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2012 Americas School of Mines

Basics of Mining and Mineral Processing

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Agenda

- Geological Concepts
- **Mining Methods**
- Mineral Processing Methods
- Mine Waste Management
- Mining and Money
- A Future of Mining

Mining Methods: The Topics

Open pit mining

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Underground mining

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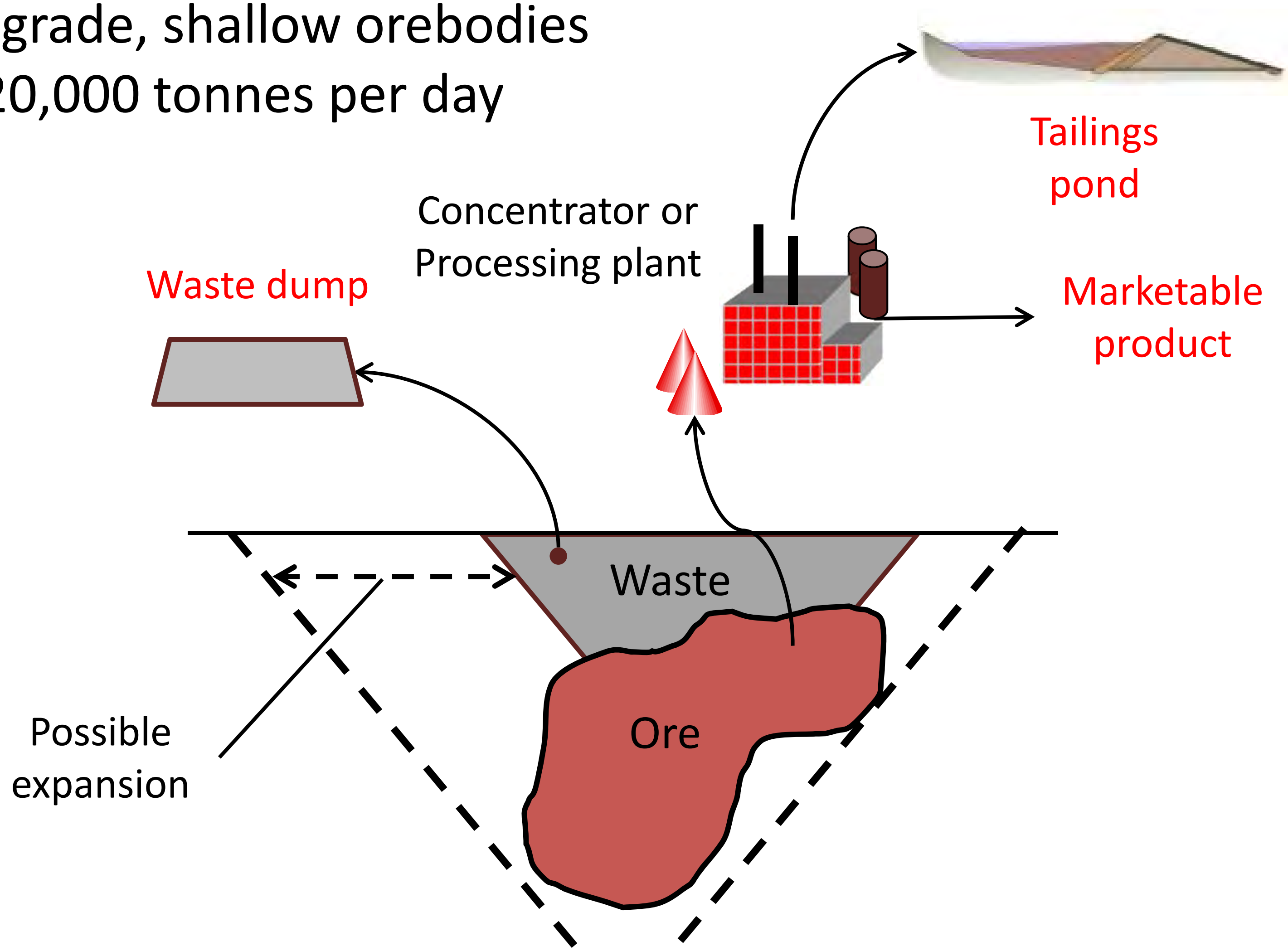
Mining equipment

↓

Mining operations

Open pit mining

Generally low grade, shallow orebodies
Mining rate >20,000 tonnes per day



Open pit mining

Open pit mines are used to exploit low grade, shallow ore bodies. However, some pits are quite deep – about 1 km.

The mining rate is greater than 20,000 tonnes per day (tpd) but is usually much greater. Some pits operate at a rate of more than 100,000 tpd

Open pit mining results in two waste streams: waste rock which contains no economic quantity of minerals but which must be removed to gain access to the orebody, and tailings which are the result of a mineral separation process in the concentrator or processing plant. The mining rate includes the mining of both waste and ore.

Open pit mining is non-selective – all high and low grade zones of the orebody are mined

The significant design issues of an open pit mine are: location of haul roads, equipment – size of trucks and fleet, pit slope angle and stability, control of water

Bagdad Pit, Arizona – looking west

Porphyry copper 170,000 tpd 9,200 ft × 5,800 ft pit
828 Mt sulfide and oxide reserves: 0.28% Cu, 0.022% Mo (2007 10K filing)
Copper and Molybdenum concentrates
Pressure leach facility for concentrate, SX/EW leach plant for oxides

Notes: Bagdad Pit Arizona – looking west

First claims staked in 1882. Property changed ownership numerous times through first half of 20th century. First mill began operation in 1928 to process ore from the underground mine. Transition to open-pit mining began in 1945. A $240 million expansion in 1973 included new haul trucks, shovels, nearly 400 housing units and concentrator. Bagdad became part of the Phelps Dodge mining portfolio in 1999 with the acquisition of Cyprus Amax Minerals Co. In 2007, Freeport McMoran merged with Phelps Dodge.

The ore is a porphyry with disseminated primary sulfides (chalcopyrite and molybdenite) with gold and silver. Low grade secondary sulfide and oxide ores are present which are soluble by acid.

Copper and molybdenum concentrates with gold and silver credits are produced and smelted at the Miami smelter. Copper is produced at a SX/EW plant for oxide ore (operating since 1970) and at a new (2003) concentrate leach facility, the world's first.
Source: http://www.fcx.com/operations/USA_Arizona_Bagdad.htm

Highland Valley Pit, British Columbia

Porphyry copper, 170,000 tons mined/day (tpd)
451 Mt reserves: 0.38% Cu, 0.007% Mo (2007 Teck Cominco report)
90% of production from Valley pit
Copper concentrate with gold and silver, Molybdenum concentrate

Notes: Highland Valley Pit British Columbia

The Highland Valley Copper mine, located in British Columbia, 60 km southwest of Kamloops is 97.5% owned by Teck Cominco.

Operations at Highland Valley began over 20 years ago by predecessor companies. The present operation is a combination of the Lornex mine and mill, the Valley Copper orebody and the Highmont mine and mill. The present mill is the old Lornex mill into which Highmont mill equipment was integrated.

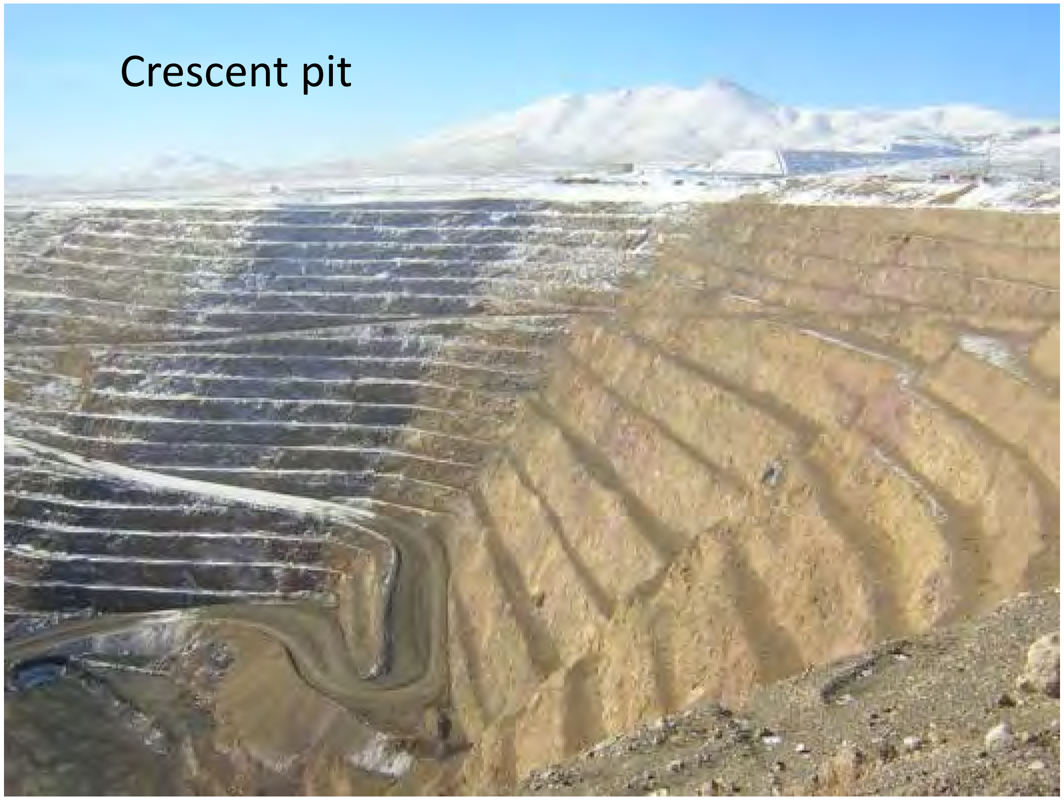
The Valley pit contains two in-pit crushers feeding a 12,000-tonne per hour conveying system that delivers ore to stockpiles at the mill. Ore from the Lornex mine is hauled to two permanent crushers with discharge to common stockpiles.

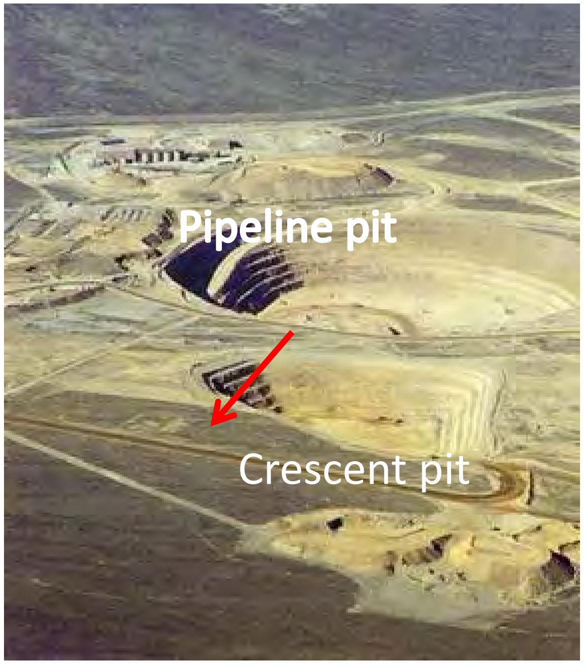
Concentrates are transported by rail eastward to domestic markets and to Vancouver for shipment to overseas markets.

The life of the mine has been extended from 2013 to 2019. The new mine plan will require a push-back of the west wall of the Valley pit. Total capital costs of the expansion project are estimated at $300 million, including $130 million for capital equipment and the balance in pre-production stripping over the period of 2009 through 2013. Approximately $50 million of mobile mining equipment will be ordered in 2007 to permit waste stripping to commence in 2009.

Source: Teck Cominco 2006 Annual Report

Cortez Gold Mine, Nevada





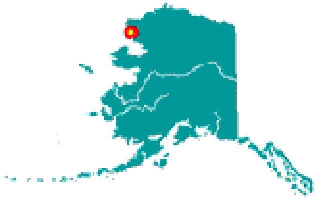
Three deposits in area: Pipeline, Cortez Hills, Pediment
14.5 Moz reserves, ore grade: 0.046 oz/t
Gold production 2010: 1.14 Moz

Bingham Canyon, Utah

Porphyry copper deposit

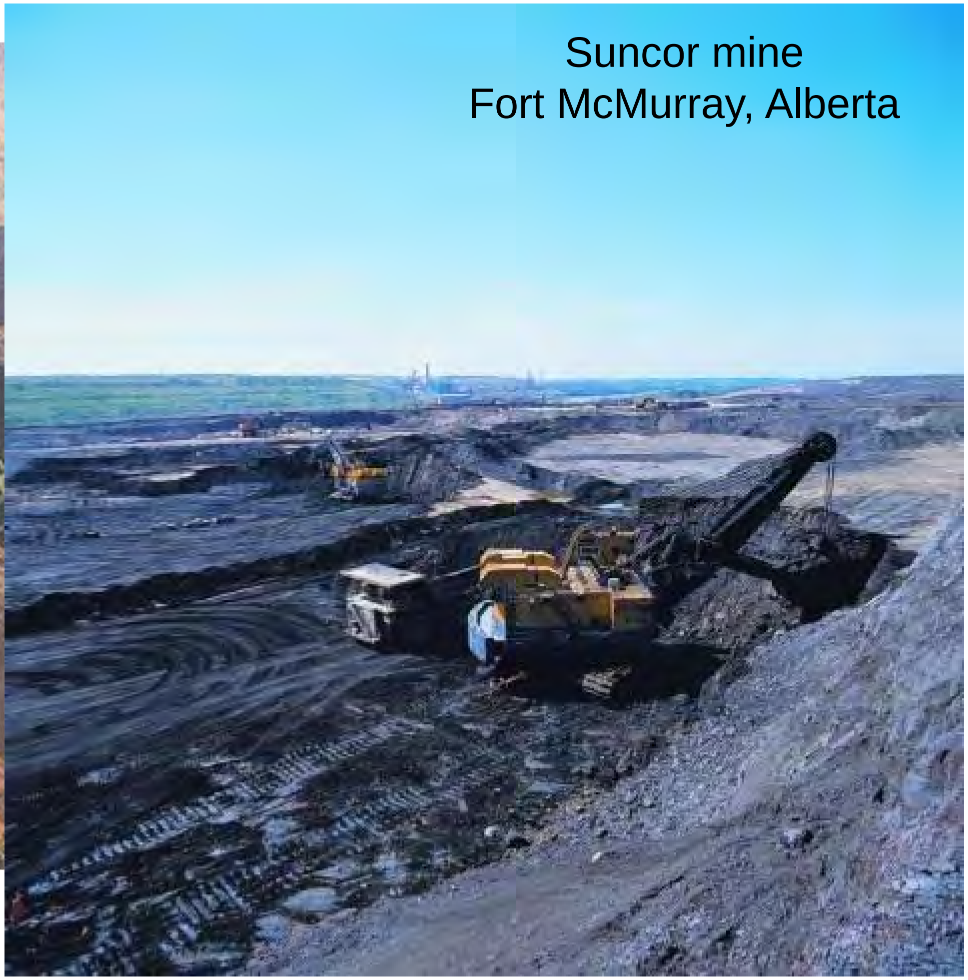
4 km diameter, 1,200 m deep

Red Dog mine, Alaska



Antamina, Peru

Coal and Oil Sands Mines



Notes: Coal and Oil Sands Mines

Coal and tar sands operations typically involve moving large amounts of waste (often called **overburden**) to gain access to the economic mineral.

Eagle Mountain is part of the Fording River operations in southeastern British Columbia. Fording River produces both **metallurgical (coking) coal** for the steel industry and **thermal coal** for power plants in Alberta. Fording River's measured and indicated reserves total over 200Mt of clean coal plus a further 286Mt in resources, over 65% of which is contained in the Eagle Mountain deposit. The coal has a low sulfur content and its volatile content ranges from medium to high. Three distinct coking coal types are available at Fording River. Fording River can mine at a rate of 10Mt/year or about 28,000 tpd.

Source: http://www.mining-technology.com/projects/fording

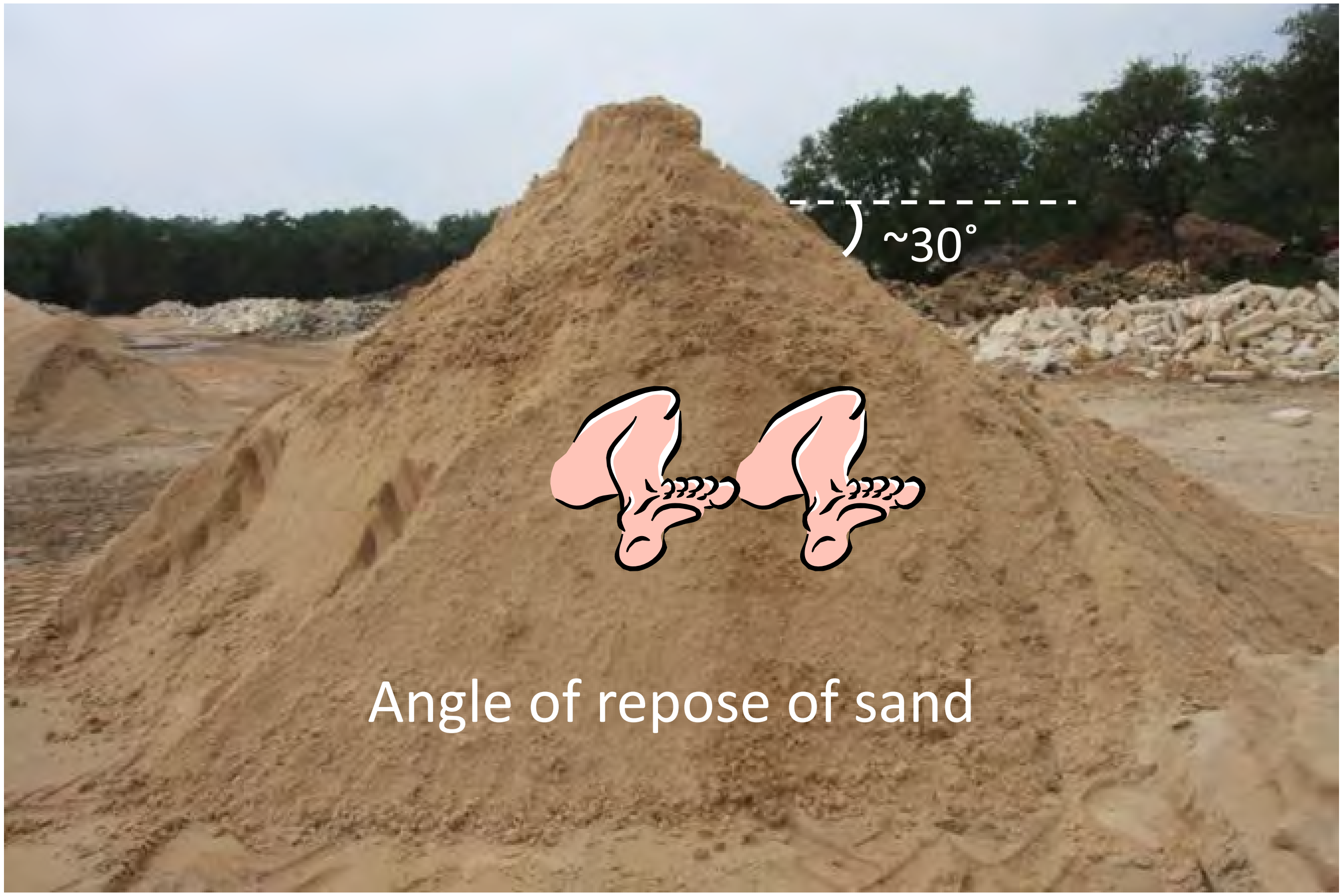
Oil sand is a mixture of **bitumen** (a thick sticky form of crude oil), sand, water and clay. The Suncor Mines extract oil sand from mines north of Fort McMurray in Northern Alberta. Using shovels with 100 ton buckets and 240 and 360 ton trucks the mine extracts about 450,000 tonnes of oil sands per day. The material is crushed and sized and made into a slurry which is delivered to the processing plant via 86 km (54 mi) of pipelines In the plant, the sands are mixed with hot water to separate the oil from the sand. In 2005 the Suncor Mines produced 171,300 barrels of bitumen per day, which, after upgrading, is ready for refining. Suncor's leases contain a resource of more than 13 billion barrels of bitumen.

Source: www.suncor.com

Pre-stripping at Oyu Tolgoi, Mongolia

Source:
www.ivanhoemines.com

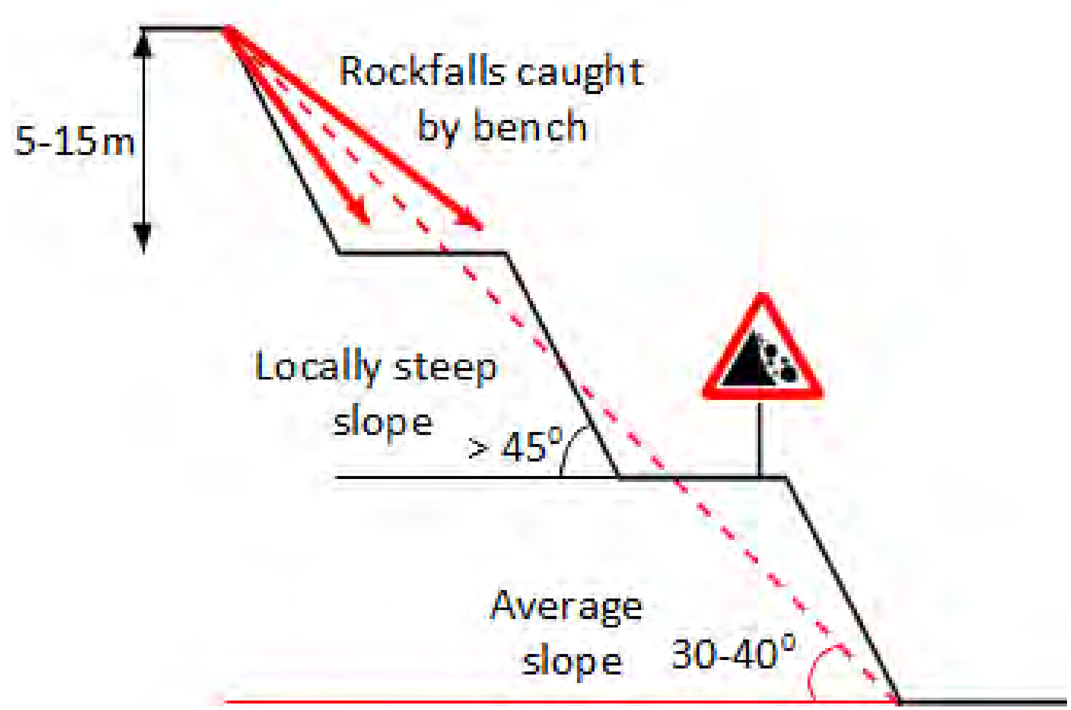
At the beach



Why the benches?

Rock is stronger than sand so its angle of repose is larger

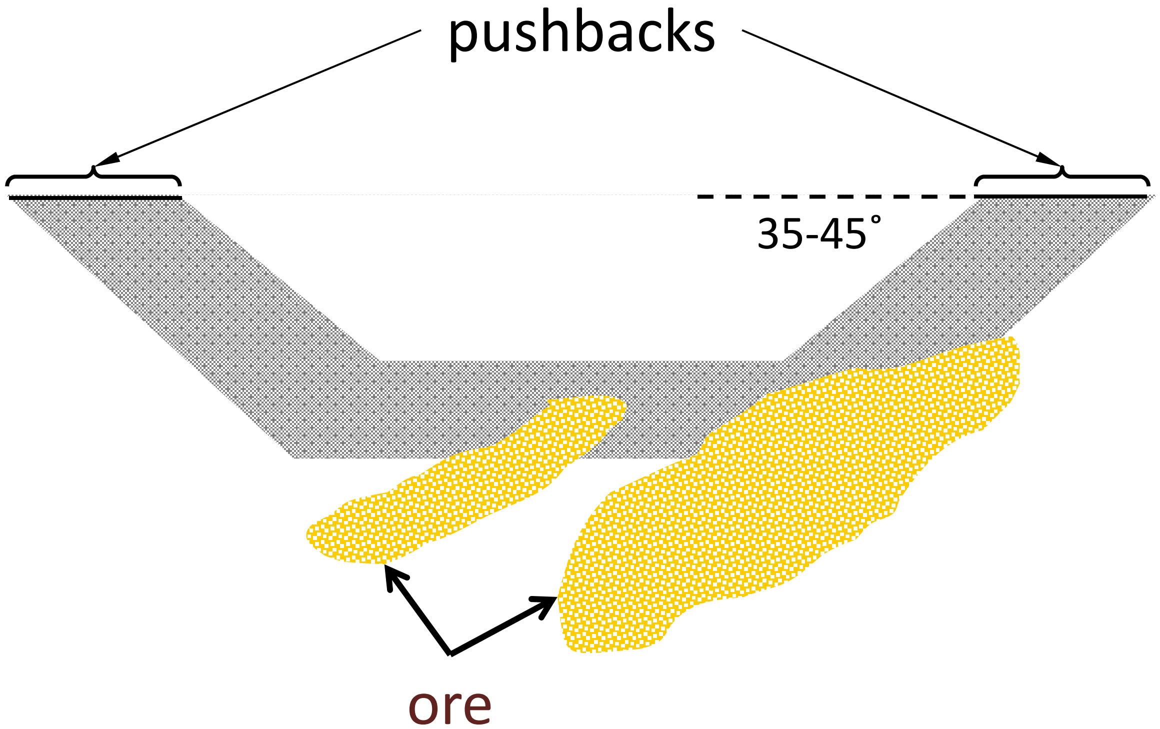
45˚ usually the maximum



Pit slopes are benched to achieve locally steeper slopes
Allows pit to intersect ore zone

To go deeper, you need to pushback

Mine some waste to get to ore



Notes: Pushbacks and benches

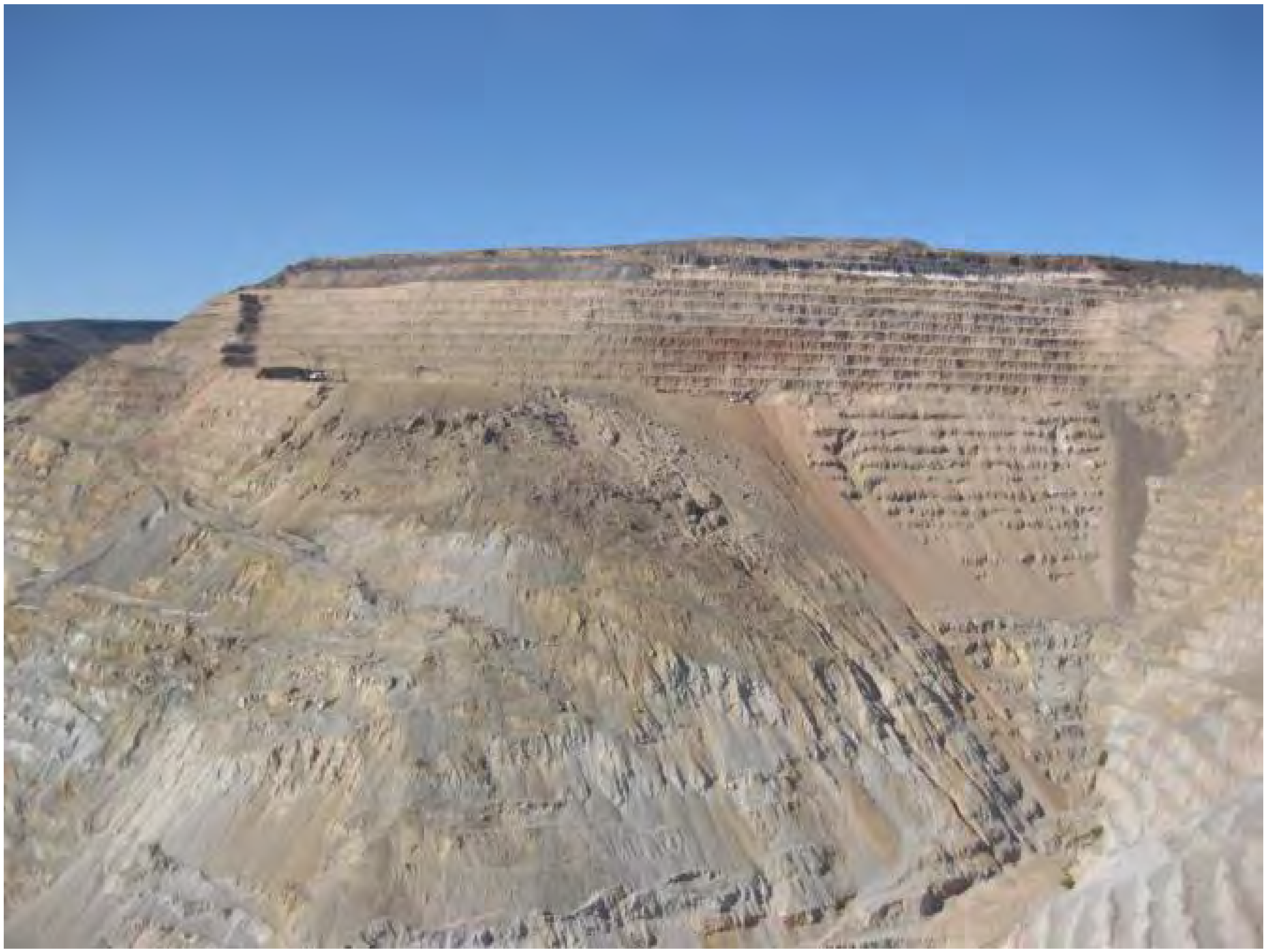
An open pit mine is developed as a series of nested pits, each larger in area than the previous pit. A **pushback** is the removal of material required to proceed from one pit to the next. The revenue from the ore must pay for the cost of excavating the waste from the pushback and for excavating the ore. But the slope cannot exceed 45˚ and remain stable so at some point it becomes impossible and/or uneconomic to continue mining.

The slopes of a deep pit are cut into a series of locally steep slopes (> 45^0) each about 5-15 meters high depending on the stability of the rock and the equipment in use. Such steep slopes can become unstable and therefore **benches** are formed at the bottom of each slope to contain any slope failures. Although parts of the slope are steep, the overall slope angle is low, say 30-40^0 .

In some pits the rock may be strong enough to allow “double-benching” where slopes about 20-30 meters high are built. The available equipment must be able to excavate such heights. The objective is to minimize waste excavation, but design and monitoring of such slopes can be difficult.

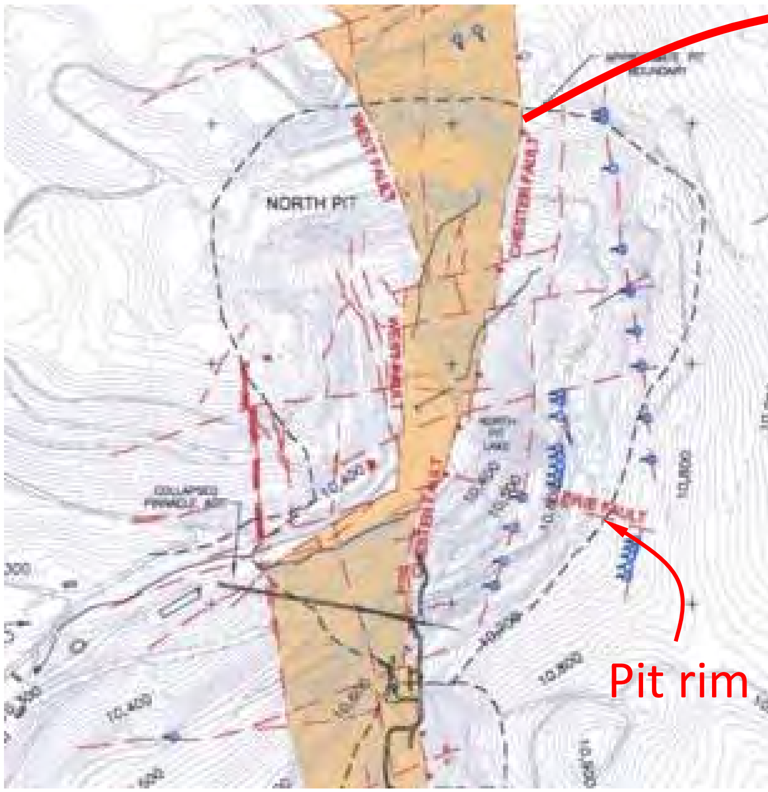
The need for locally steep slopes is illustrated by the following example. For a 500 m deep pit, the difference in volume for a pit slope of 45° slopes and a pit slope of 40° is about 25 million m^3. If the rock density is 2.7 t/m^3, that is equivalent to 67.5 Mt. Since it costs $2-3 to move a tonne of rock, the extra volume amounts to quite a large amount of money.

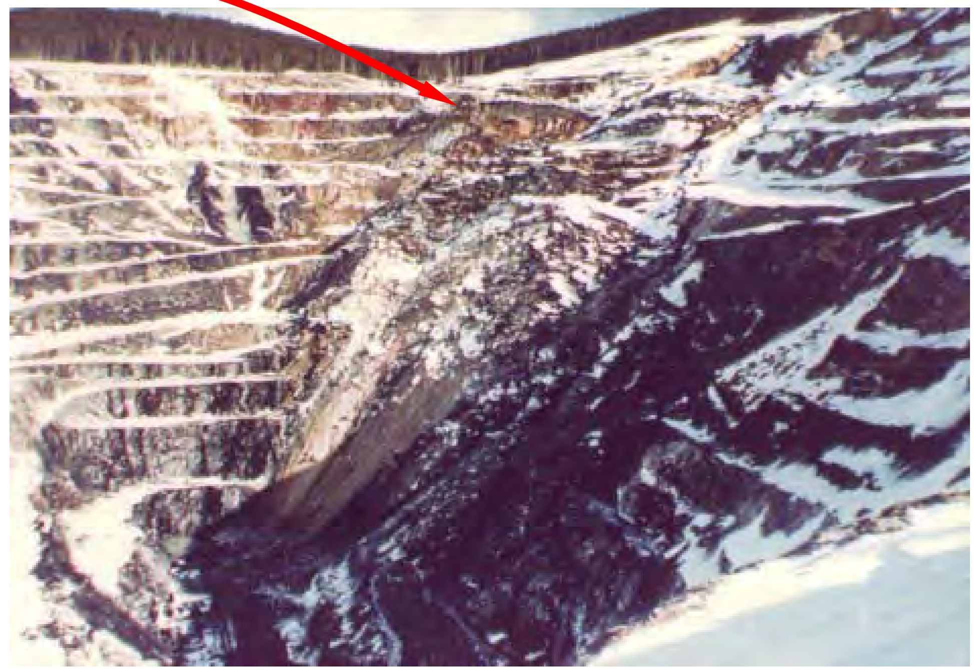
The Bagdad pushback on Sept 23, 2009



Highland Valley Mine – pushback of west wall

Straight faults and circular holes





Slope failure in March 1983

North Pit, Homestake Pitch Mine, Sargents Colorado

Notes: Straight faults and circular holes

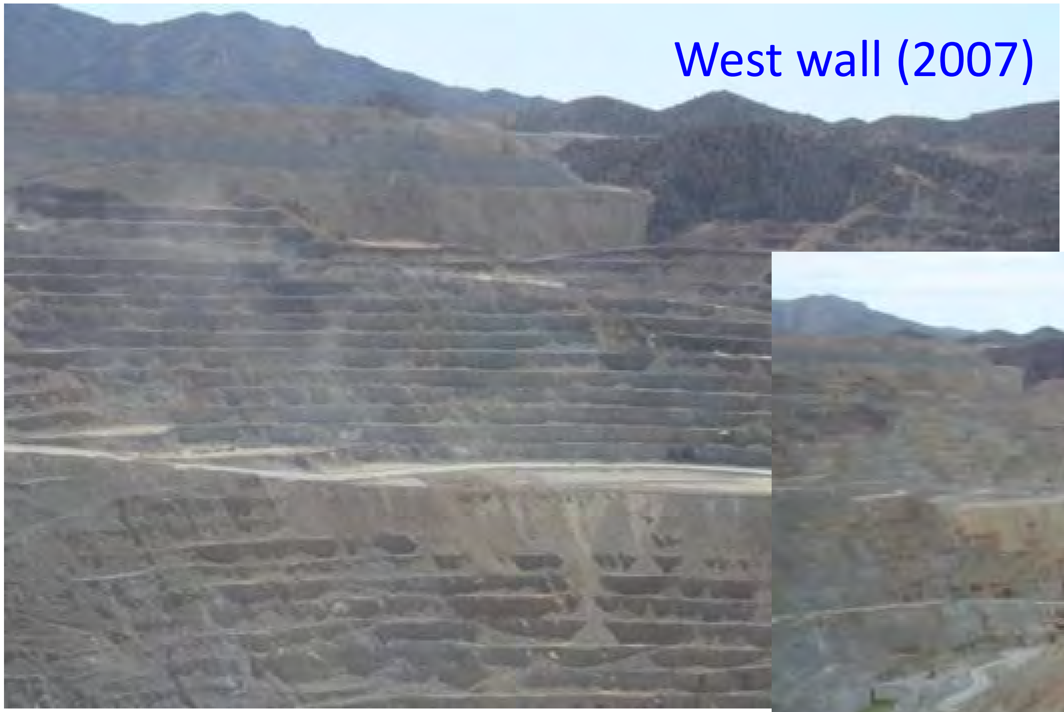
As the magma containing the minerals for an orebody rises up, it generates stresses in the host rock, rupturing it and causing faults. Thus most orebodies are related to faulting in the earth's crust. Faults are long linear features and so if an orebody is mined with a circular pit, it is likely to intersect a fault. This can lead to instability in at least two parts of the pit slope.

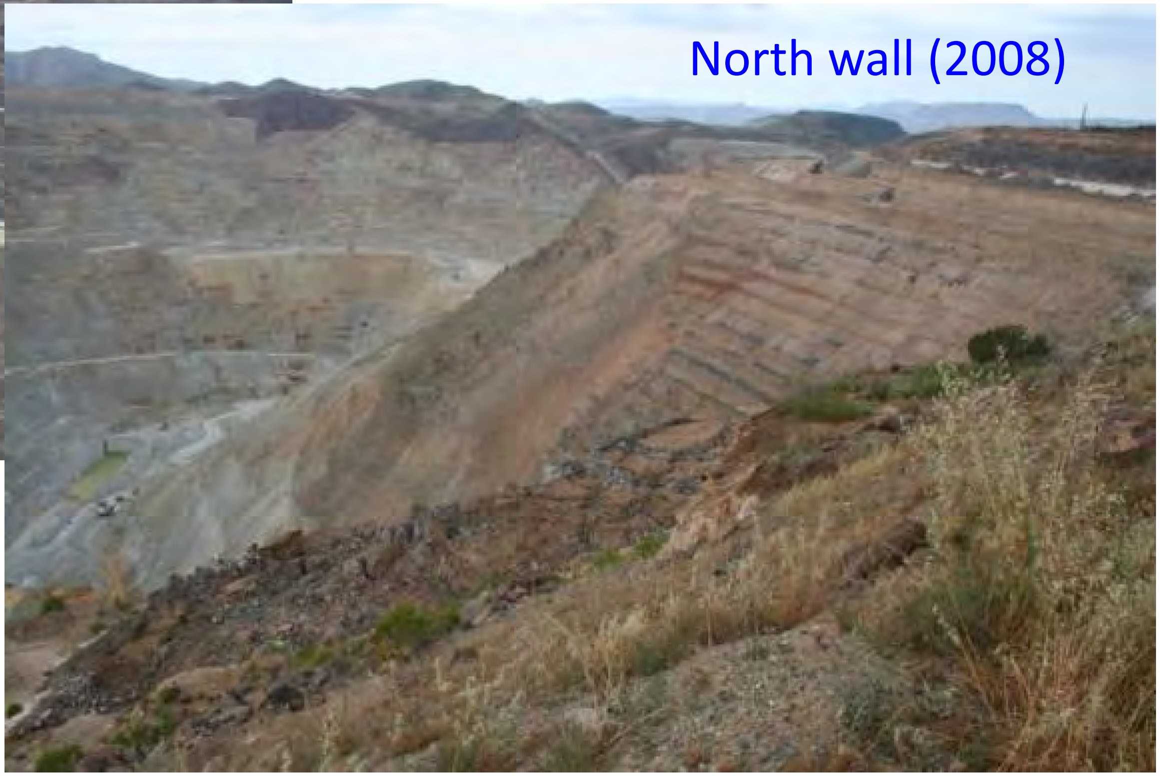
In the case of the Homestake Pitch uranium mine, pit excavation near the fault on the northeast slope led to a series of slope failures soon after mining started in 1977 and continuing through to 1980. In 1983 extreme climatic conditions led to an excess accumulation of water which weakened the northeast slope and led to the failure shown in the picture. The mine was placed under reclamation soon after the 1984 failure.

Source:

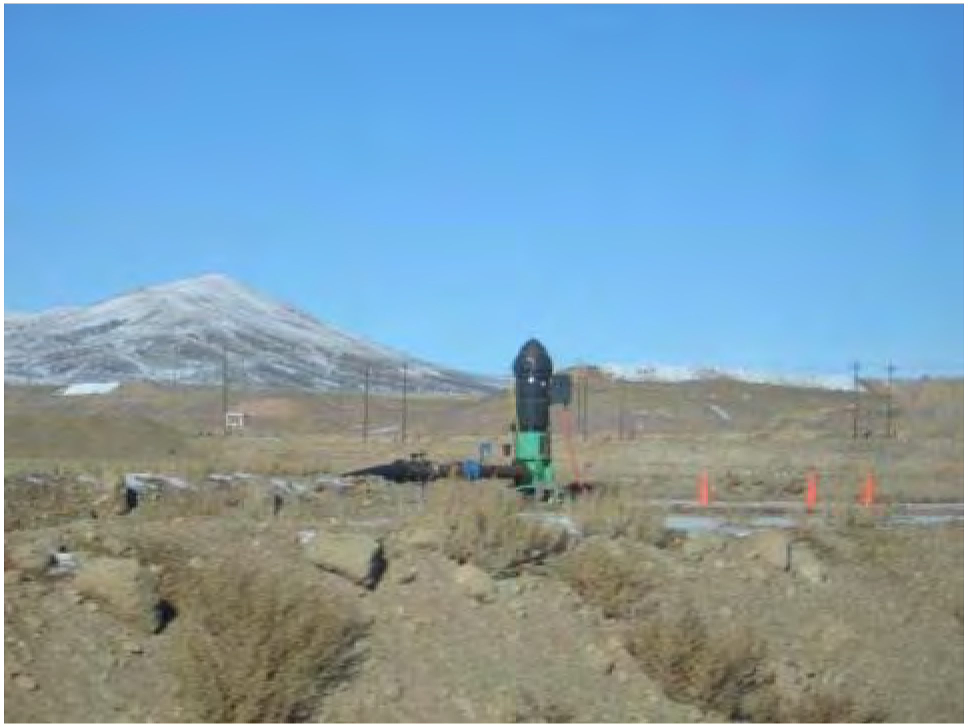
Cremeens, J., 2003. Geologic controls on complex slope displacement at the Pitch reclamation project. Engineering Geology in Colorado, Contributions, Trends, and Case Histories. *AEG Journal*

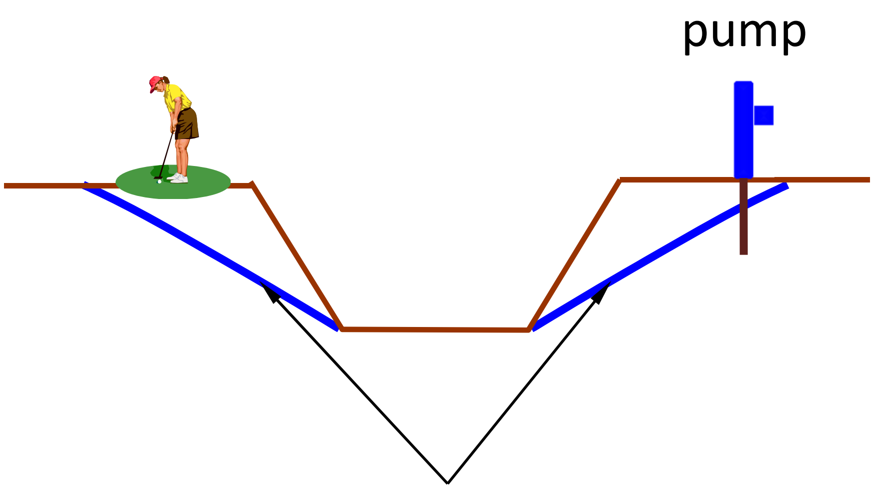
Pit Wall Stability at Bagdad





Dewatering pump at Cortez Nevada





There are 40 of these around the Cortez pit pumping water out of the ground at a total rate of 30,000 gallons per minute in order to keep the pit dry. Dewatering also helps to keep the slopes dry and more stable.

Strip Ratio

Applies to an open pit mine

$$\text{Strip ratio} = \frac{\text{Waste}}{\text{Ore}}$$

SR is the mass of waste to be mined to obtain one unit mass of ore. (*ore that goes to concentrator*)

Examples:

- Oil sands deposits in Alberta: SR = 1.0-1.5
- Highland Valley: SR ~0.45 (2007 Teck annual report)
- Bagdad mine: SR =1.4 (2007 FCX 10K filing, p.5, but oxide ore also mined – see notes)
- Red Dog mine: SR = 0.8
- Cortez mine: SR = 2.2 (2007 Barrick annual report)

Notes: Strip Ratio

Mistakes are often made when computing the strip ratio. It's all in the words and you have to watch the flow of material and how it is classified. For example, according to Freeport McMoran's 2007 10K filing, the concentrator is capable of processing 75,000 metric tons per day of primary sulfide ore and the mining fleet is capable of moving 180,000 metric tons per day. Thus If everything is working to capacity (and it usually works close to capacity) and the material moved is assumed to be waste plus primary sulfide ore, the strip ratio is (180-75)/75 = 1.4.

However, the material moved includes waste plus oxide/secondary sulfide ore and primary sulfide ore. The 10K filing and other information provided does not classify the amounts mined. However, the 2005 Phelps Dodge report states that Bagdad mined 64,093 thousand tons (kt) of material and processed 26,592 kt in the concentrator. The report also states that 23,857 kt of ore (oxides/secondary sulfides) was placed on the leach stockpiles. This means the waste is 64093-26,592-23,857 = 13,644 kt, about 21% of the material mined. So does this mean their strip ratio, waste/ore = 0.21/0.79 ~ 0.27

Not so fast. According to footnote h on page 11 of the 2005 report the leach ore includes "previously considered waste material that is now being leached." This means that some leach ore was mined prior to 2005 and was re-classified from waste to ore. The report does not state how much was mined in 2005 and placed on the leach stockpile but, according to a contact at Bagdad, the amount mined was minimal – the 23,857 kt is mostly a re-classification.

Hard to define a strip ratio when what was waste becomes ore and vice versa.

Some strip ratio algebra

$$\text{Total mined } T = O\text{re} + W\text{aste} = O + W$$

$$\text{Strip ratio } S = \frac{W}{O} \Rightarrow W = S \times O$$

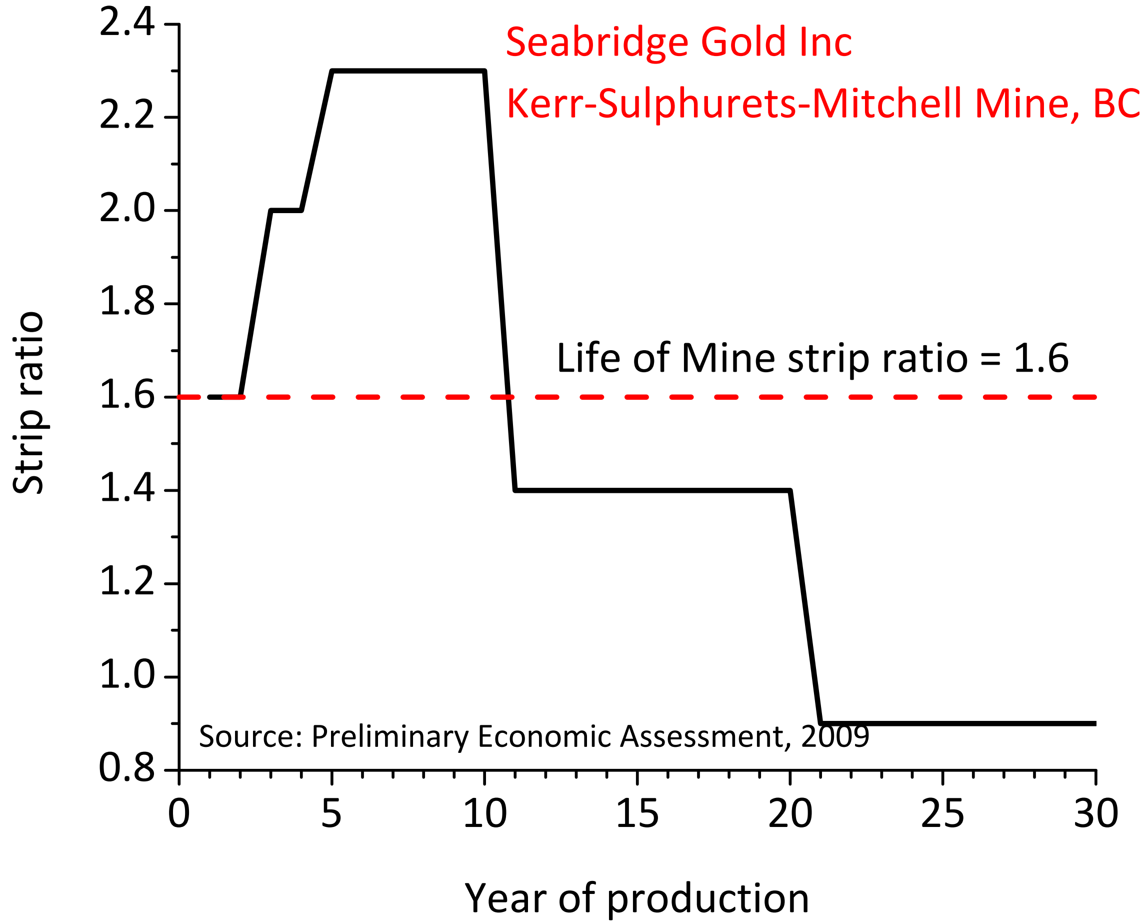
$$T = O + S \times O = (1 + S)O$$

$$O = \frac{T}{1 + S}$$

$$W = \frac{S \times T}{1 + S}$$

Example:
T = 135 kt/day
S = 0.5
O = 90 kt/day
W = 45 kt/day

Strip ratio changes over life of mine



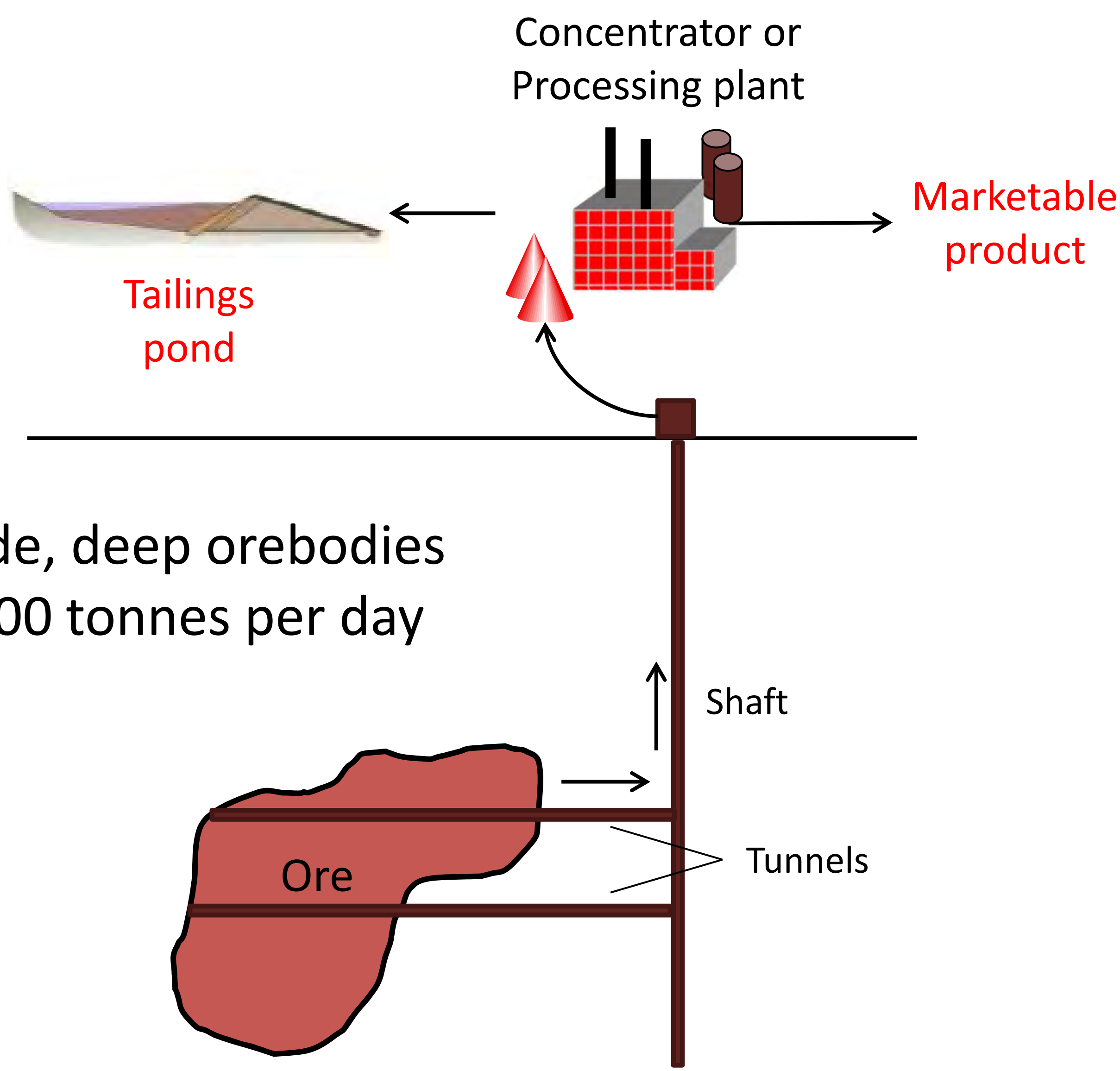
Notes: Strip ratio changes over life of mine

During production, stripping costs may be either capitalized or expensed. If capitalized, the amortization of the costs is based on the estimated value of the underlying ore and the amortization schedule will change over the life of the mine as the value of the underling ore changes. If expensed, production costs per ton of ore will vary over the life of the mine as the amount of ore produced changes.

The pushback of the west wall of the Valley pit at Highland Valley, BC will provide access to additional ore. The waste stripping associated with the pushback will be capitalized and amortized based on the estimated value of the additional ore. However, the amounts of waste and ore are subject to a number of uncertainties and could change over time. If the amount and/or value of ore changes, the amortization schedule will have to be changed.

The cost of the north wall pushback at Bagdad is treated as a cost of current production and is not related to the ore underlying the pushback. The cost per ton of ore will therefore change as the current strip ratio changes. In effect, Bagdad is buying an option on the underlying ore, the value of which is uncertain.

Underground mining



Generally high grade, deep orebodies
Mining rate <20,000 tonnes per day

Notes: Underground Mining

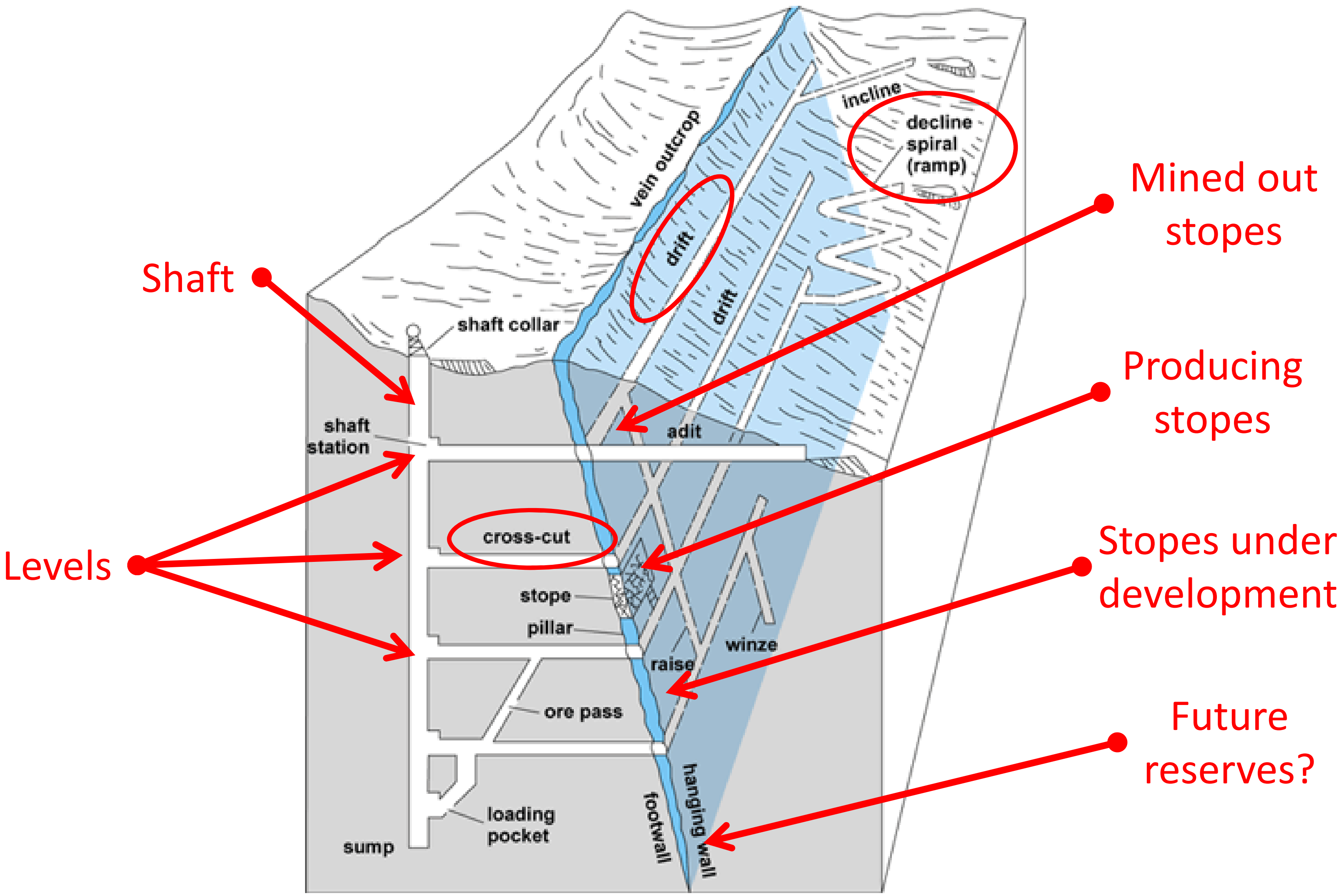
Underground mines are used to exploit high grade, deep ore bodies. However, there is no limiting grade above which underground mining is always done, nor is there a limiting depth below which underground mining is always done. It depends on the mining method used.

For underground mines the mining rate is typically less than 20,000 tonnes per day (tpd); 10,000 tpd is a large capacity (and highly mechanized) underground mine. However, the block caving method can achieve mining rates much greater than 20,000 tpd.

Underground mining results in one waste stream: tailings which are the result of a mineral separation process in the concentrator or processing plant. There is very little waste rock generated as a result of sinking the shaft or driving the tunnels to gain access to the ore.
Underground mining is generally more selective than open pit mining, but the degree of selectivity depends on the underground mining method.

The significant design issues of an underground mine are: geometry of underground mining, ground support, and logistics of materials handling.

Underground Mine Anatomy



Notes: Underground Mine Anatomy

In general for underground mines:

> Small output mines (<4,000 tpd) - hauling is done on several levels, tonnage handled on each level is small, and light equipment is used.
>
> High output mines (>4,000 tpd) - a main haulage level is used and all the ore is dropped to that haulage level via **ore passes**.

A **level** includes all the horizontal workings tributary to a **shaft** station. Ore excavated in a level is transported to the shaft to be hoisted to the surface.

Stopes are openings from which ore is mined. They may be **backfilled** with cemented waste material.

Ore passes are sub-vertical chutes for movement of ore. **Declines** or **ramps** are spiral or inclined drifts.

Note the different types of drilling: **development drilling** to open up the orebody and **exploration drilling** to better define the limits of the orebody.

The upper side of the orebody is called the "**hanging wall**" because that is where miners used to hang their lamps while working. The lower side is called the "**footwall**" because that is where their feet were planted. Nowadays, the illumination is provided by an electric grid within the mine and all miners wear headlamps on their hardhats..

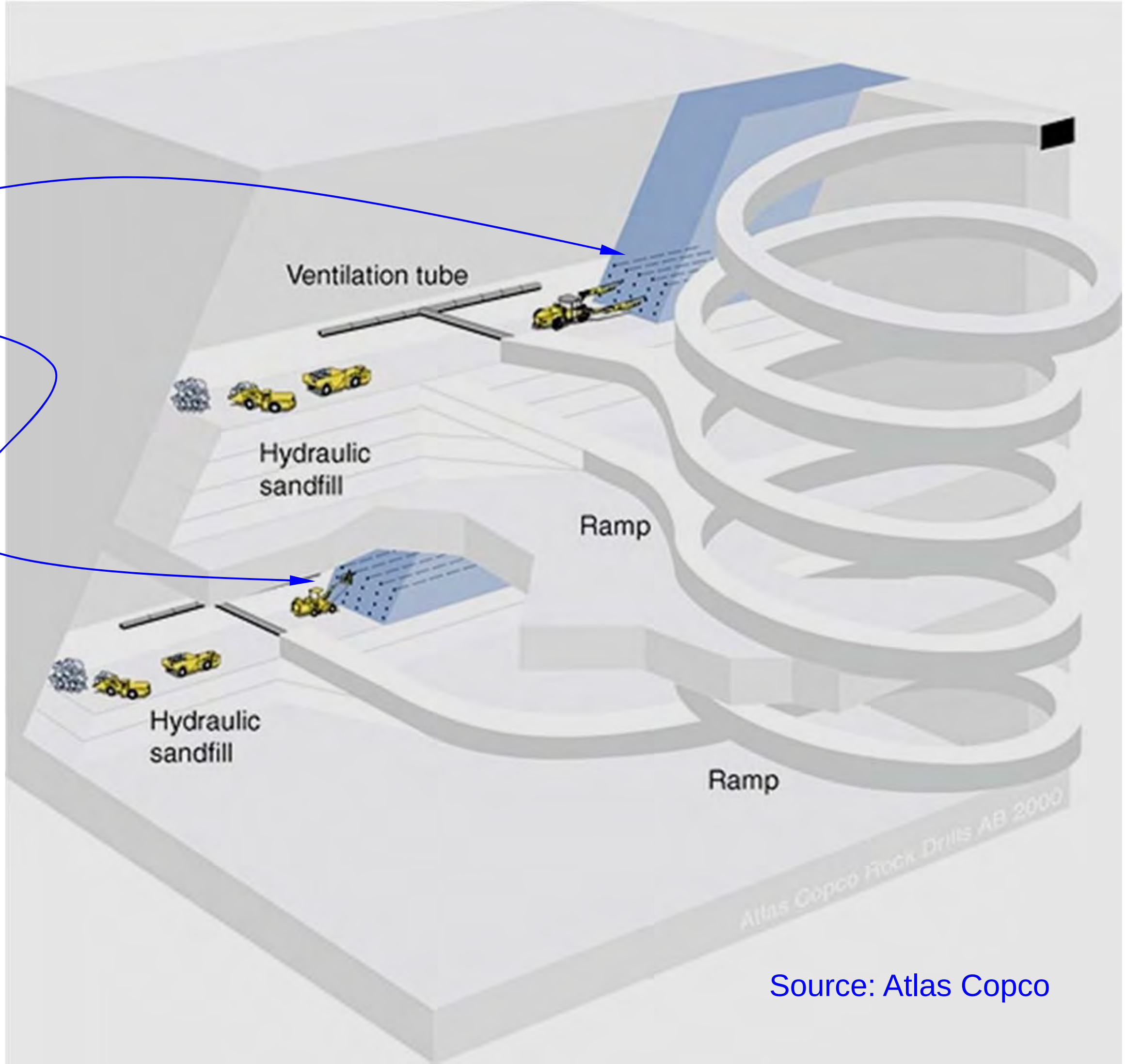
Mine shaft and shaft sinking

www.camese.org

Cut and Fill Mining

Stopes

"Fill" is some combination of tailings and cement



Source: Atlas Copco

Notes: Cut and Fill Mining

Cut-and-fill mining removes ore in horizontal slices, starting from a bottom undercut and advancing upward. Ore is drilled, blasted and removed from the stope. When a stope is mined out, the void is backfilled with a slurry of tailings which is allowed to drain to form a sufficiently solid surface. Cement may be added to form paste backfill. The fill serves both to support the stope walls and provide a working platform for equipment when the next slice is mined.

There are two types of cut and fill mining – overhand and underhand. In overhand cut and fill, the ore lies underneath the working area and the roof is backfill. In underhand cut and fill, it is the opposite, the ore overlies the working area and the machines work on backfill.

Cut-and-fill mining is applied to steeply dipping orebodies in stable rock masses. It is a selective mining method and is preferred for orebodies with *irregular shape and scattered mineralization*. 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.

Cut and fill – a picture

Jon 'ShakataGaNai' Davis (http://commons.wikimedia.org/wiki/File:Miner_In_Raise_2.jpg)

Narrow Vein Mining

Common in precious metals mines

An example:

"The Santo Niño vein was discovered by drilling at a depth of 300m below the surface and has now been traced for 2.5 km in length and 500m in depth with a width varying from 0.1-4.0m."

Source: www.firstmajestic.com/s/LaParrillaProject.asp

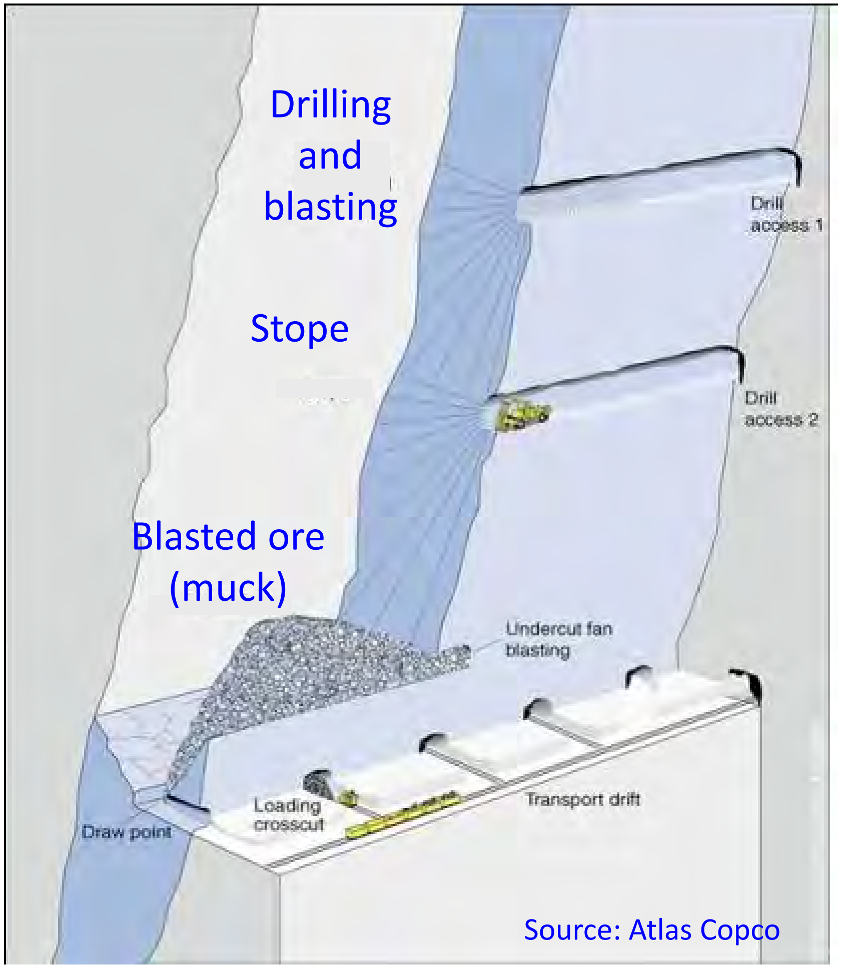
www.silverlakeresources.com.au

Notes: Narrow Vein Mining

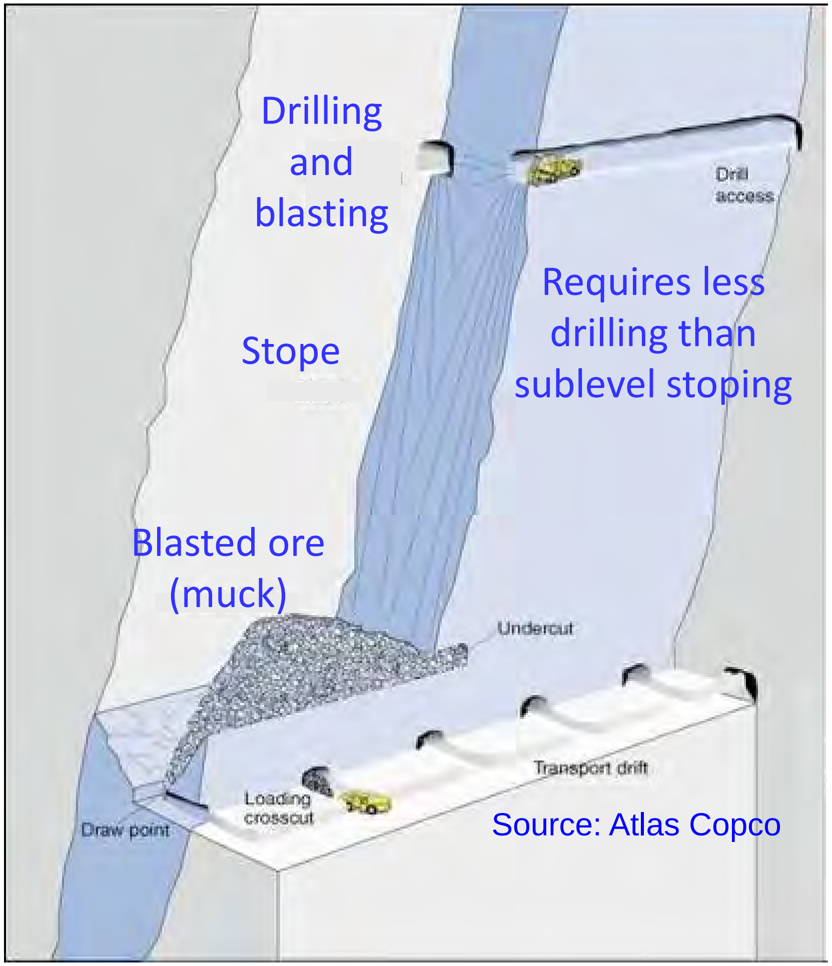
Used for very narrow orebodies, as small as a half metre wide. Very selective method; waste rock is left in the hanging wall and the footwall. In a wide vein, a standard LHD can operate inside the drift. “Slim-size” machines including drill rigs, jumbos, and 2 m^3 bucket LHDs, are available for working in drifts as narrow as 2.0 m. However, in such narrow veins the use of machines produces waste which dilutes the ore. The alternative is to use a manual technique to extract only the higher grade material in the vein. But manpower is costly, difficult to find, and manual techniques are not efficient.

Stoping

Sublevel stoping



Longhole stoping



Notes: Stoping

Stoping is used for mining deposits with following characteristics:

- Steep dip, the footwall inclination must exceed the angle of repose
- Stable rock in both hanging wall and footwall
- Both competent ore and host rock
- Regular ore boundaries

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. The stopes are normally backfilled with consolidated mill tailings. This allows for recovery of the pillars of unmined ore between the stopes, enabling a very high recovery of the orebody.

Longhole stoping uses longer (~100 m) and larger diameter blastholes, thus requiring less drilling than sublevel stoping. Greater drilling accuracy is required and non-planar irregularities in the orebody shape cannot be recovered. .

Development of the infrastructure for both these stoping methods is time-consuming, costly, and complex.

Room and Pillar Oil Shale Mine in NE Estonia

Source: www.aapg.org/explorer/divisions/2006/05emd.cfm

Potash mining – just grind away

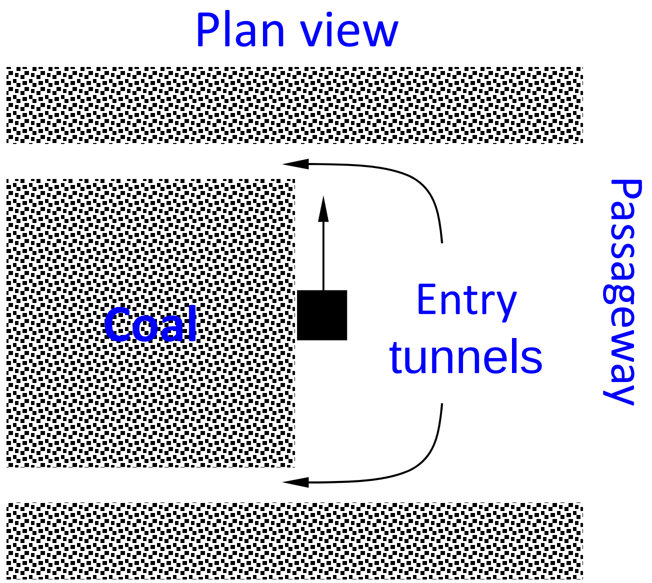
Photo source: Martin Mraz (http://www.lightstalkers.org/martinmraz) used with permission

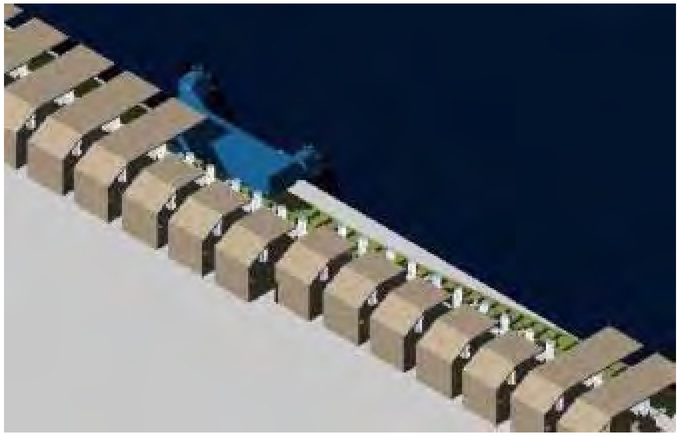
Notes: Potash Mining – just grind away

Potash (used to make fertilizer) is so soft, it can be crushed and ground in place, eliminating the need for blasting. The potash ore is transported by conveyor to the shaft and hoisted to the surface.

This mine is at a depth of 1 km and there are almost 5000 km of tunnels in the mine. At some tunnel intersections there are stoplights.

Longwall Mining of Coal





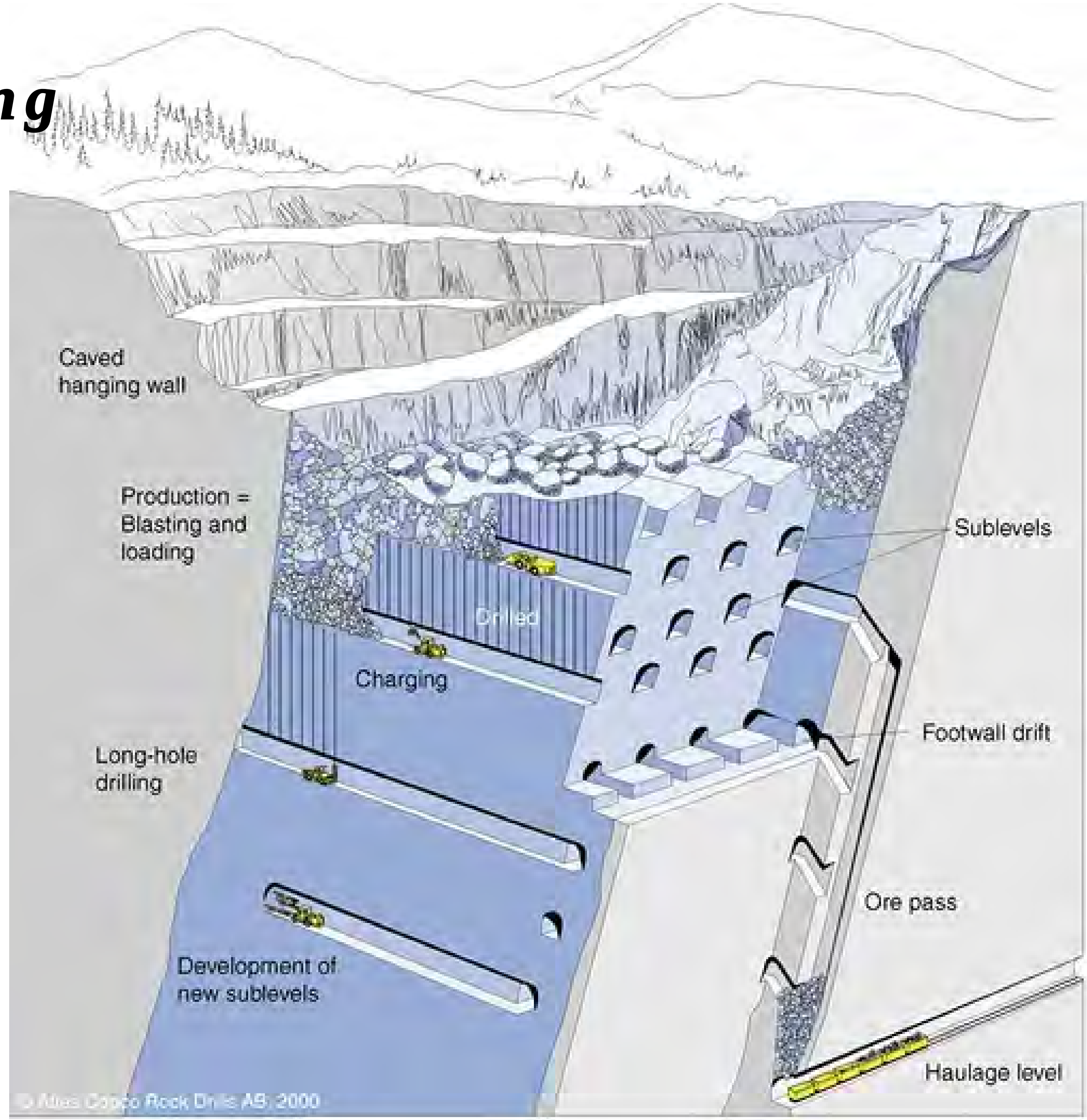
Notes: Longwall Mining of Coal

Longwall mining is a highly mechanized underground mining system for mining coal. A layer of coal is selected and blocked out into an area known as a panel. A typical panel might be 3000 m long by 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.

The longwall system would mine between entry tunnels. 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. A typical configuration of a longwall mining system is illustrated below on the left.

Sublevel caving

below a mined
out pit



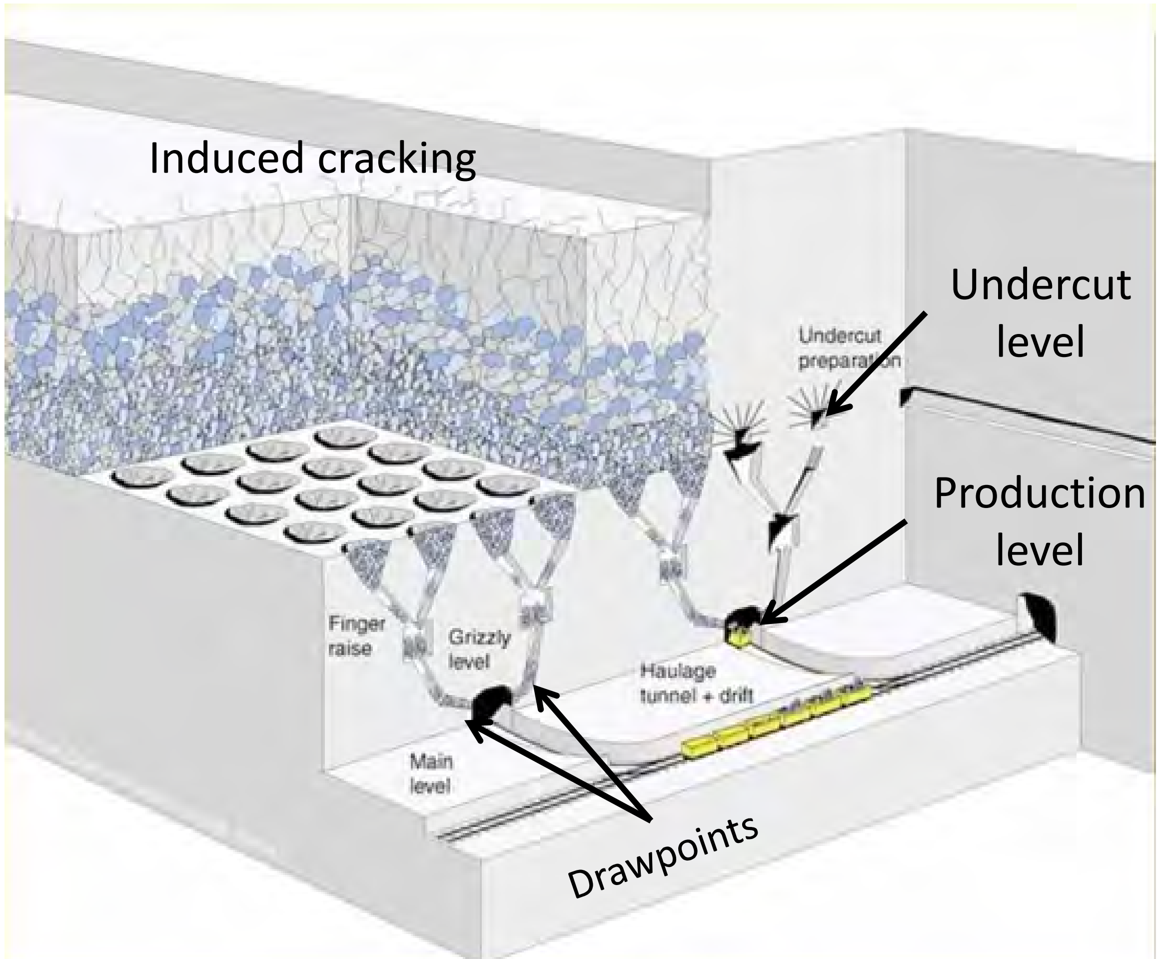
Notes: Sublevel caving

Sublevel caving is usually carried out underneath an open pit when it becomes uneconomic to mine from the pit. The underground orebody is typically a relatively narrow slab that dips at a steep angle. The method is similar to sublevel stoping except that the ore breaks into fragments (caves) by itself after an initiating blast, i.e., the blast does not do all the fragmentation.

Underground mining proceeds by constructing tunnels (drifts) through the orebody at different levels below the bottom of the pit. Holes are drilled up into the roof of each tunnel (longhole drilling), loaded with explosives, and blasted to cave the roof. After the roof caves in, Load Haul Dump (LHD) vehicles transport the muck to an ore pass where it is lifted to the surface. Drilling and blasting is sequenced in such a way that mining can take place at different levels of the mine at the same time.

As the muck is transported to the ore pass, more blasting is done to cause ore to cave into the drifts. This is repeated until the entire orebody is depleted. Ultimately rock from the pit will cave into the underground.

Block Caving – an “upside down open pit”



http://technology.infomine.com/reviews/blockcaving/

Notes: Block Caving – an "upside down open pit"

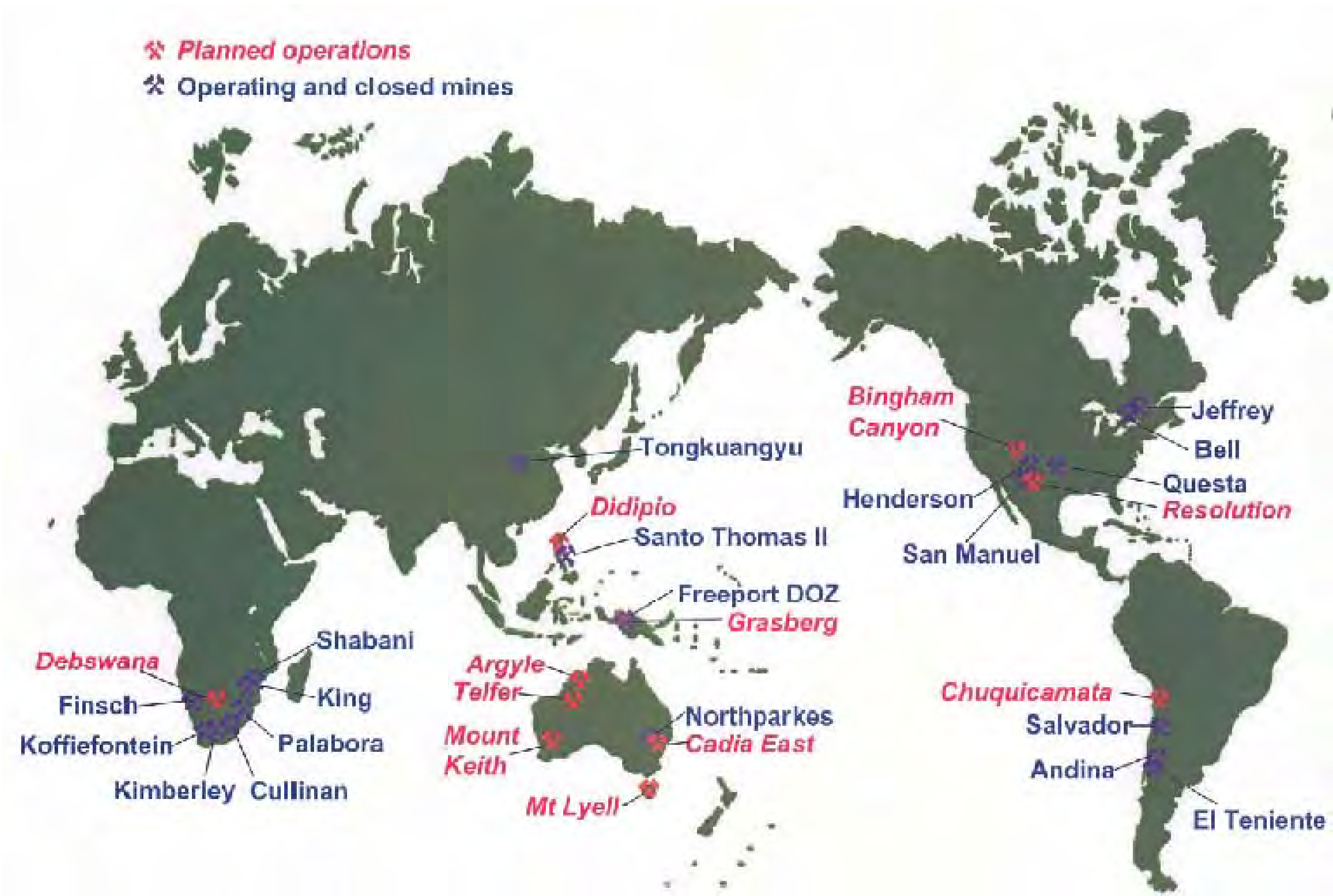
Applicable to large, deep, low grade deposits. A grid of tunnels is driven under the orebody. This can take a significant amount of time, but the rewards are high in terms of production rate. The rock mass is then undercut by blasting. Ideally the rock breaks under its own weight. The broken ore is then taken from draw points. There may be hundreds of draw points in a large block cave operation. Essentially block caving creates an underground "inverted open pit". Production rates are high. Surface subsidence can be a problem.

Mine	**Tons/day**
El Teniente – Copper South of Santiago, Chile	
Esmeralda	45,000
Sub 6	35,000
4 South	35,000
Andina – Copper and Molybdenum 100 km north of Santiago, Chile	35,000
Northparkes – Copper and Gold Australia	14,000
Henderson – Molybdenum West of Denver, Colorado	36,000
Palabora – Copper South Africa	35,000

Fragmentation at Northparkes

Large fragments may cause “hang-ups” stopping the flow of ore. They have to be broken up by secondary blasting which can be costly because a set of draw points near the blasting has to be shut down..

Block Cave Operations



Why all these underground methods?

High flexibility → Low flexibility

High operating cost → Low operating cost

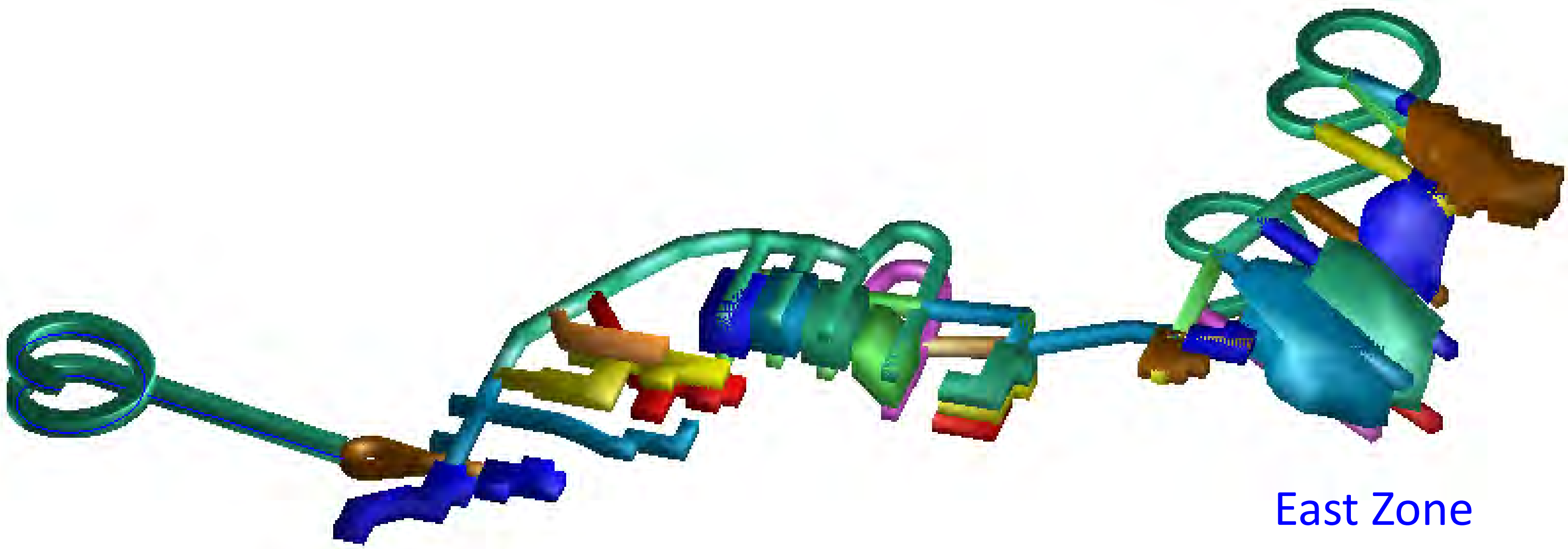
Cut and fill — Backfill support

Stoping, Room and pillar — No backfill

Longwall, Caving — Controlled collapse

Low operating cost, bulk mining operations such as block caving are desirable, but the capital costs for development of mines that use these methods are significant. In addition, there is little flexibility in a bulk mining operation – it must produce ore at a high rate almost without fail.

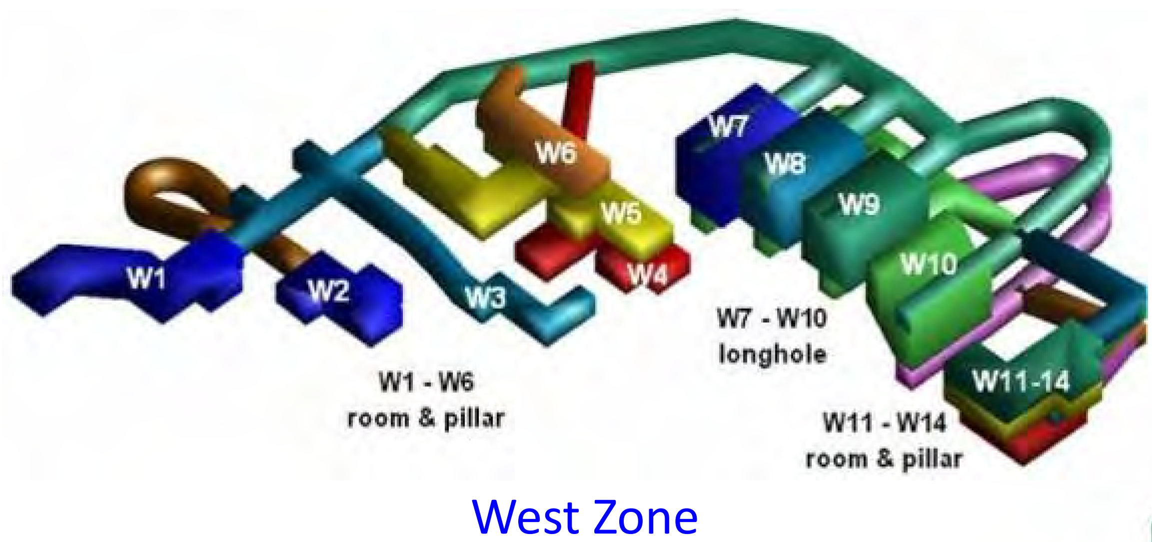
A complex ore body

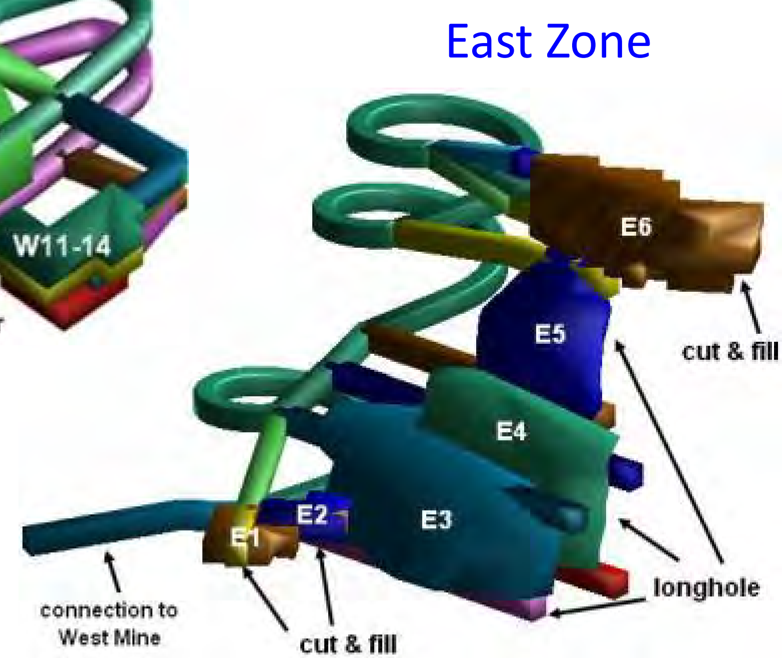


WARNING: Never lose sight of your guide if you go underground. The various twists and turns in an underground operation make it very easy to get lost.

Source: Terry Gong and Daniel Avar, 2006. *Resource Estimation and Mine Design*. Feasibility Report written for MINE 491 course at University of British Columbia.

Same ore body – different mining methods





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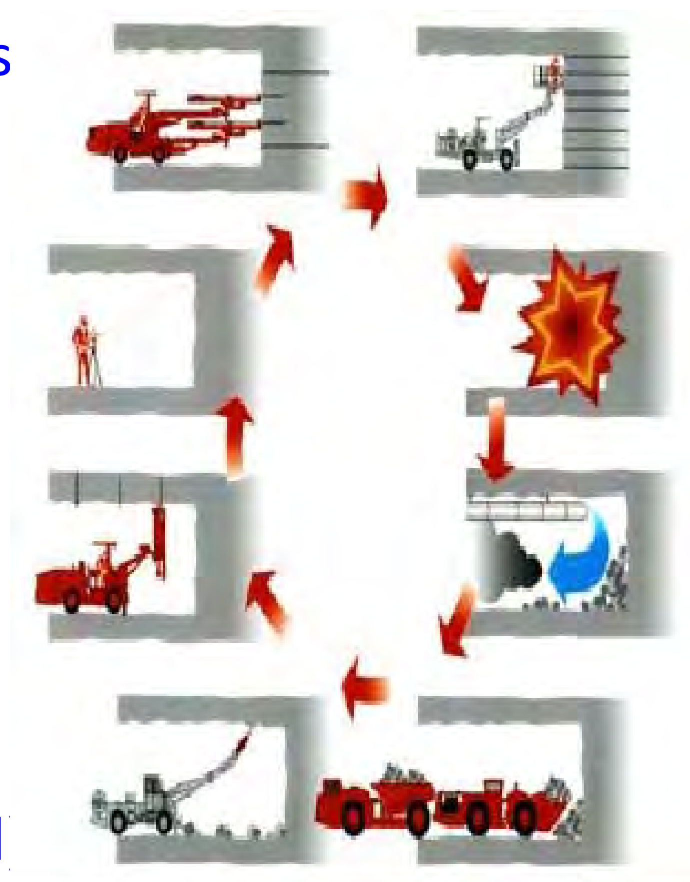
Source: Terry Gong and Daniel Avar, 2006. *Resource Estimation and Mine Design*. Feasibility Report written for MINE 491 course at University of British Columbia.

The Mining Cycle

Drill holes

Load with explosives



Survey blastholes

Blast

Install support (underground)

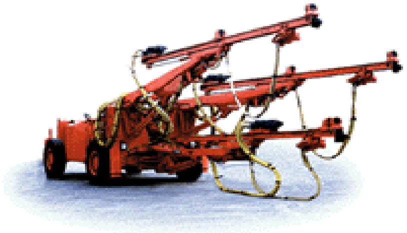
Ventilate (underground)

Scaling (underground

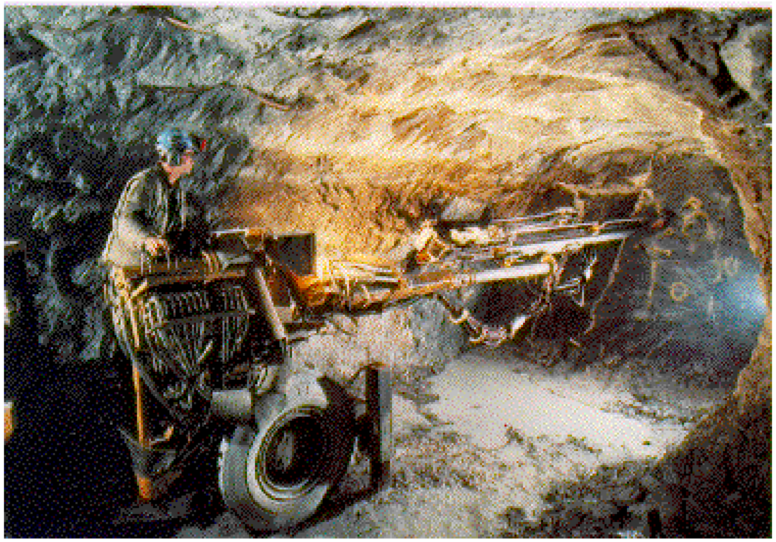
Load, haul, dump

Underground drilling

Remotely operated rig drilling into a stope



Drill jumbo



A jumbo drill is several drills (up to five) mounted on one machine and powered by a single drive system. These machines show conclusively that it is possible to do more than one thing at a time while underground.

Drilling in an open pit

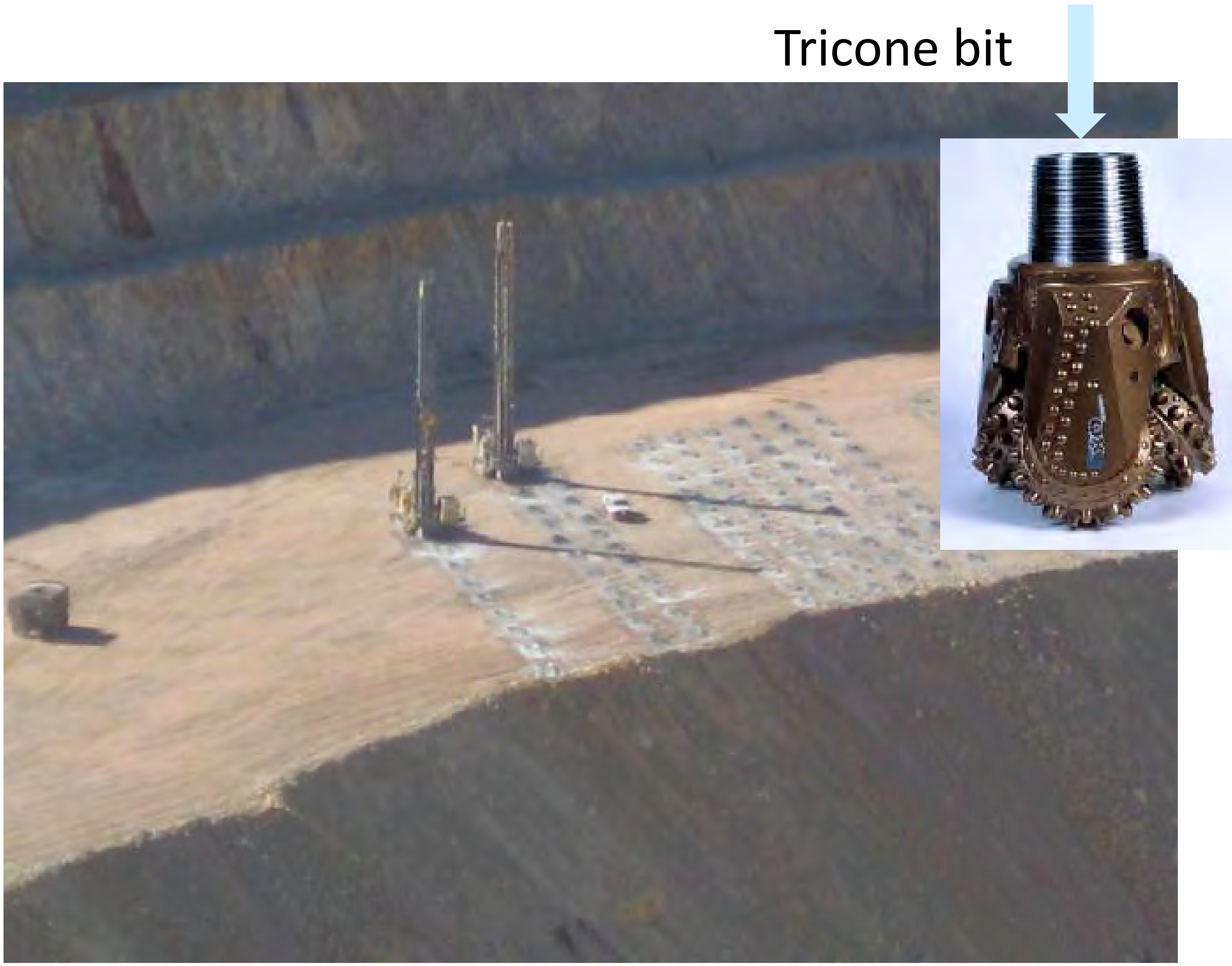
Tricone bit

Air is forced down the drill stem and out through holes in the drill bit. The **tricone** bit may be cooled with water.

Blasthole drilling at Bagdad

Air

Tricone bit



Blasting


Blast pattern at Highland Valley

Blast at Zaldivar mine, Chile

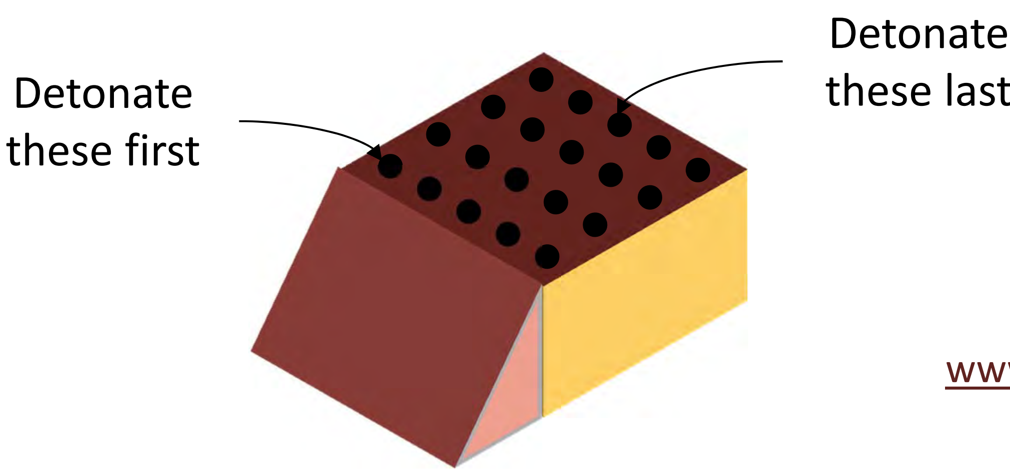
www.mining.ubc.ca/cimarchive/bymine.htm

It's never good to see a blasting technician smiling when standing next to a rock face loaded with explosives.

Notes: Blasting

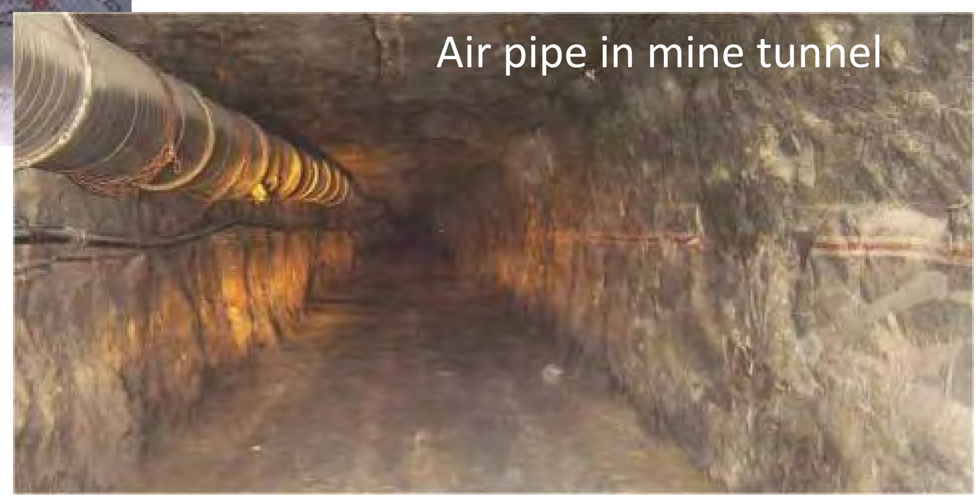
The picture on the left of the slide shows some cones in drilled holes ready for explosives to be poured into them. Note the regular pattern of the blast holes. There is also a pattern to the detonation times of the explosives in each blast hole. Typically the detonation times of the explosives in two adjacent blast holes differ by a few milliseconds (called a delay time) so that the blast proceeds in a particular direction within the blast pattern to avoid blasting too much rock. (See diagram below.)

Blasts should not "vent" and be too spectacular. If they are, it is wasted energy. The goal is to keep the blast energy in the ground to fracture the rock as much as possible. Ideally the blast should just lift the rock up and then the fractured rock settles.



Watch some detonation patterns :
www.youtube.com/watch?v=44tm26Fhqr8

Ventilation



Load Haul and Dump (LHD) – all in one

Shovel and Haul Truck

www.cbc.ca/news/business/story/2011/02/23/corporate-profits.html

www.im-mining.com/2010/10/29/

Notes: Load Haul and Dump

The Terex RH400 shovel (50 m^3 capacity) is used to load Caterpillar 797B trucks (380 ton capacity) at Syncrude Mine in Alberta. The Terex O&K RH400 shovel was designed specifically to meet Syncrude's high capacity and durability needs in the oil sands.

Image sources: www.terex.com   www.atlascopco.ca

Cocktail party trivia:

•Every 24 hours at Syncrude there is enough metal worn off the mining equipment, by abrasive oil sand, to make two full-size pick-up trucks. Source: www.syncrude.com

•The fuel tank of the Caterpillar 797 truck has a capacity of 6,800 litres (1800 gallons) – that's 12,364 extra large cups of coffee or 19,155 cans of pop.

•The Cat 797's tires are nearly 4 m (13.1 ft) tall, weigh 15,422 kilograms (34,000 lb), and cost $50,000 each (US$).

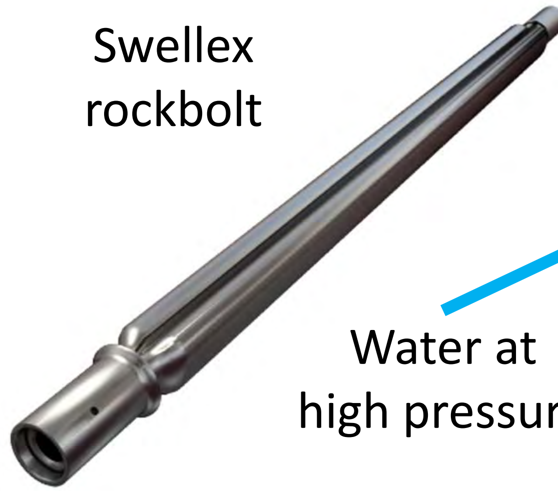
The goal of large machines is to spread fixed costs over a larger unit, i.e., obtain economies of scale. However, there is concern that maintenance costs of these large machines, particularly tire costs, are too high leading to diseconomies of scale. One manufacturer has suggested 1000 ton haul trucks by 2020. Shovels will become correspondingly larger – say 150 m^3. But …

- It may not be possible to build tires for such large trucks
- New materials and new designs may be needed to build the trucks
- Space constraints on haul roads and maintenance facilities
- Total production and transportation costs increase with size
- There are reliability and flexibility issues – if one large machine breaks down, the system stops

Shovel and trucks at Elkview

Install support

Swellex
rockbolt



Water at
high pressure

Rockbolts analogous to
rebar in concrete

Notes: Install support

Rock is strong when it is compressed – it takes a huge force to break rock by squeezing it. In the earth, rock is subjected to very large compressive forces due to the weight of rock lying above it. However, opening a hole in rock takes away this compressive force and the rock expands, maybe only a few millimeters, but this expansion is enough to cause failures along cracks. The expansion actually pulls the rock apart and rock is weak when this happens – it is said to be weak in tension.

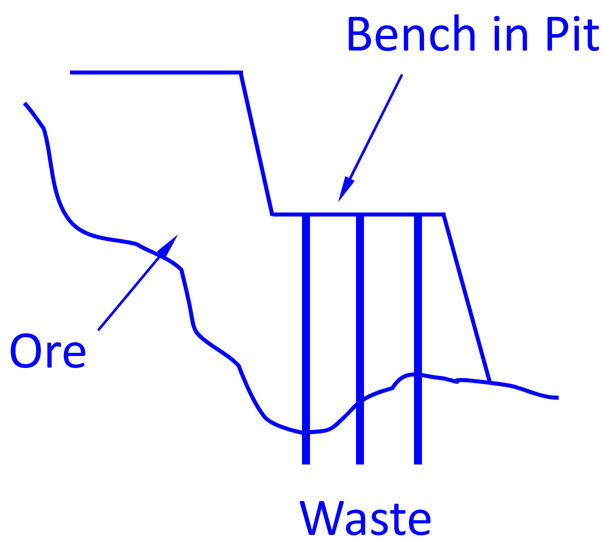
Thus cracks form on the roof and walls of a mine opening and the rock mass begins to fall apart. This might lead to large (dangerous) chunks of rock forming on the roof and walls. When these fall into the opening, it is called **spalling**. The mesh prevents this.

A compressive force can be imposed on the rock mass around a mine opening by means of **rock bolts**. These are long steel bars with wedges on one end that lock them into place at the end of a hole drilled from the mine opening. A nut on the other end of the bolt is tightened to provide compression to the rock mass by squeezing it together. Another type of rock bolt is the Swellex bolt which is compressed against the sides of the hole by means of water pressure.

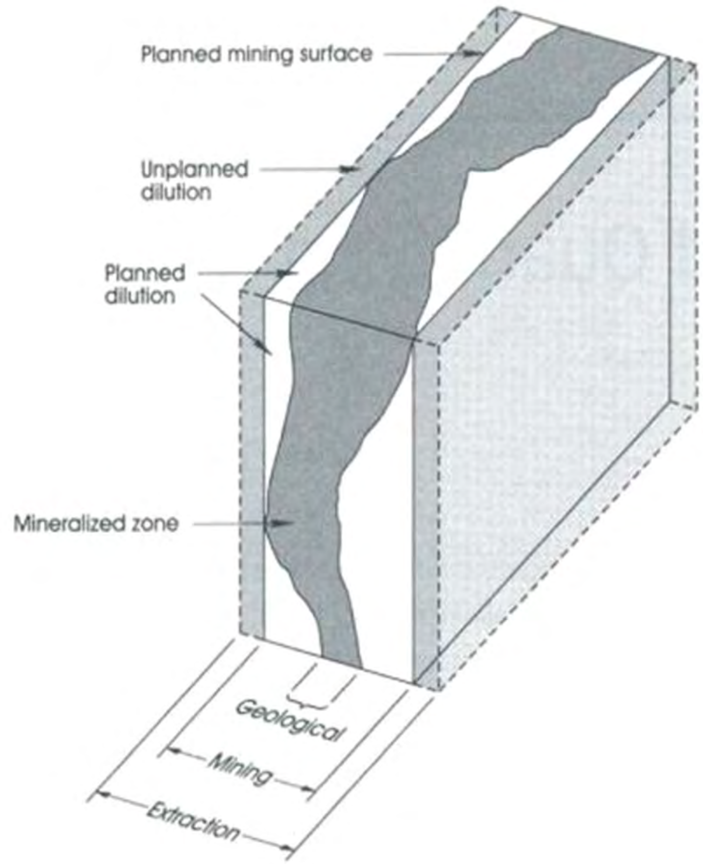
Shotcrete is a thin layer of concrete that is sprayed onto the rock face. It can take the place of mesh and is easier to install, but it can be expensive. Sometimes short narrow plastic rods are embedded to provide tensile strength to the shotcrete (Concrete is also weak in tension – that's why rebar is used in concrete construction.) Shotcrete can also provide some strength by preventing further expansion of the rock mass into the opening.

What is used depends on the rock type and its conditions. It also depends on the use of the opening – e.g., permanent or temporary.

Grade control and dilution



Equal length blast holes
drilled into waste



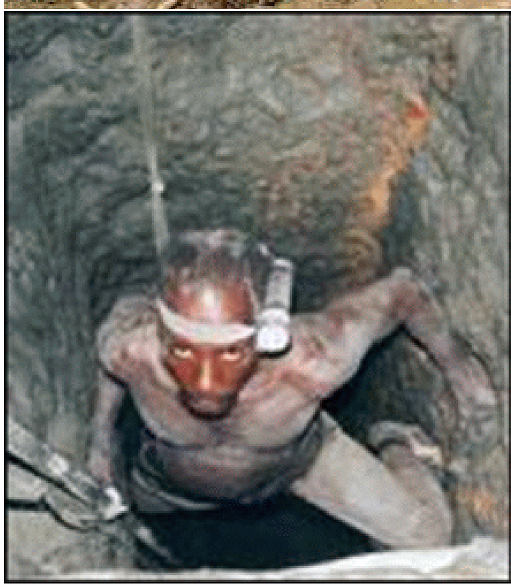
Lack of selectivity of mining
method

Notes: Causes of Dilution

It is often difficult to mine selectively and avoid dilution. In open pit operations, efforts are being made to use global positioning satellite systems (GPS) to accurately position individual shovel scoops and drills. Other methods are used to sense the ore-waste boundary so that drilling can stop at that point. In underground operations, some work is being done to separate waste from ore at the source, i.e., before it goes up the shaft.

Dilution is defined as waste/(waste+ore), i.e., a percentage of the total material extracted. Dilution is assumed to occur when and where ore is being extracted, that is the waste produced during underground development or stripping before open pit mining is not included. Dilution might be 5%-10%, but this depends on the orebody type and its geometry as well as on the level of dilution control.

Artisanal Mining



Gold-mercury amalgam
www.pictures.reuters.com

www.rfi.fr/actuen/articles/110/article_2903.asp

The horns of a miner's dilemma

Many mining companies own a mine in an area where artisanal mining occurs. Should they do anything about it? Common sense (and professional ethics) suggests doing something about such unsafe practices. Options include re-training the artisanals to work in the mine, to do another job, or help them do the artisanal mining in a better way. But doing this causes changes which can be considered just as bad or worse. Here's a quote from a newspaper article:

> … a small but noisy contingent of activists insists that Barrick is the face of corporate evil. … It has destroyed communities and wrecked the livelihoods of small "artisanal“ miners.
>
> ⋮
>
> As for the accusation that Barrick has destroyed "artisanal" mining, the truth is that the rewards from crude surface mining with a pickaxe have long since been exhausted. These days, "artisanal" mining often takes the form of dangling a six-year-old kid down a hole with a rope.

From *Our world needs more Peter Munks*
Margaret Wente, Globe and Mail, June 11, 2011

These things happen

A really stupid mistake

Luckily the driver of the red truck was working nearby when the haul truck drove over it.

WARNING: Keep clear of haul trucks if you find yourself in an open pit mine. The driver's field of view is very limited.

END OF PART 2