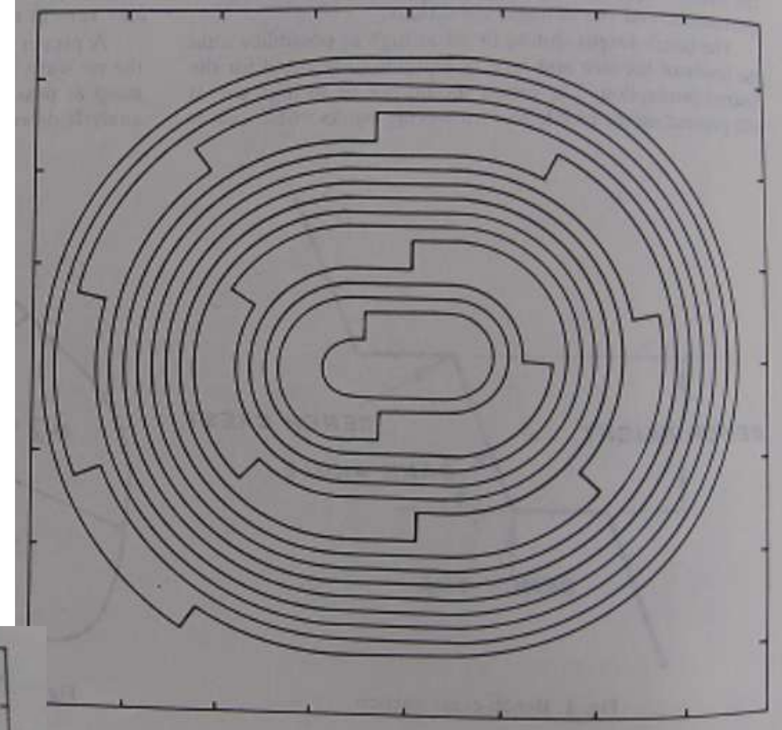


Fig.4: Pit designed with a 45^o inter-ramp slope and a road system

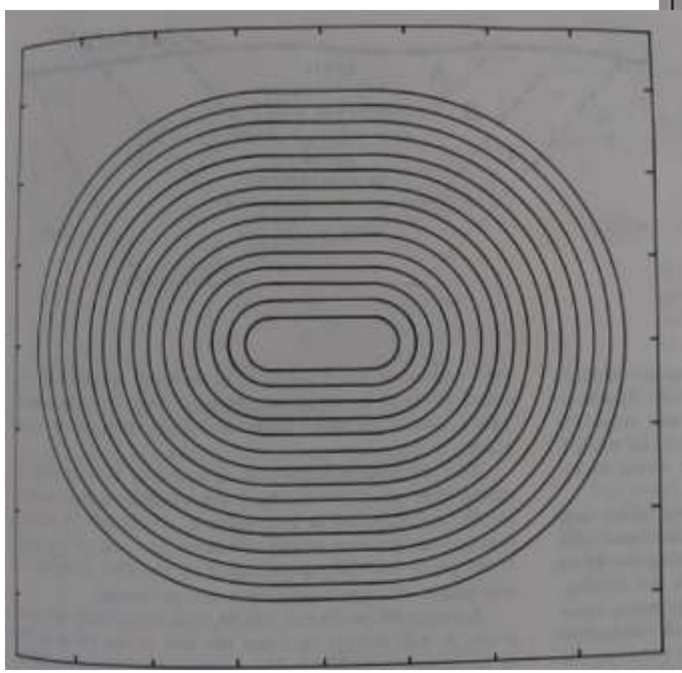


Fig.5: Pit designed with a 38^o overall slope to allow for a 45^o inter-ramp slope and a road system

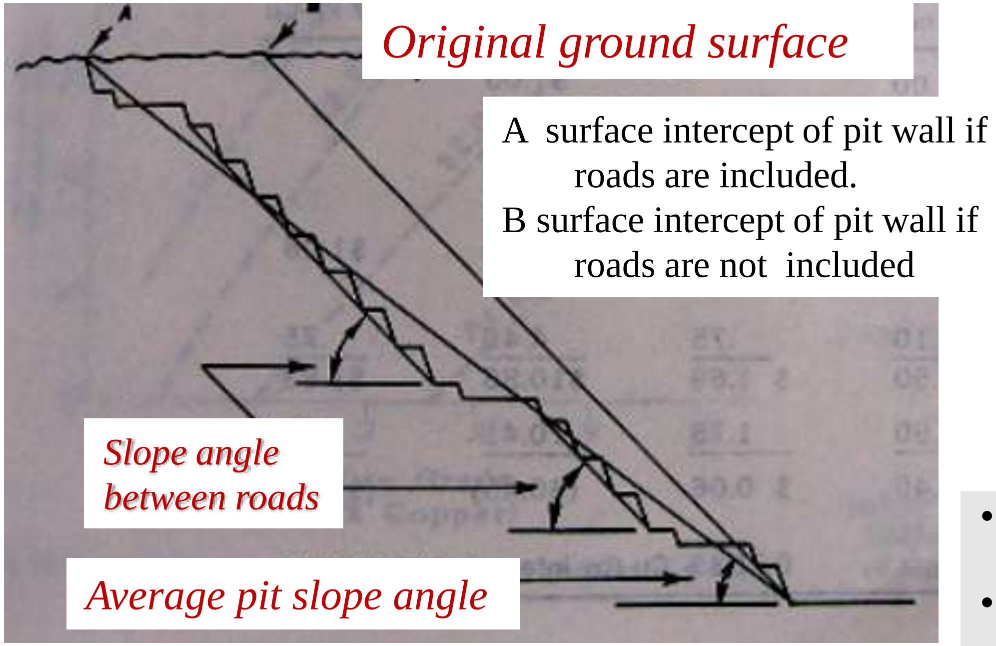


Fig.6: Vertical section through a pit wall

- Quarries in strong rock can sustain about 80 to 85 degree toe to crest slopes.
- Geology determines limits but about 58 to 72 degrees is a common range for toe to crest in open pit metal.
- Over-all slopes often more conservative
  - ➢ Frequently less than 45 degrees
    - ✓ Cannanea Mexico is nearly 60

Slope Stability

- Function of the natural angle of repose, density, surface and subsurface water flow
- Early stabilization of surfaces is critical i.e. *seeding, mulching, erosion blanket*
- Upward tracking of slopes slows sheet flow
- Eliminate points of concentrated flow using berms or using slope drains as outlets
- Slopes can be “softened” if space permits
- Difficult slopes may require riprap, gabions, or other measures for permanent stabilization

Open-pit slope failure –structural problems

Pre-mining geological structures, particularly fault planes, represent ***zones of potential weakness*** in the rock mass, and are therefore zones of potential slope failure, and should be taken into account when designing the mine.

Fault planes dipping towards the pit (as shown in the figure) present a ***greater risk*** than faults dipping away from the pit.

Faults planes often provide passage-ways for water movement, and these waters, through the process of weathering and chemical alteration of minerals, may reduce the strength of the rocks on either side of the fault plane, and reduce the *"coefficient of friction"* along it.

The coefficient of friction (the "**traction" or "grip**") along the fault will determine whether failure and slippage of rock down the fault plane is likely.

The coefficient of friction may change with time:

- as water-flow patterns are affected by mining
- as faults are exposed by the removal of rock, opening fluid pathways into faults
- by the reduction of the mass of the rock located above the fault plane.

ii) Pit Wall Stability

- Crack measuring
- Failure warning
- Movement of the walls

→

- Stable
- Instable:
  - Underlying fracture or fault
  - Magma
  - landslide

Most orebodies are related to faulting in the earth's crust.

Fault generates stresses in the host rock, rupturing it and causing faults in the rock (Figure 2).

Faults are typically long linear features so that if a circular pit is used to mine an orebody (Figure 3), ***it is likely to intersect a fault at two points, which leads to instability in at least two parts of the pit slope***.

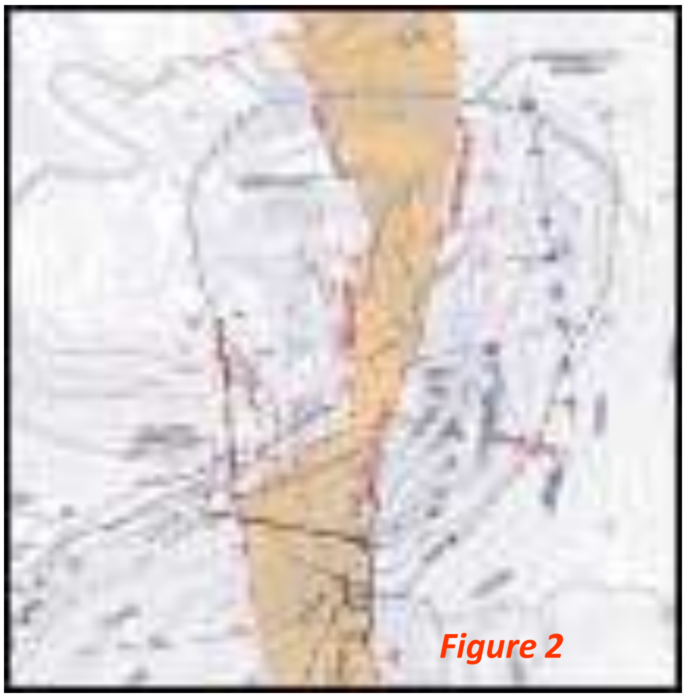


Figure 2

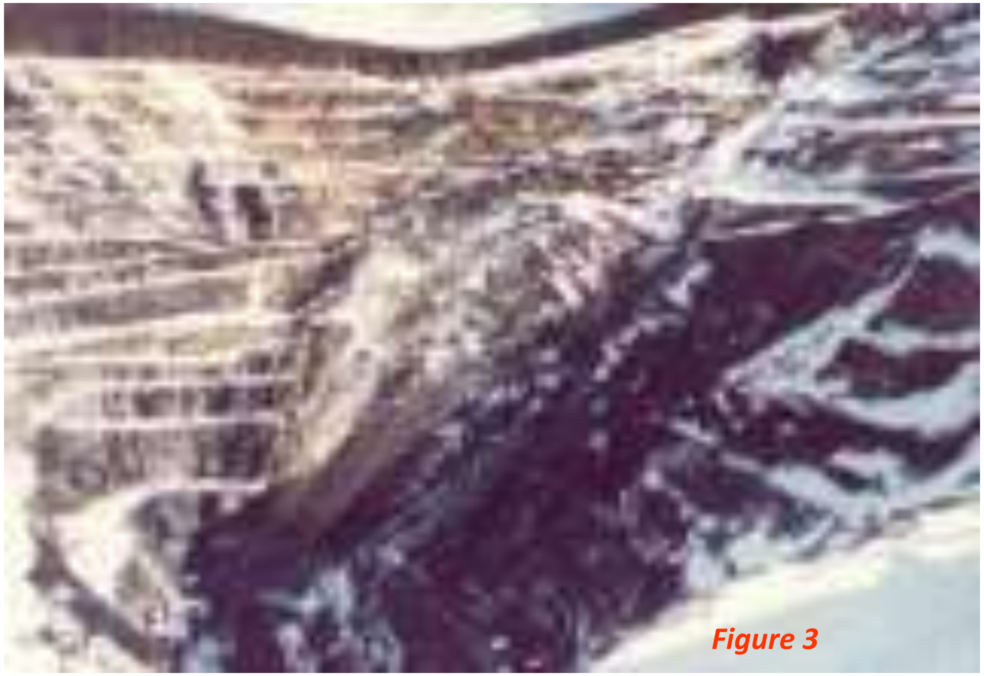


Figure 3

Figure 4 shows a landslide that occurred recently following **rain storms**. A berm was created at the base of the slide ***to protect the main haul road.***

Figure 5 shows a ***major instability***. The likely cause is an underlying fracture or fault. *The mine wishes to do a major pushback on this pit wall in order to gain access to more ore. This could be a challenging task*.

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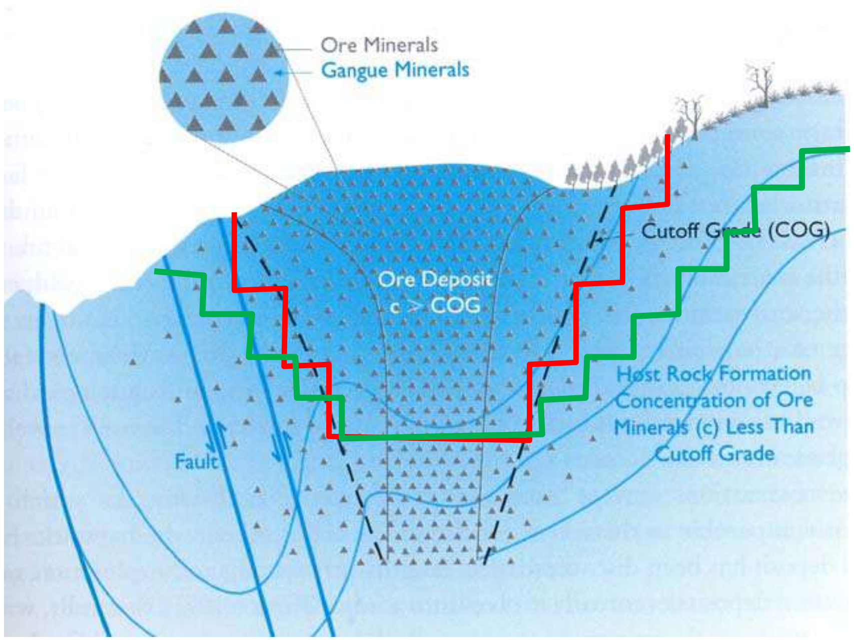
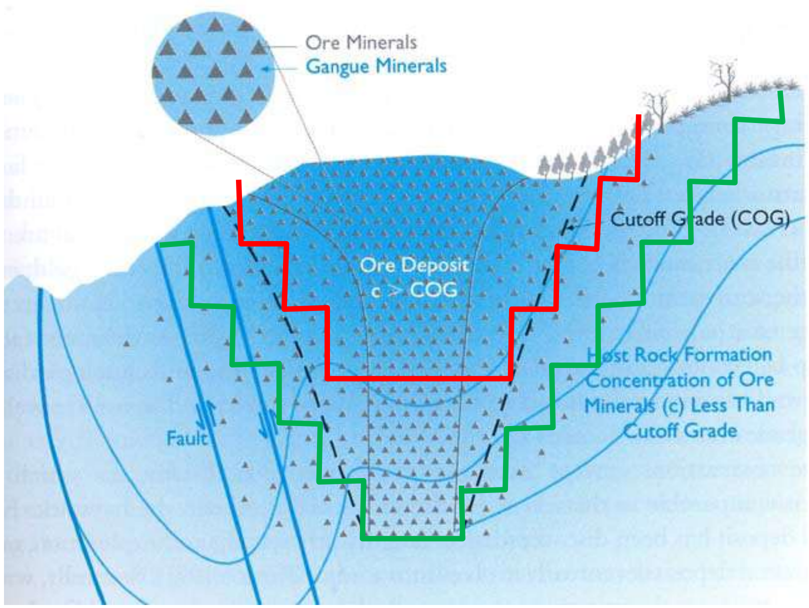
Pit slope versus rock strength

Pit depth versus pit diameter





Greater rock strength can support greater bench heights

resulting in:

i. a steeper pit,
ii. a lower stripping ratio and
iii. less waste rock.

A greater final pit depth requires a larger diameter pit (assuming rock strength and pit slope remains unchanged) .

resulting in

i. a higher stripping ratio and
ii. more waste rock.

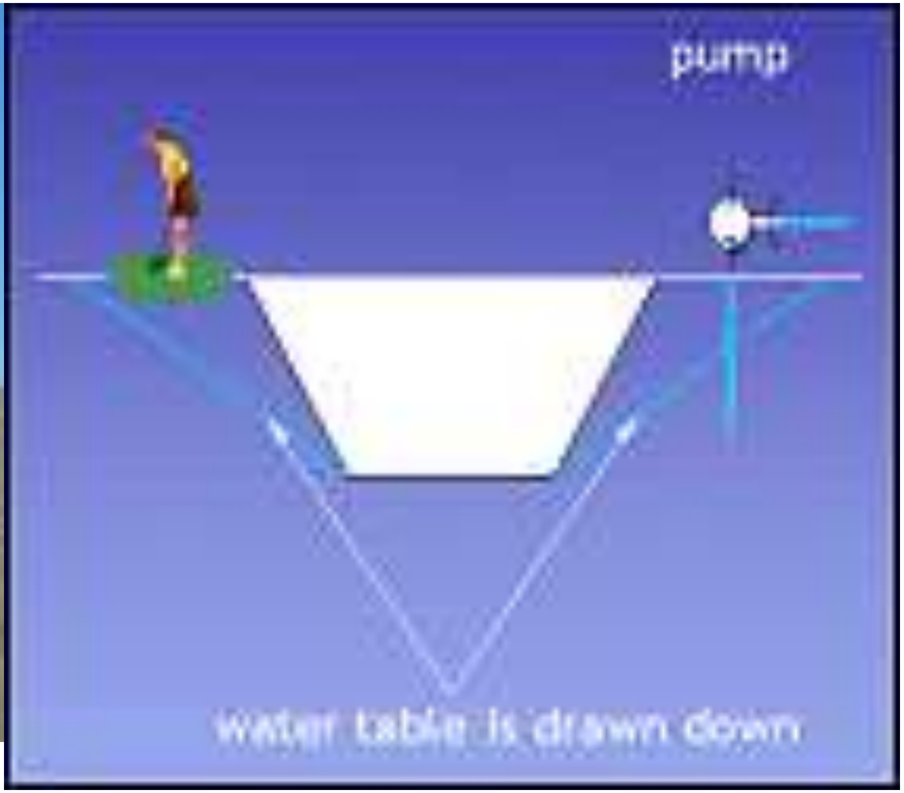
Figures from Spitz and Trudinger, 2009

The Depth Effect

- Note that as a pit goes deeper the stripping ratio increases until it reaches an economic limit.
- Rule 1 : as slope decreases S.R. increases
- Rule 2 : as depth increases S.R. increases

vi) Water Damage

- Pit most keep dry
- Dewatering also helps to keep the slopes dry and more stable.



Figures shows: In order to keep the pit dry, There are **40 dewatering pumps** around the Cortez pit pumping water out of the ground at a total rate of ***30,000 gallons per minute***.

What happens when water accumulates?

On October 9, 2003, a major landslide occurred, causing perhaps eight fatalities at the Grasberg Mine, Indonesia (Figures 8 and 9).

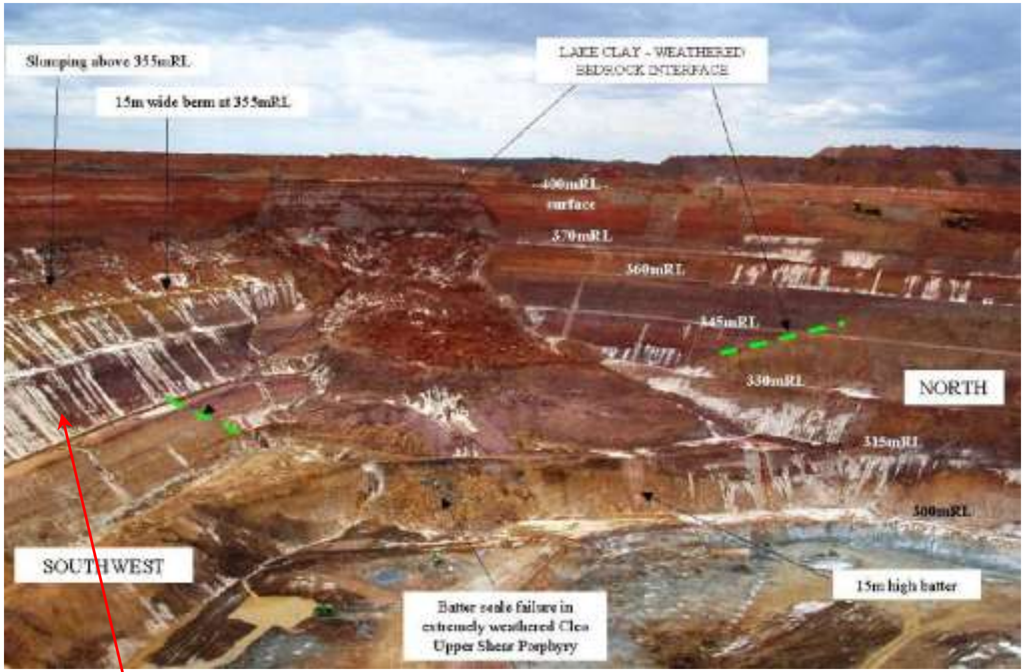
The ***accident*** was ***related to heavy rainfall and accumulation of water*** in the soil layer at the top of the pit.

Open-pit slope failure –case study –groundwater problems

<u>A slope failure occurred at the Cleo Open Pit</u> (Sunrise Dam Gold Mine, Western Australia) in December 2000. *At the time of failure the pit-floor was at 100 m depth below surface.*

<u>Two critical factors played a role in the failure</u>:

- The top of the water table is at a very high level: only 30 m below surface.
- A strong layer of younger clay sediments overlies weaker weathered bedrock.



Seepage and mineral precipitation

The failure is thought to be due to ***very high pore fluid pressures in the weathered bedrock*** that created an instability at the interface between the bedrock and the overlying clays, allowing a slippage to occur (Speight, 2002).

Figures modified from Speight, 2002.

1.8) Open-pit mining sequence

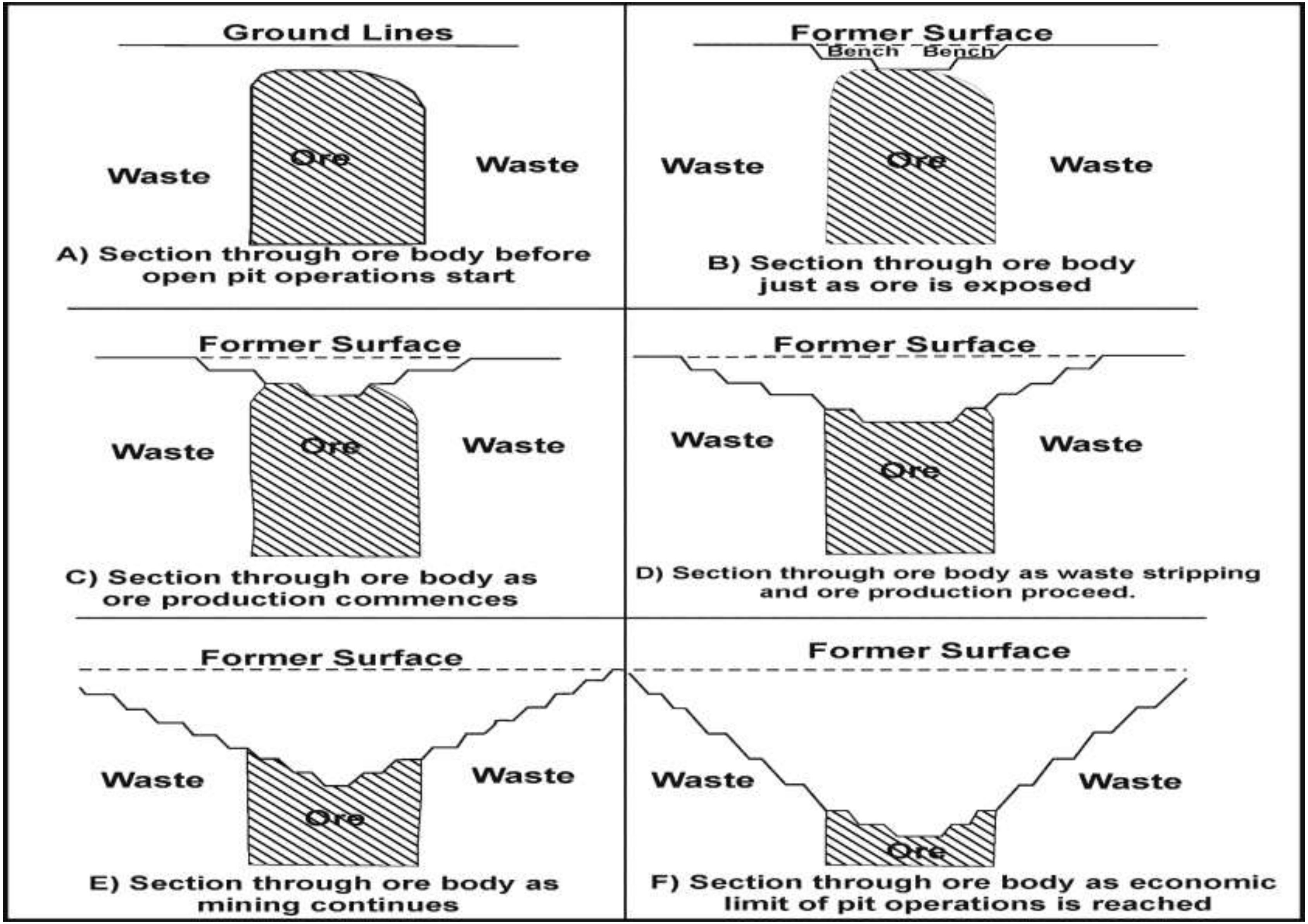


Figure 2.8 Open-pit mining sequence (for pipe-like orebody)

1.9) Various open-pit and orebody configurations

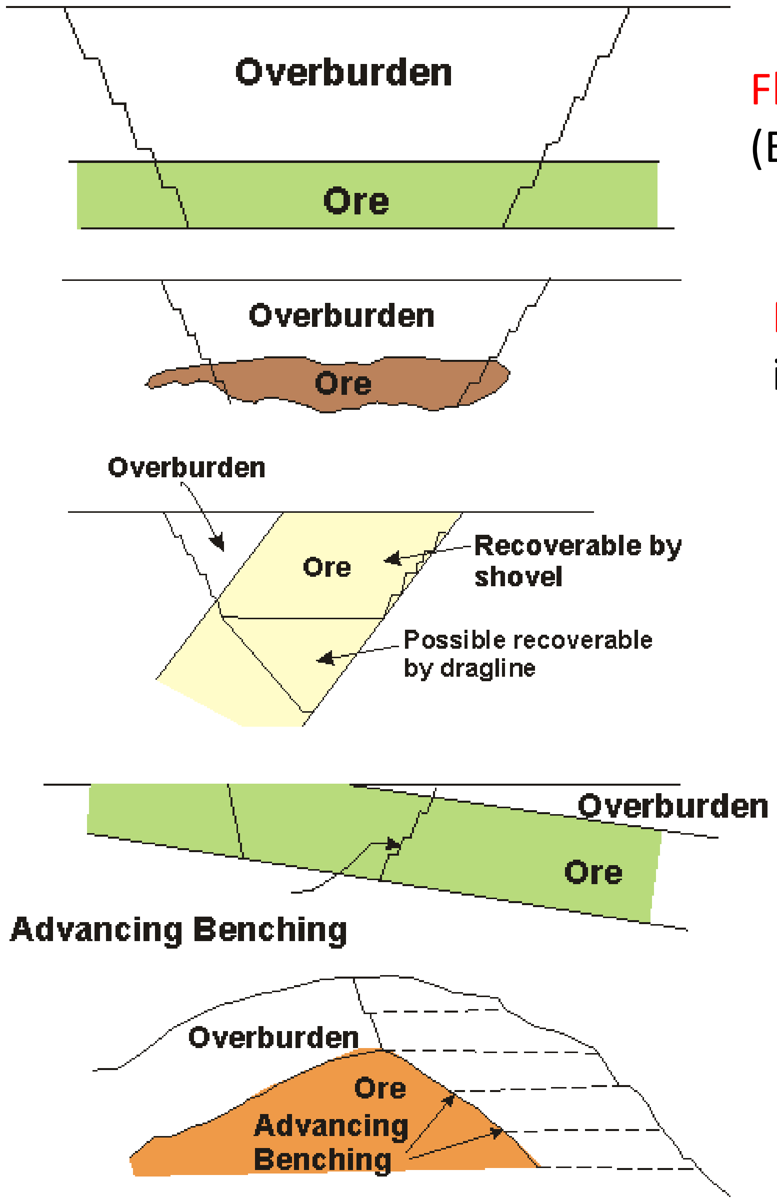


Figure from Hartman and Mutmansky, 2002.

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).