Mining

- *Any excavation where any operation for the purpose of searching for or obtaining minerals is carried out is called a Mine (Mines Act, 1952).*
- *Process of digging into the Earth for extraction of minerals.*

Second most primary and basic industries of human civilization after Agriculture

Evolution of Mining Technology

Without knowledge of the past, there is no future - Wim Grommen

Stone Age

Earliest Miner – Prehistoric Hominid

Loose rock for digging

Practice of Thermal-stress methods

Iron Age (2nd Millennium BC)

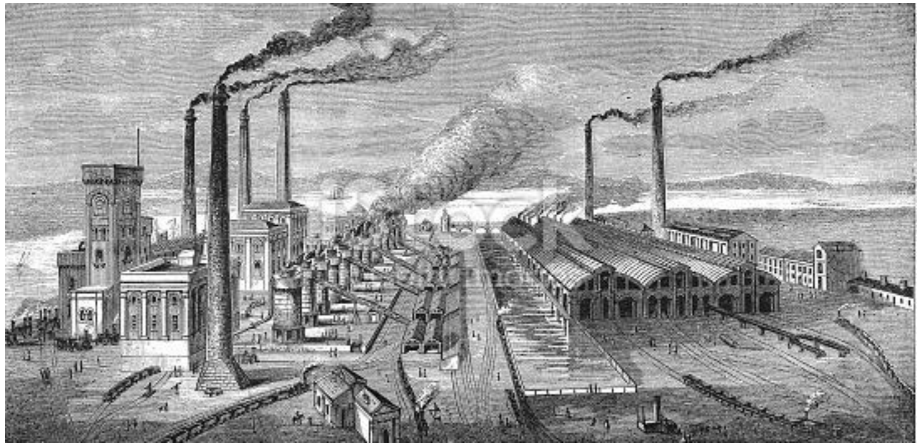
9th century CE to late 1500s

Iron tool was used to dig deeper holes extending the natural cracks

For three centuries: **Pick and wedge era**

Up to early 19th century: **Hand-labour era – Manual Hammering**

Late Iron Age lasted into **Industrial Revolution**



Source: nationalgeographic.com; alamy.com

Evolution of Mining Technology

Middle of 19th century

Search for a mechanical equipment has begun

New drilling developments were made

Improvements in rock tools and material compositions

Early 20th century
Use of electro-hydraulic equipment could be witnessed

21st Century

Use of Artificial Intelligence & Automation is booming

Source: alamy.com; epiroc

Minerals

Mineral is a
- *Naturally occurring substance*
- *Has a definite chemical composition*
- *Has Physical characteristics*

Uses
- *Tools and Utensils*
- *Weapons*
- *Ornaments and Decorations*
- *Currency*
- *Structures and Devices*
- *Energy*
- *Machinery*
- *Nuclear Fission*

Rock

Ore

Metallic Ores
- *Ores of ferrous metals*
  - *Iron, Manganese, Molybdenum and Tungsten*
- *Base Metals*
  - *Copper, Lead, Zinc, Tin*
- *Precious Metals*
  - *Gold, Silver, Platinum*
- *Radioactive Metals*
  - *Uranium, Thorium, Radium*

Non Metallic Ores
- *Industrial Minerals* - *Phosphate, Potash, Stone, Sand, Gravel, Sulfur, Salt, Industrial Diamond*

Mineral / Fossil Fuels
- *Coal*
- *Petroleum*
- *Natural Gas*
- *Uranium*
- *Marginal Sources*
  - *Lignite, Oil, Shale, Tar,*
  - *Sand, Coalbed Methane*

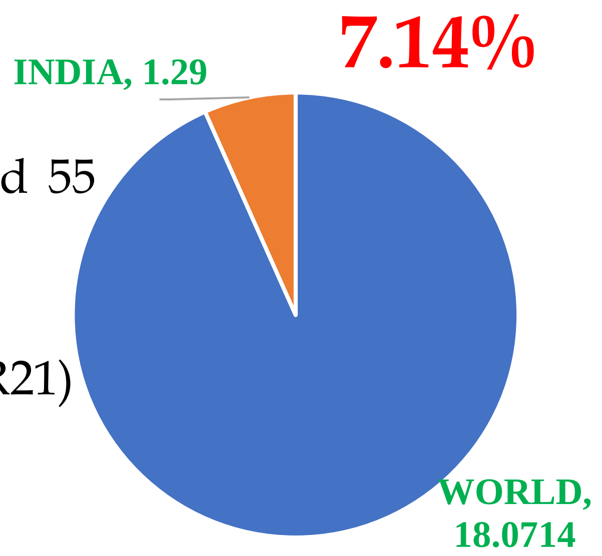
Metalliferous Mine (MMR,1961) – includes every mine other than a coal or an oil mine

Mining Scenario

Over 70 major commodity minerals are being mined worldwide (WMP@2019)

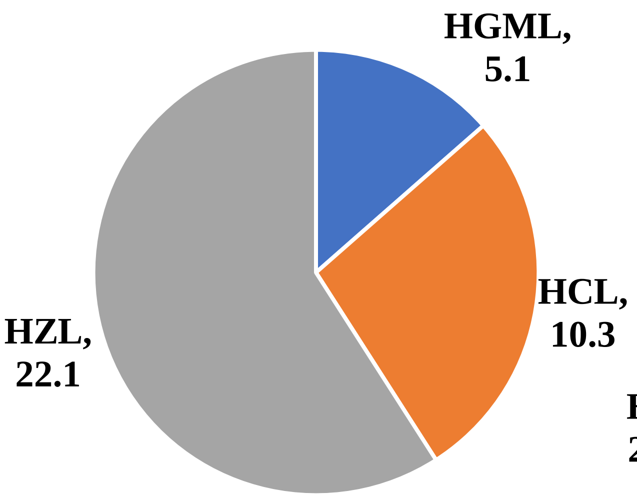
India produces - **95 minerals** (4 fuel, 10 metallic, 23 non-metallic, 3 atomic, and 55 minor minerals).

Total value of mineral production ≃ **Rs.1,90,389 crores** for FY 2021-22 (MoM AR21)

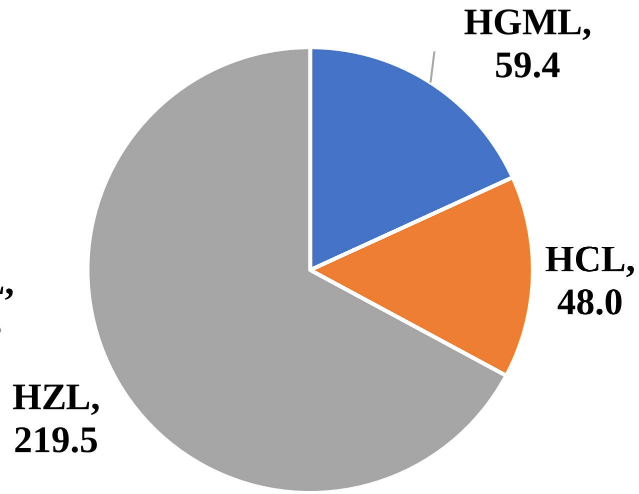


Mineral Production, Gigatons

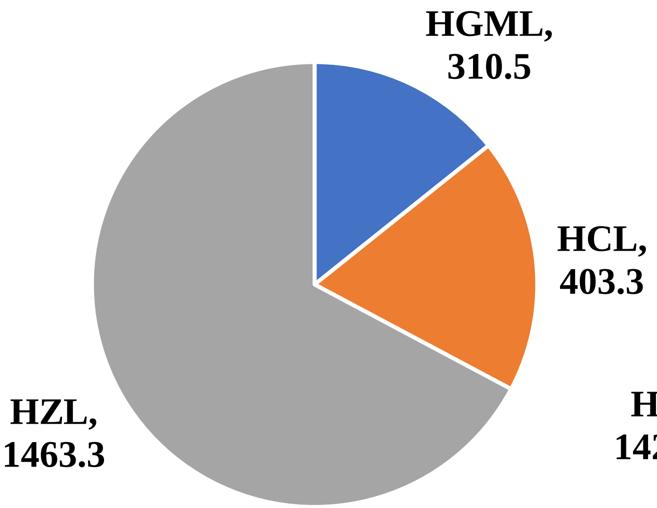
By FY 2027



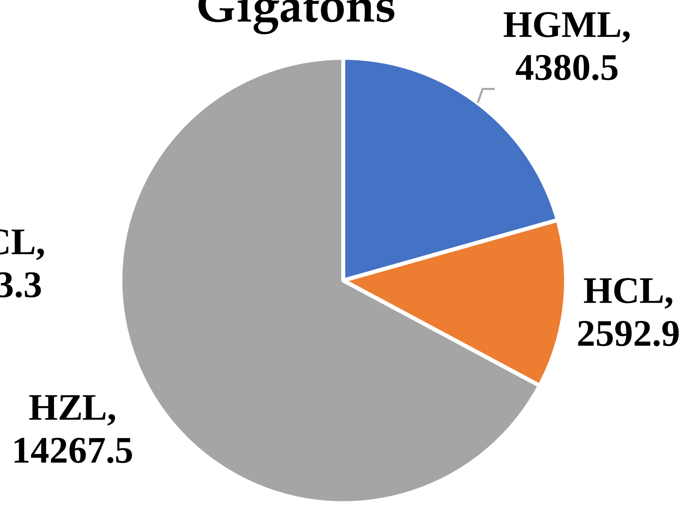
Production Requirement, MillionMT (37.5)



Development Length, km (326.94)



Drilling for Support, km (2177.9)



Face Drilling, km (21,240.9)

Mining Methods

Surface

- *Mechanical Extraction Method*
- *Benches or Steps*
- *Single Face – Quarrying, Augering, Open Cast Mining*
- *Aqueous Extraction Methods – Placer, Hydraulicking, Dredging, Solution Mining*

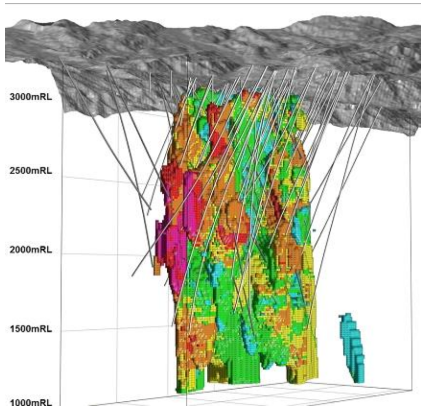
Underground

- *Unsupported*
- *Supported*
- *Caving*

The mining method is selected to:

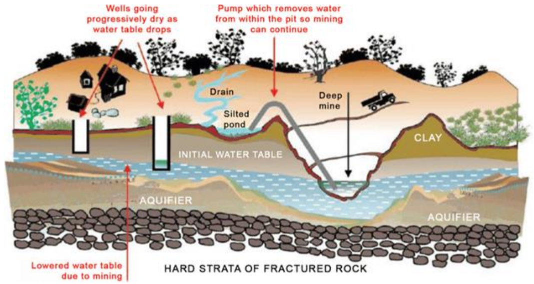
- ***Optimise rate of production***
- ***Optimize net present value***
- ***Generate maximum internal rate of return***

Planning Considerations vis-à-vis Method Selection



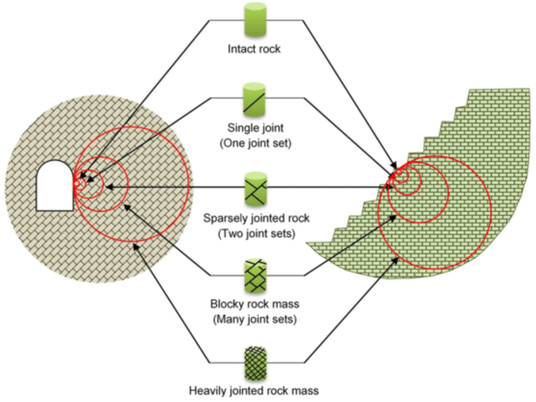
Spatial characteristics of deposit

- ***Size*** *(dimensions)*
- ***Shape*** *(tabular, lenticular, massive, irregular)*
- ***Attitude*** *(inclination, dip)*
- ***Depth*** *(mean, extreme values, stripping ratio)*



Geologic and hydrologic conditions

- ***Mineralogy, petrography, chemical composition*** *(primary, by-product minerals)*
- ***Deposit structure*** *(folds, faults, discontinuities, intrusions)*
- ***Planes of weakness*** *(joints, fractures, cleavage)*
- ***Uniformity, alteration, weathering***
- ***Groundwater and hydrology*** *(occurrence, flow rate, water table)*



Geotechnical Properties (Soil & Rock)

- ***Elastic properties*** *(strength, modulus of elasticity, Poisson's ratio)*
- ***Plastic or viscoelastic behaviour*** *(flow, creep)*
- ***State of Stress*** *(original, modified)*
- ***Consolidation, Compaction, and Competence***
- ***Physical properties*** *(specific gravity, voids, porosity, permeability, moisture content)*

Planning Considerations vis-à-vis Method Selection

Economic Considerations

- ***Reserves*** *(tonnages and grades)*
- ***Production rate*** *(output per unit time)*
- ***Mine life*** *(operating period for development and exploitation)*
- ***Productivity*** *(output per unit of labor and time, tons/shift)*
- ***Comparative mining costs of suitable methods***

Technological Factors

- ***Mine recovery*** *(portion of deposit actually extracted)*
- ***Dilution*** *(amount of waste produced with ore)*
- ***Flexibility of method with changing conditions***
- ***Selectivity of method to distinguish ore and waste***
- ***Concentration or dispersion of workings***
- ***Capital, labor and mechanization intensities***

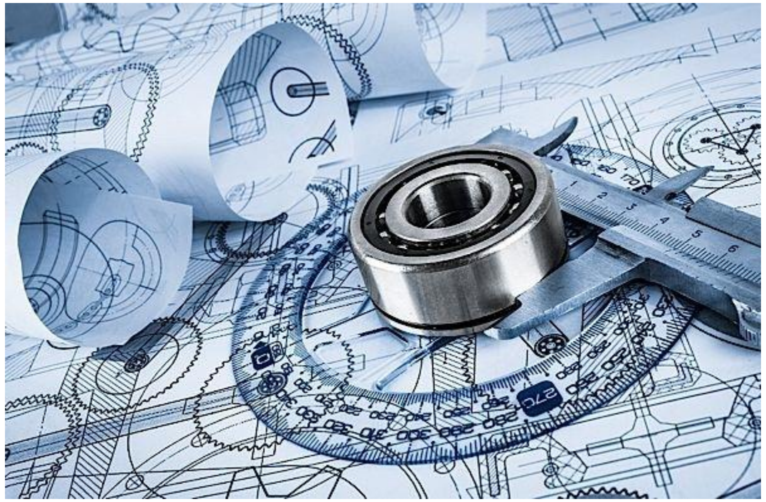
Environmental Concerns

- ***Physical, social-political-economic climate***
- ***Ground control***
- ***Subsidence or caving effects on the surface***
- ***Atmospheric control*** *(ventilation, quality control, heat and humidity control)*
- ***Work force*** *(recruitment, training, health and safety, living, community conditions)*

Stages of Mine Planning

Conceptual Study

Assess the physical characteristics and output quantities of number of mining methods



Engineering Study

Concepts are quantified and compared, resulting in firm designs and costs

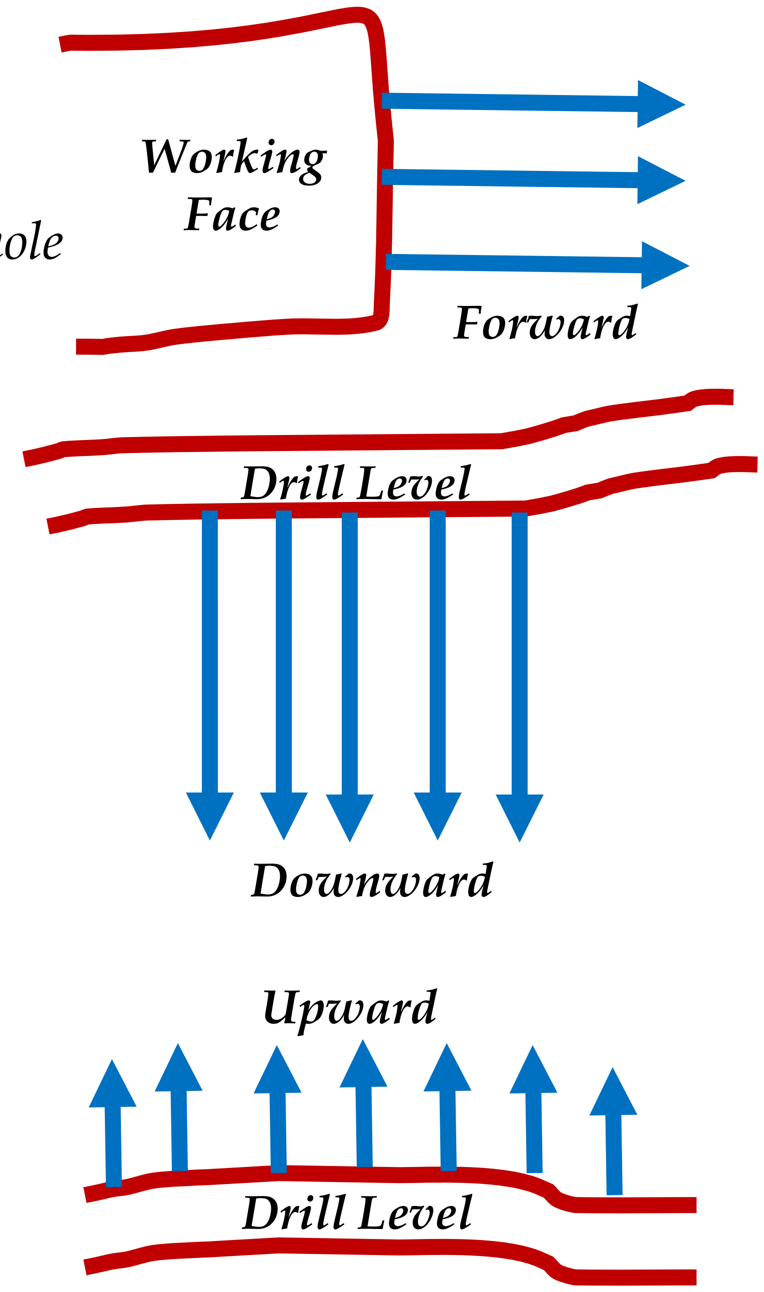
Detailed Design Study

Drawings and specifications for construction/mineral exploitation

Underground Metal Mining Methods

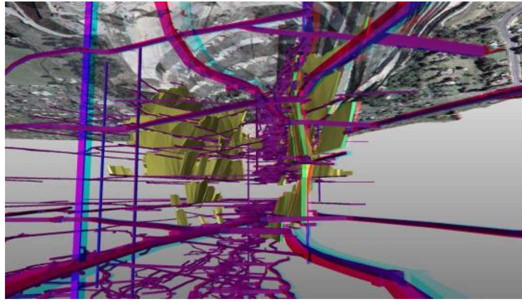
Open Stope

- ***Breast***
  - *Harring-bone*
  - *Footwall cross-cut and box hole*
  - *Room and Pillar*
  - *Scattered Pile*
  - *Breast Stope with Shifting Chute*
  - *Wide Ore Body*
- ***Underhand***
  - *Cornish*
  - *Wide Massive Veins – Heading*
  - *Glory Hole*
- ***Overhand***
  - *Overhand Bench – Stull Platform*
  - *Rill*
  - *Flat Back*
  - *Sublevel Stoping*



Filled Stope

- ***Waste Filled***
  - *Narrow Vein*
  - *Wide Vein*
  - *Cut & Fill*
  - *Crosscut*
  - *Resuing*
- ***Timbered***
  - *Square Set*
  - *Rill Face*
  - *Vertical Face*
  - *Dome*
  - *Flat Back*
  - *Underhand Square Set*
  - *Slice*
- ***Creep Set Timbered***



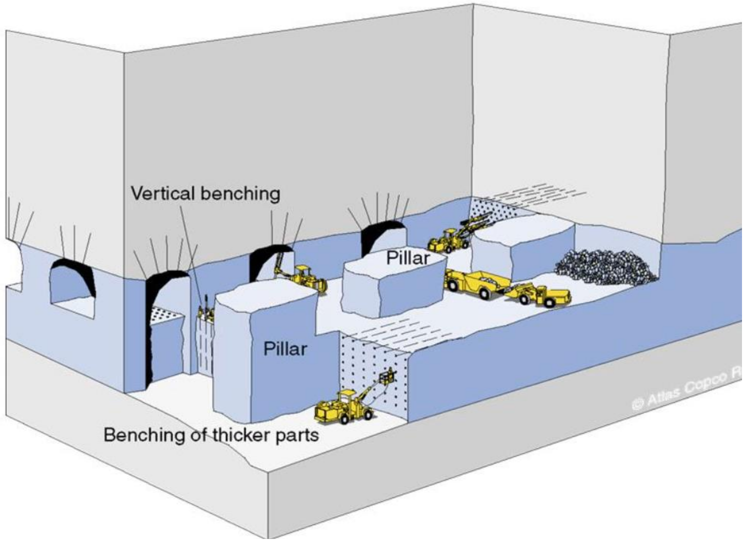
Shrinkage Stope

- ***Narrow Vein***
- ***Wider Vein***

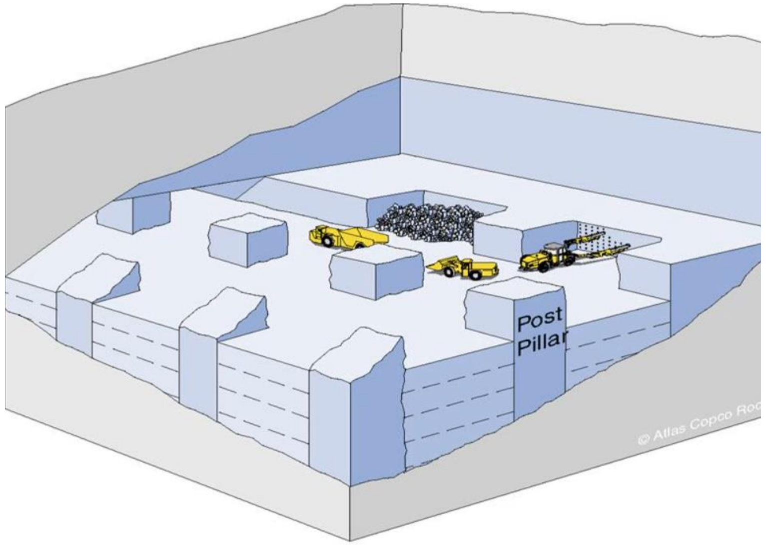
Caving

- ***Top Slicing***
- ***Sub Level Caving***
- ***Block Caving***

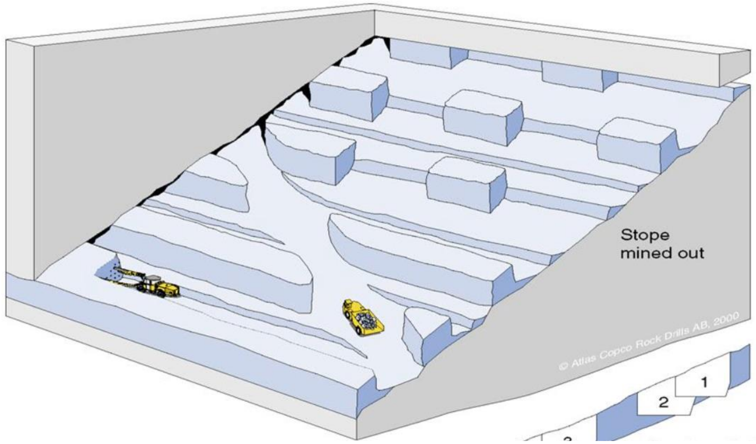
Underground Metal Mining Methods



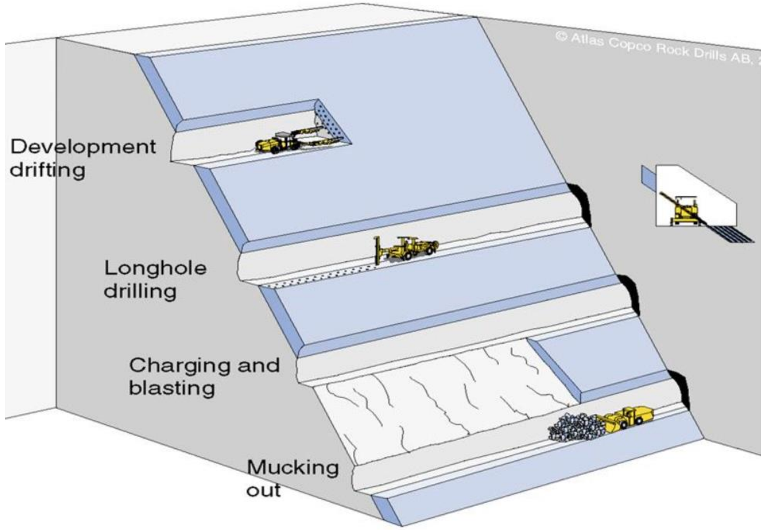
Classic Room and Pillar



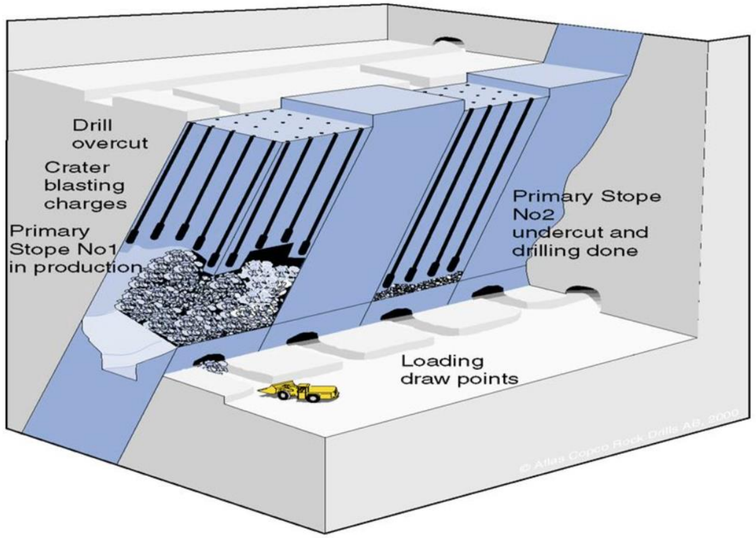
Post Room and Pillar



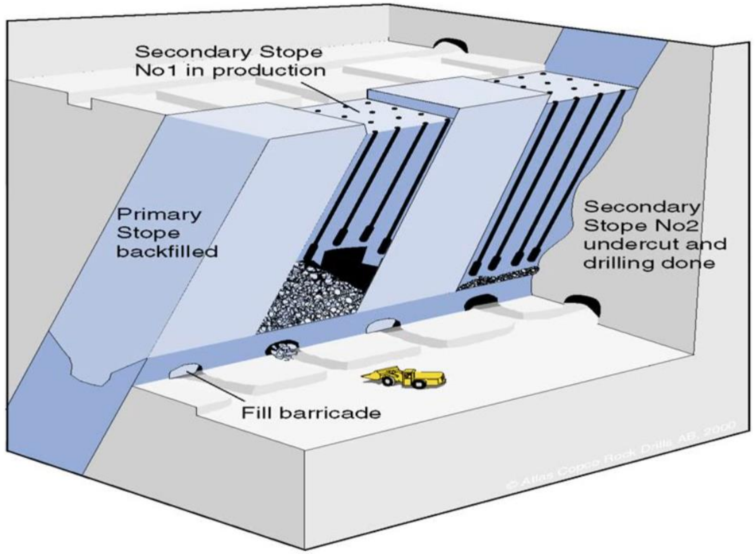
Step Room and Pillar



Narrow Vein with a Steep Dip

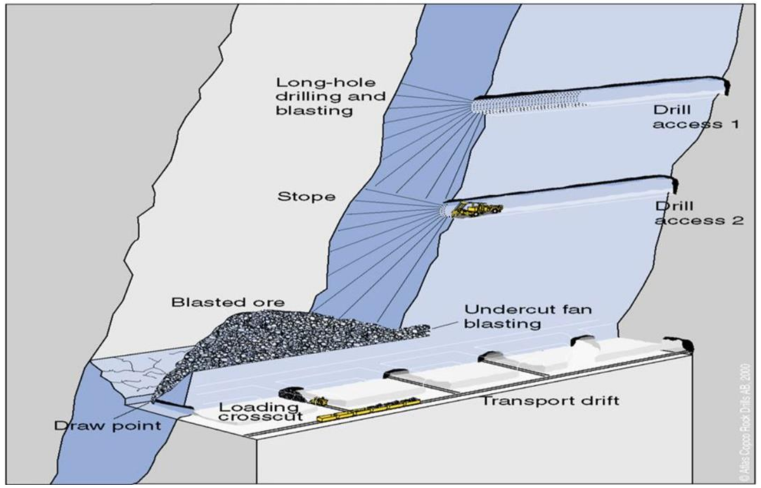


VCR Mining – Primary Stopes

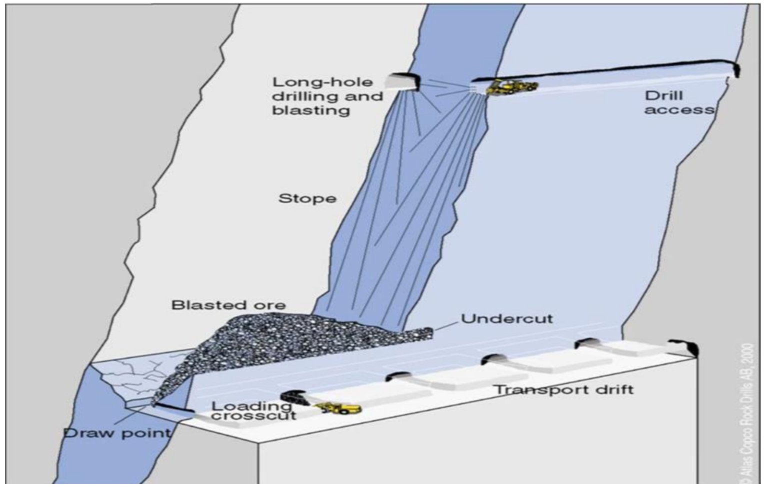


VCR Mining – Secondary Stopes

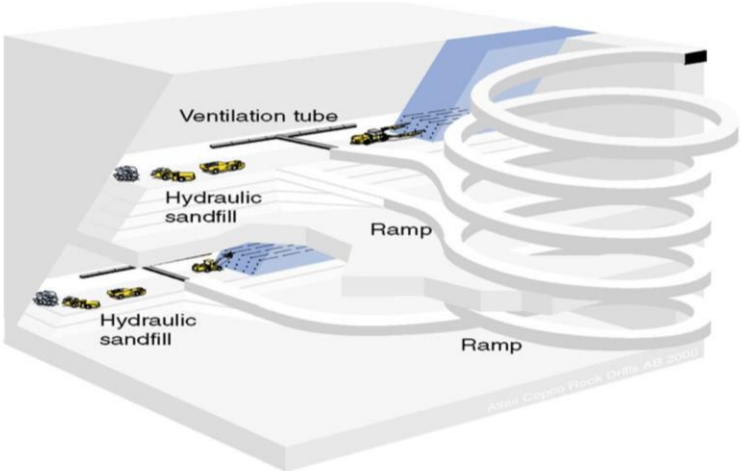
Underground Metal Mining Methods



Sublevel Open Stoping



Big Hole Open Stoping



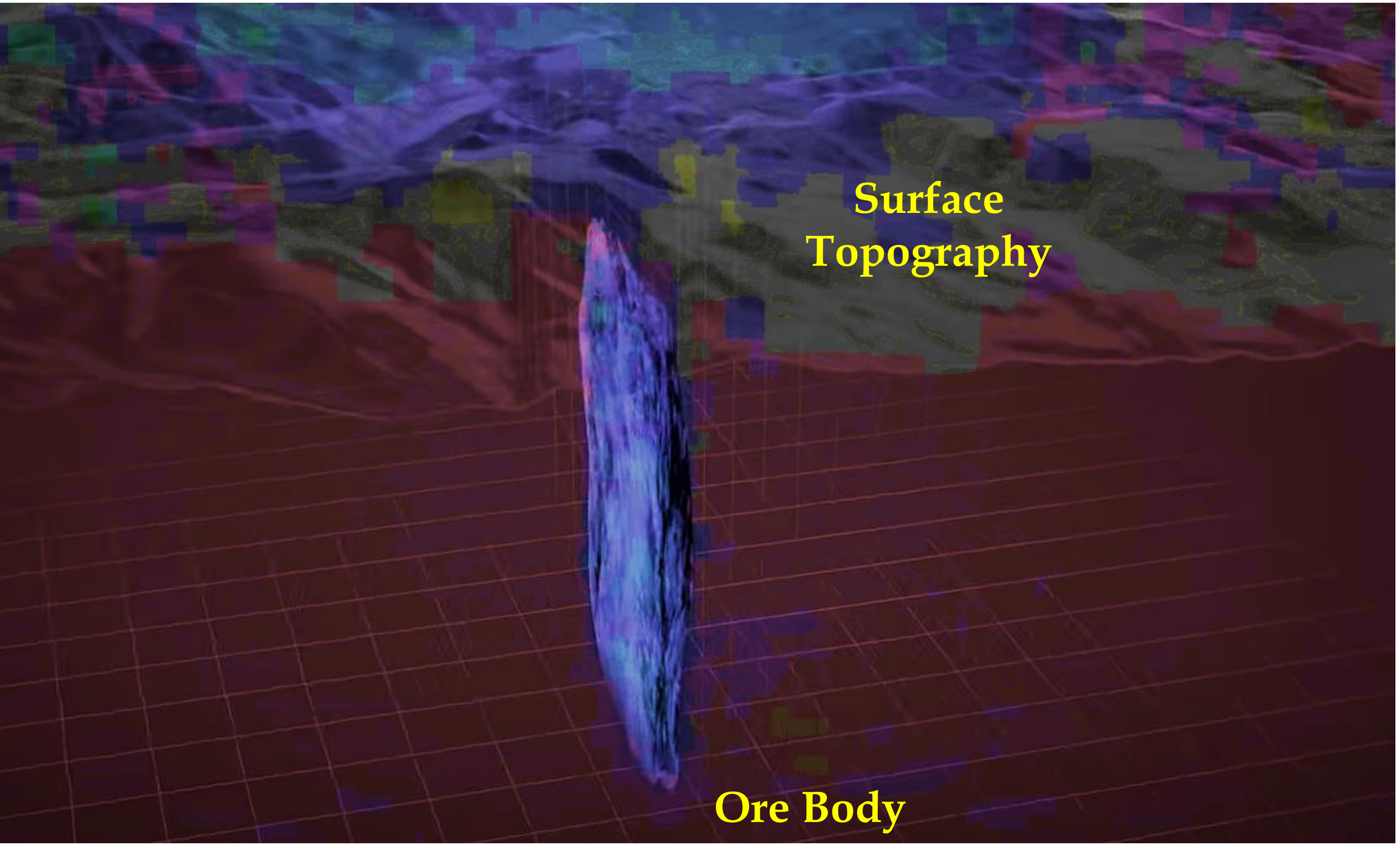
Cut and Fill

Underground Mining Methods – Review

Factor	Unsupported				Supported			Caving		
	Room and Pillar	**Stope and Pillar**	**Shrinkage**	**Sublevel**	**Cut and Fill**	**Stull**	**Square Set**	**Longwall**	**Sublevel Caving**	**Block Caving**
Ore strength	Weak to moderate	Moderate to strong	Strong	Moderate to strong	Moderate to strong	Fairly strong to strong	Weak to fairly weak	Any (should crush, not yield)	Moderate to fairly strong	Weak to moderate, cavable
Rock strength	Moderate to strong	Moderate to strong	Strong to fairly strong	Fairly strong to strong	Weak to fairly weak	Moderate	Weak to very weak	Weak to moderate, cavable	Weak to fairly strong, cavable	Weak to moderate, cavable
Deposit shape	Tabular	Tabular, lenticular	Tabular, lenticular	Tabular, lenticular	Tabular to irregular	Tabular to irregular	Any	Tabular	Tabular or massive	Massive or thick tabular
Deposit dip	Low, preferably flat	Low to moderate	Fairly steep	Fairly steep	Moderate to fairly steep	Moderate to fairly steep	Any, preferably steep	Low, preferably flat	Fairly steep	Fairly steep
Deposit size	Large, thin	Any, perferably large, moderately thick	Thin to moderate	Fairly thick to moderate	Thin to moderate	Thin	Any, usually small	Thin, large areal extent	Large, thick	Very large, thick
Ore grade	Moderate	Low to moderate	Fairly high	Moderate	Fairly high	Fairly high to high	High	Moderate	Moderate	Low
Ore uniformity	Fairly uniform	Variable	Uniform	Fairly uniform	Moderate, variable	Moderate, variable	Variable	Uniform	Moderate	Fairly uniform
Depth	Shallow to moderate	Shallow to moderate	Shallow to moderate	Moderate	Moderate to deep	Moderate	Deep	Moderate to deep	Moderate	Moderate

Cut and Fill Method

Conditions



- **Ore Strength**
  - Moderate to Strong

  (Less competent than unsupported methods)
- **Rock Strength**
  - Weak to fairly weak
- **Deposit Shape**
  - Tabular, irregular, discontinuous
- **Deposit Dip**
  - Moderate to fairly steep (35° to 90°),
  - Flatter deposits if ore passes are steeper than angle of repose
- **Deposit Size**
  - Narrow to Moderate width

  (2 m to 40 m), fairly large extent
- **Ore Grade**
  - Fairly high
- **Ore Uniformity**
  - Moderate, variable
- **Depth**
  - Moderate to deep

  (<1.2 to 2.4 km)

Evaluation

Advantages:

- Moderate productivity (10 to 20 tons / employee / shifts)
- Moderate production rate; moderate-scale method
- Permits good selectivity, sorting, can use waste as fill
- Low development cost
- Moderate capital investment, adaptable to mechanisation
- Versatile, flexible and adaptable
- Excellent recovery if pillars are mined (90 % to 100 %), low dilution (5 to 10 %)
- Surface waste can be disposed of underground as fill
- Moderately good safety record

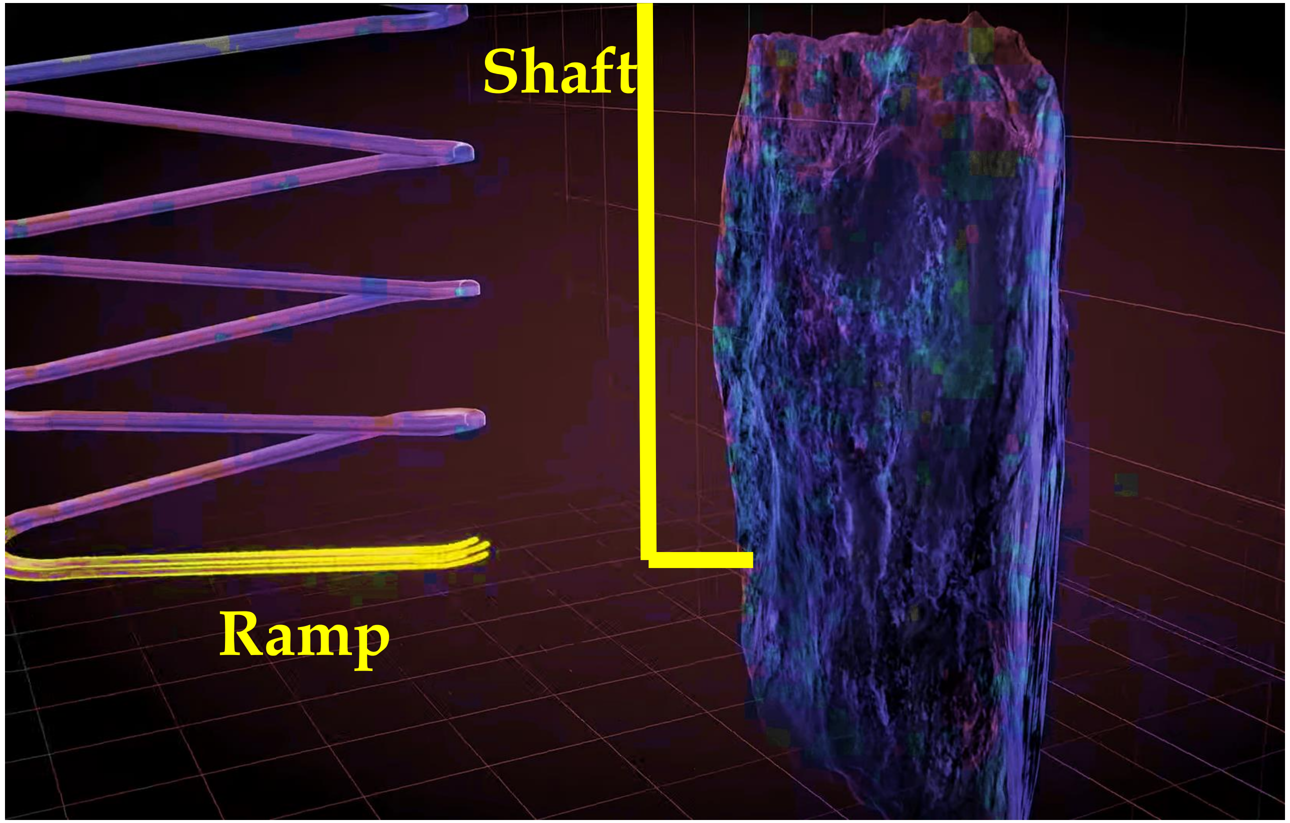
Disadvantages:

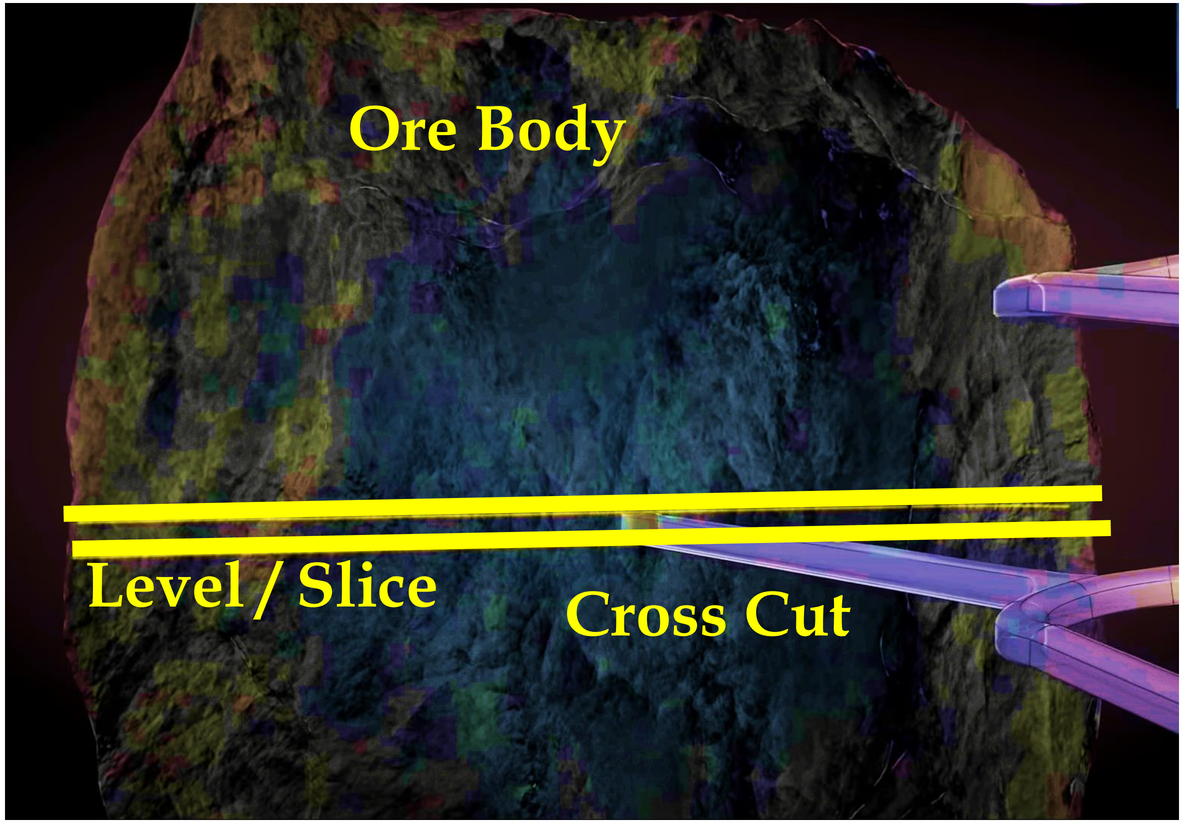
- Fairly high mining cost
- Costly handling of waste (approx. 50 % of mining cost)
- Filling complicates cycle, causing discontinuous production
- Must provide stope access for mechanized equipment
- Tends to be labor intensive, requiring skilled miners and close supervision
- Compressibility of fill risks some ground settlement and instability

Applications

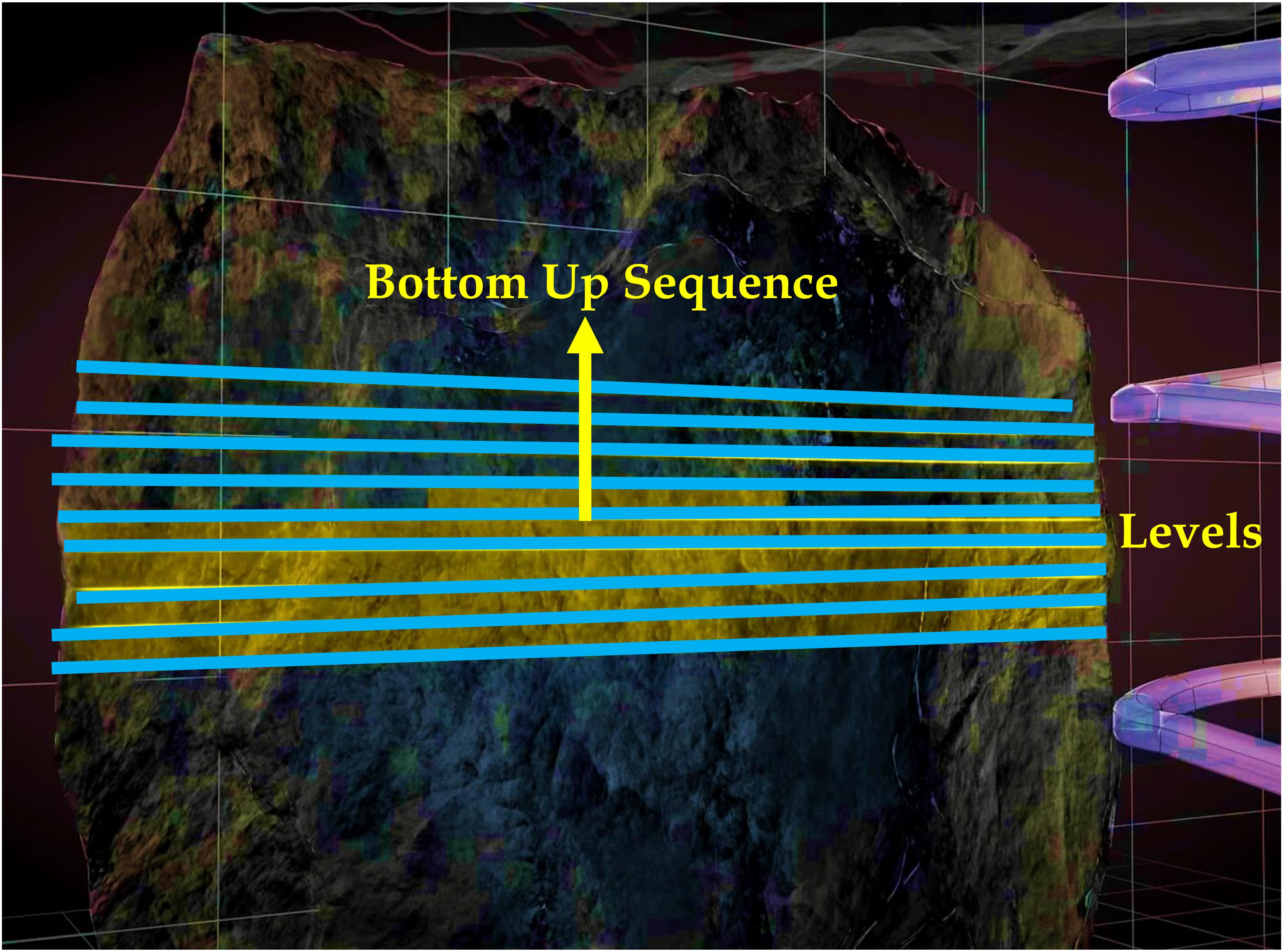
- **Copper – Magma, Arizona; Surda Mine, HCL, India**
- **Copper – Lead – Mt. Isa, Australia**
- **Gold – Homestake, South Dakota**
- **Nickel – Thompson, Manhatten; Sudbury, Ontario**
- **Silver – Star, ID**
- **Uranium – UCIL, India**

Access to Ore Deposits





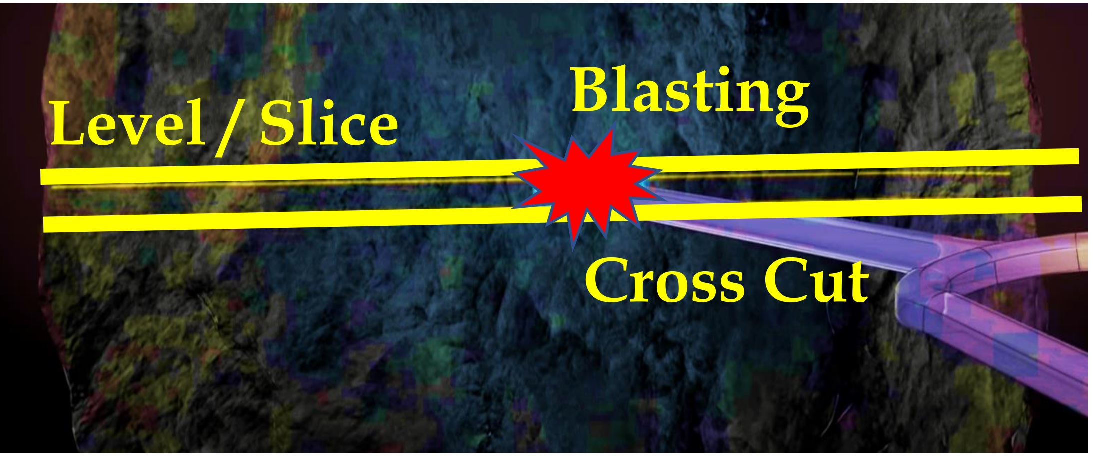
Ore Slices



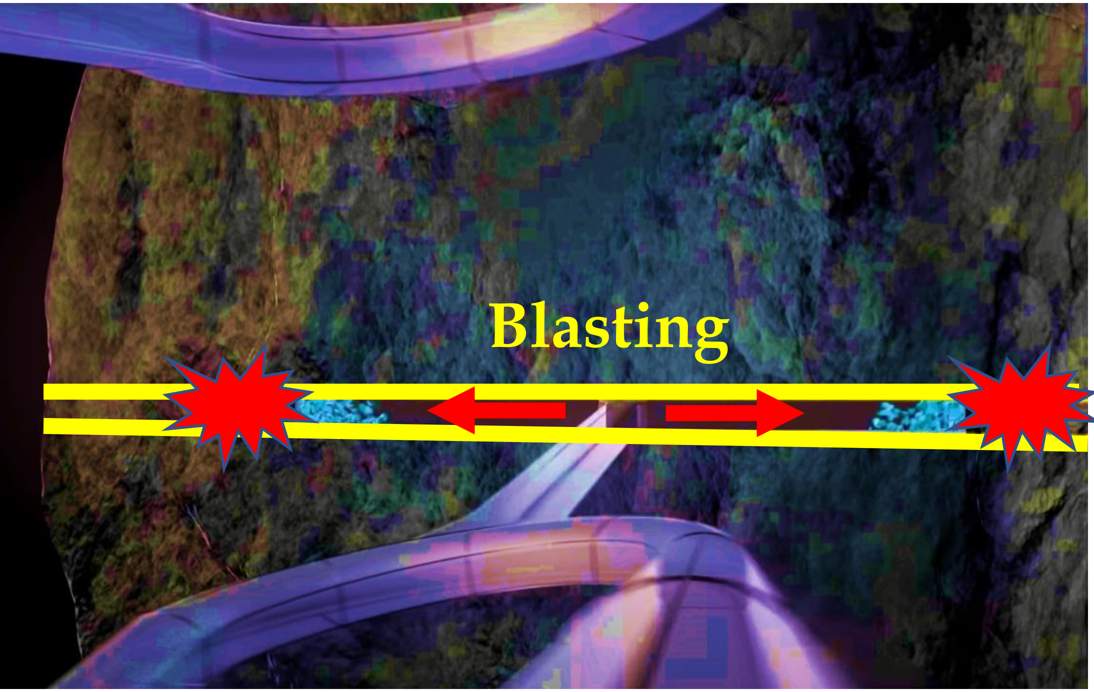
- Mining is carried out in Horizontal Slices along the ore body
- Bottom Slice - Mined First
- Bottom Up – Sequence
- Excavated Area – Backfilled
- Production Continues Upwards

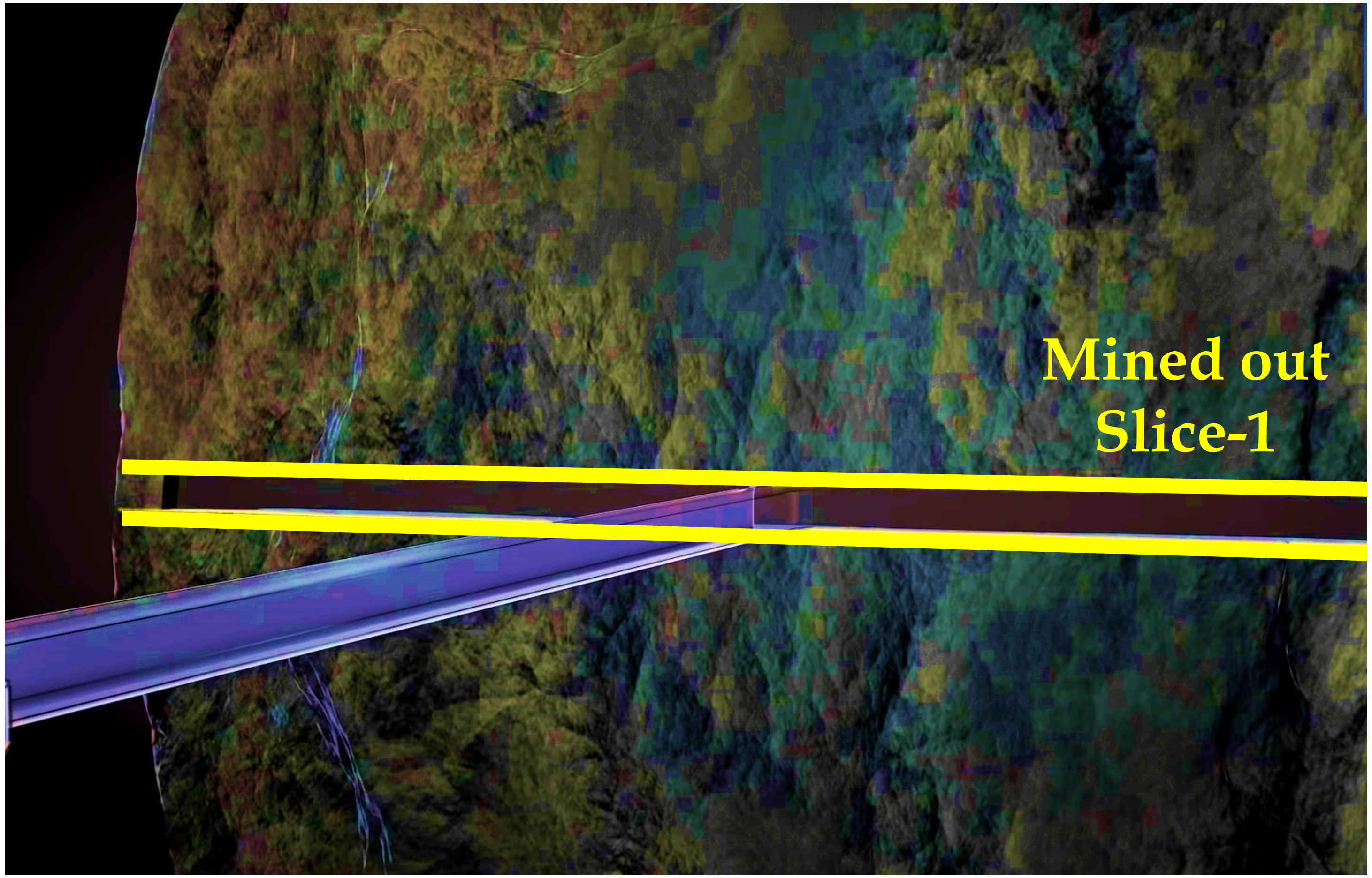
- *Variation : Underhand Cut and Fill*

Drifting & Ore Production



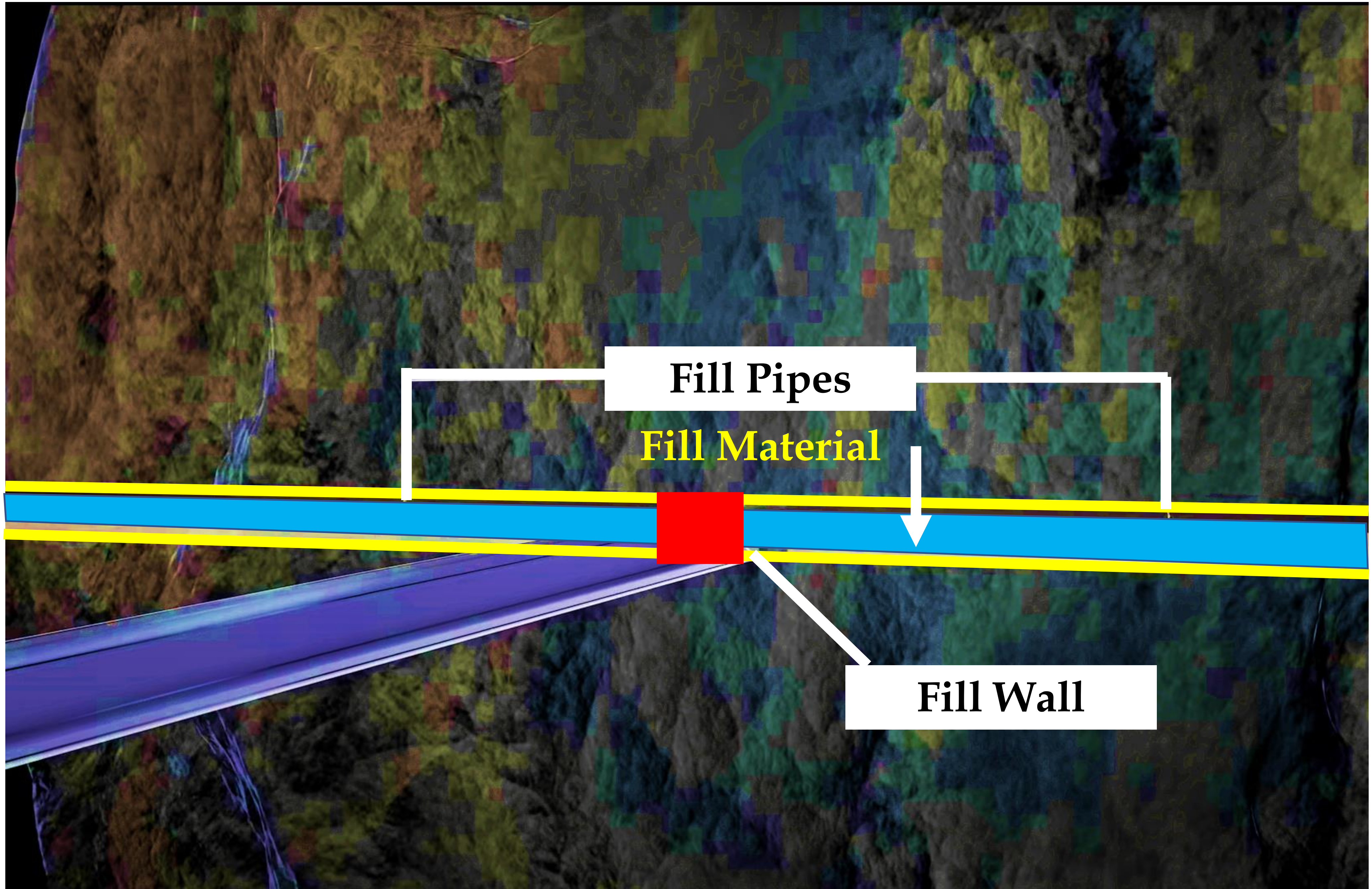
Production from Level 1





Mined out Slice-1 / Level 1

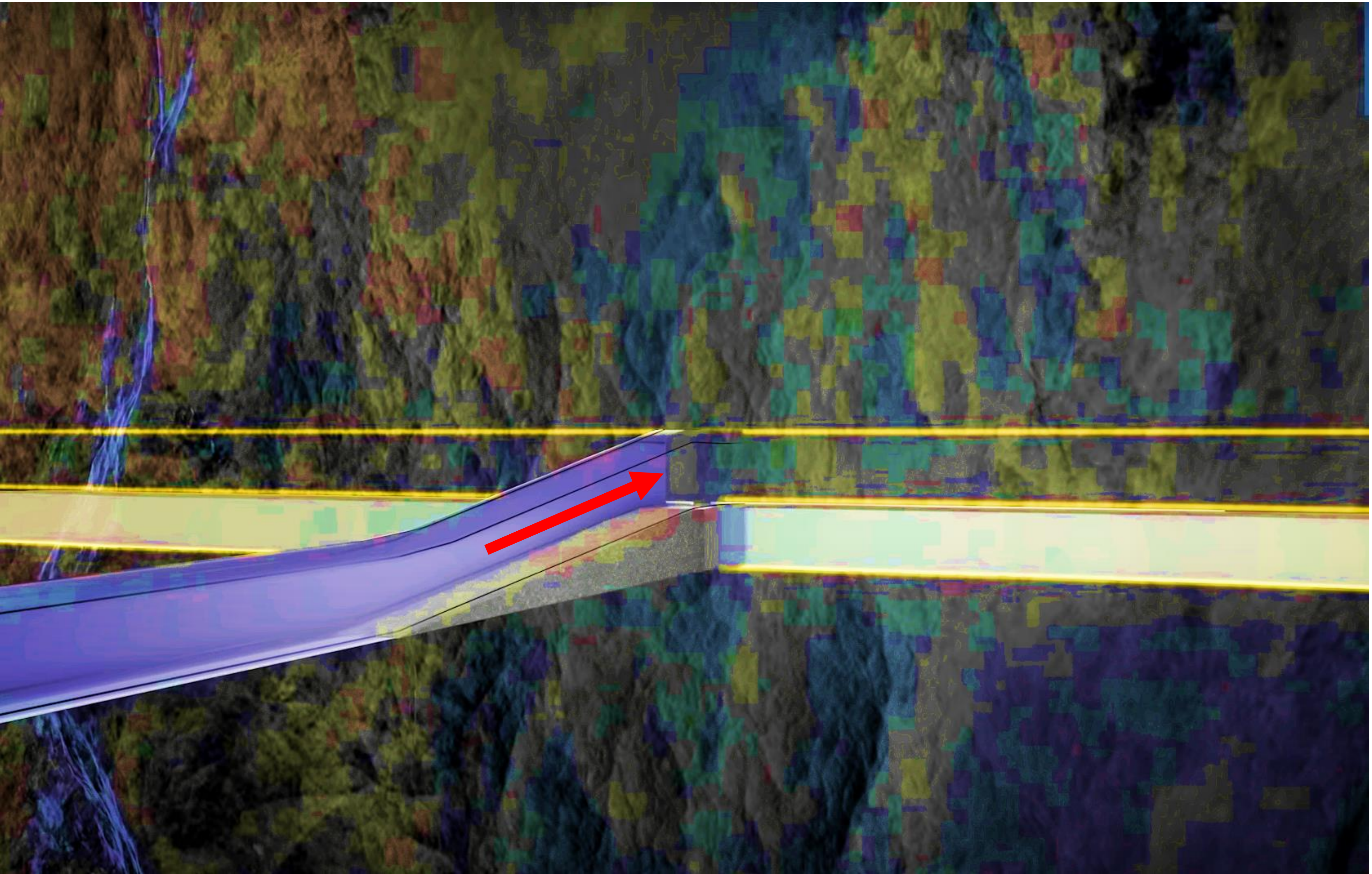
Backfill



- Mine waste such as ***mill tailings*** or waste rock from development can be ***utilised*** effectively

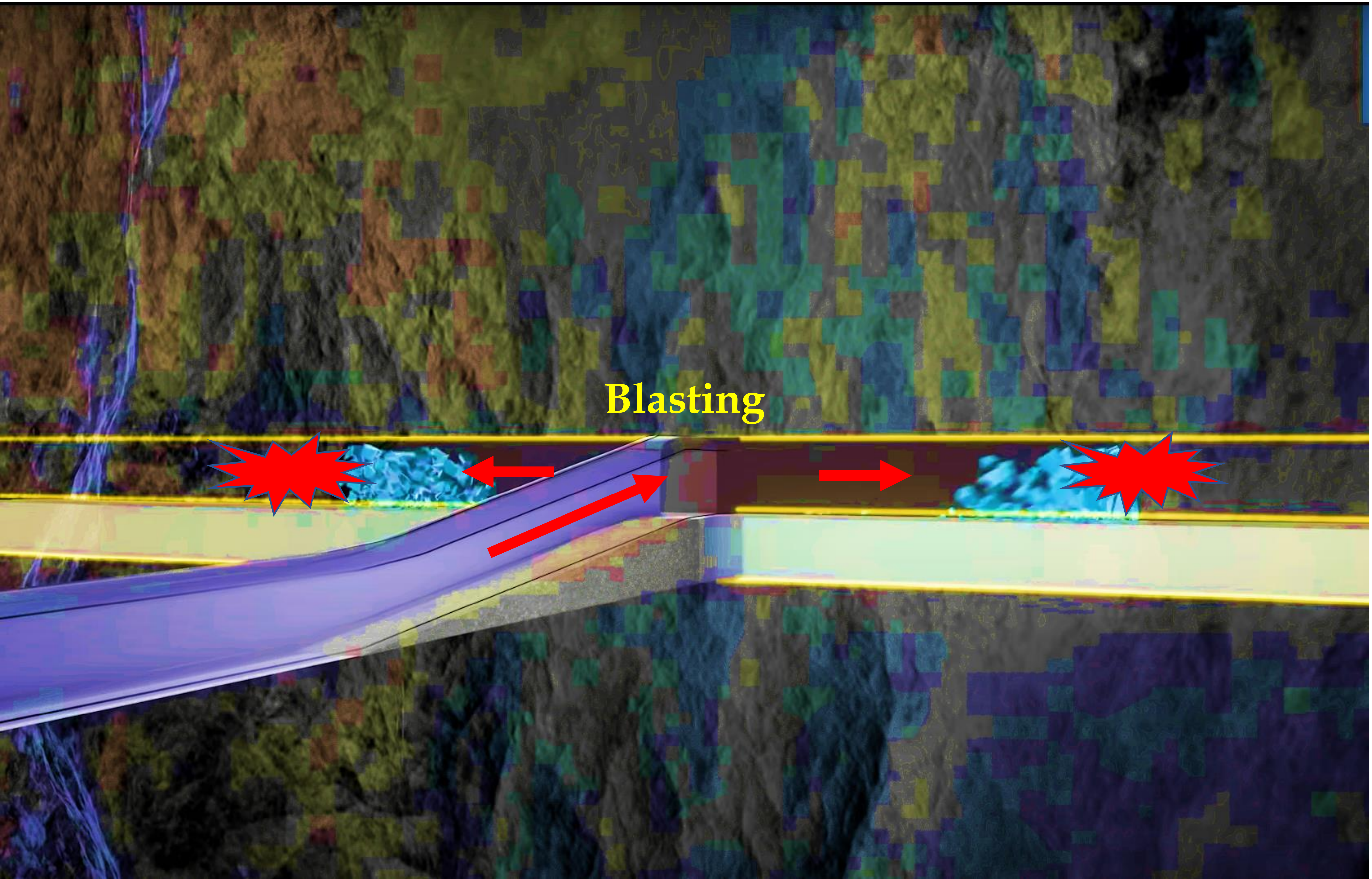
- Slice is now backfilled
- Void for the blasted rock is maintained
- Fill becomes the ***working platform*** for mining in next level

Access to Upper Slices



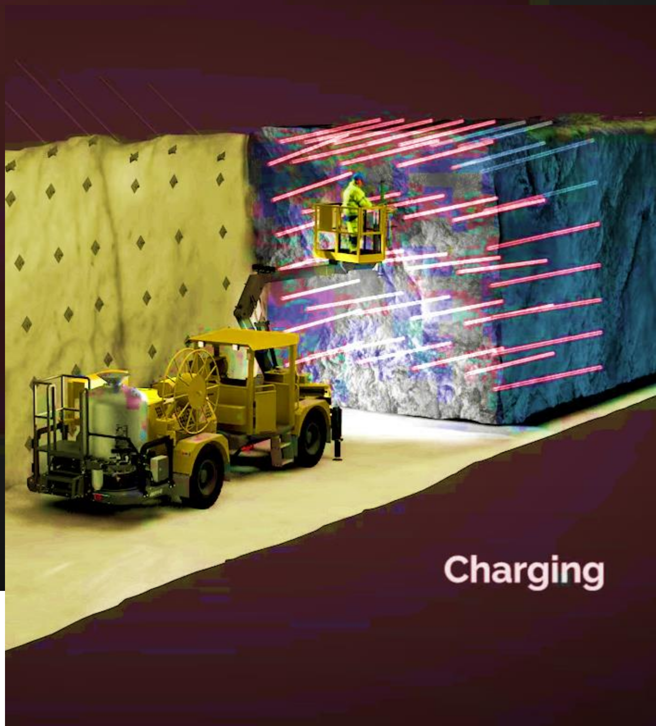
Back slashing – for providing access to upper slices within the stope

Production from Upper Slices

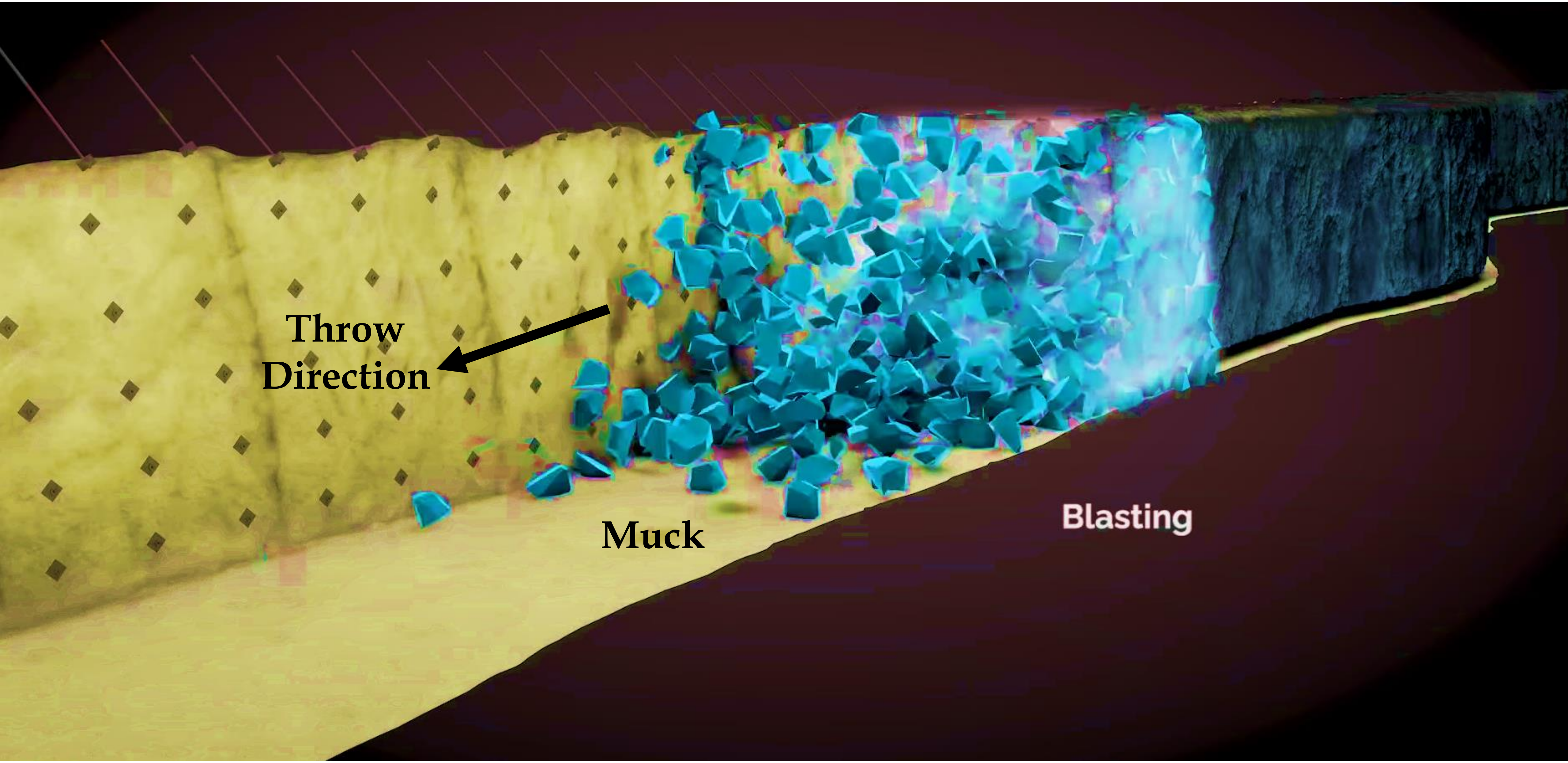


- Production from Slices continues till the stope is completed
- New access drive is created from the ramp to continue production from upper stopes

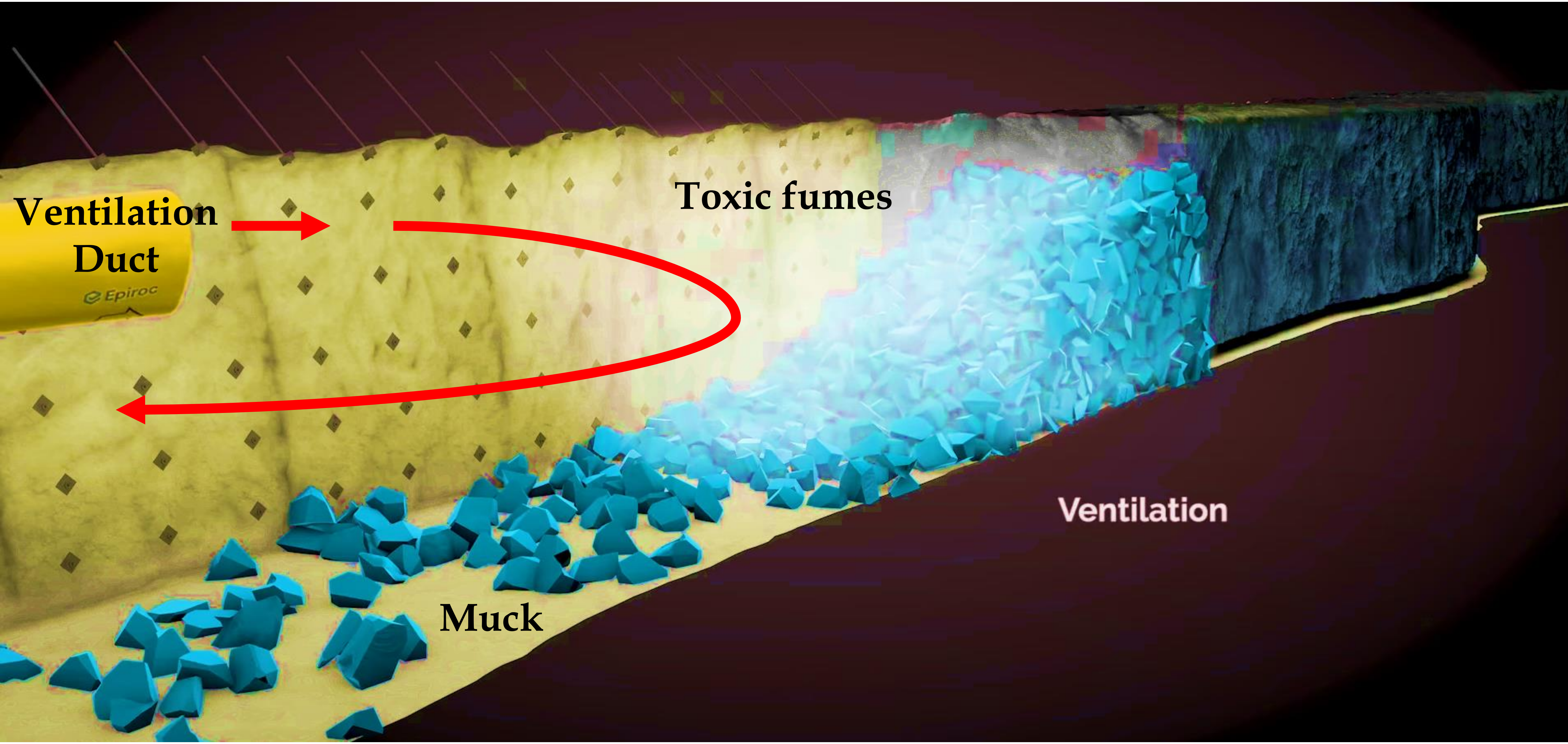
Drilling & Charging



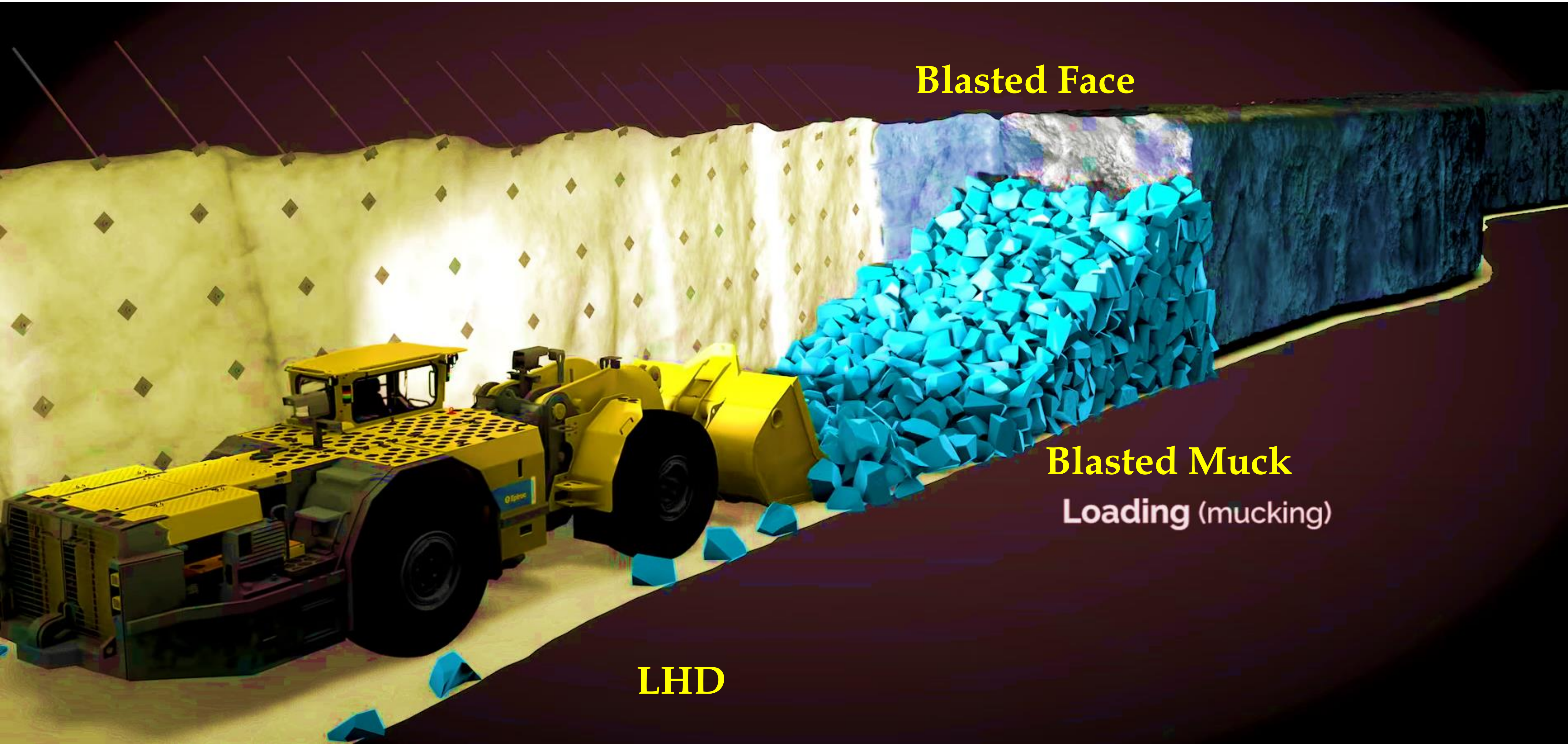
Blasting



Ventilation

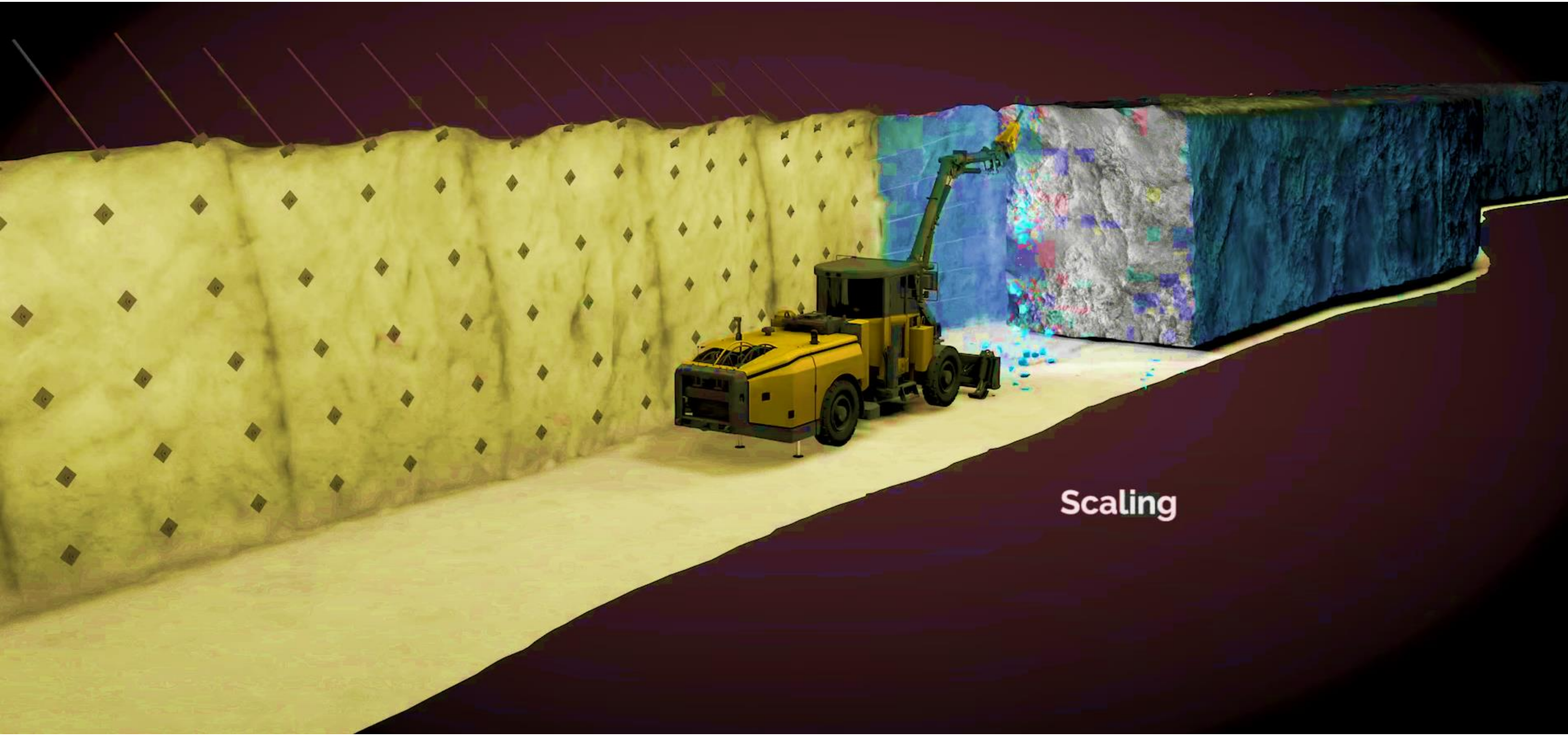


Loading

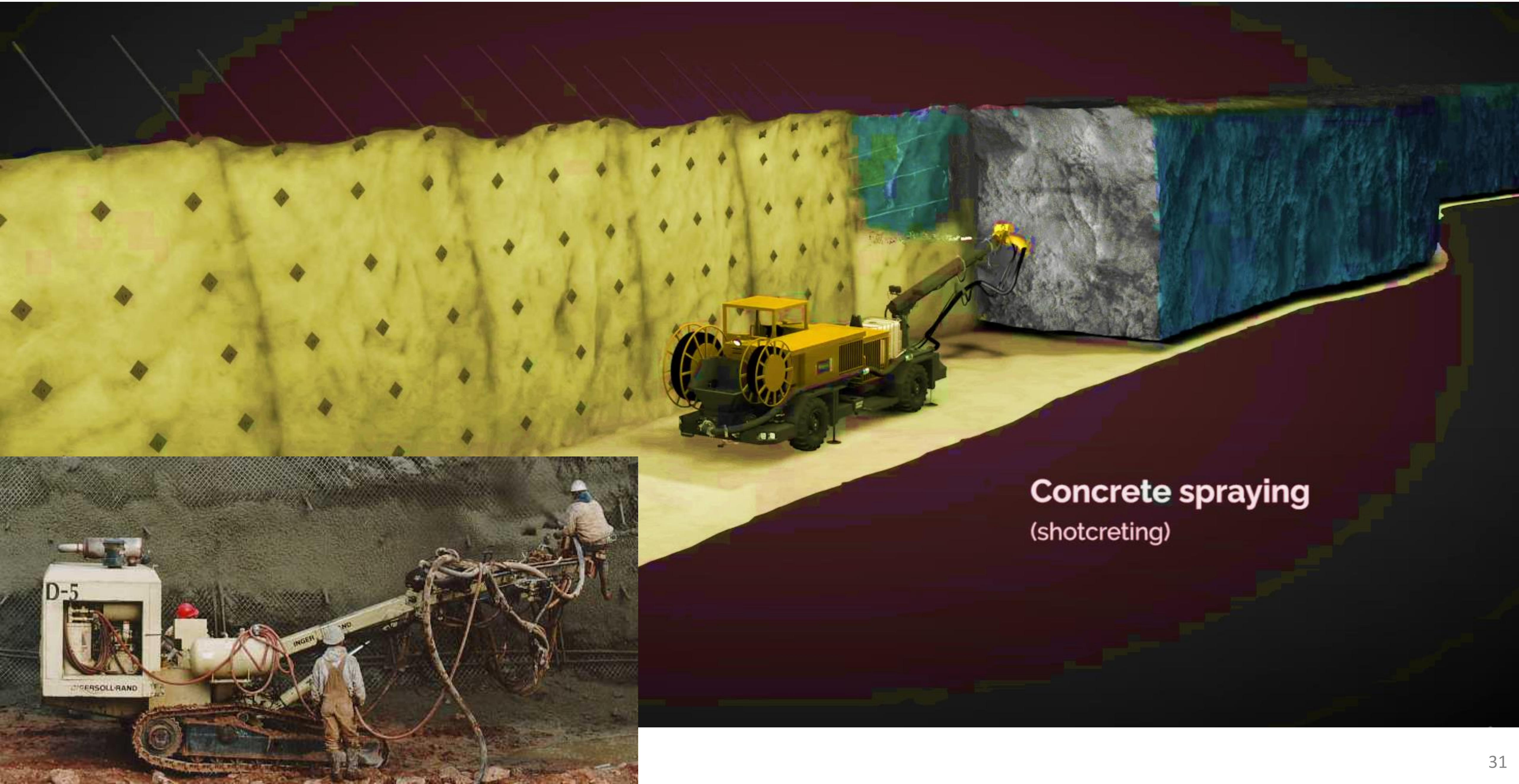


Broken ore is mucked out and loaded into trucks or ore pass

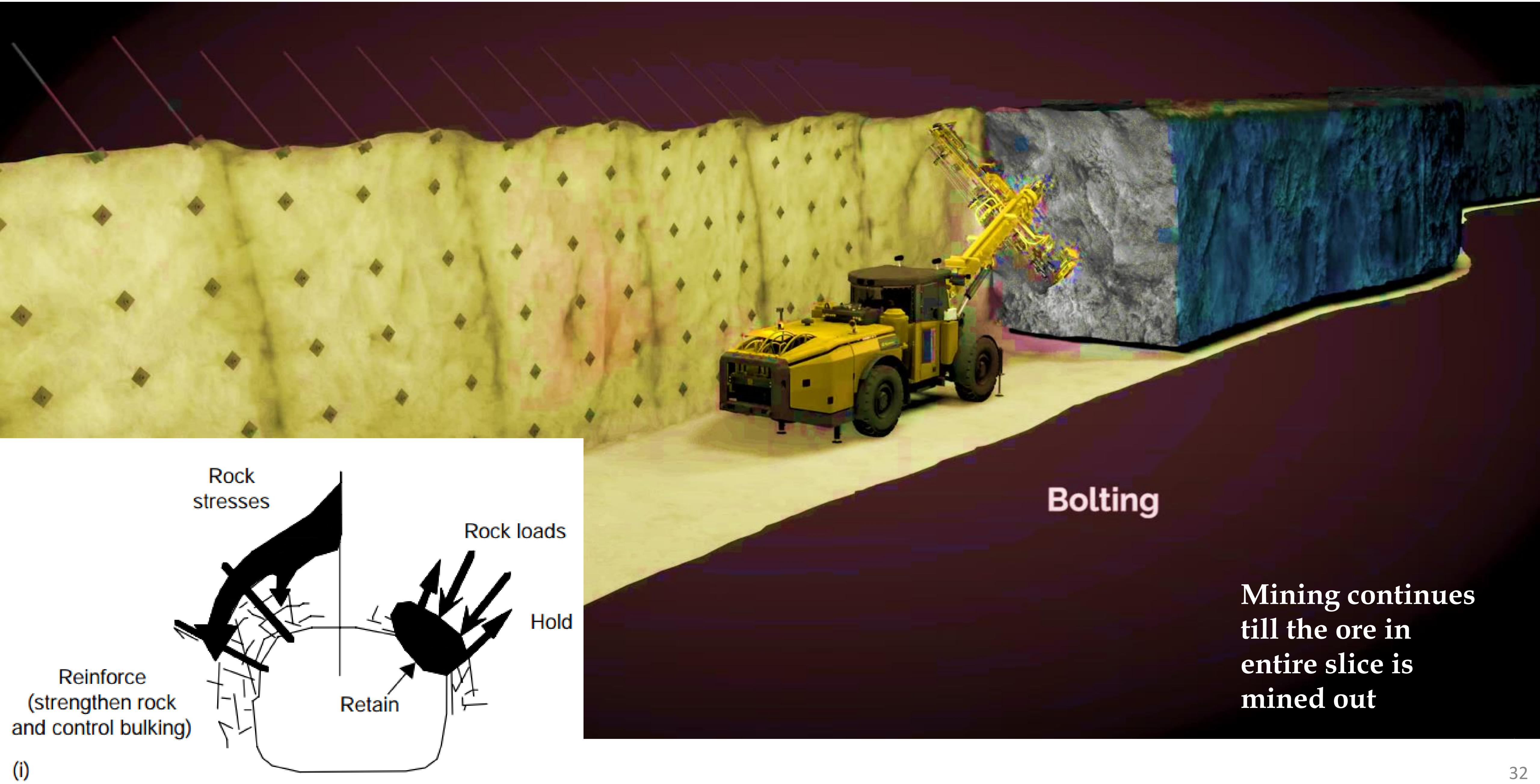
Scaling



Shotcreting

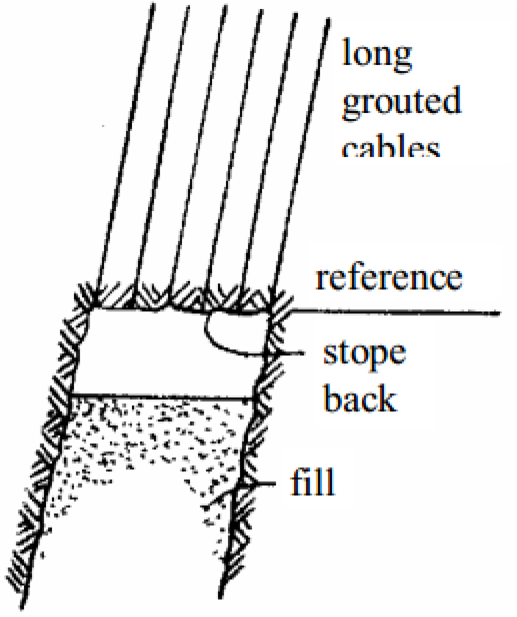


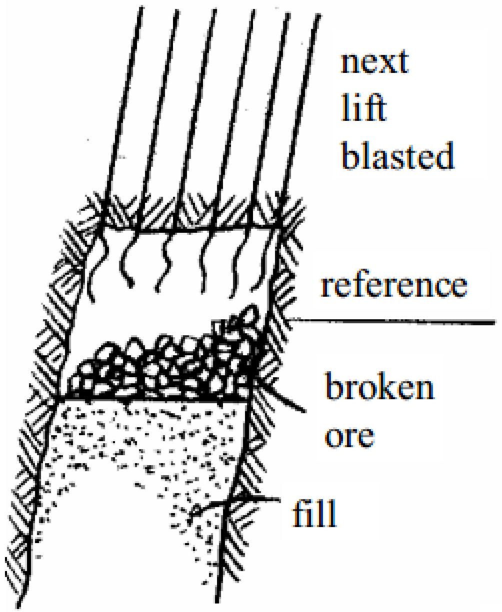
Support

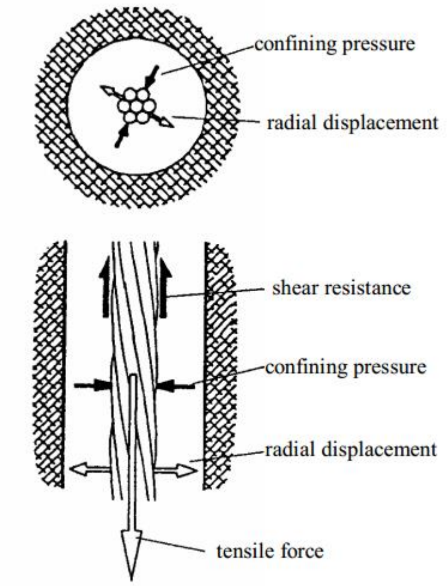


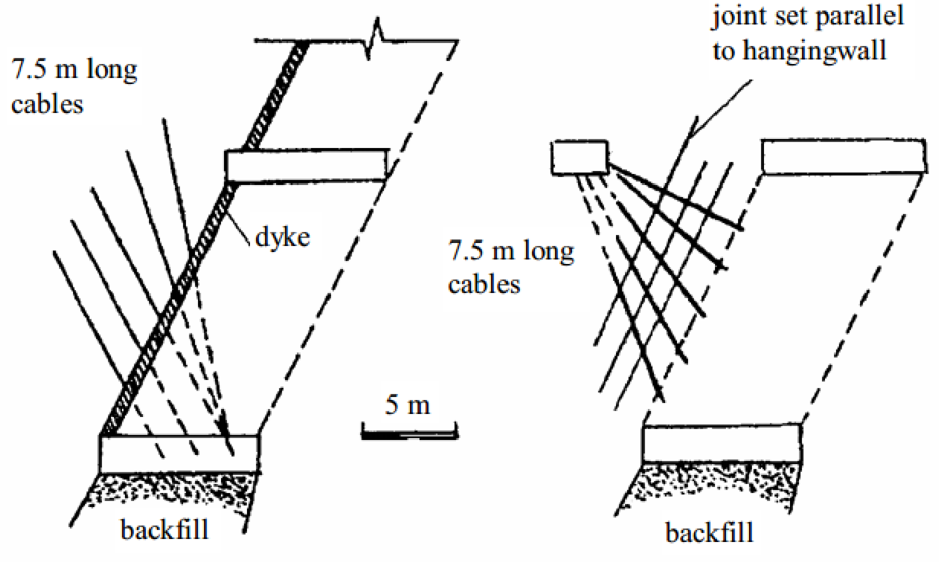
Mining continues till the ore in entire slice is mined out

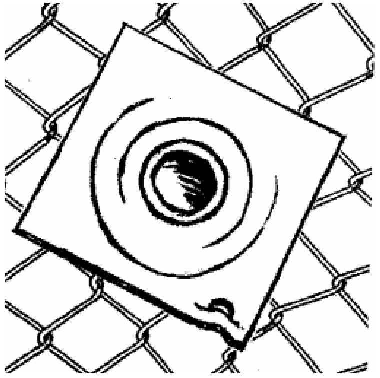
Rock Support & Reinforcement

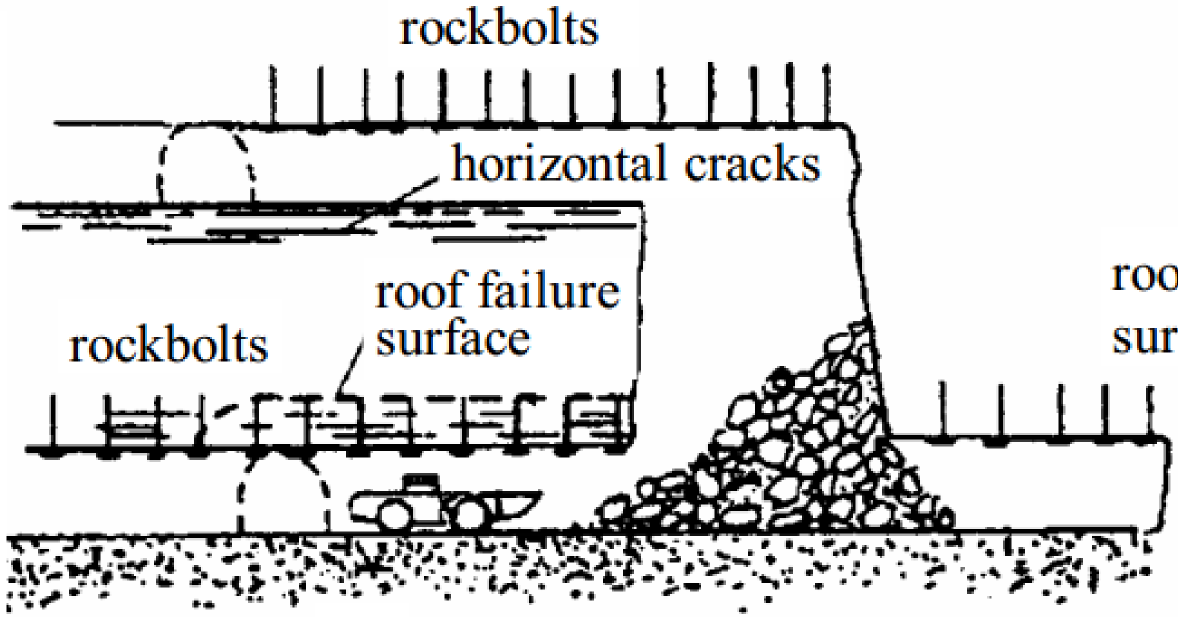


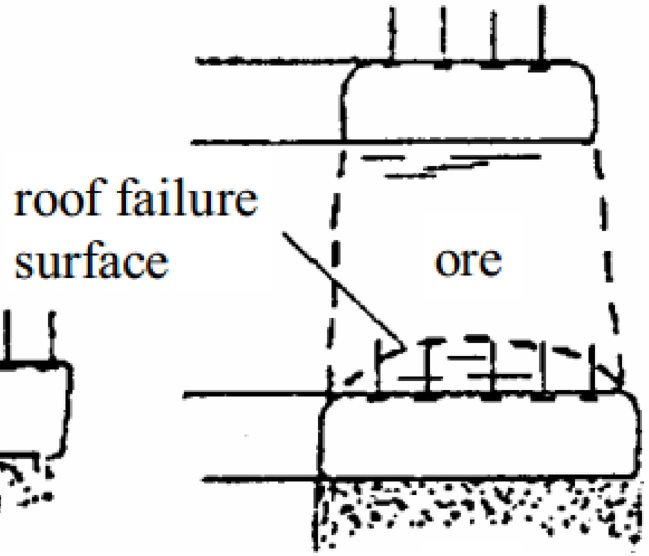




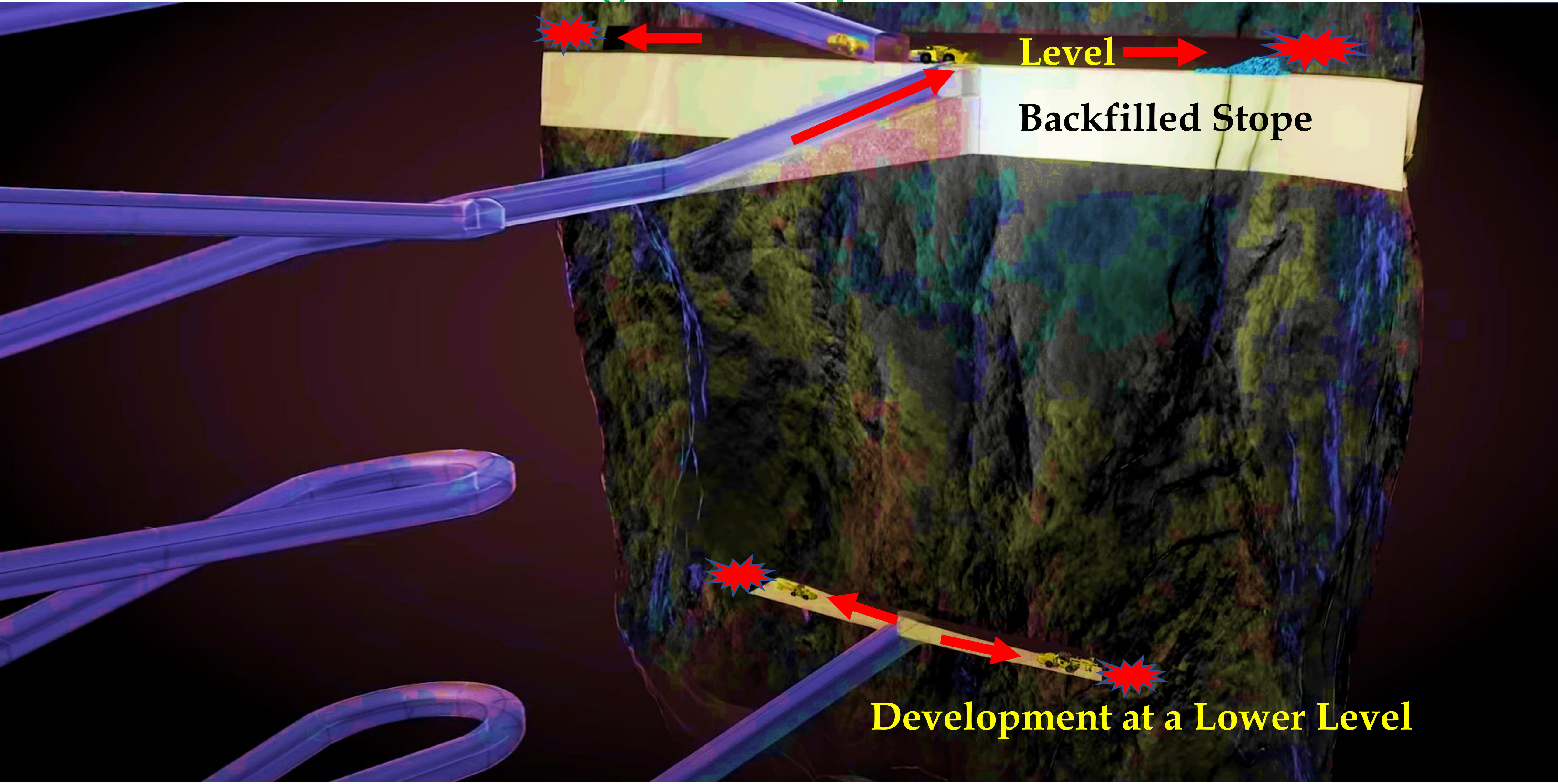




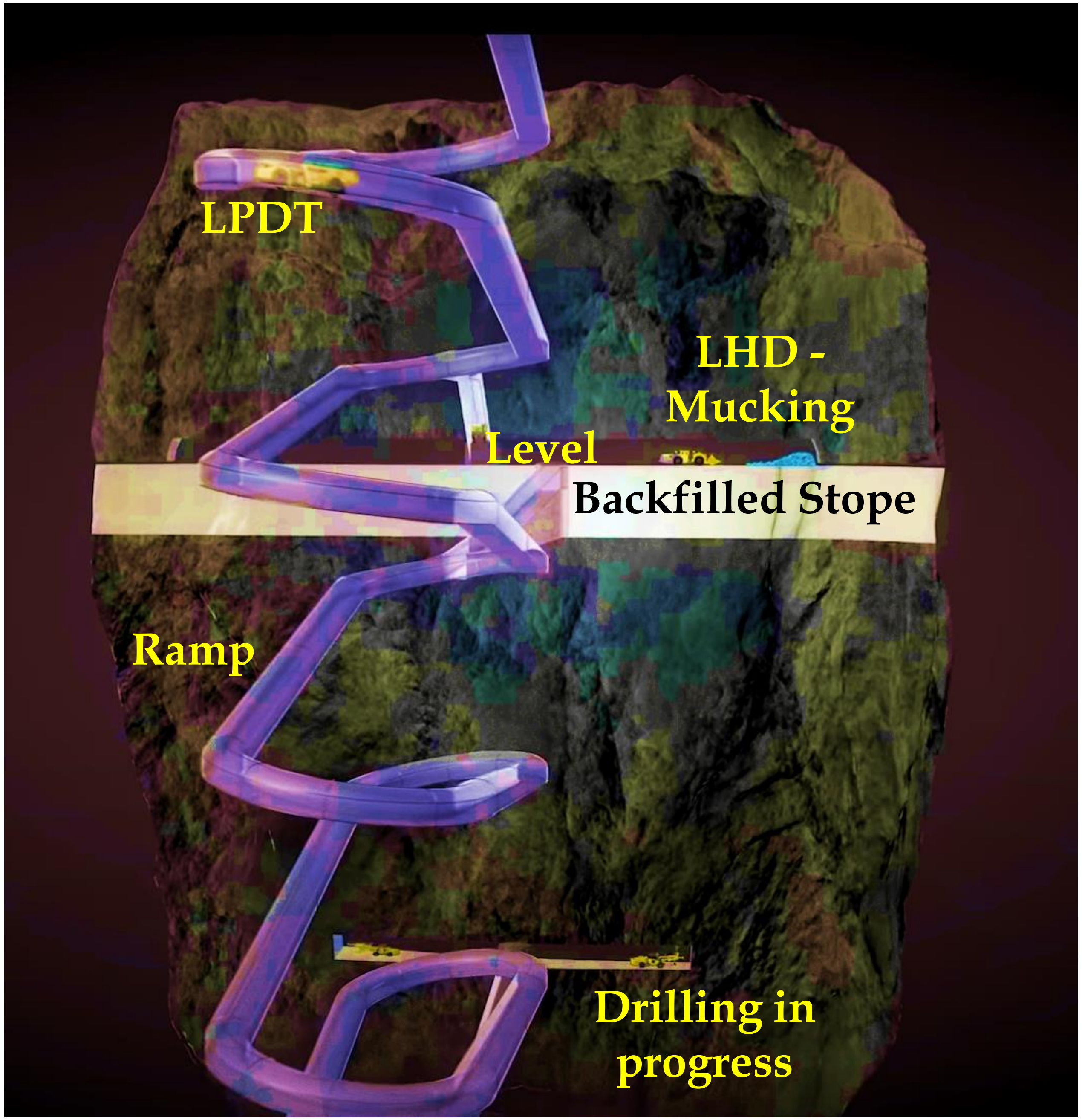


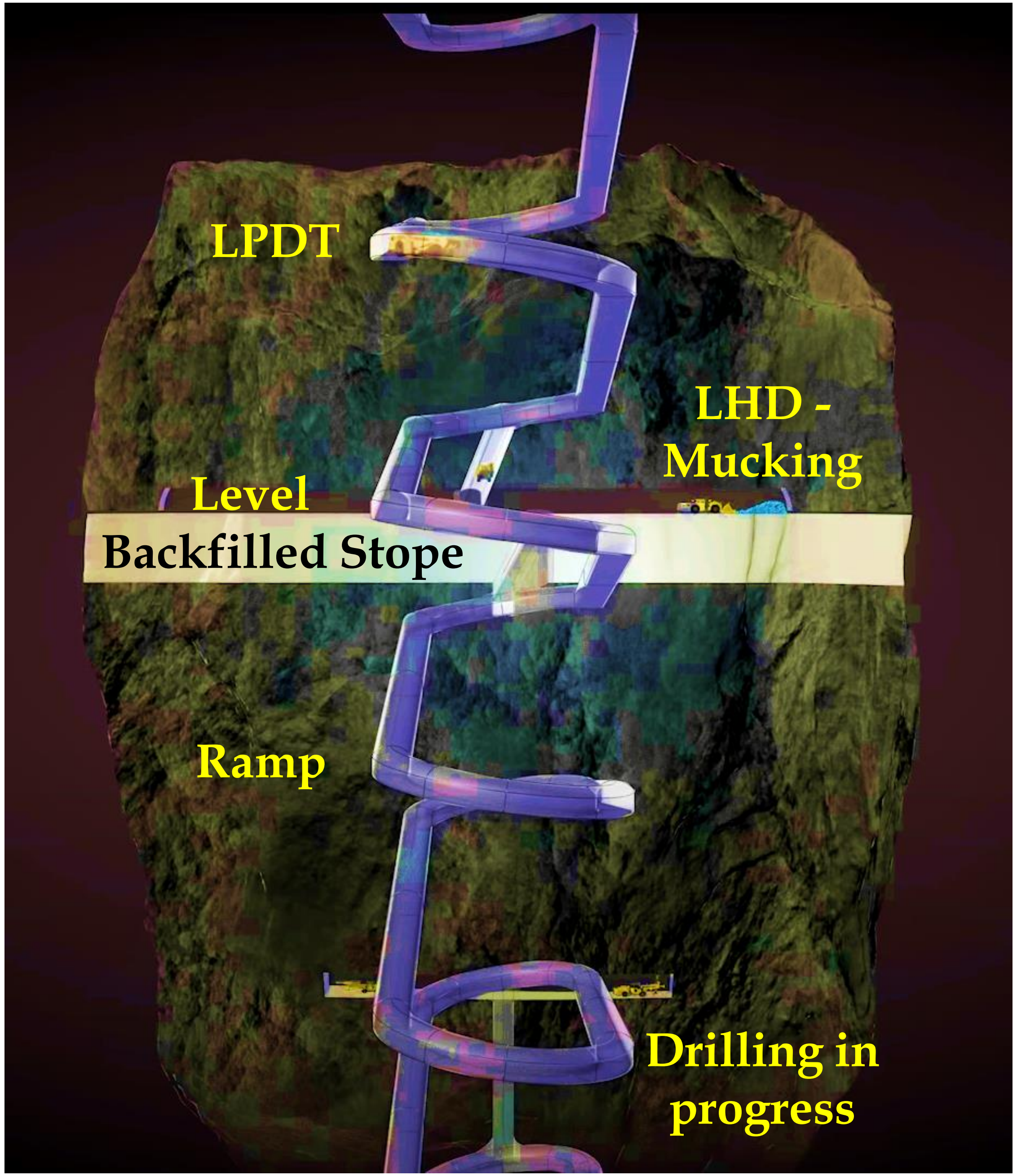


Mining in Subsequent Levels



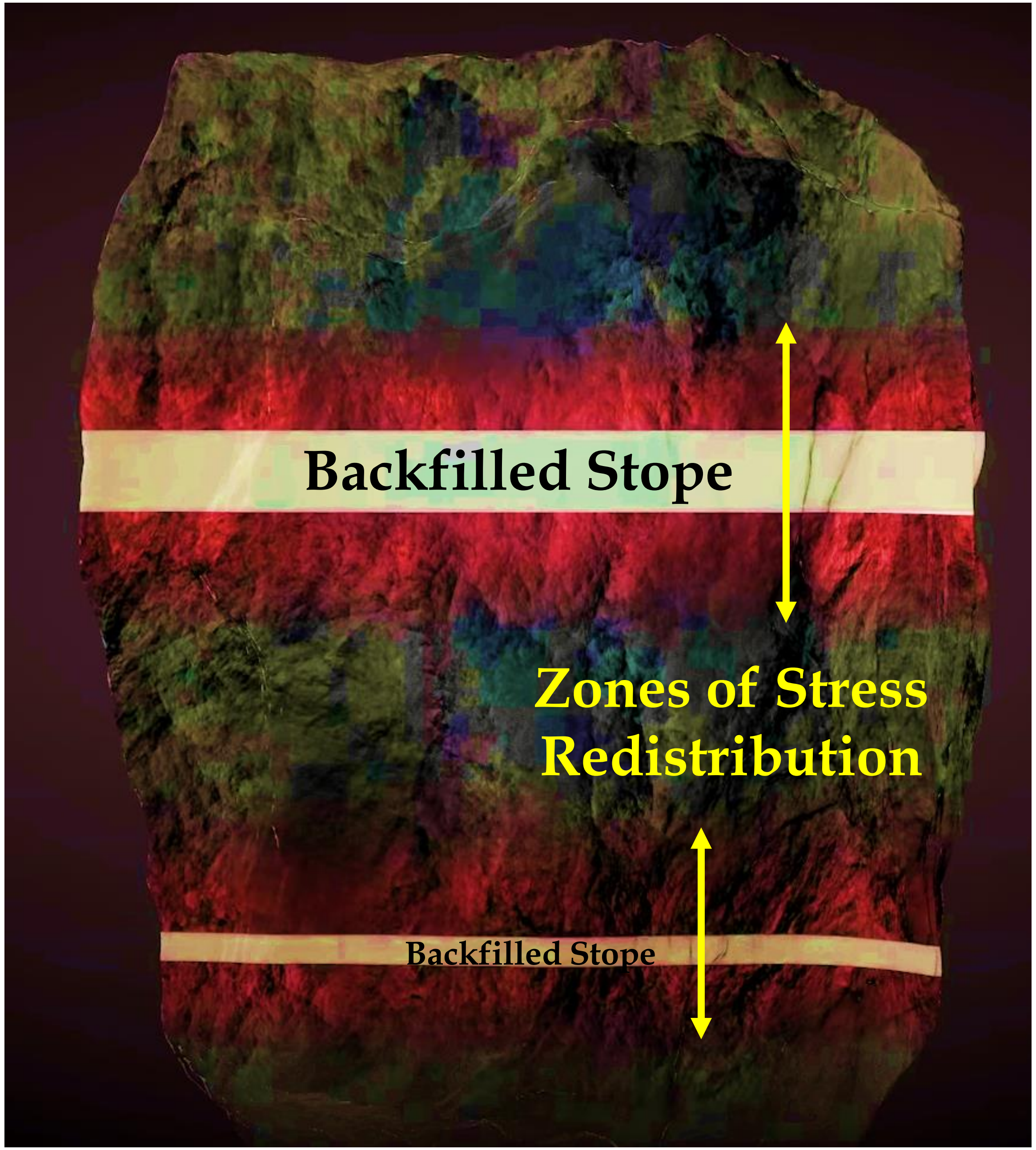
Transportation System

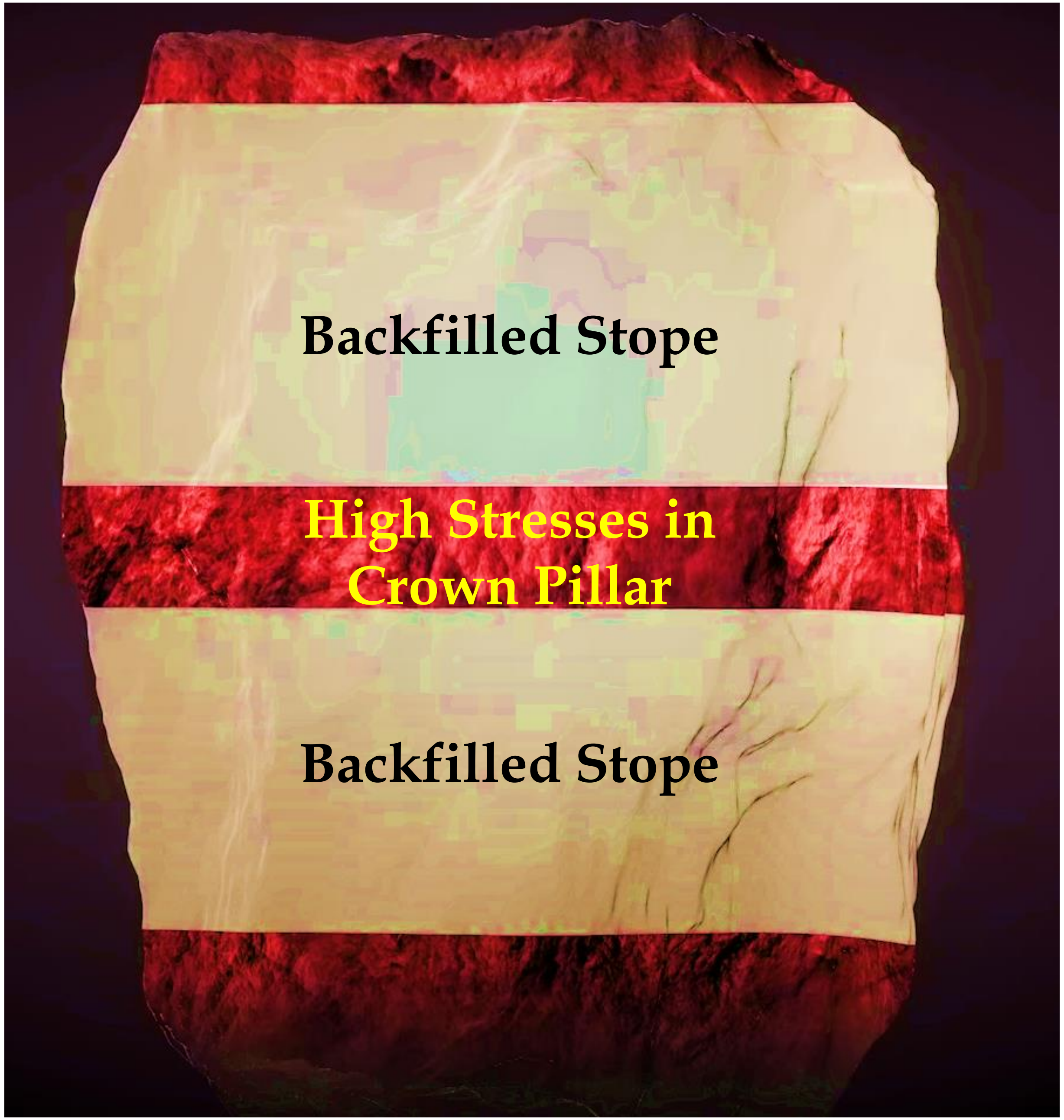




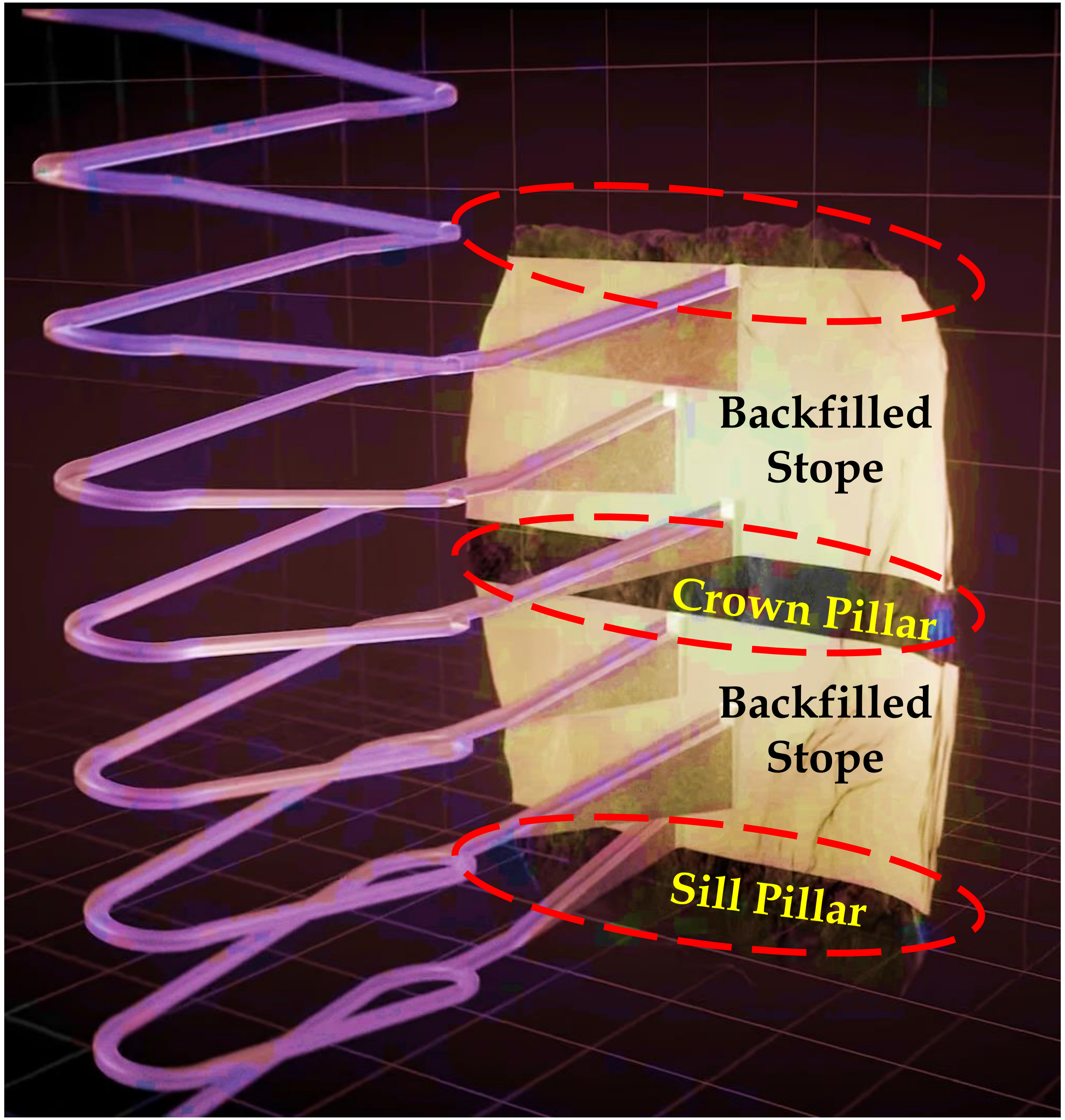
Stresses in Pillars

Rock stresses increase in pillar above the mined area





Post Mining Scenario



Concerns

- Stability of Pillars
- Surface Subsidence

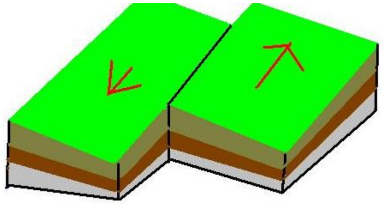
Performance Monitoring

What we need to measure ???

In Steel and Concrete structures, behavioral characteristics in terms of strength, deformation and thermal properties are known to the designer.
In rock mass structures, there are number of unknown parameters some of which can be determined in laboratory while some in-situ. However, assumptions becomes an integral part of it.

Some parameters of engineer's interest are :

a. Displacement
b. Load Stress
c. Strain
d. Seepage / Water Pressure
e. Vibration and Air Overpressure due to Blasting and Earthquake
f. Seismicity
g. Uplift pressure
h. Temperature
i. Environmental conditions
j. Alignment and Tilt



Displacement & Load

How do we Measure ?

Instrumentation

A successful instrumentation program **starts** by *defining the purpose* of installing the instruments and **ends** with *implementing the decisions* derived from interpretations of the data

Why do we need it ???

It provides data that helps engineers in every stage of a project

- Site Investigation
- Design Verification
- Construction Control
- Quality Control
- Safety
- Legal Protection
- Performance

How Instruments work ???

Sensor / Detector → **Transmitter** → **Processor** → **Data Acquisition System / Read Out Unit**

- **Sensor / Detector**: Responds to changes in the variable being monitored
- **Transmitter**: Transmits the sensor output to the read-out location (Rods, electrical cables, hydraulic lines or radiotelemetry devices)
- **Processor / Data Acquisition System / Read Out Unit**: Coverts the data into a usable form and presents them to engineer (Dial gauge, digital display, magnetic tape recorder or computer)

Technology / Working Principle

1. Mechanical
2. Optical
3. Hydraulic & Pneumatic
4. Electrical

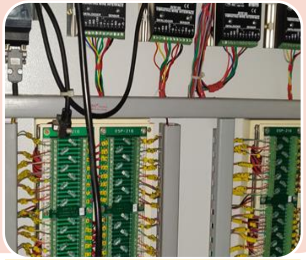
Specifications

- Sensor Type
- Range
- Resolution
- Accuracy
- Precision
- Conformance
- Robustness
- Reliability

Data Acquisition & Analysis

Manual (Readout Units)

Using Data loggers



Automated Data Acquisition / Real Time Monitoring

Data analysis is the process of evaluating data through

Analytics

Statistics

Discover

Useful Information

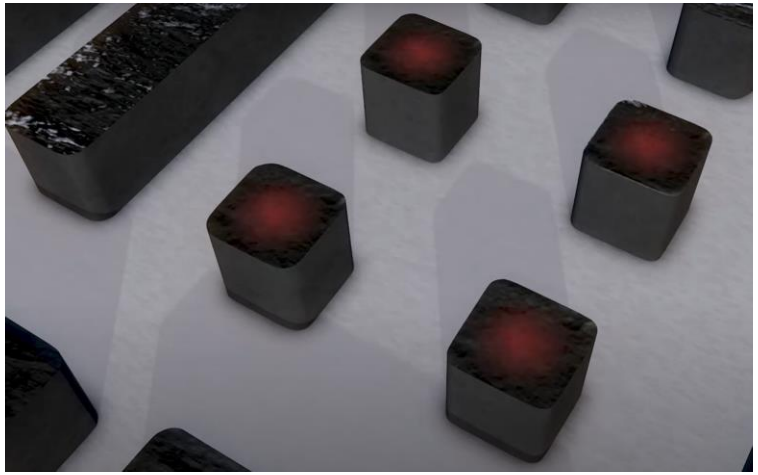
Aids in Sound Engineering Judgement

Geotechnical Instruments generate huge **data sets** which needs **frequent analysis** to **summarize and present** the data to show trends between **Observed** and **Predicted behaviors To initiate necessary action**

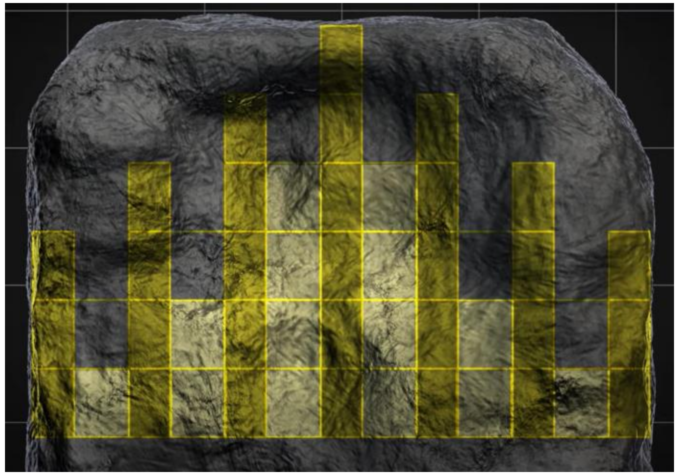
To **Access** data rapidly to detect changes that require **immediate action**

Animation

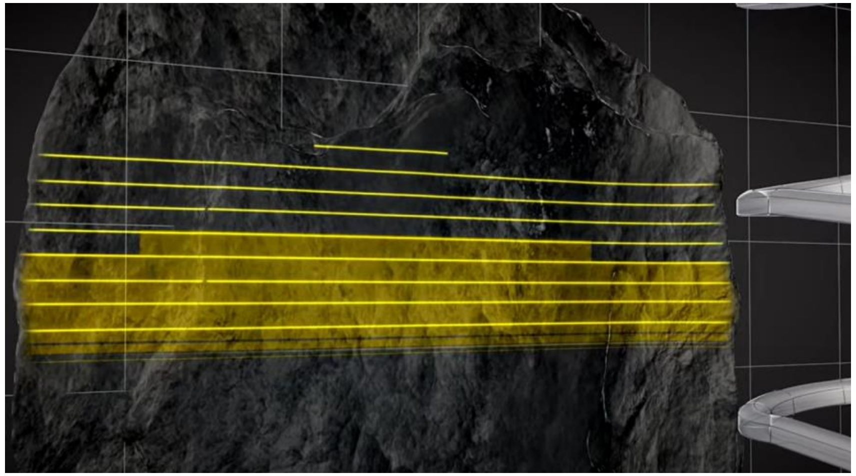
Underground Metal Mining Methods - Animation



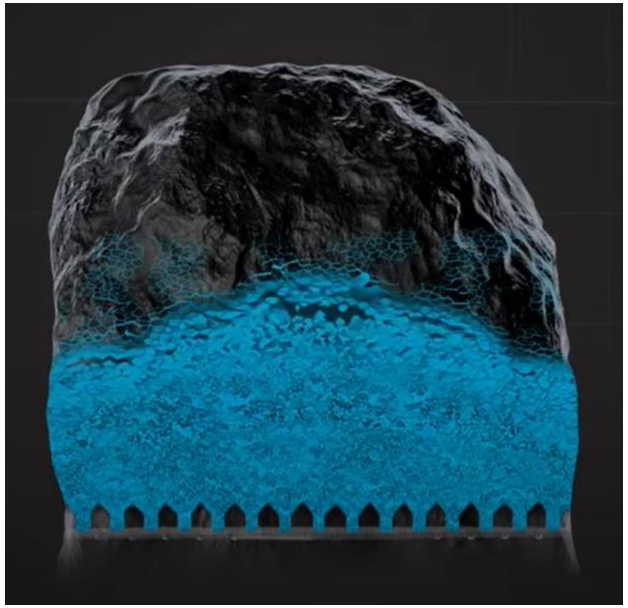
Room and Pillar



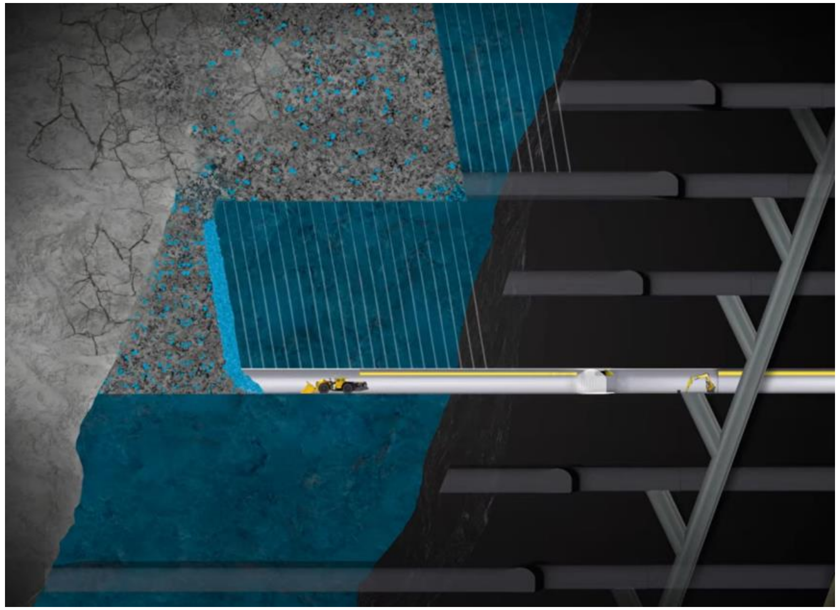
Sublevel Open Stoping



Cut and Fill



Block Caving



Sub Level Caving

Courtesy: Epiroc