Unit 3 – Land Use and the Environment (Mining)

Introduction

- **Mining:** is the extraction of valuable minerals or other geological materials from the Earth that are usually removed from an ore body, vein or seam.

- **Mineral:** is a naturally occurring, inorganic solid that has a definite chemical composition and structure.
  - This means that its atoms are neatly arranged in a specific crystal form.
  - A mineral can be composed of a specific ***element*** such as **gold** (Au), or as a ***compound*** of two or more elements such as **pyrite** [aka "*Fool's Gold*", FeS_2, iron (IV) sulfide].

Gold (Au)

Pyrite (FeS_2)
"Fool's Gold"

  - Other Examples of Minerals:
    - Iron oxide minerals such as **hematite**, Fe_2O_3 [iron (III) oxide] and **magnetite**, Fe_3O_4 [iron (II, III) oxide].
    - Nickel sulfides such as **pentlandite**, $Fe_5Ni_4S_8$
    - **Halite**, NaCl (sodium chloride, aka "table salt")

- **Ore:** is a rock containing valuable minerals of sufficient quantity that can be economically mined and then refined for human use. Example: iron ore and gold.

- **Ore body:** is the 3-D, underground concentration of a mineral.

- **Vein:** is the thin deposit of a mineral left behind after exposure to heat and pressure. The ore rises, and fills in cracks (*fissures*). Water evaporates and leaves the ore behind.

- **Seam:** is a layer of ore between two other types of rock.

- **Mining in NL** http://www.nr.gov.nl.ca/nr/mines/index.html
  - Mining is one of Newfoundland and Labrador's largest and oldest industries.
  - It is a major contributor to the economy of our province, especially in rural areas.
  - A total of 14 mineral commodities are produced or mined in the province. (A *commodity* is something valuable that is bought and sold.)
  - Seven metal mines currently produce iron ore, nickel, copper, zinc, cobalt and gold.
  - Other operations mine pyrophyllite, limestone and dolomite, plus other commodities.
  - Our mining and mineral exploration companies provide high-paying jobs to more than 8 000 men and women throughout the Province. In addition, expenditures by these companies support the economy of Newfoundland and Labrador.

- **Introduction to Mining Worksheet**

Mineral Resource Use & Exploration Technology

- The issues surrounding the development, operation, and subsequent closure of a mine are both numerous and complex.
- As we discuss the impacts of mining, it is important to remember the **three factors influencing sustainable development:** (1)the environment, (2)the economy, and (3)society and culture.
- Modern society cannot function without many of the materials produced in various mining operations. For example:
  - Iron ore – used to make steel
  - Limestone – used for cement
  - Gypsum – for gyproc and plaster
  - Quartz – for glass and crushed stone
  - Marble and granite – for ***dimension stone*** (which is natural rock material quarried for the purpose of obtaining blocks or slabs that meet specifications as to size, shape, color, texture, pattern, and surface finish.)
- Many communities depend on the income from the jobs created at the various stages of operation.
- So, in terms of the economy and society, mining has a positive impact.
- However, the extraction and processing of these minerals can have serious negative environmental as well as cultural implications.

✧ Mining Operations in NL

- Closed Mines
  - **Buchans**
    - Located in Central Newfoundland.
    - Produced over 16,000,000 tonnes of lead, zinc, copper, silver and gold between 1928 and 1984.
    - It was one of the richest *base-metal* mines in the world.
  - **Bell Island**
    - Located in Conception Bay South.
    - Was once the world's largest iron ore mine.
    - The ore deposit was vast, of high quality, and close enough to the Cape Breton coal fields to feed the giant steel mills in Sydney, Nova Scotia.
    - Bell Island iron ore was also shipped to the United States and Germany.
    - The iron mines drew Bell Island into the international network of the mining and steel industry during its period of mining operations (1895 – 1966).
  - **St. Lawrence**
    - Located on the southeast coast of the Burin Peninsula.
    - At the time of its discovery, the St. Lawrence fluorspar deposit was described as the largest in North America.
    - Fluorspar (aka "fluorite" or calcium fluoride, CaF_2) is a non-metallic ore which was used in the manufacture of aluminum, glass, and Freon (a refrigerant).
    - Was in operation from 1933 – 1978.
- Open Mines
  - **Labrador West**
    - The Iron Ore Company of Canada (IOC) has been producing iron ore (for steel production) at the Carol project since the 1960's.
    - 2014 shipments are expected to be 15.5 million tonnes.
    - The Wabush 3 deposit was submitted for environmental assessment early in 2013 and an Environmental Impact Statement in August 2014.
    - Production from Wabush 3 is scheduled to start in late 2016 and extend to about 2060.
    - IOC has also mined dolomite [calcium magnesium carbonate, $CaMg(CO_3)_2$] in Labrador West since 1986.

- 130 000 tonnes of dolomite is expected to be mined in 2014 (after a two year break) and is also used in the production of steel.
- The Leila Wynne dolomite mine that operated from 1989 to 2005 is currently in the process of rehabilitation and final closure.

▪ **Baie Verte Peninsula**
- Anaconda Mining Incorporated
  - owns and operates an open-pit gold (Au) mine and mill at Pine Cove on the Baie Verte Peninsula.
  - Gold production began in 2008.
  - The projected value for 2014 is more than $24 million.
- Rambler Metals and Mining Canada Limited (RMM)
  - owns and operates the Ming Mine and Nugget Pond mills on the Baie Verte Penisula.
  - Production of gold and copper ore was declared in November 2012.
  - Reserves will be depleted by about 2019.

▪ **Voisey's Bay**
- Mine and mill is operated by Vale Newfoundland and Labrador Limited (VNL).
- VNL is also constructing a processing plant in Long Harbour.
- Mine started operations in 2005, producing nickel, copper and cobalt.
- Production from Jan – June 2014:
  - 26 500 tonnes nickel (Ni)
  - 14 100 tonnes of copper (Cu)
  - 636 tonnes of cobalt (Co)
- Underground mine due to start ore production in 2019.

▪ **Millertown**
- The Duck Pond project is operated by Teck Resources Limited and is located about 30 km southeast of Millertown.
- Copper (Cu) and zinc (Zn) concentrates have been mined since 2007 and are expected to last until 2015.
- They are trucked to a storage and shipping facility in St. George's and then sold to smelters in North America and overseas.

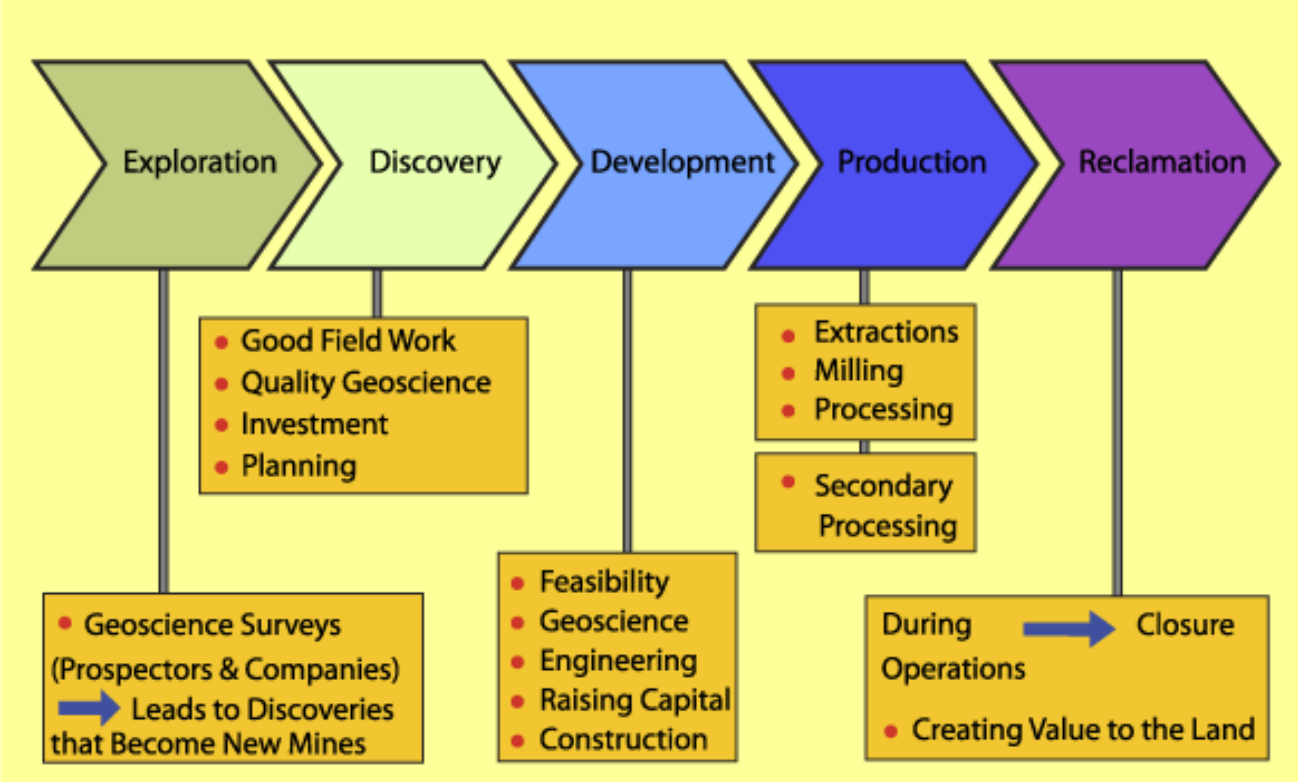
✧ **Handout / Activity: Figure 12.11 Some active mining operations in Newfoundland and Labrador (2008) –** *Place a ☑ by each open mine and an ☒ by each closed mine for this year.*

- **Handout: Producing Mines and Developing Properties (October 2014) Map**
- **Mineral Resource Use and Exploration Technology Worksheet (Part 1)**

- **Economic Impacts of Mining**
  - Increased GDP (Gross Domestic Product)
  - Increased employment
  - Increased salaries
  - Increased secondary services

- The process of opening and ultimately closing a mine are specific to the type of mineral to be mined and the technique used to extract the ore.
- In addition, the process is strictly monitored.

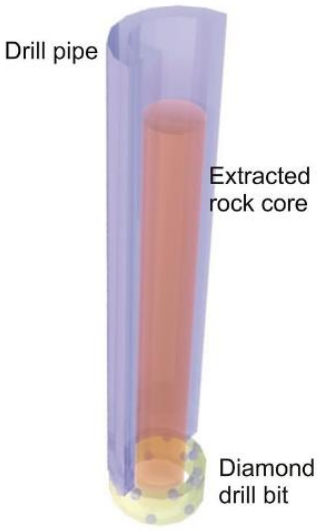
- **Stages in a Mining Cycle**
  - Exploration
  - Ore Extraction
  - Processing
  - Closure / Rehabilitation / Reclamation



- **Handout: The Essential Phases of Mining**

✧ Mineral Exploration Methods

- Satellite imaging
  - Poor vegetation is visible via satellite images, and can indicate the presence of nickel deposits.
  - Aerial photographs and images from satellites of folds, faults and other geological features are potential host sites for ore deposits.
  - Reflection data and absorption properties of soil, rock, and vegetation is collected and used to identify clays, oxides, and soil types from satellite imagery.
- Magnetometers
  - are measurement instruments used to measure the magnetization of a material or to measure the strength of the Earth's magnetic field in a certain location.
  - A change in the magnetic field is called a *geophysical anomaly*, and its location is a potential site for mining ore.
- Core Drilling
  - A cylindrical sample of rock, called the *drill core*, is removed from the Earth using diamond drills and drill bits.
  - The drill core may be hundreds of feet in length.
  - The core samples are recovered and examined by geologists via computer software and laboratory analysis to provide exploration companies the information necessary to begin or abandon mining operations in a particular area.



- Ground Exploration
  - **Grab samples**
    - Grab samples are pieces of rock that are analysed to determine if they contain valuable elements.

- The samples are taken by literally walking the ground, picking up rocks, and mapping their location.
- The grab samples are then assayed to begin forming a map of where further mineral exploration may be appropriate. (An *assay* is a chemical analysis to determine the amounts of metallic or non-metallic elements in a rock sample.)

▪ **Panning**

- Panning is a simple method of separating particles of greater density (especially gold) from soil or gravel by washing in a pan with water.
- It is one of the principal techniques of the individual prospector for recovering gold and diamonds in placer deposits. (*Placer deposits* are concentrations of valuable minerals in river gravels and beach sands formed by gravity separation/density during sedimentation.)

▪ **Geochemical**

- Geochemical ground exploration is the use of chemical properties of naturally occurring substances (such as rocks, soils, and stream sediments) to discover economically viable deposits of metallic minerals or hydrocarbons.
- In exploration programs, geochemical techniques are generally integrated with geological and geophysical surveys.
- A *geophysical survey* measures the physical properties of the Earth's surface, such as magnetic field strength, rock conductivity, density or specific gravity, and radioactivity. As mentioned previously, an abnormal value may indicate mineralization and thus a potential mining site.

✧ **Mineral Resource Use and Exploration Technology Worksheet (Part 2)**

Mineral Extraction and Impacts

✧ **Above Ground & Underground Mining**

- The actual mining process (the extraction of minerals from the Earth) is very destructive environmentally.
- Specific types of ore deposits require specific extraction techniques depending on how the ore was formed and its geology, as well as economic, social and political factors influencing the extraction of ore.

- Underground Mining
  - occurs beneath the Earth's surface in tunnels and cavities.
  - is least visible type, but results in toxic *tailings* (low grade material from processing that is disposed as waste).
  - is the most dangerous and unhealthy form of mining for the miners!
  - The deposit (commonly coal, diamond or gold) must be relatively pure, distinct, and concentrated in layers, veins or shafts.
  - The valuable minerals are removed, leaving the other surrounding rock (*host* or *country rock*) to form and support the tunnels.
  - Today, Canadian underground miners are usually unionized professionals who receive risk pay or compensation because of the associated health and safety issues of underground mining.

- Above Ground Mining
  - **Placer Mining**
    - Placer mining is an above ground mining technique that involves extraction of materials such as gold, platinum, chromium, tin, titanium and diamonds from river and beach gravels.
    - They have accumulated in these sediments because of differences in density.
    - As a result, distinct layers are formed.
  - **Panning**
    - For gold (Au) is a traditional technique used for placer deposits.
    - Pure Au is 19× more dense than H_2O, so it concentrates in layers.
    - Swirling the sediment layers in a shallow pan and pouring off the excess water reveals the heavier gold flakes concentrated in the bottom.
    - Commercial placer mines in the Yukon and Alaska no longer use panning.
  - **Dredging**
    - Dredging or excavating, followed by filtration and sorting are now used to mine for gold above ground.
    - The same placer mining technique is also used to extract diamonds from beach and river deposits in Namibia (a country on Africa's southwest coast) and Australia.
    - It is also used to remove tin and titanium minerals from beach sands in Indonesia and Malaysia.
    - Excess sediment is discarded in piles (which can potentially contaminate the surrounding environment).

- However, it is sometimes possible to re-mine these waste piles as market prices and technology change to make it economically viable.

▪ **Quarrying / Open Pit Mining**
- Open pit mines are called *quarries*.
- is used when underground mining is impractical or too expensive.
- is the only way to mine dimension stone (marble / granite / Labradorite / slate) for building construction.
- is the most economical way to extract gravel and crushed stone for building roads and the manufacture of concrete, sand and limestone for cement, gypsum for wallboard, and clay for pottery and ceramics.
- Copper deposits in igneous rocks are sometimes mined in quarries:
  - requires complete rock removal
  - and landscape levelling.
  - British Columbia, Yukon, and western United States
- Iron ore is mined in open pits near Labrador City-Wabush.

o The choice between open pit or underground mining depends on the individual characteristics of the site.
o For example, in the case of mining coal.

o Coal Mining
▪ Deposits in **eastern North America** (Nova Scotia and Pennsylvania) were mostly underground operations.
- Coal was relatively hard (*anthracite*).
- Surrounding rock was strong.
- Seams were thick, easier for tunneling.

▪ Deposits in **western North America** (British Columbia, Alberta and Wyoming) were mostly open pit.
- Coal was relatively soft (*lignite*).
- Surrounding rock was weak.
- Seams were thin with coal exposed near surface.

✧ **YouTube Video: Modern Marvels "Coal Mines"**
(Coal Mines Documentary, 44:20, Rachel Handfield)
http://www.youtube.com/watch?v=PVRx4ZgHdhY

- **Impacts of Underground Mining**
  - Ground subsidence http://en.wikipedia.org/wiki/Subsidence
  - Human health issues
  - Disturbance of topography / viewscape
  - Loss of habitat
  - Pollution (noise, dust/air, water)
  - Erosion

- **Impacts of Open Pit Mining**
  - Disturbance of topography / viewscape
  - Loss of habitat
  - Pollution (noise, dust/air, water)
  - Erosion

- **YouTube Video: Frontline "Alaska Gold"**
  (Alaska Gold: Documentary on Alaska's Battle Between Wildlife and High Profit Mining, 56:10, Adolf Einstein) http://www.youtube.com/watch?v=UNDQpiNlg3c

- **Video Worksheet: Alaska Gold**

- **Handout: April 2014 + November 24, 2014 Updates on the Pebble Mine**

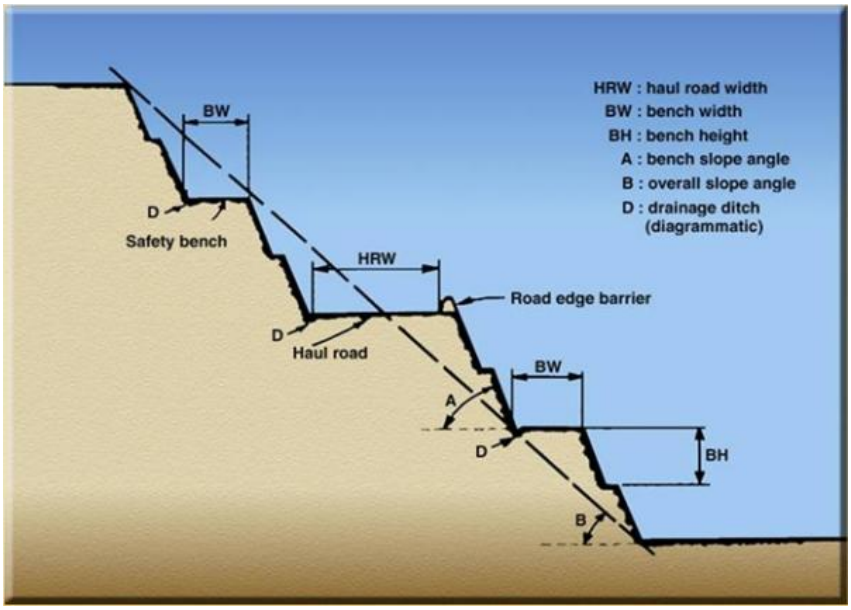
- **Mitigation Efforts to Lessen the Impacts of Open Pit Mining**
  - Mitigation is the action or process to make a condition or consequence less severe or less harmful.

  - In terms of mining, mitigation efforts would involve activities and methods that lessen the negative impacts of mining on the environment.

  - Mitigation Efforts Include / Consider:
    - Mine design
    - Waste rock and tailings management
    - Dust control
    - Remediation planning

- Mine Design
  - Modern open pit mining sites are designed and planned to be located upwind from nearby residential areas to avoid, as much as possible, the negative health-related effects of dust / air pollution. (See below.)
  - Designs and plans for construction and operation of mines must meet strict environmental guidelines, and depend on the specific mineral(s) to be mined.
  - The ores in an open pit mine are covered by *overburden* (*the rock, soil, and ecosystem that lies above a coal seam or ore body*). Both the ores and overburden are removed in *benches* (*the "steps" or ledges that form a flat surface level for mining operations*) ranging from 9 m to 30 m high. A thin deposit may require one or a few benches, but a thick deposit needs more benches.

  - **Design Aspects of Open Pit Mining:**
    - Ultimate pit depth. (*This is the maximum depth of the mine that it will reach at the end of its life*.)
    - Bench Height.
    - Bench Slope.
    - Overall pit slope. (*The overall pit slope is always less than the bench slope.*)
    - Bench Width. (*This is usually decided based on the space required for the operation of the equipment on it.*)
    - Haul Road Width & Slope. (*This depends on the size of the trucks and other hauling equipment used in the mine. It is always wider than the bench width.*)
    - Bench Length. (*The length of the bench depends on the production rate. A bench will be longer for higher production rate*.)



- Waste Rock and Tailings Management
  - As mentioned previously, *tailings* are the waste products of mineral processing, and are often toxic to the environment.
  - *Waste rock* is another name for *overburden* (mentioned above).
  - As an example, consider the **Hope Brook gold mine:**
    - operated from 1987 to 1997 by Royal Oak Mines Inc., the owner of the mining site.
    - Ownership was transferred to the Government of NL on December 13, 1999.
    - The waste rock dumps and tailings impoundment areas were two of the six major environmental concerns after the mine closed (along with acid mine drainage, heap leach materials, hazardous waste and garbage disposal).
    - Millions of dollars have since been spent on reclamation of the site.

- Dust Control
  - Blasting and digging in an open pit mine creates dust (air pollution) which negatively impacts on-site miners and support workers.
  - Airborne dust particles can be transported by wind to nearby residential areas which decreases air quality and can trigger several health-related issues such as allergies and asthma.
  - Also, the dust produced contains high levels of the minerals mined at the site, some of which are highly toxic.

- For example, the asbestos (which is *carcinogenic* or cancer-causing) that was mined on the Baie Verte Peninsula in Newfoundland and also in Québec.
  - Breathing asbestos fibres increases the risk of silicosis and lung cancer.
  - *Silicosis* is a lung disease caused by inhaling tiny bits of silica. Silica is a common mineral component of sand, rock and ores like quartz. People who work in jobs where they could breathe in these silica particles—like sandblasting, mining, construction and many others—are at risk for silicosis. The silica dust can cause fluid build-up and scar tissue in the lungs, reducing the ability to breathe. Silicosis cannot be cured, but it is preventable with appropriate precautions and safety measures.
- Dust also damages nearby plants by blocking their *stomata* (the small pores in their leaves that take in carbon dioxide to be used in photosynthesis).
- In addition, it blocks sunlight from penetrating plant leaves, and from allowing oxygen to exit the leaves, thus further inhibiting the process of photosynthesis.

- Remediation Planning
  - is an on-going process throughout the mining cycle.
  - *Remediation* in mining refers to the process of reversing environmental damage and restoring the environment to its pre-mine state.
  - The preparation and planning for a mine's reclamation occurs prior to it ever being granted a permit, and must demonstrate that the site will not pose a threat to the health of the environment or society in the future.
  - Financing must be guaranteed and available for the mine site clean-up and restoration in the event that the company responsible is unable to complete the mine closure as planned.
  - Ultimately, remediation planning creates useful landscapes that meet a variety of goals ranging from the restoration of productive ecosystems to the creation of new industrial and municipal resources.
  - It is a regular and essential part of modern mining practices, and helps to minimize the negative environmental effects of mining.

✧ **Mineral Extraction and Impacts Worksheet**

Methods and Impacts of Processing Ore

✧ Introduction

- Different materials or minerals require different processing techniques.
- For example, high grade coal may need no further processing, gravel may only require washing, and granite may only require cutting and polishing.
- However, many ores involve extensive processing.
- For example, nickel, copper, and gold ores.
  - The nickel mined at Voisey's Bay contains less than 3% Ni.
  - Copper ores are often 1% Cu or less.
  - Profitable gold ore is usually expressed in grams (or ounces) of Au per tonne of rock.

- Processing ore generally involves:
  - Preparation (crushing, grinding and milling)
  - Concentration
  - Smelting
  - Refining

✧ Preparation

- **Milling:** is a mining process where the raw ore is moved through a series of rod and ball mills to crush and grind the ore into a fine powder.
- Dry Milling
  - does not use a liquid(s).
  - It produces a lot of dust!
- Wet Milling
  - uses a liquid (usually water) to create a slurry from the powdered raw ore.
  - Some minerals, such as gold ore, require the wet milling process even though there is the potential for negative environmental impact.

✧ Ore Concentration

- **Ore concentration:** is the process of removing impurities and water from the milled ore to increase its grade or purity for transportation and further processing.
- It is achieved by physical and/or chemical methods.
- The milled ore is separated into high-grade material (rich in the desired mineral) and low-grade material (tailings) to be disposed of as mining waste.

- Physical & Chemical Concentration Methods
  - Gravity separation
  - Magnetic separation
  - Leaching
  - Flotation

- Gravity Separation
  - is a physical concentration technique that uses the force of gravity to separate materials.
  - The milled ore is mixed with water and the heavier (more dense) minerals settle at the bottom.
  - **YouTube Video: "The Gravity Separator – Oliver Manufacturing"** (Oliver manufacturing, 4:27) http://www.youtube.com/watch?v=FQkK7hdK270

- Magnetic Separation
  - is a physical concentration technique that uses magnetic force to separate materials.
  - works with naturally magnetic minerals such as iron ore.
  - The milled ore is mixed with water to form a pulp, and passed over a revolving magnetic drum to which the magnetic minerals attach. They are scraped off and kept, while the non-magnetic particles are discarded with the water.
  - **YouTube Video: "Magnetic Separation"** (TutorVista, 1:27) http://www.youtube.com/watch?v=_3BT86WfyAI&safety_mode=true&persist_safety_mode=1&safe=active

- Leaching (means "to filter out of", or "to drain away from")
  - **Heap Leaching**
    - is a chemical concentration technique that often uses toxic liquids to dissolve metals from milled (powdered) ores by percolating (dripping) the liquid down through the ore.
    - For example, sulfuric acid [$H_2SO_{4\ (aq)}$] is used to extract copper or uranium from ore.
    - Gold and silver is leached using cyanide (CN^-) containing liquids which is then collected and processed to further concentrate the metals.
    - Both sulfuric acid and liquids containing cyanide are extremely toxic!

- The dissolved metal ions precipitate out of the leach solution as solid metals (Cu, U, Au and Ag).
- In 1887, a Scottish chemist (John Stewart MacArthur) developed the process (with brothers, Dr. Robert and Dr. William Forrest) for the extraction of gold ores. By suspending the crushed ore in a cyanide solution, a separation of up to 96% pure gold was achieved. http://en.wikipedia.org/wiki/Gold_cyanidation
- 1 m^3 of ore requires about 3000 L of cyanide solution to extract the metal.
- This is triple the amount of cyanide as the amount of ore! (Note that *1 m^3 = 1000 L* .)
- **Health Hazard:**
  - Cyanide exposure can be fatal!
  - Low level exposure over time results in:
    - Breathing problems
    - Central nervous system trouble
    - Digestive tract issues
- Older mining operations (and some less developed countries today) used heap leaching on the exposed ground or in artificial ponds.
  - Toxic chemicals used were then a threat to wildlife.
  - Cyanides and acids could leach into the rock beneath the piles of ore, or through the ponds, thus contaminating the groundwater.
  - In some cases, a break in the artificial ponds released cyanide or toxic acids into the streams and rivers killing fish at the site as well as those far downstream.
- Today, chemical leaching is conducted in closed tanks and the liquids are recycled where possible.

- **Bioleaching**
  - is a new biochemical processing technique to extract gold and copper from ore using special bacteria (*chemolithotrophs*).
  - This class of bacteria obtain their energy to live, grow and reproduce by breaking down ("eating") inorganic materials like sulphide ores containing the valuable gold and copper.
  - The metals are released as *ions* (charged particles) in solution and are then converted back to solid metals using electricity to drive the chemical reaction.

- **Advantages of bioleaching:**
  - Simple and cheap
  - Very effective (~90% of desired metal results)
  - Environmentally friendly! (It eliminates the emissions from smelting and reduces the impact on the landscape.)
- **Disadvantages of bioleaching:**
  - Slower
  - Not economical for some ore processing

- Flotation
  - is both a physical and chemical concentration technique.
  - It is the process of separating minerals from the surrounding ore by mixing the crushed ore with water, oil and other chemicals.
  - The powdered ore is mixed in water, chemically treated and exposed to bubbles of air.
  - The minerals attach to the air bubbles, rise to the surface and are removed with the froth that forms on top of the pulp.
  - The waste settles at the bottom of the floatation tank.
  - The flotation process is used for the separation of a large range of sulfides, carbonates and oxides prior to further refinement. Phosphates and coal are also upgraded (purified) by flotation technology.

✧ Smelting

- **Smelting:** is the process of extracting metal from an ore. It purifies metals by melting and separating the pure metal from the impurities.
- It involves very intense heat (very high temperatures where the ore is in a molten phase like lava coming out of a volcano), and a source of carbon (usually "coke" which is made from coal, or charcoal) as its reducing agent.
- It produces *slag* (solid waste) and several gases such as carbon dioxide and sulfur dioxide, as major waste products from the smelting process.
- Smelting is a type of *pyrometallurgy (a process through which ores and metals are heated in blast furnaces to produce a finished product of workable compounds, high purity metals, and alloys. The pyromet process includes: drying, roasting, smelting, refining, and alloying, plus others.)*

✧ Refining

- **Refining:** in the mining industry means purifying an impure material after the smelting process.
- **Metallurgy:** is the refinement of metals.
- Two refining processes are:
  - **Pyrometallurgical technology**
    - aka "pyromet" technology
    - "pyro" comes from the Greek word "pyr" meaning fire
    - uses heat to separate the metal from the ore concentrate
  - **Hydrometallurgical technology**
    - aka "hydromet" technology
    - "hydro" refers to water
    - uses water to recover dissolved metals of value
- The target metals for both of these refining processes are either precious metals such as gold, platinum, and palladium, or more common industrial metals like copper, nickel, and zinc.

✧ Waste Water / Mine Waste Treatment

- Types of waste:
  - Acid mine waste
  - Leachate
  - Dust
  - Tailings
  - Slag
  - Wastewater
  - Chemical effluents
- New approaches for treatment:
  - Containment ponds
  - Effluent treatment
  - Tailings piles
- Risks associated with treating and/or containing mine wastewater:
  - dam failure
  - leakage