

2 Metal Mining and environment

2.1 Why Metals Are Important?

Metals make up over 80 % of all the elements in the periodic table of the elements. They are structurally important (cars, re-bars for building, window frames, kettles, fridges etc etc), and are chemically important. A huge variety of very important chemicals contain metals including salt, most precious stones (excluding diamonds).

Metals are hugely important for life, and no iron means no hemoglobin which means oxygen isn't moving round your body. No calcium means no bones, and that is before we talk about enzymes, co-enzyme complexes and movement of ions across the cellular membrane (the last being the basis for life itself). Metals are catalysts and speed up chemical reactions.

Metals give fireworks their bright flashes and vivid colors. Metals give color. No life would be possible as we know it without metals... no magnesium, no photosynthesis, no trapping of the sun's energy and therefore no food chain and no life. Buildings... concrete... calcium again. Electricity is generated in batteries by the difference in reactivity between two metals. Gold and silver... no jewellery!



Figure 2-2: Some metals; nickel, silver, palladium, gold, copper, .

2.2 What the Environmental Concerns Are?

Operations and waste products associated with metal extraction and processing are the principal causes of environmental concerns about metal mining, which may:

1. Physically disturb landscapes as a result of mine workings, waste rock and tailings disposal areas, and facility development.
2. Increase the acidity of soils; such soils can be toxic to vegetation and a source of metals released to the environment.
3. Degrade surface and groundwater quality as a result of the oxidation and dissolution of metal-bearing minerals.
4. Increase air-borne dust and other emissions, such as sulfur dioxide and nitrogen oxides from smelters, that could contaminate the atmosphere and surrounding areas.

Modern mining operations actively strive to mitigate these potential environmental consequences of extracting metals. The key to effective mitigation lies in implementing scientific and technological advances that prevent or control undesired environmental impacts.

2.3 How Science and Technology Can Help:

As scientific and technological advances increase the understanding of the physical and chemical processes that cause undesired environmental consequences, metal mines and related beneficiation or smelting facilities apply this understanding to prevent and resolve environmental problems. Ongoing mining operations and mine closure activities employ several different mitigation approaches including:

1. Reclamation of disturbed lands,
2. Treatments and stabilization of metal-bearing soils,
3. Prevention and treatment of contaminated water,
4. Controls on the amount and character of emissions to the atmosphere,
5. Minimizing waste and recycling raw materials and byproducts.

Better, more cost-effective approaches are needed for dealing with the environmental impacts of mining, beneficiation, and smelting, especially measures that prevent undesired environmental impacts. Scientific and technological research, focused on understanding the underlying processes important to these problems, can provide the foundation for new, cost-effective solutions. The challenge for future metal production is to develop environmentally sound mining and processing techniques that can also contribute to more widespread mitigation of historical environmental problems.

2.4 Why Metals Are Important

Metals are a class of chemical elements with very useful properties, such as strength, malleability, and conductivity of heat and electricity. Most metals can be pressed into shapes or drawn into thin wire without breaking, and they can be melted or fused. Some metals have magnetic properties, while others are very good conductors of electricity. For example, gold

is used in electronic equipment because it is an exceptional conductor of electricity and heat and it does not tarnish or corrode.

Metals and other minerals are essential components in such everyday necessities as our homes, cars, appliances, and tools. Indeed, we find ourselves becoming increasingly dependent on a vast array of new technologies - computer information systems and global communications networks - all of which need metals. Metals are also integral to the basic infrastructure of our society: transportation systems (highways, bridges, railroads, airports, and vehicles), electrical utilities for consumer power, and food production and distribution. Metals are important for the following reasons:

1. High stiffness and strength and can be alloyed for high rigidity, strength, and hardness.
2. Toughness and can absorb energy better than other classes of materials.
3. Metals are conductors with good electrical conductivity.
4. Metals conduct heat better than ceramics or polymer with good thermal conductivity.
5. Cost – the price of steel is very competitive with other engineering materials.

As the population increases and our standard of living advances, so does our need for metals. We now use three times as much copper and four times as much lead and zinc as we did 75 years ago.

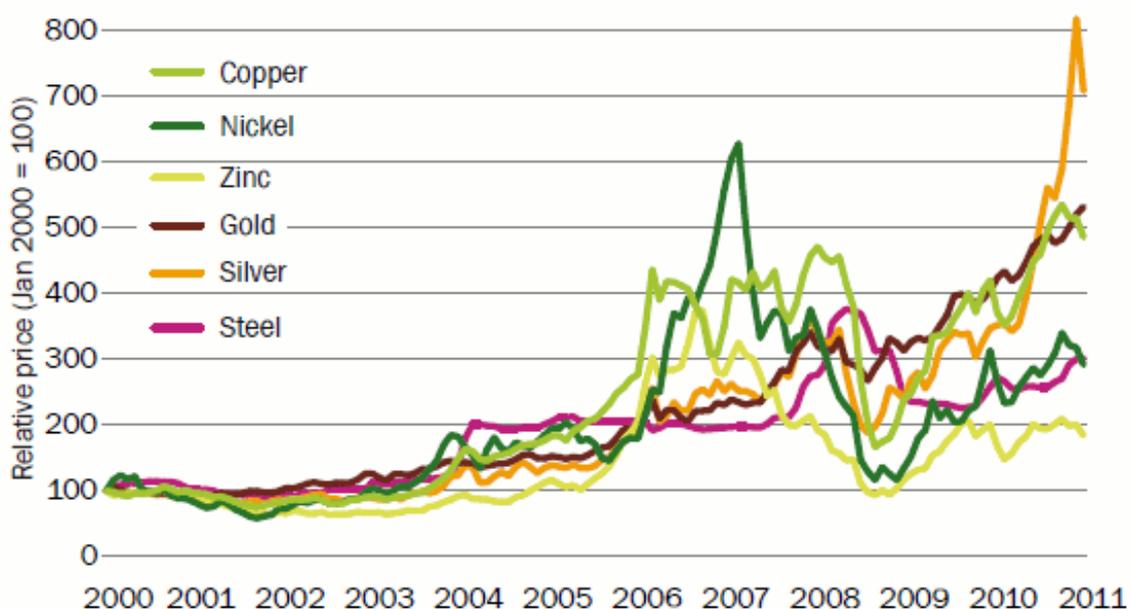


Figure 2-3: Some metals prices since 2000; copper, nickel, zinc, gold, silver, and steel.

The increasing need for metals in the world is a need shared throughout the world. The desire to raise global living standards, coupled with a growing world population, will increase worldwide demand for metals in the future. This demand means that metal mining - the industry responsible for extracting metals from the Earth for use in our daily lives - will continue to be vital and necessary.

2.5 The Metal Mining Cycle

The mining industry operates through a sequence of stages: exploration, discovery, development, production and reclamation. All stages of this Mining Cycle provide direct economic stimulus.

Exploration can take place in many forms, by both prospectors and exploration companies, and usually begins with research to select target areas. Once the targets are selected, **geological mapping** as well as many types of geochemical and geophysical surveys

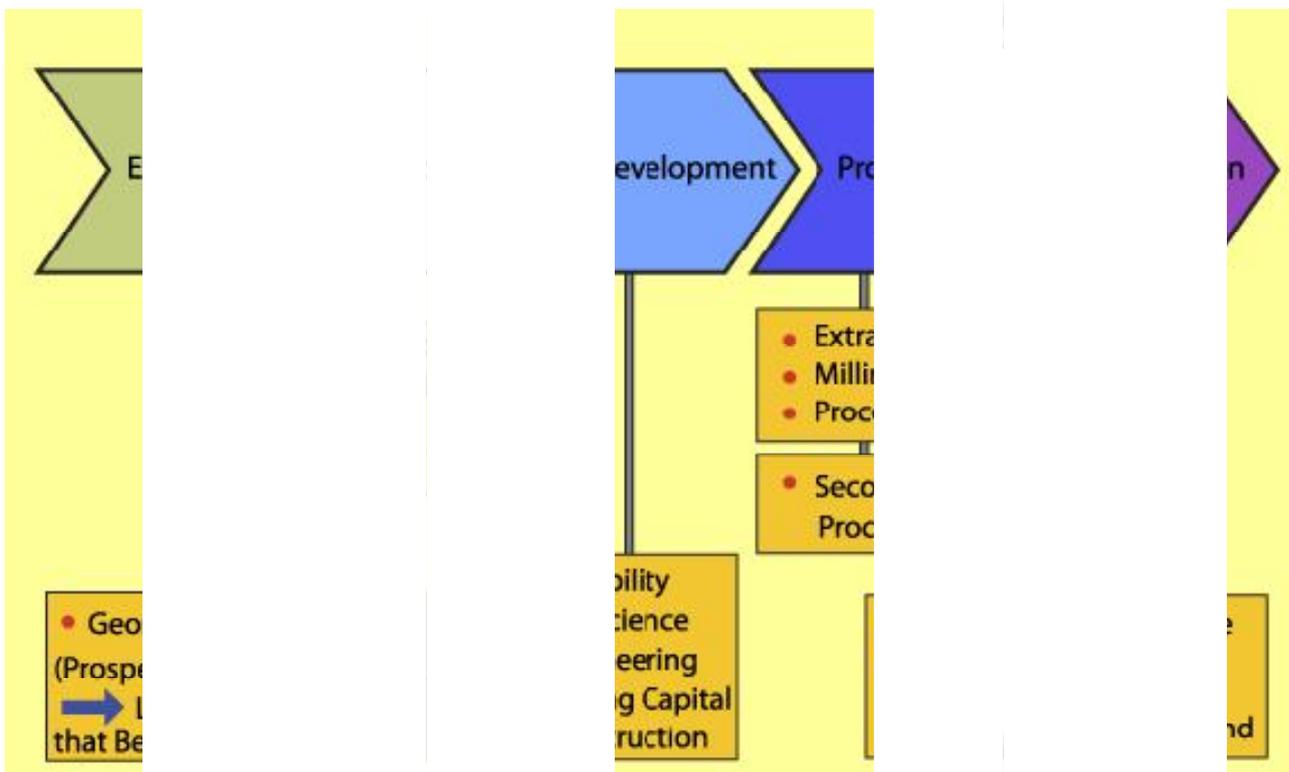


Figure 2-4: The detailed metal mining cycle.

can take place. This type of activity, even in its simplest form, can lead to discoveries of the **economic mineral deposits** that society requires for much of the raw materials and manufactured products that we use every day. **Exploration activity** on a property rarely leads to a new mineral discovery. Once exploration geologists find an area with metals, they determine whether it is of **sufficient size and richness** to be mined profitably. If the deposit is rich enough, activities to extract the metals from the Earth begin.

Discovery happens when something of value is found. Discoveries rely on good field work, quality geoscience, investment and planning to bring them to the development stage. New discoveries are crucial because our growing society increasingly consumes more manufactured products, and our known mineral deposits become depleted. Very few discovered mineral deposits become producing mines. At this stage permits, leases, and licenses are required and the project may be referred for environmental assessment.

The mine development stage includes **feasibility, geoscience and engineering studies**. If all of these outcomes are favorable and all approvals are in place, the company then decides if they will go ahead with the project. At this stage the company raises money in order to begin construction and develop a mine. This is the most expensive phase of the mining cycle.

The production phase includes **extraction, milling and processing of raw materials**, such as metals, industrial minerals and aggregate. The length of time a mine is in production depends on the amount and quality of the mineral or metal in the deposit and profitability of the operation.

Extraction, the next part of the cycle, involves mining to **remove the metal-bearing minerals** from the Earth, **mineral processing** (beneficiation) to **concentrate** the metal bearing minerals, and **smelting** to liberate metals from the minerals that contain them. Although **beneficiation** and **smelting** are the most common processes, other processes such as **chemical leaching** are used for some types of metal extraction.

Mine closure is the final step in the mining cycle. Mining eventually depletes the metal-rich material that could be economically removed at a specific mine. When mining can no



Galena or lead sulfide, the most important ore of lead.



Cinnabar or mercuric sulfide, the only known ore of mercury.



Uraninite crystals from Topsham, Maine



Argentite rock sample



Hematite Trigonal iron oxide Mina Gerais, Brazil



Twinned chalcopyrite, Ouray County, Colorado.



Manganotantalite from Alto do Giz, Brazil



Tantalite, Pilbara district, Australia.

Figure 2-5: Geological shape of some metal minerals.

longer be profitably conducted, the mine and related facilities used in beneficiation or smelting will be closed. Closure involves many activities specifically conducted to prevent or mitigate undesired environmental and social impacts. These activities involve reclaiming disturbed areas, removing facilities, mitigating safety hazards, cross-training employees, and other activities that lead to environmentally benign and safe conditions where mining once took place.

Mining in the early days took place at a time when environmental impacts were not as well understood and most importantly, not a matter of significant concern. During these times, primarily before the 1970s, the mining cycle did not necessarily include closure activities specifically designed to **mitigate environmental or social impacts**. As a result, historical mine sites may still have unreclaimed areas, remnants of facilities, and untreated water. This inherited legacy of environmental damage from mining is not indicative of the mining cycle today. Now, mine closure and a number of activities to mitigate the social and environmental impacts of mining are an integral part of all metal mine planning and mineral development from the discovery phase through to closure.

Mine site **reclamation and protection of the environment** starts at the beginning of a project and continues after closure. Mines must have **closure and reclamation plans** and are required to post a bond for the **estimated cost of reclamation**. In many cases mine site reclamation can add significant value to land in communities for recreational purposes and future development. Progressive reclamation is recommended during the entire life of the mine.

2.6 Exploring for metals:

The recovery of metals from the Earth starts with exploration. Mining companies expend tremendous amounts of time, effort, and money in the search for metallic resources. Metallic orebodies are rare; to find new ones, exploration geologists must understand how metals naturally occur, the special geologic processes that control orebody development, and how ore bodies are physically and chemically expressed in the Earth.

2.6.1 The Geologic Foundation:

Metals come from rocks and minerals in the **Earth's crust**. **Minerals** are naturally formed chemical elements or combinations of elements that have specific chemical compositions and physical properties. Metallic and nonmetallic minerals occur in ordinary rocks throughout the Earth's crust, but only a few minerals contain high enough concentrations of metals to be mined profitably.

Certain metals, such as **copper**, **lead**, and **zinc** have a strong natural affinity for the element **sulfur**, and they combine with it to form minerals called **sulfides**. Probably the most familiar sulfide mineral is **fool's gold (pyrite)**, which is composed of iron and sulfur. The mining and processing of sulfide minerals has historically been the source of most environmental concerns with metals extraction.

2.6.2 Mineral Deposits:

Identifying deposits where geologic processes have concentrated **sulfide minerals** is a continuing challenge for exploration geologists. They search for mineral deposits that contain rich enough concentrations of metal-bearing minerals to economically justify mining. Metallic mineral deposits can be dispersed through entire mountains and can cause environmental impacts naturally - whether or not they are mined. For example, the mineralized deposits on the facing page are a natural source of acidic and metal-bearing water that enters the watershed.

Special geologic processes lead to the development of mineral deposits having high concentrations of metal-bearing minerals. These types of mineral deposits are rare, and they occur in very diverse locations. Large mineral deposits are being mined today from various environmental and geographic settings, such as high mountainous rain forests located in Indonesia, arid deserts in Arizona, and the treeless Arctic tundra of Alaska.

The settings where **mineral deposits** occur can play a significant role in determining the nature and the extent of environmental concerns at specific mine locations. The potential environmental impacts of mining the same type of mineral deposit can be very different in different locations and settings. For example, mining in arid parts of Arizona has different potential impacts on surface water and groundwater quality than if the same mining had occurred in areas of temperate climates, such as the Rocky Mountains or the midwest. Although many metallic mineral deposits have been identified through exploration, only a few deposits are large enough and have a metal content great enough to support commercial operations. The economically important part of a mineral deposit is known as the “ore” or “orebody”.

Once an orebody is identified within a mineral deposit, geologists determine its form. The form of the orebody is important for two reasons: the shape of an orebody helps determine the best way to mine it, and the orebody form influences the potential environmental impacts associated with mining. Although every mineral deposit has distinctive features, they generally exist in two common forms. In one form, the orebody can have dimensions (length, width, and depth) measured in miles (kilometers) and can include a large volume of rock at or near the surface. These ore deposits are most efficiently mined from surface excavations called open pits.

The other general orebody form is one characterized by tabular shapes in which either the vertical or horizontal dimension is much greater than the other - at the most one or two miles (1 to 3 km) in depth or length. These types of deposits can extend to considerable depth and are most commonly mined by underground mining techniques. Large massive orebodies occurring at depths greater than about 1000 feet (350 meters) also must be extracted by expensive underground mining techniques.

2.6.3 Exploration Process:

Mineral exploration is a challenging enterprise that takes geologists to remote regions throughout the world and requires a variety of scientific and technical skills. Exploration geologists need exceptional perseverance, for they may examine dozens and dozens of

mineral deposits without finding one ore body that is rich enough to support mining. On a worldwide scale, however, geologists find a few new orebodies each year.

The exploration process begins with a geologist examining satellite images, geologic maps, and reports to identify areas favorable for mineral deposits. Once these areas are defined, the geologist conducts field examinations to create more detailed maps and rock descriptions. Geologists commonly augment their field examinations with geochemical and geophysical exploration techniques that help them identify specific mineral deposits. Geochemical techniques are used to analyze samples of rocks, soils, water, vegetation, or stream sediments which may contain elements that are important clues to possible nearby metal deposits. Geophysical techniques, such as magnetic surveys, can help characterize rocks beneath the surface. Very detailed studies are done to determine if a mineral deposit contains an orebody. The geologist carries out these studies by making detailed maps of the surface geology and combining these with detailed characterizations of rocks extracted from the mineral deposit. Drilling into a mineral deposit commonly recovers cores or chips of the subsurface rocks that geologists then examine and analyze chemically. Verifying the subsurface character and form of an orebody requires extensive drilling.

In general, the exploration process - from initial office compilation to extensive drilling - is expensive and time-consuming. It may take years of work and millions of dollars of expense to reach a development decision for a specific mineral deposit. In most cases, this work and expense will be incurred only to determine that an orebody is not present. In that case, the disturbed sites will be reclaimed and the exploration process starts over and the search for another favorable area begins. Perseverance and insightful geologic analysis are the keys to success - eventually they can lead to the excitement of an orebody discovery, the ultimate reward for an exploration geologist. Discovery of an orebody is the first step toward making the metals available.

Dr. Saadi M.D. Al-Nuzal

2.7 The mining of metals:

The mining process, from the surface in open pit mines or from underground, separates the ores from the surrounding rocks. Although both surface and underground mining disturb the landscape, the scale of these disturbances differs markedly.

2.7.1 Surface Mining

Open pit mining commonly disturbs more land surface and earth material than underground mining. The leading mines in the world are open pit mines. The open pit mining process includes blasting the ore loose, hauling it to a crusher, and breaking it into pieces small enough for milling (Fig 2-6). Technology has evolved to handle tremendous volumes of material in this highly mechanized process of open pit mining. Mines like the one shown on these pages produce up to 150,000 tons of ore daily. Typically, for every ton of metal ore produced, as much as two or three tons of waste rock are also produced. As mining operations expose the orebody, the mine geologist will continue to map and describe it to ensure that the most cost-effective mining plan is developed and implemented.



Figure 2-6: Lead mining in the upper Mississippi River region of the U.S., 1865.

Waste rock, the name for rocks and minerals that enclose the ore and need to be removed in order to recover it, contains too few valuable minerals to process. Although the metal content of waste rock is too low to be recovered profitably, the environmental issues related to its characteristics and handling are very important.

Large volumes of waste rock are created during the open pit mining process. For example, the waste rock disposal areas that develop at a surface mine like the Bingham Canyon mine sometimes cover hundreds or even thousands of acres (tens of km²) and may be several hundred feet (one to two hundred meters) high. Waste rock disposal areas are commonly one of the most visible aspects of a surface mine.



Figure 2-5: The Bingham Canyon Mine of Rio Tinto's subsidiary, Kennecott Utah Copper.



Figure 2-5: Chuquibambilla, Chile, site of the largest circumference and second deepest open pit copper mine in the world.

2.7.2 Underground Mining

Figures 2-6 to 2-8 illustrates the underground mining process. Underground mines may use vertical shafts as shown, or mine openings driven into mountainsides, known as “adits.” Although the primary challenge for underground and open pit mining is the same - to remove ore economically from the enclosing rocks - underground mining differs in two important ways.

First, the size of the operation is much smaller than in open pit mining, and the mining activities are not as visible at the surface. Figure 2-6 to 2-8 shows examples of relatively large underground openings and related mining equipment. Over the life of an underground mine, the volume of ore produced is most commonly only a few hundred thousand to a few million tons. This compares to production at larger open pit mines where one million tons of ore may be produced in just one week of operations.



Figure 2-6: Chalcolithic copper mine in Timna Valley, Negev Desert.

The second big difference is the volume and disposal of waste rock. It is common in underground mining for the volume of waste rock to be equal to or less than the volume of the ore produced. In optimum situations, very little waste rock is generated and the waste rock can be used to fill underground areas where access is no longer needed. Where waste



Figure 2-7: Baluba Mine underground closed because of high cost of doing business.



Figure 2-8: Underground mining operations, bogger loading truck.

rock must be hauled to the surface, the resulting disposal areas, although much smaller in size and volume than those at open pit mines, may still be highly visible. As underground mining was the most common mining method before 1900, waste rock disposal areas at the portals of mine workings are common in historical mining districts.

2.8 Potential Environmental Impacts of Mining:

The most common environmental concerns associated with metal mining operations are:

1. Physical disturbances to the landscape.
2. Waste rock disposal.
3. Development of metal-bearing and acidic soils and waters,
4. Public safety.

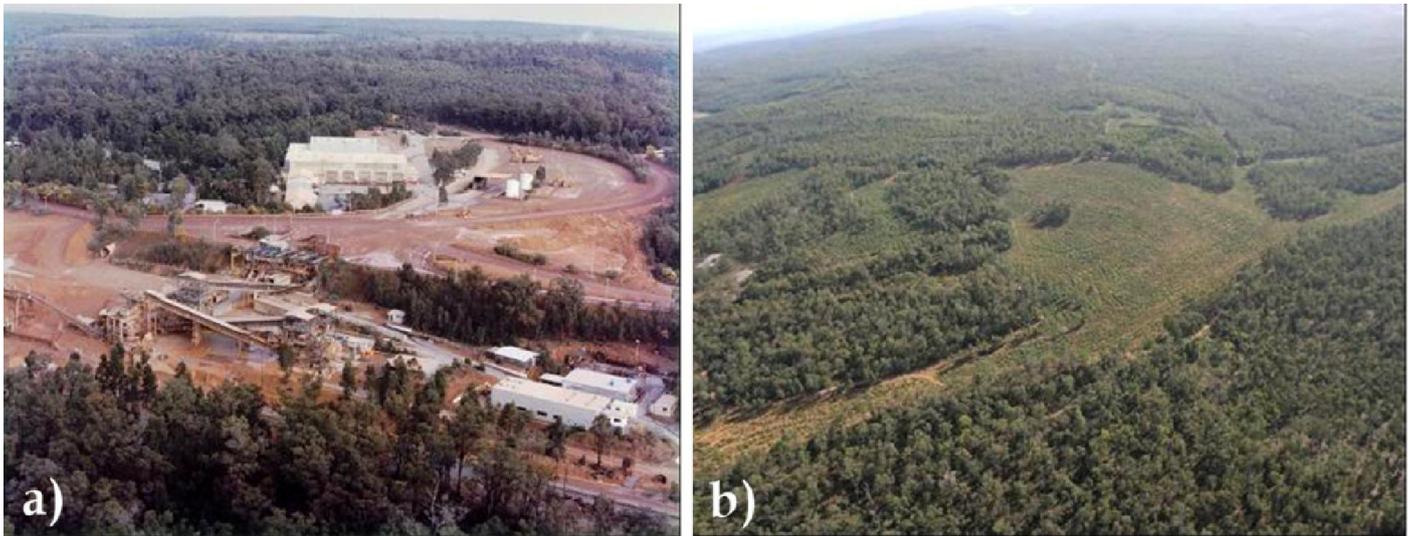


Figure 2-9: Reclamation of Degraded Landscapes due to Opencast Mining

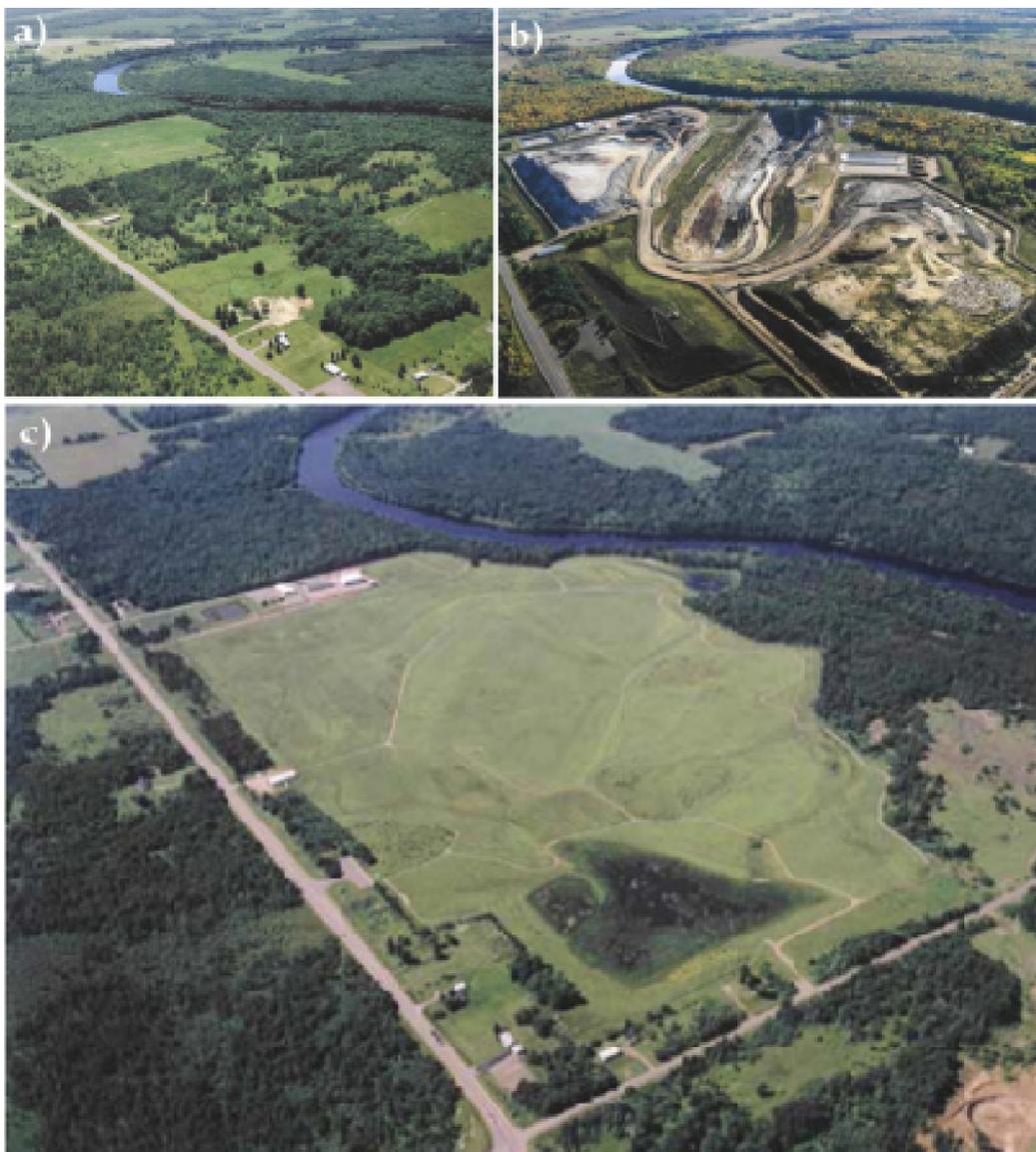


Figure 2-10: Flambeau Mine Site: a) before mining (1991), b) during mining (1996), and c) after mining (2002).

2.8.1 Physical Disturbances to the landscape:

The largest physical disturbances at a mine site are the actual mine workings, such as open pits and the associated waste rock disposal areas (Fig.). Mining facilities such as offices, shops, and mills, which occupy a small part of the disturbed area, are usually salvaged or demolished when the mine is closed. The open pits and waste rock disposal areas are the principal visual and aesthetic impacts of mining. These impacts remain on the landscape until the disturbed areas are stabilized and reclaimed for other uses, such as wildlife habitat or recreation areas, after mining has ceased.

Underground mining generally results in relatively small waste rock disposal areas ranging from a few acres in size to tens of acres (0.1 km²). These areas are typically located near the openings of the underground workings. Some waste rock areas, if not properly managed, can be sources of significant environmental impacts, such as stream sedimentation if erosion occurs, or the development of acidic water containing metals.

Open pit mining disturbs larger areas than underground mining, and thus has larger visual and physical impacts. As the amount of waste rock in open pit mines is commonly two to three times the amount of ore produced, tremendous volumes of waste rock are removed from the pits and deposited in areas nearby. During active mining operations, this type of waste rock area and the associated open pit, are very visible physical impacts. Although the physical disturbance associated with metal mining can be locally significant, the total land area used for metal mining is very small compared to other major types of land use.

2.8.2 Waste Rock Disposal:

Waste rock disposal areas are usually located as close to the mine as possible to minimize haulage costs. Although the waste rock may contain metals, such as lead, zinc, copper, or silver, the rock is still considered a waste, because the cost to process it would exceed the value of the metals it contains. If not properly managed, erosion of mineralized waste rock into surface drainages may lead to concentrations of metals in stream sediments.



Figure 2-12: Waste Rock Disposal sites.

This situation can be potentially harmful, particularly if the metals are in a chemical form that allows them to be easily released from the sediments into stream waters. When this occurs, the metals are considered to be “mobilized” and “bioavailable” in the environment. In some cases, bioavailable metals are absorbed by plants and animals, causing detrimental effects. Although current U.S. mining and reclamation practices guided by environmental regulations minimize or prevent waste rock erosion into streams, disposal of waste rock in places where it could erode into surface drainages has occurred historically. These conditions still exist at some old or abandoned mines.

2.8.3 Acidic and Metal-Bearing Soils and Waters

Although the character of waste rock varies with the type of ore, many waste rocks contain sulfide minerals associated with metals, such as lead, zinc, copper, silver, or



(a)

(b)

Figure 2-14: (a) Yellow boy in a stream receiving acid drainage from surface coal mining. (b) acid mine drainage in the Rio Tinto River, Spain.

cadmium. An important sulfide mineral common in waste rock is pyrite, iron sulfide (FeS_2). When pyrite is exposed to air and water, it undergoes a chemical reaction called “oxidation.” Oxidation of pyrite results in the formation of iron oxides that typically impart an orange or red “rust” color to waste rock (Figure 2-14). The oxidation process, which is enhanced by bacterial action, also produces acidic conditions that can inhibit plant growth at the surface of a waste pile. Bare, non-vegetated, orange-colored surface materials make some waste rock areas highly visible, and they are the most obvious result of these acidic conditions. If water infiltrates into pyrite-laden waste rock, the resulting oxidation can acidify the water, enabling it to dissolve metals such as copper, zinc, and silver. This production of acidic water, is commonly referred to as “**acid rock drainage.**”

If acid rock drainage is not prevented from occurring, and if it is left uncontrolled, the resulting acidic and metal-bearing water may drain into and contaminate streams or migrate into the local groundwater. The acidity of contaminated groundwater may become neutralized as it moves through soils and rocks. However, significant levels of dissolved constituents can remain, inhibiting its use for drinking water or irrigation. Where acid rock drainage occurs, the dissolution and subsequent mobilization of metals into surface and

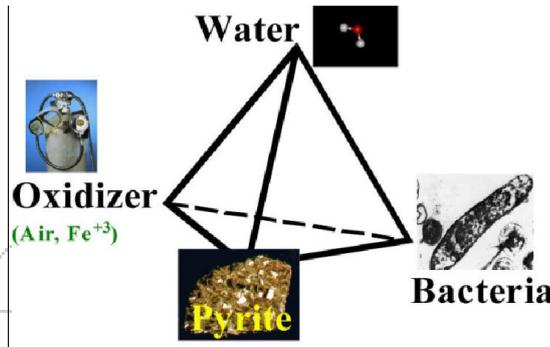


Figure 2-15: Acid rock drainage tetrahedron.

groundwater is probably the most significant environmental impact associated with metallic sulfide mineral mining. Acidic and metal-bearing groundwater occurs in abandoned underground mine workings and deeper surface excavations that encounter the groundwater of a mineralized area. Because they are usually located at or below the water table, underground mines act as a type of well which keeps filling with water. Removal and treatment of this accumulated water in underground mines must be continuous in order to conduct operations. However, after mining ceases, the mine workings will fill up with water and some of the water may discharge to the surface through mine openings. Because these waters migrate through underground mine workings before discharging, they interact with the minerals and rocks exposed in the mine. If sulfide minerals are present in these rocks, especially pyrite, the sulfides can oxidize and cause acid rock drainage. If left unmanaged, significant volumes of acid rock drainage can form at large mine workings, which can degrade the quality of surface waters into which it flows. Preventing and treating acid rock drainage from mine workings is a key environmental challenge.

2.8.4 Public Safety:

Old mining sites are inherently interesting to people, but potentially dangerous as well. They may have surface pits, exposed or hidden entrances to underground workings, or old intriguing buildings. Another safety consideration at some mine sites is ground sinking or “subsidence.” The ground may sink gradually where underground workings have come close to the surface. Because an unexpected collapse can occur without warning, such areas usually are identified and should be avoided. When modern mines are closed, mine owners

mitigate such hazards by closing off mine workings, regrading and decreasing the steep slopes of surface excavations, and salvaging or demolishing buildings and facilities.

In some area where old mining areas are common, such as Colorado and Nevada, current mine owners, government agencies, or other interested parties may undertake reclamation and safety mitigation projects that address hazards at these sites. At a minimum, these programs identify hazards, install warning and no trespass signs, and fence off dangerous areas. The closing of entrances to old underground workings may also be done as a part of these efforts. Some abandoned mine workings have become important habitats for bat colonies. Closure of mine openings can be designed to allow the bats continued access and protection. This practice is especially valuable for endangered bat species. Because many old mine sites may not be safe, the casual visitor to such sites is cautioned to exercise care and avoid entering them.

2.9 **Concentration metals:**

Because ore is a mixture of minerals, it is necessary to separate the minerals that contain metals from the others. Beneficiation is the step in the mining process that crushes the ore, separates, and concentrates the valuable minerals. Beneficiation includes milling or leaching, flotation, and the creation of a waste product called tailings.

2.9.1 **Milling and Leaching**

Large rotating mills use metal balls or rods to grind the ore into tiny particles to the consistency of silt, sand, and clay. The actual particle size can vary, but the objective is to break the ore into individual mineral grains. The crushed and ground ore leaves the mill as a water-rich slurry, which may be processed in a variety of ways to concentrate the valuable metallic minerals.

A concentration process commonly used for sulfide ores of copper, lead, and zinc is “flotation”. In this process, the water-rich slurry from the mill is passed through large vats containing special bubble-making chemicals or “reagents”. The vats are agitated and the



Figure 2-12: (a) Mill and (b) flotation instillation at the Batu Hijau copper mine, Indonesia.

metal-bearing minerals selectively attach themselves to the reagent bubbles and float off the surface of the vats - hence, the name flotation. Water is filtered from the bubble-rich liquid, and the resulting material is an ore concentrate that is rich in metal-bearing minerals.

Flotation leaves behind minerals, such as quartz and pyrite, that do not contain valuable metals. The nonvaluable minerals remain as part of the water-rich slurry in the agitated vats until almost all of the valuable metal-bearing minerals have been floated off. After it has been stripped of valuable metals, the slurry is a waste product called tailings. The tailings are pumped into large ponds, called “impoundments”, for disposal.

Tailings are the primary waste material and a potential source of environmental impacts from the milling process. In some cases, tailing have high concentrations of pyrite (up to tens of percent by volume). Some of the most significant environmental issues associated with j stem from the disposal of sulfide-rich tailings.

Instead of milling, some metals - mostly from certain kinds of copper and gold ores - are concentrated through the process of leaching. After the ore has been placed in large piles or heaps on specially designed pads, water containing solutions of sulfuric acid or dilute sodium cyanide is dispersed throughout the ore leach pile. The solutions percolating down through the pile of ore dissolve the desired metals before being collected from the base of the



Figure 2-16: Direct Leaching Process is a pioneering atmospheric leaching method for zinc concentrate.

pile. Well-designed leach pads have synthetic or natural clay liners that prevent leakage of the chemical- and metal-laden fluids into the ground.

The dissolved metals are precipitated in various ways from the collected waters, which are then returned to the top of the pile to start the leaching process over again. Although leaching avoids milling and the generation of tailings, it leaves behind large heaps of metal depleted materials that may contain residual chemicals from the leach waters that have passed through them. Rinsing spent leach piles is done to ensure that the chemicals have been removed. Spent leach piles are nevertheless a source of environmental concern, and they must be properly reclaimed and closed.

2.10 Potential Environmental Impacts of Beneficiation:

The potential environmental impacts of tailings impoundments and leach piles include several aspects similar to those of waste rock disposal areas. However, in some ways the wastes from beneficiation processes present greater challenges than those from waste rock. The potential impacts include:

1. Physical disturbances to the landscape,

2. Development of acidic soils and waters,
3. Erosion of tailings by wind and water,
4. Leach piles containing residual chemicals.

2.10.1 Physical Disturbances:

Tailings impoundments and leach piles vary in size, but both can be very large. To save energy, tailings impoundments are commonly created somewhere down slope from the mill so that gravity will help move the tailings slurry to the impoundment. Tailings impoundments may be located miles (kilometers) away from the mill where they are produced. The impoundments associated with some of the largest mills, such as at open pit copper mines, can cover thousands of acres (tens of km²) and be several hundred feet (about 100 m) thick. Some tailings impoundments present reclamation challenges even more significant than those presented by waste rock.



Figure 2-17: Modern industrial gold mining destroys landscapes and create huge amounts of toxic waste. Due to the use of dirty practices such as open pit mining and cyanide heap leaching, mining companies generate about 20 tons of toxic waste for every 0.333 ounce gold ring. The waste, usually a gray liquid sludge, is laden with deadly cyanide and toxic heavy metals.

2.10.2 Acidic Soils and Waters:

Tailings produced from the milling of sulfide ores - primarily copper, lead, and zinc ores - may have concentrations of pyrite that are greater than those common in waste rock. Also, because tailings are composed of small mineral particles the size of fine sand and smaller, they can react with air and water more readily than waste rocks. Therefore, the potential to develop acidic conditions in pyrite-rich tailings is very high.

The resulting acidic soil conditions give some tailings impoundments orange and buff-colored, nonvegetated surfaces, similar to some sulfide-bearing waste rocks. Tailings are saturated with water upon disposal. If it is not prevented or controlled, acidic waters, commonly a form of acid rock drainage, can seep from their base (Figure 2-18). Some parts of tailings impoundments contain high proportions of very fine-grained material. This clay-size material, called “slimes,” is relatively impermeable, and surface waters can form ponds on it (Figure 2-19). The ponding of water on a tailings surface keeps the tailings saturated with water and enables seepage to continue indefinitely.

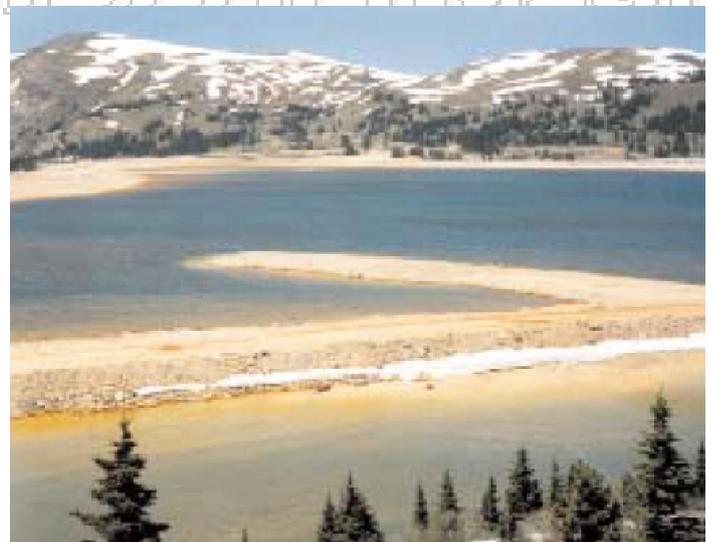
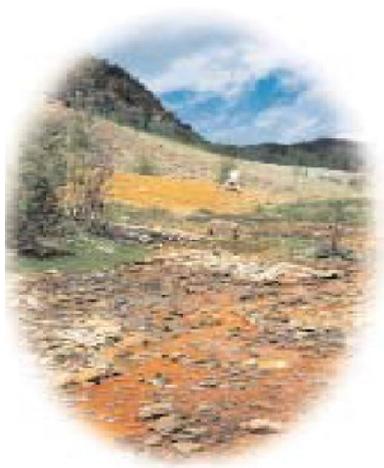


Figure 2-18 (Left): Metal-bearing waters seep from the base of a mill tailing impoundment along Silver Creek in the Rico mining district of southwest Colorado. This situation may lead to seeps in impoundments that lack an impermeable barrier which prevents drainage.

Figure 2-19 (Right): Low permeability of the tailings caused surface water to collect as a large pond on top of this tailings impoundment in Colorado.

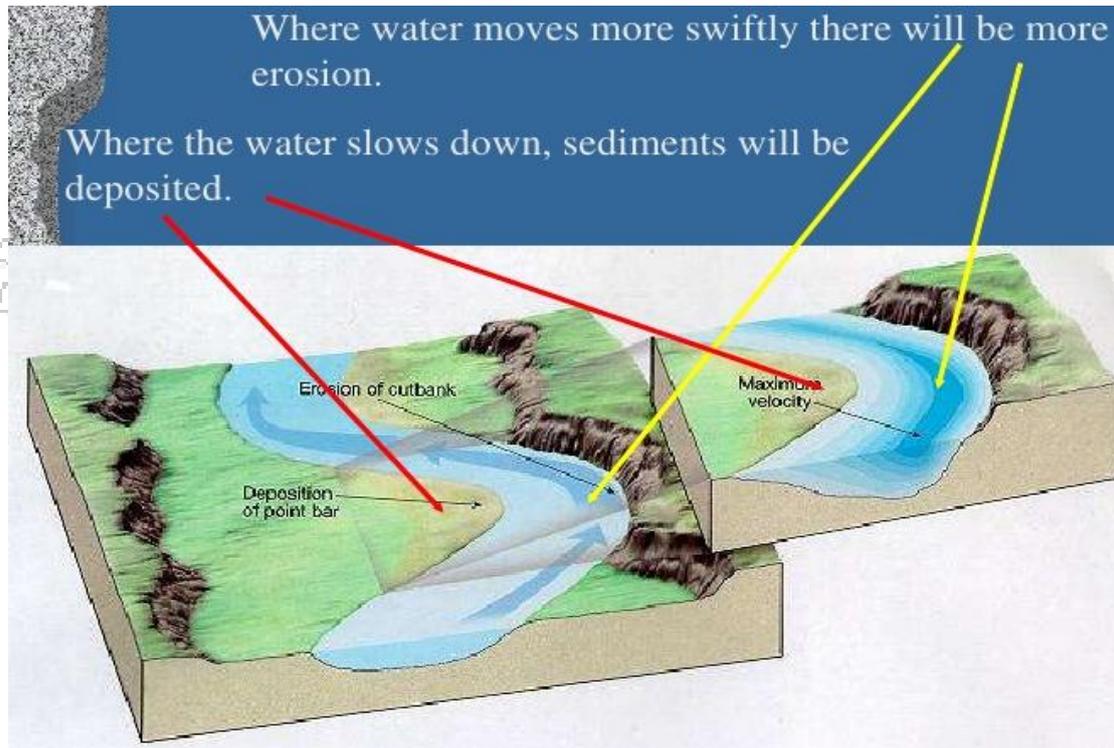


Figure 2-21: Stream erosion and deposition

This situation presents a formidable challenge for closure. However, the saturated condition of a tailings impoundment also prevents the fine particles of tailings from becoming wind borne and creating fugitive dust.

Seepage from tailings can be prevented or minimized by placing an impermeable barrier, such as clay, at the bottom of the impoundment before tailings disposal. Many pre-1970s tailings impoundments did not have such barriers. The infiltration of surface water into tailings can be prevented by using reclamation methods that facilitate runoff rather than ponding of surface waters. If not prevented or controlled, the acidic and metal-bearing waters from tailings can impact stream habitats and groundwater. Fortunately, the reagents used in the beneficiation process can neutralize the acidity of the tailings, making acid and metal-bearing waters less of an environmental issue.

2.10.3 Erosion and Sedimentation

If tailings ponds are not satisfactorily stabilized, erosion by both wind and water can take place. Because tailings contain high volumes of fine-grained material, wind can easily pick up and transport dust from the surface of a tailings impoundment (Fig. 19). Tailings dust

may create health concerns if people or wildlife breathe it. Its migration into homes can increase human exposure to any harmful constituents that may be present.

If tailings are eroded by surface water runoff and enter streams (Fig. 20), metallic minerals can be dispersed into stream, lake, and even ocean sediments. In some cases, instability of a tailings impoundment has led to catastrophic releases of metals into stream sediments. Historically, some tailings were disposed of directly from the mill into streams or other water bodies, rather than being stored in stabilized impoundments. Although this practice is no longer conducted in the United States, some streams and lakes still contain concentrations of widely dispersed metals in their sediments stemming from this old practice.

Metals in sediments can be a problem if they are in a chemical form or setting that allows them to be dissolved in water, or readily ingested and absorbed by plants and animals. In these situations, concentrations of bioavailable metals can be high enough to be toxic to organisms. Some metals can be dissolved and made bioavailable if the tailings oxidize and release acid in metal-bearing water. If metal-bearing sediments remain unoxidized and physically remote from interaction with wildlife, they will not create significant environmental impacts.



Figure 2-20: The Malakoff Diggins, California, showing the effects of hydraulic mining on a hillside over a century later. Much of the effects of the mining was beyond the hills themselves, on the areas downstream of the water and sediment flow they produced.

2.10.4 Leaching Solutions:

If appropriate prevention and control measures are not taken, the leaching processes, which use sulfuric acid to dissolve copper and dilute water/cyanide solutions to dissolve gold, may be a potential source of contamination harmful to plants, animals, and in some situations, even people. Cyanide naturally degrades rapidly in the presence of sunlight, atmospheric oxygen, and rainfall. Potential toxicity problems with this chemical are most likely to occur if concentrated cyanide solutions are accidentally spilled or released during leaching operations. A combination of impermeable liners on the bottom of leach pads, leak-detection monitors, and solution-collecting facilities is commonly used to minimize leakage of leaching solutions. Because some leaching chemicals may be left behind in the residual materials on the leach pad after the metals have been removed, a combination of rinsing, physical isolation, and detoxification of heap leach pads is common practice before the leach piles are reclaimed.

2.11 Removing impurities:

Mining concentrates ore, and beneficiation concentrates valuable minerals. The processing step called “**metallurgy**” further concentrates the metals by separating them from their parent minerals. The most common technique for doing this has involved heating the minerals to a melting point. This type of pyrometallurgy is also the most significant with respect to environmental issues.

2.12 Smelting:

The heating process in pyrometallurgy is generally called smelting. Historically, smelting facilities, called “**smelters**,” have been large industrial developments located near mines or in other areas that can provide the necessary transportation facilities, water, and energy supplies.

In the smelting process, the ore concentrate is mixed with other materials known as “**fluxes**” and then heated in furnaces until it melts. As the molten metal's or the metal-



Figure 2-21: Smelting is a form of extractive metallurgy; its main use is to the process of separating the metal from impurities by heating the concentrate to a high temperature to cause the metal to melt.

bearing minerals separate from the other materials, they accumulate in the bottom of the furnaces and are removed. The other constituents, primarily iron and silica, float to the top of the furnaces. After they are removed, they cool to a solid glassy substance called “slag” (Fig. 21). In some cases, the large piles of dark-colored slag that remain near smelters make it the most visible solid waste product produced by the process.

In addition to slag, the other significant by-products from smelting are gases, which contain suspended particles. The gases are collected as they rise off the top of the smelter furnaces, and they are treated to remove certain constituents. Sulfur dioxide gas is typically captured and converted to sulfuric acid, which is sold as a by-product of the smelting

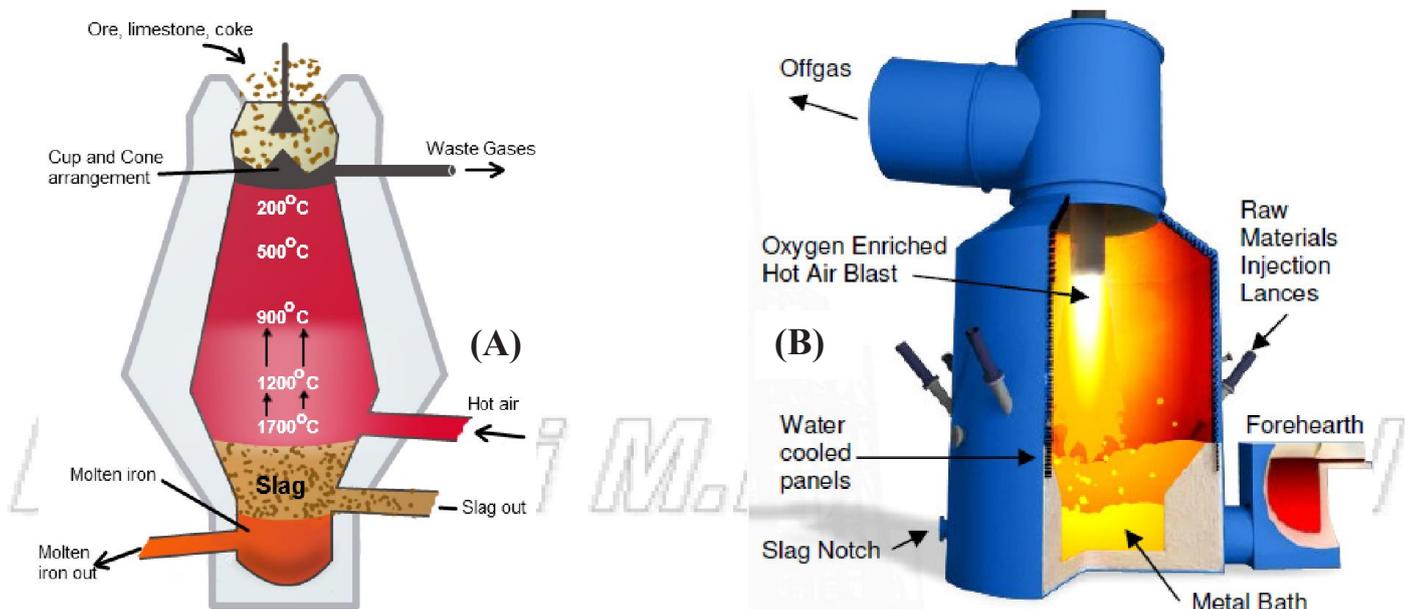


Figure 2-22: Melt reduction for iron and steel sector in (A) traditional furnace, and (B) Hismelt Reduction Vessel.



Figure 2-23: The principal solid waste product of the smelting process is slag, an iron and silica-rich glassy material that typically has a dark color and wavy, irregular surface (B)

process. Treated gases enter the atmosphere through vents and stacks (Fig. 22). Historically, uncaptured sulfur dioxide was the constituent of greatest concern in smelter emissions, but other constituents, such as lead and arsenic, were locally important (Fig. 23).

2.13 Potential Environmental Impacts of smelting:

The environmental concerns related to the smelting process are primarily smelter stack emissions and, in some cases, disposal of slag material and flue dust.

2.13.1 Smelter Stack Emissions:

At some sites, gas and particulate emissions that were released to the atmosphere from historical smelting operations have been a source of human health concerns and environmental impacts. Recognizing the importance of minimizing and mitigating this impact, modern smelters use processes that drastically reduce particulate and sulfur dioxide emissions (Fig. 24). In the past, sulfur dioxide has been the most common emission of concern, because it reacts with atmospheric water vapor to form sulfuric acid or “acid rain.” The acidic conditions that develop in the soils where these emissions precipitate can harm existing vegetation and prevent new vegetation from growing. Barren areas near smelting operations have been an enduring environmental impact of historical smelting. Some impacted areas that have existed for decades are now beginning to recover.

In some cases, the emissions from older metal smelters may have affected human health. For example, elevated levels of lead in blood have been measured in residents of some communities located near lead-zinc smelters during their operation. Today, smelting operations, combined with environmental controls, are implemented to prevent potential environmental and health issues related to emissions.

2.13.2 Slag Disposal:

The principal solid waste from the smelting process, slag, is an iron and silica-rich glassy material that may contain elevated concentrations of metals, such as lead and arsenic. The actual composition and form of slag will vary depending on the type of ore and smelting technology used. Most slags, because they are composed primarily of oxidized, glassy material, are not as significant a potential source of metals released into the environment as mine wastes and mill tailings. However, some slags may contain remnant minerals that can be a potential source of metal release to the environment.

The main problems with slag are the physical disturbances and aesthetic impacts associated with large slag piles that cannot support vegetation (Fig. 21). Slag piles can cover tens to hundreds of acres (0.1 to 1 km²) and be over 100 hundred feet (30 m) high. Reclaiming these piles so that slag disposal areas can be used for other purposes is commonly done today.

2.14 Protecting the environment:

The major potential environmental impacts associated with metal production - mining plus associated mineral processing operations are related to:

1. Erosion-prone landscapes,
2. Soil and water quality, and
3. Air quality.

These potential impacts are recognized and addressed in current mining operations as well as in some former mining operations by:

1. Reclaiming areas of physical disturbance to prevent erosion,
2. Stabilizing soils containing metals or chemicals to prevent unwanted metal releases into the environment,
3. Preventing and/or treating water contamination,
4. Controlling air emissions.

At many sites, the key reclamation, soil treatment, and water quality concerns owe their origin to the same process - the oxidation of sulfide minerals, especially the iron sulfide, pyrite.

Oxidation of sulfide minerals can produce acidic conditions that release metals in both waste materials and water (Fig. 25).

2.15 Prevention is the Key:

Preventing the oxidation of sulfide minerals is a critical step toward mitigating the environmental impacts of metal mining and processing. If oxidation is allowed to take place, acidic conditions develop in soils and waters changing the residual metal into more bioavailable forms.

Developing more efficient and cost-effective approaches for handling mining-related environmental impacts is desirable, particularly if the approaches promote the widespread cleanup of old mining sites. Innovative methods for preventing and mitigating mining impacts will also help ensure cost-effective development of future mines and the continued supply of metals. Environmentally sound mining and metal production practices will meet the key challenges of:

1. reclamation,
2. soil treatment,
3. water treatment,
4. prevention of acid rock drainage,
5. control of gas emissions, and
6. recycling.

2.15.1 Reclamation:

Reclamation entails the re-establishing of viable soils and vegetation at a mine site. Figure 26 illustrates a simple design for the reclamation of mine waste rock and tailings. Although regulatory agencies may require more complex reclamation designs, this simple approach can be very effective. It depends on adding lime or other materials that will neutralize acidity plus a cover of top soil or suitable growth medium to promote vegetation growth. Modifying slopes and other surfaces and planting vegetation as part of the process stabilizes the soil material and prevents erosion and surface water infiltration. Even this simple approach is likely to cost a few thousand dollars per acre to implement. Where soils have a sustained high acidity, the costs of using this approach can increase, sometimes to tens of thousands of dollars per acre.

The challenge to find cost effective reclamation approaches continues. Promising reclamation options in the future may include using sludge, “biosolids,” from municipal waste water treatment processes as an organic soil amendment and growing plant species that are more tolerant of acidic conditions (Fig. 27).

2.15.2 Soil Treatment:

High levels of metals in soils, not just acidity, can be harmful to plants, animals, and, in some cases, people. A common approach used in dealing with contaminated soil is to move it to specially designed repositories (Fig. 28). This approach can be very expensive and

controversial, but it is sometimes required. With this approach, the volume and toxicity of the soil is not reduced, the soil is just relocated. Effective soil treatment approaches in the future depend upon better understanding of the risks associated with metals in mine wastes. These “natural” metals in minerals may not be as readily available in the biosphere, and therefore, they may not be as toxic as the metals in processed forms, such as lead in gasoline.

Future approaches may include:

1. Using chemical methods to stabilize metals in soils, making them less mobile and biologically available.
2. Using bacteriacides that stop the bacterial growth that promotes the oxidation of pyrite and the accompanying formation of sulfuric acid.
3. Using bioliners, such as low permeability and compacted manure, as barriers at the base of waste piles.
4. Permanently flooding waste materials containing pyrite to cut off the source of oxygen, stop the development of acidic conditions, and prevent mobilization of metals (Fig. 29).

2.15.3 Water Treatment:

The most common treatment for acidic and metal-bearing waters is the addition of a neutralizing material, such as lime, to reduce the acidity. This “active” treatment process, which causes the dissolved metals to precipitate from the water, usually requires the construction of a treatment facility (Fig. 30). The ongoing maintenance that such a plant requires makes this treatment technique very expensive.

Aside from the expense, some active treatment plants generate large amounts of sludge. Disposal of the sludge is a major problem. Because of the cost and the physical challenges of dealing with sludge, alternatives to active treatment facilities are needed. Some possible alternatives include:

1. Using “passive” wetland systems to treat metal-bearing water. This approach has been successfully used where the volumes and acidity of the water are not too great. Passive wetland systems have the added advantage of creating desirable wildlife habitat (Fig. 31).

2. Using in-situ treatment zones where reactive materials or electric currents are placed in the subsurface so that water passing through them would be treated.

3. Combining treatment with the recovery of useful materials from contaminated water.

2.15.4 Acid Rock Drainage:

Although the discharge of acidic drainage presents several challenges to protecting water quality, the significance and widespread occurrence of acid rock drainage warrant special efforts to prevent or minimize its occurrence. Prevention must be addressed during exploration activities, before the beginning of newly-planned mining operations. In some cases, it may even be possible to prevent or reduce acid rock drainage in old or abandoned mining areas. Current and potential treatment approaches for acid rock drainage are similar to those already described. Possible measures to prevent or significantly reduce acid rock drainage include:

1. Flooding of old underground mine workings to cut off the oxygen supply necessary to the sustained generation of acidic waters.
2. Sealing exposed surfaces in underground workings with a coating of material that is non-reactive or impermeable to inhibit the oxidation process.
3. Backfilling mine workings with reactive materials that can neutralize and treat waters that pass through them.
4. Adding chemicals to the water in flooded surface and underground mine workings that can inhibit acid-generating chemical reactions and precipitate coatings that will seal off groundwater migration routes.

5. Isolating contaminated waters at depth by stratification, allowing viable habitat to develop near the surface in the water that fills large open pits.

2.15.5 Smelter Emissions:

Smelter emissions, especially sulfur dioxide and particulate materials, have historically presented significant environmental problems. Modern smelting technology has met this challenge by drastically reducing the amount of emissions. An example is the modernized smelter built by Kennecott Utah Copper that processes ore concentrates from the Bingham Canyon Mine near Salt Lake City. Using technology developed by the Finnish company Outokumpu, this smelter has reduced sulfur dioxide emissions to 95 percent of previous permitted levels (p. 39). This smelter, which came online in 1995, is the cleanest in the world. It captures 99.9 percent of the emitted sulfur.

2.15.6 Recycling:

Recycling can be an alternative source of metals that reduces the need for new metal mines. However, recycling facilities themselves are industrial developments having their own set of environmental impacts. Even so, recycling is a significant source of metals (Fig. 32).

According to the U. S. Bureau of Mines, which completed a data synthesis on U. S. metal recycling in 1990, the value of recycled metals totaled \$ 37 billion, or only \$ 2 billion less than the value of newly mined metal in that year. The five metals listed in Figure 32 accounted for 99 % of the quantity and 92 % of the value of recycled metals in 1990. Precious metals - gold, silver, and platinum-group elements - and chromium accounted for 6 % more of the value and the remainder came from recycling of at least 14 other metals.

Recycled metals meet varying fractions of U.S. metal consumption. This variance occurs primarily because the end uses of some metals inhibit their effective recovery and because recycling systems and technologies are less efficient for some metals. Although recycling is

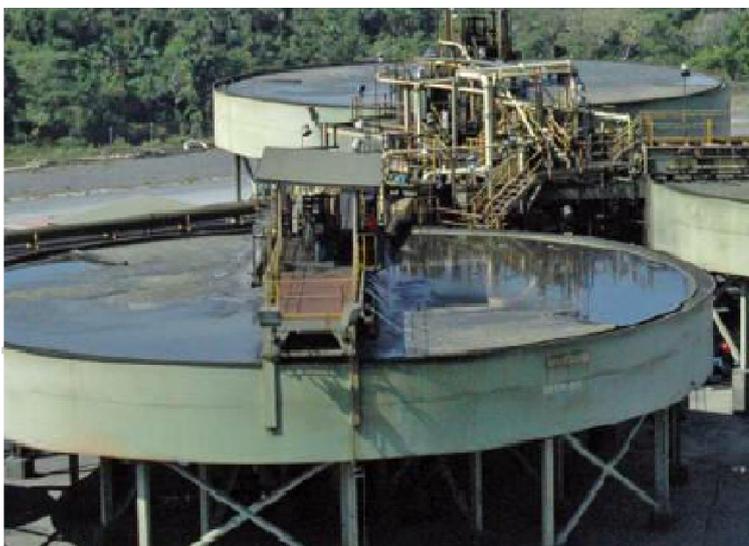
important, there is an upper limit to the amount of metal that recycling can provide. For example, recycled lead, which is predominately used in batteries and for which secondary recovery systems are well-developed, could satisfy 78 % of U. S. demand by 2000, but recycled zinc will probably not increase above 35 to 40 % of consumption.

Table 2-1: Preliminary metal recycling figures for 1998.

Metal	Amount of Recycled Metal (metric tons)	Percent of U.S. Supply
Iron & Steel	58,000,000	59 % *
Aluminum	3,500,000	39 %
Copper	1,500,000	37 %
Lead	1,145,000	66 %
Zinc	425,000	22 %

*Percent of U.S. production.

Even though extensive and efficient recycling is an important commitment, metal mining and production will still be necessary to meet society's demand for metals.



Thickener.

Thickening of tailings is a common step prior to pumping the thickened slurry to the tailings pond and ultimately disposing of the thickened slurry. Thickening minimizes the amount of water placed in the pond and the pond size. Thickening is usually accomplished by settling slurries in large tanks, known as thickeners.

Thickener.



Heap leaching operation in Arizona, USA.

Photo 4.7: Heap leaching operation in Arizona, USA.





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First, the size of the operation is much smaller than in open pit mining, and the mining activities are not as visible at the surface. Figure 5 shows examples of relatively large underground openings and related mining equipment. Over the life of an underground mine, the volume of ore produced is most commonly only a few hundred thousand to a few million tons. This compares to production at larger open pit mines where one million tons of ore may be produced in just one week of operations.

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