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Mining

Fundamentals of mining operations in general

Mining operations involve several stages including exploration, removal and processing of the ore[16]. The substances dealt with in mining operations can basically be divided into two groups: metals, which include gold, silver, lead, copper, nickel, zinc, molybdenum and iron, and non-metals, which include asbestos, gypsum, potash, salt, titanium, sulphur, silica and peat. It should be noted that statistics generally include a third group classified as construction or “quarry” materials, which include granite, limestone, marble, sandstone, slate, sand, gravel, lime and cement.

An ore deposit is mined by removing from the ground the minerals and their gangue materials through open-pit mining (surface mining) or underground mining. In open-pit mining, the ore is removed by constant digging and widening of the pit. In Quebec, the best known surface deposits are the asbestos mines of the Thetford Mines and Black Lake region, some of which have a diameter of up to 2 kilometers. In underground mining, the ore is removed by means of vertical shafts and horizontal tunnels which follow the veins or lodes of the materials being mined. Metals such as copper, zinc and gold are generally removed through underground mining operations.

The mined ore must undergo preliminary processing on site to remove most of the gangue. This operation, called mineral dressing, generally involves three stages: preparation, concentration and conditioning. Pollution is produced in varying degrees during these operations, as described below.

Ore preparation consists of crushing the materials so that sizing can be performed. Concentration is the operation whereby the ore pellets (metal or non-metal) are removed from the gangue. The techniques used include gravity (based on the density or weight of the material), magnetic separation and flotation. This latter technique is based on processes whereby the mineral and metal particles are brought to the surface of a liquid. Various chemicals are used to alter the properties of the materials to facilitate their concentration. For example, cyanide is used with gold or silver, whereas copper and zinc are recovered by flotation. Finally, conditioning is the operation whereby the ore is made ready for handling or further metal processing. The purpose of all these operations is to increase the purity of the

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16 An ore is a rock containing a high concentration of useful minerals or metals which can be recovered at a profit. An ore also contains materials without value called gangue. There are some 3,000 types of ores on our planet and these include, for example, chalcopyrite ($CuFeS_2$) and malachite ($CuCO_2.CU(OH)_2$) which contain copper as a useful metal.

ore so that it will contain greater concentrations of the substances being mined (gold, copper, zinc, etc.), but the purity achieved can be rather low - in the order of 20 to 40%.

Melting and refining are used to obtain pure metal or to prepare alloys; these processes are partly carried out on site. In the case of gold, in Quebec, the product that leaves the mine for metallurgical processing is pure to about 96%. This section will not deal with the environmental

effects of foundries, steel plants and aluminum smelters (for example, see the grid showing the impacts of aluminum production).

Canadian socio-economic overview

In Canada in 1995 there were 88 metal production operations, 127 operations producing non-metal substances and 318 sites identified as quarries or facilities for the production of building materials. Mining industry revenues came mostly from metal mines (68%), followed by non-metal mines (17%) and quarries (15%). Most of Canadian mining production (80%) is exported; this industry ranks second in export revenues (behind logging). Metal and non-metal products account for 14.6% of total Canadian exports. In 1994, exports from the mining industry contributed $11.7 billion to the trade surplus. In terms of jobs, there were 35,000 workers in metal mines, 10,800 in non-metal mines and close to 6,000 in quarries and operations producing building materials.

Canada is the world's leading exporter of minerals. It ranks first in the production of zinc (28% of world production) and potash (36%). It is second in the production of nickel (17%), cadmium (12%), asbestos (19%) and elemental sulphur (22%). The Canadian mining industry is most active in Ontario (30%), followed by British-Colombia (18%) and Quebec (16%).

Quebec socio-economic overview

Close to 30 mineral substances are mined in Quebec. In 1996, the main metals mined were iron ore (15 million t), copper (127,000 t), niobium (2,362 t), cadmium (333 t) and zinc (200 t). The main non-metals mined were silica (527,000 t), asbestos (519,000 t) and sulphur (156,000 t). Metallic substances produced in Quebec accounted for 24% of total mining production in Canada and for 19% of metals. The percentage of mining in the Quebec Gross Domestic Product has been stable for several years at about 1%.

Gold mine operations

Background on gold mining

Gold is a metal that is non-corrosive, very ductile, malleable and conductive. It is sought for its many industrial uses such as in electronics, high technology and dentistry. Its greatest use is for jewelry-making (84% of demand).

However, world demand for gold, which greatly influences decisions on whether or not to open new mines, is driven by the monetary policies of central banks and financial institutions in general. These policies have an effect on the price of gold which, for example, declined from $417 an ounce in February 1996 to $212 in January 1998. With such conditions, opening a new mine can be delayed; if the price of gold is too low, mining operations could face a deficit.

In 1996, the world production of pure gold was 2,328 metric tonnes, the majority of which came from South Africa (490 t) and the United States (300 t). Canada produced 160 tonnes of gold in

1996, of which 42 tonnes came from Quebec where this precious metal is mined in some 20 underground mines, all in the areas of Abitibi and Chibougamau.

Gold ore is usually trapped in a quartz or sulphide gangue. In Quebec, 85% of gold comes from gold-bearing quartz mines. This is worth mentioning since contrary to sulphide ore, quartz ore produces minimal acid mine drainage (see below). To remove the metal from its gangue, gold ore is processed using various methods based on the use of cyanide. The gold is dissolved in a sodium or calcium cyanide solution and is then recovered (by precipitation) using a zinc powder (old method) or by electrolysis with activated charcoal (more recent method).

Pollution produced by heavy vehicles

The movement of heavy trucks in the communities near a mine can cause in a serious pollution problem. With today's ore mining and purification techniques, it is much more cost-effective to process the ore in a plant located outside the perimeter of the mine itself. This can involve movement of 500 to 1,000 tonnes of ore a day, the equivalent of 20 to 40 trailer-loads. This activity increases the risk of accidents, causes damages to roads and leads to greater air and noise pollution.

Water pollution

The mining industry in general uses a considerable amount of water for ore processing. In the case of gold mining, in Quebec, each year over one million tonnes of water is used, or approximately 2.3 m^3 per tonne of crude ore processed. The general pollutants that can be found in mining effluents include suspended particulate matter (SPM) and various metals attached to the gangue. Emphasis should be placed, however, on two types of pollution that are especially harmful to the environment: acid mine drainage and the use of cyanides.

Acid mine drainage (AMD)

Acid mine run-off water produced during mining operations is the mining industry's greatest long term environmental problem. This acid mine water is produced because most metals are trapped in sulphide ores, such as iron pyrite. The exposure of sulphide ores to air and humidity results in oxidization, which releases sulphuric acid. This acid production can continue for hundreds of years and becomes almost impossible to stop. The speed of the process increases under the effect of naturally occurring bacteria which catalyzes the reaction by oxidizing the iron sulphide and elemental sulphur. Microbiological oxidization is 500,000 to a million times faster than open-air oxidization under similar environmental conditions. These bacteria belong to the type *Thiobacillus* sp, which is harmless to mammals.

Acidity of mining effluents or leaching run-offs from tailing storage areas (referred to below) is a threat to aquatic wildlife, but does not pose any real problem for public health. Acid mine drainage can increase the toxic effect of cyanide, especially by promoting the formation of hydrocyanic acid (HCN), which is very toxic (see below). Furthermore, high acidity in water causes the release of various metals (aluminum, arsenic, cadmium, copper, iron, lead, nickel and zinc) found in the gangue and also in the parent rock on which the water flows. It should be noted that AMD is especially a problem in the case of copper, zinc or polymetal mines. In gold mining, run-off water is alkaline and therefore sulphides are not oxidized into sulphates.

AMD can be controlled in several ways, including by overwashing non-oxidized mine tailings. With this approach, the tailings are submerged in water, which prevents the oxygen from reaching the sulphide ore and initiating chemical oxidization.

Cyanides

Gold processing involves, first of all, the use of a sodium cyanide solution in an alkaline medium. This dissolves the gold, which is then separated from the tailings by absorption of the cyanide complexes. The gold is then submerged in a hot sodium hydroxide solution to allow stripping (and reuse) of the cyanide. The result is a concentrated solution of the precious metal. Although most of the cyanide is reused, the run-off water from the product that was used to filter the cyanide-gold complex can contain low residual quantities of this toxic substance.

It should be noted here that cyanides contain various types of inorganic and organic compounds in the CN group, which is formed by a triple link between a carbon atom and a nitrogen atom. Based on their physical and chemical properties, cyanides can be classified as a free, simple, complex or organic. In an aqueous environment, free cyanide corresponds to the total of free anions (CN), in equilibrium with a molecular type, e.g. hydrocyanic acid or hydrogen cyanide (HCN), the pH being the determining factor in this equilibrium. Simple cyanides are compounds where the CN radical is associated with metals or non-metals; in water, these compounds break down easily to form the CN anion. Complex organic cyanides are formed mostly with iron (ferrocyanides), copper (cuprocyanides) and zinc; these complexes are very persistent in the environment. The formation of thiocyanates should also be mentioned here. These are the product of the amalgamation of cyanides and sulphide compounds found in various ores or generated by AMD.

The presence of cyanides in surface water is usually the result of human activity, especially gold mining. In certain extreme cases, cyanide concentrations of 26 mg/L have been identified in mining effluents; according to directive 019 of the Quebec Department of the Environment, the CN level should not exceed 0.1mg/L.

Cyanides break down under the sun's rays, especially UV rays. The risk of water contamination is especially high in spring because during winter, ice prevents the ultraviolet rays from reaching the cyanides in free-floating water or in water that has accumulated in a pond mostly covered with ice. Therefore, no wastewater should be released between November and April. If water is released too early in the spring or if there is a leak in the restraining dikes, water laden with

cyanides can be spilled into the environment. The breakdown of cyanides by the sun's rays is a process that is widely used to help eliminate cyanides in ponds spread out over large areas.

There is a close link between the toxicity of cyanides and their types. Free cyanide is the most toxic form. Simple cyanides, however, break down quickly into free cyanide in water. Hydrocyanic acid (HCN), the form generally found at the pH levels in surface freshwater, is also very toxic. HCN penetrates quickly into the organism and starts acting by adhering to the ferric iron group (Fe^{+3}) which plays an active role in several enzyme systems. In humans, over 40 enzyme systems can be deactivated by cyanide, the most important being the cytochrome oxidase complex, which is at the top of the chain of respiratory carriers for mitochondria. With the inhibition of this system, the generation of ATP stops, and this produces the same pathological effect as a lack of oxygen in the blood. Oxygen can reach the cells, but they are unable to use it. Cyanide acts quickly and can be fatal within several minutes. The typical symptoms are weakness, headaches and tachycardia. Poisoning by cyanide can be treated when a kit containing various antidotes is available.

It is highly improbable that humans could be poisoned because of the presence of cyanide in mine wastewater. However, since this compound is so toxic, its presence in water is always a concern because the LC_{50} (96 hours) varies between 0.03 and 0.15 mg/L in most freshwater fish. This makes it a more powerful toxin than mercury and all of the heavy metals. In the spring, there have been many reports of Canada geese dying after having stopped in ponds where the water had a high cyanide content.

Mine tailings

Mining losses can include overburden which is made up of the layers covering a deposit. However, such losses are produced in limited quantity and do not have a real harmful effect on the environment, except when they produce dust that can be raised by the wind, or when rainwater can cause erosion. The most harmful wastes are the mine tailings themselves, which fall into two categories: waste rock and mineral processing waste. Waste rock is rock that contains insufficient quantities of metal (or non-metal) to be commercially mined. This material is produced when digging the access ramps, tunnels and underground shafts to reach the gold-bearing areas of the mine. Ore processing waste includes mostly the gangue that is removed through the various concentration operations.

Mine tailings can be stored in piles, depending on their particle-size. Most typical of these in Quebec are the piles of asbestos tailings in the Thetford Mines area. In Quebec, there are close to 150 mine tailing storage areas covering approximately 12,000 hectares. Gold mining accounts for one third of these sites. These tailing storage areas also provide excellent sites for the development of acid mine drainage.

Various methods can be used to restore mine tailing storage sites to an environmentally acceptable condition. Water run-off can be contained and controlled, and contact with the air can be prevented. These are necessary steps to prevent AMD. Abandoned tailing sites can be covered with impervious soil on which vegetation can be planted.

Sector: Mining Activity: Underground Gold Mining

STRESSOR/ EXPOSURE	Type of Stressor	Environmental Impact	Area of Influence	Control Measures	Standards or Recommendations
Technological disaster	- rupture of retaining dikes	water pollution from cyanides and heavy metals	mine and receiving watercourse, if any	- monitoring	
	-collapse and flooding of tunnels			- solidification of tunnels	
Gaseous or air emissions	suspended matter	- deposit on vegetation, appearance	- site and perimeter	- dust control liquid on access roads - vegetation cover on abandoned tailings	150 Fg/m^3 (24 hrs) Q-2, Reg. Qual. Atmosph.
Liquid emissions or discharge into water	- cyanides	- high toxicity for aquatic organisms: (CL_{50}: 0.03 to 15 mg/L)	-receiving water courses and water bodies	- retention pond (to facilitate degradation)	- 0.2 mg/L (Drinking Water Reg., DEW) - 20 Fg/kg/j (EPA)
	- heavy metals (Al, Cd, Cu, Zn, Pb, Fe, Ni, etc.)	- varying toxicity for aquatic organisms	- receiving watercourses and water bodies	- treatment pond	- 5 F g/L (Cd), 0.5 mg/L (Pb) (Drinking Water Reg. DEW) Al <0.1 mg/L (to prevent Alzheimer's disease)
	- pH reduction (sulphuric acid)	- toxicity for several aquatic organisms	- receiving watercourses and water bodies	- prevent sulphide ore oxidation	- pH 6.5 to 9.5 (Mining Guidelines, DEW)
Solid emissions or discharge into the soil	- overburden	- appearance (possibility of dust in atmosphere)	- site and perimeter	- adequate storage	- Mining Act and Mining Guidelines (DEW)
	- waste rock and tailings	- appearance (possibility of cyanide & heavy metals in water)	- site perimeter and vicinity	- adequate storage, prevent sulphide ore oxidation	- idem
Disamenities	- dust	- healthy conditions, appearance	- site, perimeter and vicinity	- covering, dust control	
	- noise (mobile and fixed sources)	- healthy conditions	- site, perimeter and vicinity	- buffer zone	- L_{eq} 45 dB(A) 8 hrs nighttime and 50 dB daytime
Indirect impacts or other exposure					

STRESSOR/ EXPOSURE	Effect on health	Population at risk	Probability of occurrence	Environment/ biological indicator (monitoring)	Information/ references
Technological disaster	- see "cyanides" and "heavy metals"	- workers	- occasional	- morbidity/mortality reports, CSST	
	- injuries, deaths				
Gaseous or air emissions	- various respiratory problems	- workers, vicinity	- rare	- complaints, levels of atmospheric particulate matter	
Liquid emissions or discharge into water	- weakness, headaches, tachycardia, death	- vicinity, people drinking contaminated water	- very rare	- total cyanide levels in mining effluents and in receiving watercourses	- Gossels and Bricker (1994); OECD (1994)
	- various toxic effects	- vicinity, people drinking contaminated water	- very rare	- heavy metal levels in mining effluents and watercourses	- Gossels and Bricker (1994)
	- none	- N.A.	- N.A.	- N.A.	
Solid emissions or discharge into the soil	- none	- N.A.	- N.A.	- N.A.	
	- see cyanides and heavy metals in water				
Disamenities	- hygiene, infections	- workers, vicinity	- rare to occasional	- complaints	
Indirect impacts or other exposure					

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