ethical council

A COLLABORATION BETWEEN
FIRST–FOURTH AP-FUNDS

The environmental impact of the mining industry

A broad review of the potential environmental impact of the mining industry

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Pension Fund/AP2 and the Ethical Council.
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The Ethical Council of the AP Funds

The First, Second, Third and Fourth AP Funds function as ‘buffer’ funds within the Swedish National Pension system, serving to balance periods of surplus and deficit experienced by the pension system. Having been organized in this form since January 2001, the mission of the AP Funds is to invest pension assets with a view to generating a high long-term return. The way in which these funds invest their assets is governed by the Swedish National Pension Funds Act, § 2000:192. The preamble to the Act states that the Funds shall pay due regard to environmental and ethical considerations in investing their assets, but without compromising the overall goal of generating a high return at low risk. The ethical principles on which the investment approach adopted by the AP Funds is grounded derive from the international conventions to which the Swedish State is a signatory.

Since 2007, the First, Second, Third and Fourth AP Funds have had an Ethical Council that focuses on ethical and environmental issues affecting the Funds’ foreign shareholdings. Ethical issues relating to the Funds’ Swedish shareholdings are still handled by each Fund on an individual basis. The Ethical Council reviews the Funds’ portfolios with a view to identifying and analysing companies that infringe international conventions on the environment or human rights. As a result of this review process, some ten or more ‘focus companies’ are selected, with which the Ethical Council conducts an active dialogue, to promote change in these companies. In several cases, the Ethical Council cooperates with other Swedish or international investors, to increase pressure on the selected companies. If such dialogue fails to achieve the desired result, the Ethical Council may recommend the individual Fund to exclude the company in question.

The Ethical Council consists of an ordinary member from each Fund, with the right to appoint an additional deputy member. GES Investment Services assists the Ethical Council with analyses of the companies, advice and coordination of the Ethical Council’s work. The Chair alternates between the Funds. In 2007, the First AP Fund chaired the Council, and it was the Second AP Fund’s turn in 2008 and to the Third AP Fund in 2009.

Summery

The mining industry provides society with minerals that are employed to satisfy basic needs. At the same time, it is a high-risk industry associated with major health, safety and environmental risks, as well as infringements of human rights. The mining industry offers many examples of negative environmental impact, deriving both from the inadequate routines associated with various processes, and from accidents. One example with which the AP Funds' Ethical Council is well versed is Freeport – McMoRan Copper & Gold Inc's copper-and-gold mining operation on the Indonesian island of Papua. Mining operations in this area involve extensive negative environmental impact, in contradiction of the UN Convention on Biological Diversity (Indonesian Ministry of Environment, 2006). The wide-ranging environmental consequences of Freeport's mine in Indonesia, and of many other mines, have convinced the AP Funds' Ethical Council that there is an increased need for improved knowledge of the mining industry and its potential impact on the environment.

The Report is intended to promote a better understanding of the potential environmental impact of the various phases in the life cycle of a mine: from prospecting, exploration and development to the actual exploitation of the mine, the enrichment process, waste management and rehabilitation. The Report provides an overall view of the situation and describes processes and potential environmental impact in general terms. It also addresses the commonest production methods and the potential environmental impact of eleven minerals, selected because of their significance in modern society or because their production may involve major environmental impact. These minerals are aluminium, lead, gold, iron, coal, copper, nickel, molybdenum, platinum, uranium and zinc.

Potential environmental impact during a mine's life cycle

Prospecting and exploration – Prospecting means searching for the geological phenomena that indicate the existence of a potential ore. If an ore is detected, the deposit is explored to determine the form, quantity and value of the ore find. (Hartman and Mutmansky, 2002) The greatest potential environmental impact of prospecting and exploration is the opening up of previously virgin areas, making it easier for people to move in (Miranda et al., World Resources Institute, 2003). This can lead to conflict with the indigenous inhabitants and the destruction or fragmentation of many species. In some so-called "no-go" areas, mining operations are totally inappropriate, which should be noted right from the start, at the prospecting phase.

Development – The development phase refers to development of the find into a functioning mine, although this is often conducted in parallel with its exploitation. In determining whether conditions are appropriate for the establishment of a mine at the new find, the following factors must be addressed: the natural environment, weather conditions, access to basic facilities, the commercial prospects, the political situation and environmental legislation. (Hartman and Mutmansky, 2002) Just as with prospecting and exploration, the environmental impact of the development phase is greatest if implemented in an area previously spared from exploitation. Mine development involves an increasing water requirement, which can lead to conflict over water rights, if access to water is already limited in the area. The development of surface mines disfigures the landscape and denudes it of forest, reducing the amount of protective cover necessary to animals in the area, and increasing the risk of erosion. Underground mines involve the risk of subsidence and alterations in the flow of watercourses, which may dry up or overflow their banks. Mining operations have a major impact on the surrounding ecosystem and can cause a decline in biological diversity. (Miranda et al., World Resources Institute, 2003)

Exploitation – Exploitation refers to the mining of ore in commercially viable quantities. The mining method selected is determined by the nature and position of the find. (Hartman and Mutmansky, 2002) Most mining is conducted above ground, since it is more economical and the extraction processes for surface mining are becoming more efficient all the time. (Aswathanarayana, 2003) The Report covers open pit mining, leaching, hydraulic methods and underground mining, with or without backfill. Industrial-scale mining has a huge impact on the local environment. Open pit mining disfigures the landscape, results in deforestation and generates large amounts of waste. Changes to the landscape lead to increased risk of erosion, which can in its turn cause sedimentation in the surface water and have a highly negative impact on marine life. Open pit mines spread dust and have a significantly more adverse effect on air quality than underground mines. As for water quality, the impact of both surface and underground mines is probably equally great. Underground mines involve the risk of subsidence and alterations to water flows. The mining industry uses a lot of energy, with combustion of fossil fuels being the most common source. This results in the emission of greenhouse gases and, in all likelihood, changes in the climate. Mining operations also generate dust, particulate emissions, sulphuric oxides, nitric oxides and other dangerous substances, producing a whole range of health and environmental problems. (Marcus, 1997)

Enrichment – Enrichment often initially involves crushing and grinding of the ore, after which a number of different methods may be employed to separate the desired mineral from the rest of the ore. Common methods for increasing the concentration of desired minerals include gravimetric enrichment, flotation, magnetic separation, electrostatic separation and leaching. Many enrichment processes are highly energy-intensive: where the energy source is fossil fuel, it results in the emission of greenhouse gases (Mining, Minerals and Sustainable Development, 2002). Toxic chemicals, such as sulphuric acid and cyanide, can cause serious pollution if they leach into the surrounding soil or watercourses. The enrichment process also generates a lot of dust, which permeates the immediate environs, having an inevitable impact on health and the environment. (Ripley et al., 1996)

Waste management and rehabilitation – Mining operations generate huge quantities of waste, in the form of overburden, gangue, tailings slurry and leaching waste. Waste from sulphidic ores poses severe challenges and must be managed over a very long period, in view of their potential for an extensive and highly negative impact on the environment if in contact with oxygen and water. The overburden and gangue can be stockpiled and in some cases used as a construction material or as backfill for mines. Tailings slurry is often stored in tailings ponds, but examples even exist where this waste is poured into the sea or in rivers, with far-reaching and highly negative environmental consequences.

Leaching waste is rinsed to remove residual chemicals after the leaching process, and is subsequently stored as gangue or tailings slurry. The greatest potential environmental hazard posed by the mining industry in general, and the waste management process in particular, is seepage of acidifying leachate and a rise in the incidence of heavy metals, collectively more commonly referred to as 'acid drainage'. The problem arises when the sulphide ions contained in sulphidic ores react with air and water. Once this decomposition process has started, it is difficult to stop, leading to extensive and long-lasting environmental consequences. To prevent this from happening, the sulphide-rich mine waste must be insulated from contact with oxygen by a layer of water or boulder clay. To ensure this, tailings slurry is often stored in a tailings dam, constructed for very long-term survival, even when subjected to various forms of seismological activity, extreme weather or other hazards. (Mining, Minerals and Sustainable Development, 2002)

Potential environmental impact of different minerals

As noted above, one of the commonest environmental problems associated with mining operations is seepage of acidifying leachate and heavy metals. Uranium, coal and base metals such as lead, copper, nickel and zinc (as well as metals that are often mined in conjunction with base metals, such as gold and molybdenum) are often extracted from sulphidic ores. It is when handling these waste products that problems can arise. (Mining, Minerals and Sustainable Development, 2002) A number of other mineral-specific environmental risks also exist, such as the enrichment of gold by cyanide leaching. This method involves a risk of cyanide dispersal, which is toxic for both humans and animals, and which can cause considerable harm if released onto land or in water (Ripley et al., 1996). Another example is the production of aluminium, in which the waste product (known as red mud) can lead to major problems in the form of dust dispersal and seepage of numerous metals into watercourses (Aswathanarayana, 2003). The production of aluminium consumes huge amounts of energy, which may involve substantial emissions of greenhouse gases and accelerate climate change (Aluminiumriket Sverige, 2008). Methane, which is often released in conjunction with coal mining and creates the risk of an explosion, also contributes to the build-up of greenhouse gases and climate change (World Coal Institute, 2008). The mining of coal also spreads dust and particulate emissions, causing major environmental and health problems (Aswathanarayana, 2003). In the case of uranium mining, the greatest environmental impact derives from the fact that uranium and its decay products are radioactive, posing a hazard to any humans, animals and plants that may come into contact with them (Ripley et al., 1996).

Determining the environmental impact of a mine

Many aspects need to be considered when determining the environmental impact of a specific mine. During the preparation of this Report, the following aspects have appeared to be of the greatest significance. The geographical location of the mine is very important, especially if sited in previously virgin territory, if access to water is limited, if the topographical conditions are adverse or if the area is seismologically active. The mining method selected is largely determined by the position and nature of the ore, but every method involves some form of environmental impact. The enrichment method employed and the degree of environmental hazard posed by the tailings slurry is determined by the type of ore extracted.

Incorrect management of the tailings slurry from sulphidic ore leads to risk of acidification and the release of heavy metals. The amount of tailings slurry generated depends on the concentration of desired minerals in the ore and the demand for minerals. Normally speaking, several chemicals are employed in the enrichment process. These chemicals can often be recycled, but if not, and they leak into the surrounding environment, they can cause considerable damage. High energy and water consumption, during enrichment and other processes at the mine, can also have an adverse effect on the environment. Energy consumption often involves the emission of greenhouse gases, which are highly likely to contribute to climate change. High water consumption can result in a shrinking supply and conflict over water rights.

Even if stringent measures have been implemented to prevent the mine from having a negative impact on the environment, accidents could still have considerable environmental consequences. Mining companies should therefore adopt a preventive approach, identifying critical aspects of their operations and implementing crisis management systems that can be activated should an accident occur. To ensure that the environmental footprint left by the mine in the long term is minimal, a plan to manage the area once mining operations have been completed must be devised from the outset. This plan should also state how closure of the mine and the land-rehabilitation process is to be financed.

Plenty of international initiatives have been proposed about what the mining industry could do to minimise environmental impact, and which may prove useful when a mine is to be assessed from an environmental perspective. The report produced following the UN World Summit on Sustainable Development, held in Johannesburg in 2002, describes approaches for achieving sustainable global development and addresses ways in which the mining industry must contribute to realise this goal (World Summit on Sustainable Development, 2002). The International Finance Corporation (IFC) is part of the World Bank that is engaged in providing finance and advice to the private sector in developing countries, with a view to combating poverty. The IFC makes recommendations to governments concerning areas that should be protected by legislation and about agreements with the mining industry (International Finance Corporation, 2008).

The industry organisation International Council on Mining and Metals (ICMM) has established ten principles of sustainability. It requires that members openly report their performance as per these principles, in accordance with the Global Reporting Initiative (GRI), while also allowing external auditing of its own work in this area (International Council on Mining and Metals, 2008). The UN Convention on Biological Diversity constitutes an important tool when addressing issues relating to the mining industry and biodiversity (Mining, Minerals and Sustainable Development, 2002). There are also many mineral-specific and country-specific initiatives. One example of the former is the Cyanide Management Code, which makes recommendations as to how companies should manage cyanide (Cyanide Management Code, 2008).

Contents

1 Introduction

Mines exist to extract the minerals essential to society's basic needs. However, mining is also a high-risk industry, associated with major health, safety and environmental risks, as well as the violation of human rights. There are plenty of examples of mines that have had an adverse environmental impact, such as the tailings-dam failure at the Boliden Aspirsa mine in Los Frailes, Spain, in 1998. The wall of the tailings dam collapsed, and some seven million cubic metres of tailings material and water was released into the river delta. The tailings contained high levels of heavy metals and acidic water. No-one was injured, but the impact on adjacent agricultural areas, a nature preserve, local fauna and water quality was considerable. This dam incident clearly demonstrates that accidents can and do happen, even when totally unexpected, and that it is vital that mining companies, public and municipal authorities and other interested parties are aware of the potential risks incurred by mining activities. (Räddningsverket, 1999) Boliden Aspirsa was forced to pay SEK 400 million for the clean-up operation, subsequently going into liquidation. The legal implications for Boliden Mineral and Boliden AB have yet to be finalised, and there is a risk that the companies could be liable to fines amounting to billions of kronor. (Sunesson, 2008)

Another example of adverse environmental impact is Lafayette Mining's open pit mine in the Philippines, blocking watercourses with slurry runoff and releasing cyanide, poisoning the water in nearby rivers and streams and harming plant life and fish stocks. The mine is sited on the island of Rapu-Rapu, with a coastline that features coral reefs, mangrove swamp and kelp beds. An ocean area of significant biological diversity, it supports five of the world's seven species of turtle, the world's largest fish species – the whale shark – and dolphins. The release of cyanide into the local environment has led to the company being fined but, more importantly, enquiries commissioned both by the country's president and by the environmental organisation Greenpeace have concluded that mining operations should not be permitted in the area at all, because of its rich biological diversity. (Greenpeace, 2008)

An example with which the AP Funds' Ethical Council is especially well versed is Freeport – McMoRan Copper & Gold Inc's copper, gold and silver mining operation on the Indonesian island of Papua. Freeport's mining operations in this area are associated with extensive negative impact on the environment, in conflict with the UN Convention on Biological Diversity (Indonesian Ministry of Environment, 2006). The Ethical Council is engaged in a dialogue with Freeport in the hope of persuading the company to state what it is doing to minimise its effect on the environment and to encourage it to draft a plan for rehabilitating the area once mining operations have ceased. The wide-ranging environmental consequences of Freeport's mine in Indonesia, and of many other mines, have convinced the AP Funds' Ethical Council that there is an increased need for improved knowledge of the mining industry and its potential impact on the environment.

The Report is intended to promote a better understanding of the potential environmental impact of the various processes employed by the mining industry. It provides an overall view of the situation and describes in general terms the potential environmental impact of the various activities in which the mining industry is engaged.

The data on which the Report is based derives mainly from books, research reports, websites and articles. To gain an in-depth understanding of the subject, interviews have been conducted with a number of different experts in the field. The Report describes in broad terms the relevant processes involved throughout the entire life cycle of an industrial-scale mine, from prospecting to enrichment of the extracted minerals and rehabilitation of the mine site, as well as the environmental impact of these processes. It also addresses the commonest production methods and the potential environmental impact of eleven minerals, selected because of their significance in modern society or because their production may involve major environmental impact. These minerals are aluminium, lead, gold, iron, coal, copper, nickel, molybdenum, platinum, uranium and zinc. Platinum-group metals is the collective term for platinum, iridium, osmium, palladium, rhodium and ruthenium. This Report focuses on platinum alone, and not on the other platinum-group metals. The second chapter of the Report describes the different phases in the life cycle of a mine, and the environmental impact of each phase. Chapter three presents the production processes and the environmental impact of the minerals addressed in the Report. The Report concludes with a chapter summarizing the areas to be considered when determining the potential environmental impact of a mine.

2 Mine life cycle and environmental impact

Mining is a very large-scale industry, involving tens of thousands of people, the shifting of millions of tons of rock and ore and, more often than not, operates on a global market. Mining operations are conducted in geographically distinctly different areas and during highly varied climatic conditions. There is huge variation in the types of mineral extracted, and the extraction and enrichment processes are many and various. The sheer scale and variety of mining industry operations means that its environmental impact varies from mine to mine, making any analysis of its environmental impact a difficult and complex business.

Generally speaking, a mine's life cycle can be broken down into the following phases: prospecting, exploration, development, exploitation, enrichment and rehabilitation (see fig. 2.1). Each phase of the mining cycle, and its potential environmental impact, is addressed individually. The way the large quantities of waste generated by mining operations are managed can have a dramatic impact on the environment. For this reason, a separate section of the Report is dedicated exclusively to this issue.

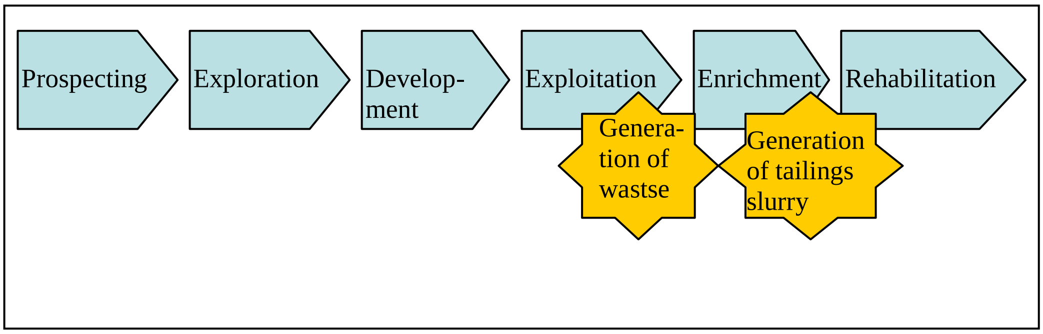


Fig. 2.1 Mine life cycle

2.1 Prospecting

Ore is a naturally occurring, metal-rich mineral deposit, from which the extraction of the desired mineral deposit is commercially viable. If the mineral deposit is too small to make commercial exploitation viable, it is called a mineralization. (The Swedish Museum of Natural History, 2008) Ores may be classified as resources or reserves. 'Resource' defines a mineral deposit, or a sufficient abundance, that is commercially interesting and that offers a reasonable prospect of extraction. A 'reserve' is that part of a 'resource' whose extraction is deemed both technically and commercially viable. Rising market prices can transform a resource into a reserve overnight. (Mining, Minerals and Sustainable Development, 2002)

Prospecting refers to the search for geological phenomena that may indicate the potential existence of an ore deposit. The decision as to which mineral such prospecting should focus on is determined by the mineral's potential and the political situation. Political factors that can have a bearing on what is prospected include taxes, environmental legislation, regulations, conservation areas, infrastructure, the availability of labour and socioeconomic agreements (Hartman and Mutmansky, 2002).

Mineral deposits can be found both at the surface and deeper in the ground. Direct prospecting techniques, employed to detect surface deposits, involve visual surveys, geological studies, aerial photography and geological mapping. The majority of surface deposits are already thought to have been found however, so indirect prospecting techniques are often used to complement the search process. The use of geophysics – involving physical measurement of the Earth's crust – is the most commonly applied indirect prospecting technique. Examples of geophysical methods include electromagnetic readings, magnetic readings and readings to determine rock density (Boliden, 2008). Other examples of indirect prospecting techniques are geochemical analysis and geobotanic analysis, where chemical structures and biological patterns are analysed to detect anomalies that could indicate the presence of minerals. (Hartman and Mutmansky, 2002)

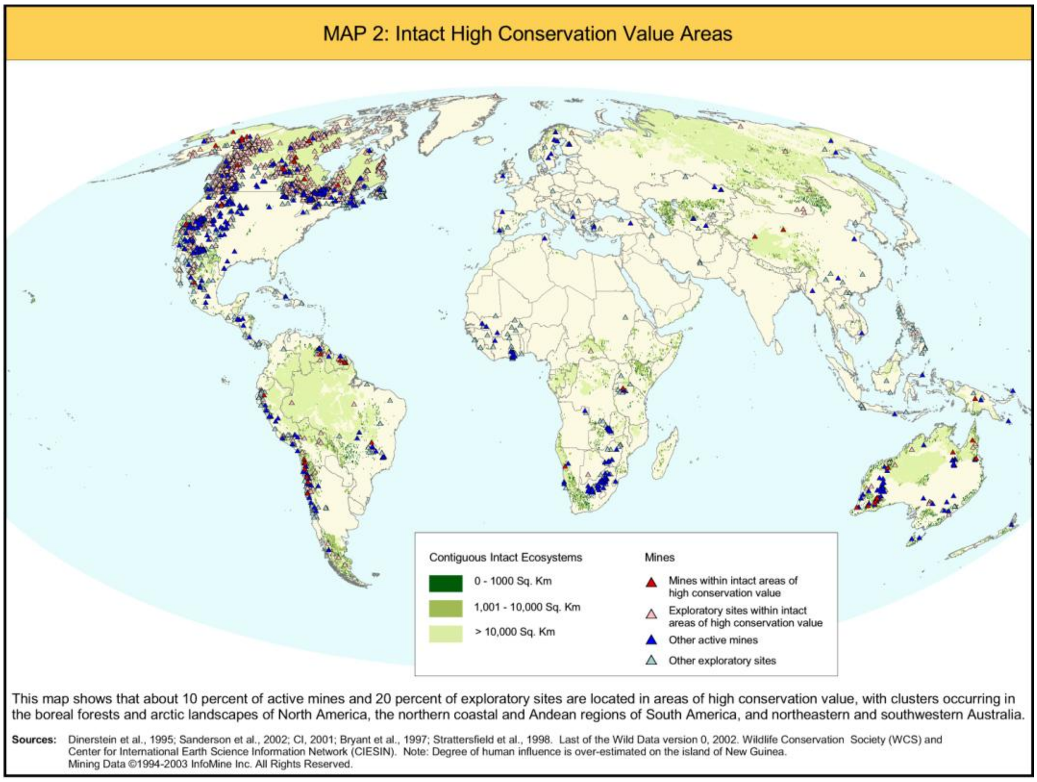
2.1.1 Potential environmental impact of prospecting

Prospecting involves the use of various forms of transport, with the risk that the area may be affected by waste products, fuel spills and so on, although normally speaking, prospecting has little impact on the environment. Prospecting is conducted at a significantly greater number of locations than the number eventually developed as mines, but the impact on the land and the local ecology is much briefer and much less extensive (Ripley et al., 1996). The greatest potential environmental hazard that derives from prospecting is that previously undisturbed areas are opened up for exploration, involving the construction of roads and camps, facilitating access and making it easier for hunters and anglers to exploit the area. Prospecting in virgin areas can disrupt the local community and indigenous population and lead to the destruction or fragmentation of the habitat on which several species depend. (Miranda et al., World Resources Institute, 2003) It is worth remembering, however, that it is more economical for mining companies to prospect in areas close to existing mines than in virgin areas (Boliden, 2008).

2.1.2 No - go areas

When prospecting, attention must be paid to whether mining operations are appropriate in the area in question. For example, does the area contain ecosystems of high conservation value, and would mining operations involve a serious environmental risk? A high degree of seismological activity may also mean that mining operations should not be conducted in the area, since construction of tailings dams capable of withstanding such conditions may not be feasible (Mining, Minerals and Sustainable Development, 2002). The possible establishment of 'no-go areas' for the mining industry is currently the subject of global debate, and a dialogue is being conducted between the International Union for Conservation of Nature (IUCN) and the International Council of Mining and Metals (ICMM) concerning biological diversity and mining operations (International Union for Conservation of Nature, 2008). The current position, according to the ICMM's principles of sustainability, is that mining companies shall respect areas that are protected by law, as well as during the terms of the World Heritage Convention. Otherwise, the mining industry believes that assessments of a mine's impact on the environment should be made on a case-by-case basis. The IUCN feels that mining operations should be avoided in areas it defines as of exceptional conservation value, according to categories I-IV and the conditions pertaining to World Heritage Sites. These areas represent, respectively, ten and one percent of the world’s entire land area. It is difficult to assess biological diversity and to compare different areas in terms of their relative conservation value.

For this reason, it is by no means certain that all the areas that *should* be protected are listed as World Heritage Sites or come during IUCN Management Categories I-IV. (Mining, Minerals and Sustainable Development, 2002; Miranda et al., World Resources Institute, 2003) At present, 44 mines are located in various World Heritage Sites. Fig. 2.2 shows that some ten percent of the world’s mines are sited in areas that the IUCN considers to possess exceptional conservation value.



This map shows that about 10 percent of active mines and 20 percent of exploratory sites are located in areas of high conservation value, with clusters occurring in the boreal forests and arctic landscapes of North America, the northern coastal and Andean regions of South America, and northeastern and southwestern Australia.

Sources: Dinerstein et al., 1995; Sanderson et al., 2002; CI, 2001; Bryant et al., 1997; Strattersfield et al., 1998. Last of the Wild Data version 0, 2002. Wildlife Conservation Society (WCS) and Center for International Earth Science Information Network (CIESIN). Note: Degree of human influence is over-estimated on the island of New Guinea. Mining Data ©1994-2003 InfoMine Inc. All Rights Reserved.

Fig. 2.2 Sites of exceptional conservation value and active mines. Source: Miranda et al., World Resources Institute, 2003.

Many developing countries are dependent on revenue from the mining industry, yet lack the legislation, judicial system and social structure necessary to ensure that mining operations are conducted in a responsible manner. This places a heavy responsibility on international mining companies, investors and purchasers of metal products, to ensure that mining operations are conducted at appropriate sites and in an appropriate manner .(Miranda et al., World Resources Institute, 2003)

2.2 Exploration

Exploration is carried out to determine the form, extent and value of the find. Excavation and drilling are used to extract ore samples for analysis. Drilling is both economically and practically preferable to excavation, accounting for 95 percent of all ore samples taken. (Hartman and Mutmansky, 2002)

The three commonest drilling techniques are diamond drilling, rock drilling and percussion drilling. Diamond drilling is used for hard bedrock, deep drilling and when the drill head must remain intact. Rock drilling is used for soft to medium-hard bedrock and where only relatively shallow boreholes are required. This type of drilling is often used to penetrate the top layer of earth and rock, before changing to a diamond drill. When drilling is not intended to produce a core sample and involves shallow to medium-depth boreholes, percussion drilling is used. The main benefits of this method are low cost and high drilling rate. (Hartman and Mutmansky, 2002)

The bore core and bore dust are analysed to determine the nature of the mineral deposit and rock type, and the properties of the sample. The size of the reserve is assessed by drilling a pattern of boreholes. Maximum data can be achieved at minimum cost when boreholes can be drilled in a regular pattern, but this is seldom possible. A number of metallurgical tests are carried out to determine which enrichment techniques are best suited for processing any find that may be located. The prospecting and exploration process concludes with the preparation of a detailed feasibility study, which charts the prospects for developing such a find into a full-scale mining operation. (Hartman and Mutmansky, 2002)

2.2.1 Potential environmental impact of exploration

As in the case of prospecting, exploration normally has little impact on the environment, in spite of the physical effects of the drilling process. The greatest potential impact on the environment is the exploitation of previously undisturbed areas, facilitating outside access and opening up the area to hunting and fishing for the first time. Increased in-migration to the area, and the exploitation of resources, can have a major impact on local communities, indigenous peoples and biological diversity. (Miranda et al., World Resources Institute, 2003)

2.3 Development

The development phase refers to the development of a find into as functioning mine. It is often difficult to make a clear distinction between development and exploitation. In general, it can be said that the development phase is initiated some years prior to the actual exploitation of the mine, and ends some years prior to the termination of commercial mining operations. The reason these phases are conducted in parallel is that the mine-development process is simply too costly to complete without the benefit of revenue generated by exploiting the mine’s resources. Furthermore, the technology may well change during the mine’s operating life, forcing development in a new direction. (Hartman and Mutmansky, 2002) Many factors must be considered when developing a mine. The most critical factors determining whether the position of a find is appropriate for the establishment of a commercial mining operation are:

- **Natural and geographical features** – During the development phase, for example, the following aspects must be taken into consideration: topography, the nature and size of the ore deposit, the geological conditions, the rock’s properties, the volume of overburden (the volume of earth and rock covering the deposit) and the find’s chemical and metallurgical properties, which often determines the mining processes chosen. (Hartman and Mutmansky, 2002) The natural features of the find’s site are also important. If the site is forested, mining operations will result in deforestation of a large area, which could have a considerable impact on biodiversity and contribute to climate change. (Aswathanarayana, 2003)

- **The impact of weather** – A number of weather factors must be ascertained so that mining operations can be adapted accordingly. For example, levels of rainfall should be determined, so that pumps and transportation systems can be appropriately dimensioned. Temperature and levels of atmospheric humidity must be considered when designing the mine’s ventilation system. A study must be carried out to determine the possibility of extreme weather conditions or other natural phenomena such as earthquakes, volcanic eruptions, insect invasions, floods, forest fires, extreme winds and hurricanes, as all these factors can impact on mining operations and affect the total number of working days per year. (Aswathanarayana, 2003)

- **Transportation systems** – Ore deposits seldom occur at sites that facilitate delivery to and transport from the mine. The geographical location of a mine is especially critical if at some distant arctic location. In such instances, the mining company must often choose between establishing an entire mining town or constantly flying personnel in and out. (Hartman and Mutmansky, 2002)

- **Availability of labour and basic facilities** – When addressing the labour requirement, the mining company must consider demographic factors, the professional skills available in the local community and mineworkers’ levels of job satisfaction. It is also important to take factors such as housing, training, healthcare, recreational opportunities and so on into account. (Hartman and Mutmansky, 2002)

- **Economic factors, political situation and environmental legislation** – Political stability, environmental legislation, the taxation of mining companies, restrictions and grants effect both development and exploitation phases. The stringent environmental legislation applied in industrialized countries has convinced many mining companies based in these same countries to look for new deposits abroad. This can create new potential risks, however, in the form of political instability, terrorism and other criminal activities, as well as a lack of infrastructure. (Hartman and Mutmansky, 2002)

The feasibility study conducted on conclusion of the exploration phase often serves as the initial planning document for the development. In an open pit mine, development involves extracting the ore by excavating the overlying layers of earth and rock, for removal to a waste management site. The development of an underground mine involves process optimisation during the exploitation phase, and the amount of ore excavated during this development phase is relatively modest compared with a surface mine. It is during the development phase that the mining method is determined, an important decision that affects the choice of mining equipment and the size of the workforce. Production, service and waste management facilities must also be planned and constructed during this development phase. Furthermore, transportation and communication systems must be built and power supplies secured for the mine. The judicial aspects of mining operations must be satisfied and financing has to be arranged during the development phase. The mining company must secure rights to the land it wishes to exploit, either by acquisition or leasing, as well as mining permits. If legislation requires an environmental impact assessment (EIA), this is carried out in conjunction with the mine development process. The recruitment and training of mine personnel is often the final part of the development phase. (Hartman and Mutmansky, 2002)

2.3.1 Potential environmental impact of development

When a mine is developed at a site where the mining company has had no previous operations, the area normally becomes increasingly populated and increasingly exploited during the development phase. This is partly because more people are involved in the development of the mine and its subsequent operation, but also because more and more people move into the area as it becomes more and more accessible and more built-up. An example of this is the fact that for every kilometre of pipeline laid in the Amazon delta, some 400-2 400 hectares of forest were felled, due to in-migration made possible by the new access roads. The amount of hunting and fishing also rises in proportion to the inflow of migrants, which can lead to the extinction of certain species. (Miranda et al., World Resources Institute, 2003)

The development of a mine also means increased demand for electricity, as well as drinking and process water. Increased demand for water can lead to conflicts, if water resources in the area are limited. The development of surface mines deforms the landscape and leads to deforestation. This removal of vegetation deprives the ground soil and animal life of its natural protection and increases the risk of erosion (Marcus, 1997). Underground mines create the risk of subsidence and can alter water flow patterns, resulting in the drying out or overflowing of local watercourse. Establishing mines, transportation systems, production and service facilities causes the spread of dust and exhaust gases. A variety of mining processes can lead to the release of chemical elements into surface and groundwater. (Miranda et al., World Resources Institute, 2003)

2.3.2 Biodiversity

Biodiversity may be defined as a wealth of species, of genetic variation within species and of diversity in ecosystems (National Encyclopaedia, 2008). Mining operations can have a significant impact on surrounding ecosystems and can lead to changes in the number of species or number of individuals comprising a species. An Australian study suggests that the mining industry is responsible for 1.1 percent of the presumed extinctions of endangered species. This may be compared with the figures released for grazing and agricultural land which, according to the same study, respectively cause 38.2 and 49.4 percent of the extinctions of endangered species. Every phase of the mining cycle can have a detrimental effect on biodiversity. Normally speaking, however, the impact is greatest prior to the exploitation phase, especially if the mine is established in a previously undisturbed area. When developing an open pit mine, the clearance of vegetation and topsoil from large areas often leads to accelerated desertification, which can have a far-reaching impact on biodiversity and natural ecosystems. (Mining, Minerals and Sustainable Development, 2002) Finds made in the Democratic Republic of the Congo of columbite-tantalite ore, or ‘coltan’, which contains the rare metals tantalum and niobium, provide one such example, where the mining industry has contributed directly to a decline in biodiversity.

These metals are widely used in the manufacture of capacitors for electronic devices, and the price of coltan rose dramatically between 1997 and 2000. Significant surface deposits of this ore are found in the east of the Democratic Republic of the Congo, where it is easy to extract from shallow pits using picks and shovels. The result has been a modern-day ‘gold rush’ into the region, triggering a dramatic decline in wildlife and plant life. Hunted for food and for trade, evidence suggests that the indigenous population of Grauer’s gorillas has declined by 80–90 percent over the past five years. (Mining, Minerals and Sustainable Development, 2002)

Different species are assessed differently, usually with reference to their rarity, origin and number, and whether the area is protected in terms of biodiversity. If mining operations contribute to extinction of a species, the impact irreversible. The UN Convention on Biological Diversity is an important tool in addressing such issues. This Convention addresses three key objectives: 1) The preservation of biodiversity; 2) Sustainable use of global resources and 3) Correct and equitable distribution of the benefits to be gained from the Earth’s genetic resources. The sharp rise in the global population has increased pressure on natural resources in recent years. If the world’s biological diversity is to be sustained, all three of the Convention’s objectives must be realised. (Mining, Minerals and Sustainable Development, 2002)

2.4 Exploitation

Exploitation is the phase of the mine cycle where ore is mined in commercially viable quantities. This is the phase that finances the other phases. The mining method selected is of crucial importance, and it is important to try to match the method to the specific circumstances that apply to the particular mine. Many of the factors presented in the section on development must be taken into account when selecting the mining method. Exploitation includes production processes and support processes. The four most common production processes at this phase of the mine cycle are drilling, blasting, lading and transport. Hard rock must be drilled and blasted to enable excavation. With softer mineralized rock, a mechanical digger may prove adequate. Drilling is primarily used to enable blasting and for fastening or making room for various types of equipment or pipes and cables. Support processes include various types of tests and measurements, waste management, ventilation, pumping of water, transportation, maintenance and so on. (Hartman and Mutmansky, 2002)

Figures released in 2000 revealed that 60 percent of all large mines, with an output in excess of one million tons a year, were surface mines – and almost 70 percent of all ore came from surface mines (Aswathanarayana, 2003). The fact that the majority of all mining operations are on the surface is because it is more economical to extract ore from surface deposits, and because the efficiency of surface extraction processes is increasing all the time. Surface mining operations offer the advantage that metals or minerals can be mass produced at relatively low cost. The advantage with underground mines is that they permit the extraction of many different types of find. Nevertheless, a choice between surface mining operations or no mining at all, rather than between surface or underground operations, is most normally the case. (Hartman and Mutmansky, 2002) A combination of surface and underground mining can be employed, to exploit the find in the most efficient manner (Ripley et al., 1996).

2.4.1 Surface mining operations

Surface mining operations offer higher productivity and produce more ore per mine than underground mining operations. It is easy to organize labour and equipment, lead times are short and it is relatively cheap to develop new finds into a functioning mine. Furthermore, the level of safety is higher compared with underground mines, as a result of which mineworkers naturally prefer this type of mine. (Aswathanarayana, 2003) The climate is of greater relevance to surface mining operations than to underground mines. Other factors to be considered when deciding whether to establish a surface mine are the nature of the terrain, the availability of water and the depth and shape of the ore body. When planning surface mining operations, care of the environment and a decision on the cost of resolving possible environmental challenges related to the find are further vital considerations. These environmental challenges may be the hostile climate, inaccessible terrain or the possibility that the area may be susceptible to various forms of natural disaster. (Hartman and Mutmansky, 2002) The two commonest methods employed in surface mining – open pit mining and leaching – are described below. Hydraulic mining is also described, since it can have a dramatic effect on the environment. For a more detailed description of different mining methods, please refer to Appendix A at the end of this Report.

- **Open-pit mining** – Open-pit mining involves removal of the overburden (topsoil and rock) above the find, freeing the ore for subsequent extraction. The method is capital intensive, making it appropriate for mechanisation and requiring a relatively small workforce. Productivity is high, cost relatively low, and the method does not incur the safety and health risks associated with an underground mine. The method is not applicable beyond a depth of approximately 1000 metres and, for commercial reasons, it is not feasible to mine finds with densities less than 0.8 - 0.4 cubic metres per ton. This type of mine is highly dependent on weather conditions: extreme weather can shut down mining operations completely. The extensive area involved in open-pit mining means that a very large area will subsequently be due for rehabilitation: it also creates a major waste-management challenge. (Hartman and Mutmansky, 2002) Fig. 2.3 shows a typical open-pit mine.

Fig. 2.3 The Aitik open-pit mine. Source: www.boliden.se

- **Leaching –** In leaching, water or a chemical solution is used to extract the minerals. A solution is injected into the ore through boreholes, to catalyse precipitation of the desired mineral. The dissolved ore is then pumped up and the required mineral extracted. The method can be applied direct to ores while still in the rock – ‘in situ leaching’ – or to ore that has been extracted by other methods and subsequently crushed and ground. The advantages of this method are that the cost is low, it requires a minimal workforce, can be applied to relatively small finds and can function as a complement to other mining operations. The method is also advantageous from the health and safety viewpoint. The great disadvantage is the considerable space requirement for disposal and stockpiling of leaching waste. These huge volumes of waste can also endanger plants and birdlife, since they may retain chemical residues from the leaching process. It can be difficult to rehabilitate the site and there is a risk that the groundwater may be poisoned. (Hartman and Mutmansky, 2002) From an environmental perspective, it is of paramount importance that all solutions are recovered, to preclude any seepage. To ensure this result, readings must be taken to determine how much extra water is added in the form of rain, which must also be collected for purification. (Mining, Minerals and Sustainable Development, 2002).

- **Hydraulic method** – The hydraulic method is used to extract metals from a bank of ore by directing a high-pressure jet of water at it, blasting it into fragments. The water, sand, soil and sought-after metals are flushed into a channel, from which the metals are then washed out. This method can, for example, be used to extract gold, diamonds, titanium and platinum. The advantages of this method are its high productivity, relatively low cost, fairly basic equipment requirement and the fact that it can be operated by a limited number of workers. The drawbacks are its potentially major impact on the environment, unless stringent precautionary measures are implemented, the vast consumption of water and that fact that it can be difficult to regulate the way in which the bank is broken down. (Hartman and Mutmansky, 2002)

2.4.2 Underground mining operations

Underground mining operations are of secondary importance for the extraction of many minerals, given the advantages of open-pit mining in terms of mass production and low costs. However, many geologists believe that the majority of surface deposits have already been found, thereby enhancing the likely future importance of underground mines, where it will continue to be possible to extract a range of different types of metals and minerals. In an underground mine, extraction is possible year-round, 24 hours a day, irrespective of weather. The impact above ground is less than with surface mining, and less soil and rock have to be shifted. This in turn reduces the area of land that must be rehabilitated when the mine is closed, and means that less soil and rock risk pollution during mining operations. The factors that are most critical to the development of an underground mine are the ore itself, the proximity of groundwater, the stability of the rock and the relative change in temperature as mining operations penetrate deeper underground. This type of mine demands a more skilled workforce: it may also be more difficult to finance an underground mine, because of the greater safety risk. The development of an underground mine requires less excavation than an open-pit mine, but the demands made on the ventilation system are considerable, since a constant supply of fresh air is essential. (Hartman and Mutmansky, 2002)

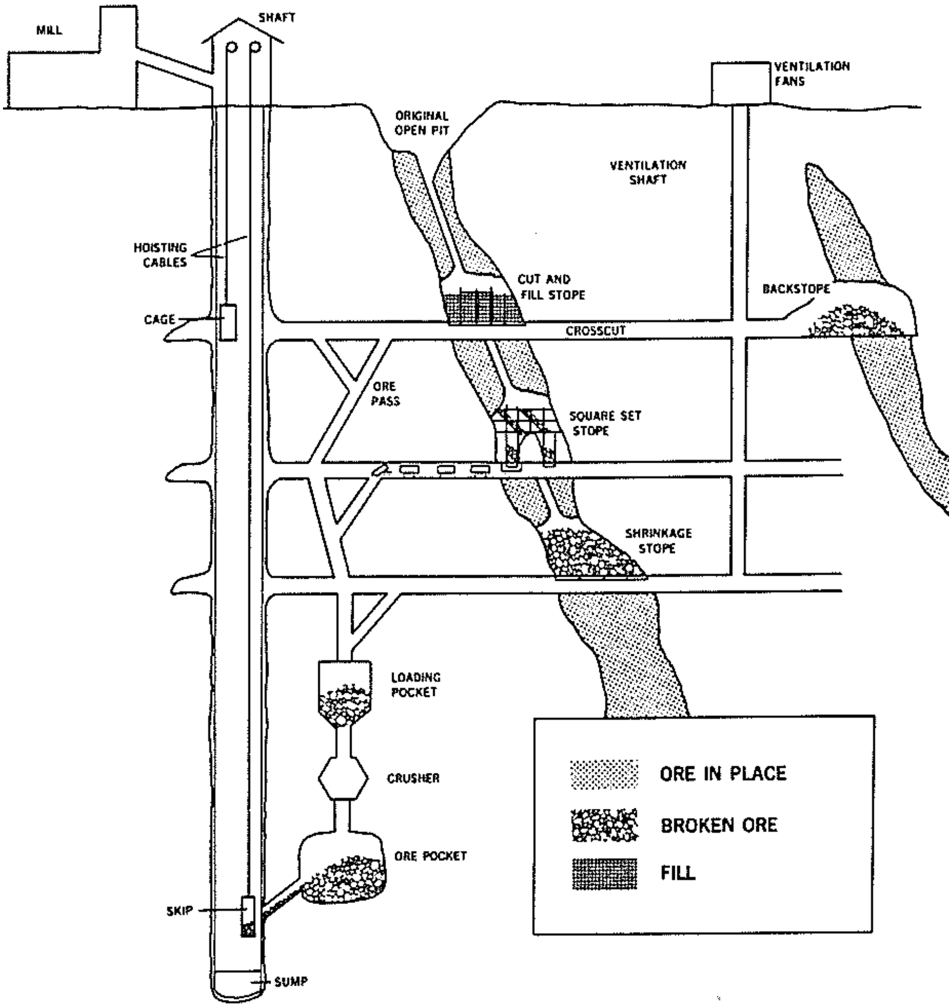


Fig. 2.4 Underground mine, featuring different mining methods. Source: Ripley et al., 1996

Underground mining operations mean that the ore must be extracted below ground and transported to the surface by a system of ramps and shafts. To reach the ore, tunnels must be dug into the gangue. In environmental terms, underground mining can be placed under two categories: with or without backfill. Backfill refers to the refilling of shafts and tunnels with mine waste. The decision whether to use backfill or not depends on the strength and shape of the ore body and the cost of refilling. If the type of rock surrounding the ore is very porous, backfill must be used to prevent rock falls and subsidence. Backfill consists of overburden, gangue or tailings from the enrichment process, in the form of a paste or slurry, and reduces the amount of waste that must be handled in some other way. (Ripley et al., 1996) Fig. 2.4 shows a schematic drawing of an underground mine, where different mining methods are used for different crosscuts. The drawing also shows how the ore is transported to the surface via ramps and shafts. Appendix A provides a more detailed description of three different mining methods that do not employ backfill, one method that does, and three different caving methods.

2.4.3 Potential environmental impact of exploitation

Industrial-scale mining operations can have an adverse impact on the terrain, air and water, while changes to the ecosystem can have an adverse impact on biodiversity. A brief description of the effect mining operations can have on these different areas, as well as the damaging nature of noise and vibration (also defined as environmental impact), is given below.

Terrain – Industrial-scale mining operations have a major impact on local terrain. Open-pit mines produce a radical alteration of the landscape: forests are felled, large quantities of waste are generated and great swathes of land are used as waste-disposal sites. The removal of vegetation, alterations affecting the flow of water, the creation of steep gradients and the extraction process itself all increase the risk of erosion. It is often difficult to fully restore the landscape once open-pit operations have been completed. The material removed to access the ore in open-pit mining is often stockpiled to facilitate restoration of the site once mining operations have terminated. Even so, it may take decades, or even hundreds of years, before the soil recovers the properties it possessed prior to the start of mining operations. The overburden removed to expose the ore results in physical and chemical disturbance to the natural system, which can affect the water. If sulphides are present in the extracted ore, there is a risk that this may trigger decomposition of the waste material, which can lead to acidification and heightened levels of trace metals in the local environment. Underground mines and, in some cases 'in situ' leaching, can cause subsidence. The scale of subsidence is often related to the amount of material extracted, the bearing ability of the rock above the extracted ore and the depth at which it is extracted. (Marcus, 1997)

Air – Surface mines have a greater impact on air quality than underground mines (Ripley et al., 1996). Dust presents a problem in virtually all forms of mining operation. It is created primarily by the passage of trucks over unpaved roads, drilling and the stockpiling of ore. As much as five percent of the ore or concentrate stockpiled in heaps can vanish in the form of dust. More dust and particulates are dispersed from surface mining operations than underground mines. Dust can pollute air, water and land, which in turn can have deleterious effects on vegetation and animal life. The inhalation of some types of dust can produce health problems, such as silicosis. Extremely fine dust particles can cause explosions. Coal heaps, for example, can react with oxygen, to initiate spontaneous combustion. Dust dispersal reduces visibility, which can make miners' working conditions still more difficult, and can clog various types of equipment and filters. (Aswathanarayana, 2003)

The mining industry uses a lot of energy to transport ore, overburden and gangue by truck, or by hoist in underground mines. Other highly energy-intensive aspects of the mining industry include the cooling systems used for underground mines, compressed-air equipment and crushing equipment. The mining industry is thought to account for four to seven percent of global energy consumption, although there are considerable variations between the minerals extracted and the countries in which they are mined. Electrical power is one of several different energy sources used within the mining industry. In 1998, total consumption of electrical power by the mining industry in the OECD countries amounted to 104 000 gigawatt-hours, compared to the 89 000 gigawatt-hours consumed during the same period by all rail networks in the same region. The environmental impact of electrical energy depends on the way it is generated. Fossil fuels can be used to generate electricity or as a direct source of energy. Combustion of fossil fuels leads to emissions of greenhouse gases and, in all likelihood, climate change. (Mining, Minerals and Sustainable Development, 2002) For a more detailed consideration of climate change and other environmental problems, please refer to Appendix B.

The use of various forms of equipment and transportation causes emissions of environmentally harmful pollutants such as sulphuric oxides, nitric oxides, volatile organic compounds and carbon monoxide. These emissions lead to reduced visibility, acidification, smog, ground-level ozone, health problems and a decline in biodiversity. Lead, arsenic, cadmium and nickel, which can occur in the topsoil as a result of mining operations, can in some cases be dispersed into the air, although this is thought to be a limited problem. (Marcus, 1997)

Water – The extent to which surface and underground mines affect water quality is probably about equal (Ripley et al., 1996). Changes in the landscape lead to increased risk of erosion, which in turn can cause sedimentation in surface water. Fish and other forms of marine life are affected by sediment in that it increases the turbidity of the water, reducing the amount of sunlight that is able to penetrate, causing reduced visibility and a decline in photosynthetic activity. Lower photosynthetic activity means fewer algae, which are an important food source for many species. Sediment can also cover marine plant life, also reducing access to food. When covered in sediment, the oxygen/carbon dioxide conversion process that is vital to the survival of fish spawn is hindered. If the sediment also contains organic material, this further reduces oxygen levels, as oxygen is needed for the decomposition process. (Marcus, 1997)

Water that has come into contact with ore and mine waste, or that has been utilised for other processes, can pollute surface and groundwater with toxic elements, causing a decline in water quality. The most serious and pervasive environmental problem related to mining is the seepage of acidified leachate from tailings slurry, commonly referred to as acid drainage, or AD (2.6.6 Seepage of acidifying leachate and metals). (Marcus, 1997) Underground mines risk redirecting the natural flow of water, affecting the local hydrology by bringing together different watercourses that have previously been separate, or by increasing the volume of water, so that nearby rivers or dams dry out or overflow. Changes to watercourses can affect both surface and groundwater. (Miranda et al., World Resources Institute, 2003)

Biology – The impact of mining operations on vegetation varies greatly. If it proved possible to rehabilitate the area after mining operations have concluded, the impact on vegetation and biodiversity may be minimal. During mining operations, one of the most obvious visible consequences of open pit operations is the removal of vegetation. If this is not restored, it can lead to erosion, with the result that sediment and toxic waste end up in nearby watercourses, causing a decline in downstream water quality. Acidification, the increased incidence of trace metals, cyanide and other toxic emissions can undermine the revegetation of barren areas. In determining how mining operations impact on local biodiversity, the following aspects should be considered: physical damage, to what extent the various habitats have been damaged/fragmented, the number of wetlands and other important habitats destroyed, toxicity, the degree to which human activity has increased, alterations in hunting customs and methods, and the size of the barriers separating the different areas. (Marcus, 1997)

Noise and vibration – Mineworkers are subjected to high noise levels from drilling equipment, loaders and other types of transportation equipment, often for prolonged periods. This can lead to a temporary or permanent loss of hearing. Mining operations are associated with three different types of vibration: mechanical vibration, vibration generated by combustion, and aerodynamic vibration. Mineworkers who use manually-operated equipment are subjected to high vibration levels and can suffer from ailments in their hands, arms and shoulders, as well as from various forms of nerve damage. Noise and vibration from mining operations can also cause structural damage. For example, shockwaves from blasting operations can cause windows to crack and shatter. (Aswathanarayana, 2003) Table 2.1, on the following page, summarises the mining methods most commonly used for industrial-scale mining operations, and indicates the environmental benefits and drawbacks of these different methods.

Table 2.1 Environmental benefits and drawbacks of different mining methods. Source: Ripley et al., 1996.

Position	Method	Environmental benefits	Environmental drawbacks
Above ground	Open pit	Ease of access and lower risk than for underground mineworkers.	Radical alteration of the landscape, felling of forest, dust dispersal, atmospheric emissions and large volumes of waste. Risk of acid drainage and escape of trace metals from mine and tailings.
	Leaching	Reduction of gangue, tailings and deformation of the terrain compared to open-pit mining. Lower risk than for underground mineworkers.	Large quantities of leachate need to be managed, risking pollution of groundwater and subsidence.
Below ground	Methods not involving backfill	Less waste than open-pit mining.	Major risk of subsidence, acid drainage and release of trace metals from mine and tailings.
	Methods involving backfill	Less risk of subsidence and less waste to be stored at surface disposal sites than without backfill.	Risk of oxidation or combustion of backfill, which could lead to emissions. Risk of acid drainage and release of trace metals that could pollute watercourses. Can affect the natural flow of watercourses.

2.5 Enrichment

Nowadays, the concentrations of sought-after minerals in extracted ore are so low that most ores must be enriched. In most cases, this means increasing the concentration of the required mineral. Sometimes, however, the concentration in the ore is so high that all that is needed is to clean the ore from impurities. The enrichment method selected depends on the type of ore, the mix of minerals in the ore, which valuable minerals it contains and the method's impact on health and the environment. Normally, the first stage of the enrichment process involves pulverising the ore, by crushing and grinding it into fine particles, which are then subjected to a series of different processes to optimise the subsequent screening process. Gravimetric enrichment, flotation, magnetic separation, electrostatic separation and leaching are common techniques for enhancing the concentration of required minerals (see fig. 2.5.). Enrichment is often conducted close to the mine, because transportation of all the extracted ore would be very costly.

The product of the enrichment process can be sold direct to the market, or transported for further refining. The pulverised residue, often mixed with water to form a slurry, is known as tailings slurry. (Ripley et al., 1996)

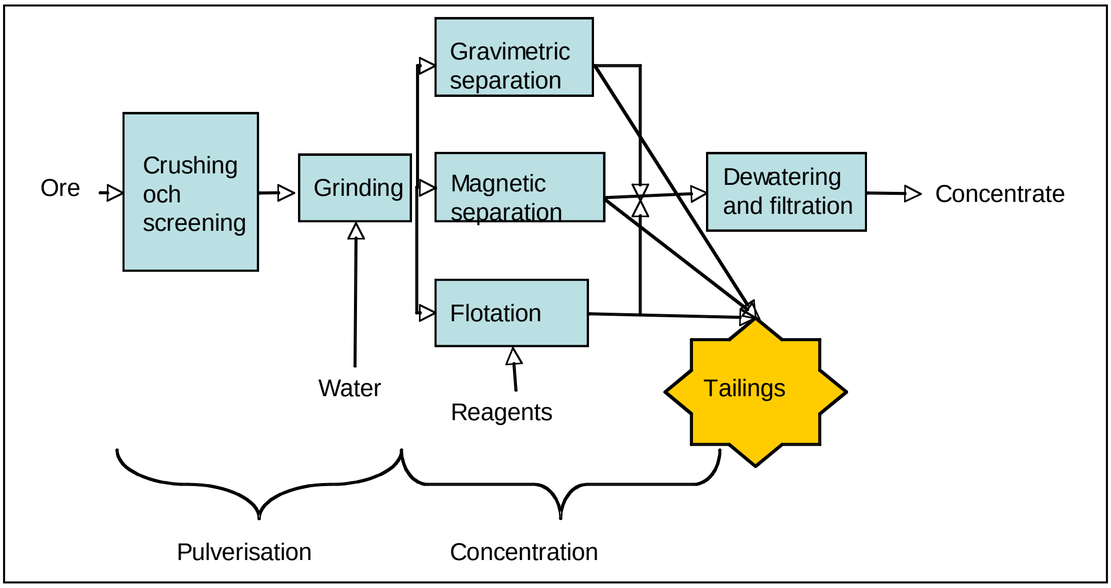


Fig. 2.5 Simplified diagram of enrichment processes. Source: Ripley et al., 1996

Crushing is normally a dry process, after which the ore is sorted according to size, known as screening. Once crushed, it progresses to grinding, which involves several stages. The ore is ground with some form of grinding medium, such as pebbles, steel balls or bars of some other material, or acts as its own medium. After grinding, it is classified by the size of the particles. This normally involves migration of the mineral ore particles through water, separation depending on speed of migration. Dry separation, in which air is the separating medium, is also used, often for coal. (European Commission Research Centre, 2004) Once the ore has been pulverised, it progresses to one of the following concentration processes:

• **Gravimetric enrichment** – Gravimetric enrichment is an old enrichment method, the minerals being separated in air or water due to their density, form and size. The method has largely been replaced by flotation, but is still employed for coal, industrial minerals and oxide minerals. (Ripley et al., 1996)

• **Flotation** – Flotation, which is the commonest form of enrichment for base metals, involves blowing air through a solution of minerals and flotation reagents. Different reagents are added to control the pH value, to produce foam and bind with the mineral in question. Non-soluble mineral particles are trapped by the air bubbles and can be skimmed off at the surface. Several flotation stages are normally required to achieve a correct concentration of the desired minerals. Flotation may also sometimes be used to extract water-soluble mineral particles, which sink to the bottom of the solution, from which they can be collected. The great advantage of flotation is that it demands relatively little energy. The disadvantage is that chemicals must be added to the process on a continuous basis, it requires skilled and qualified personnel, and it generates a considerable amount of solid waste. The fact that the process is relatively inexpensive has led to the development of many different flotation methods, such as electrochemical flotation (for the extraction of copper) and cation-silicon oxide flotation for magnetic extraction of iron. (Aswathanarayana, 2003

- **Magnetic separation** – In magnetic separation, magnetic minerals are separated from non-magnetic minerals using a magnet or electromagnet. The magnet used may be high or low intensive, based on the mineral's magnetic properties. The separation process can be in water or air. (European Commission Research Centre, 2004) This method is especially important for the enrichment of iron (Ripley et al.,1996).

- **Electrostatic separation** – In the case of electrostatic separation, the mineral to be separated is placed in a vessel with two electrodes, one positive and one negative. Charged or polar particles are attracted to the cathodes, while uncharged particles fall straight to the bottom. However, the method requires that the mineral is completely dry and control of atmospheric humidity. (European Commission Research Centre, 2004)

- **Leaching** – Leaching involves dissolving the minerals, either chemically or with microorganisms, after which the desired minerals are precipitated out. The method can be applied directly to small finds (where underground mining is uneconomical) or to waste and extracted ore that has been crushed and then placed on a suitable surface or in a tank. (Ayres et al., 2003) Bacterial leaching employs bacteria to extract valuable metals, such as gold and silver, or base metals. Bacterial leaching consumes a minimal amount of energy, is cost efficient and generates extremely limited emissions and amounts of waste. The predominant bacteria used for bacterial leaching is Thiobacillus Ferrooxidans (Aswathanarayana, 2003).

2.5.3 Potential environmental impact of enrichment

Many enrichment processes, such as grinding, cyanide leaching and flotation, are extremely energy-intensive. As noted earlier, fossil fuels constitute the primary energy source, generating greenhouse gas emissions and contributing to climate change. The declining concentrations of valuable metals in ores also further increases the amount of energy required for their extraction. The concentration of valuable metals is often higher in recycled material than in newly extracted ores, with energy consumption levels for extracting metals from recycled material often being considerably less than for the extraction of the original ore. (Mining, Minerals and Sustainable Development, 2002) Toxic chemicals, such as sulphuric acid and cyanide, are used both in chemical enrichment and flotation processes, which can create major pollution unless the flow of these materials is stringently controlled. Waste water from various enrichment processes often contains a high incidence of ore particles, waste material and chemical additives, suffocating marine life and bottom-dwelling creatures in local watercourses. (Ripley et al., 1996)

The enrichment process generates a large quantity of dust, which is dispersed throughout the surrounding area. This dust can be harmful to mineworkers and those living near the mine. Furthermore, certain dust particles can pollute local water and land and destroy the vegetation. (UNEP, 2000) Waste from this enrichment process – tailings slurry – creates the risk of acid drainage and the release of heavy metals into the local environment, which is the greatest environmental problem posed by the mining industry (se 2.6.6: *Seepage of acidifying leachate and metals)*. Table 2.2

summarises the environmental benefits and drawbacks of different enrichment methods.

Table 2.2 Environmental benefits and drawbacks of different enrichment methods. Source: Ripley et al., 1996.

Method	Environmental benefits	Environmental drawbacks
Gravimetric enrichment - dry	No reagents or process water.	Demands large airflows. Process air must be stringently controlled and cleaned.
Gravimetric enrichment - wet	No process air required and the medium can normally be recycled.	Use of a heavy medium can cause water pollution.
Flotation	Process water can be recycled.	The method requires large volumes of water and reagents, and the water often contains ore particles and heavy metals.
Magnetic and electrostatic separation	No reagents used, negligible water consumption with dry processes and the water for wet processes can be recycled.	Dry processes can disperse particles in the air, and wet processes in the water.
Leaching	Reduction in tailings.	Large quantities of leaching waste to be managed, groundwater pollution risk and land subsidence. Use of toxic elements such as cyanide.

2.6 Waste management

Mining operations generate large amounts of waste that must not only be managed and processed in parallel with the ongoing production process, but even after mining operations have concluded. The volume of waste generated by surface mines is much greater than from underground mines. Not all mine waste can be returned to the mine, however, whatever the mining technique employed. Because the extracted material absorbs water, and air is trapped between the ore particles, it swells. This waste must be managed over a very long time, imposing a considerable challenge, since some of the mine waste has a severely adverse impact on the environment, if it comes into contact with air and water. (Ayres et al., 2003)

There are a number of different types of waste:

- **Overburden and gangue** – Overburden is the rock that covers the ore and that must be moved to permit extraction and gangue is ore that contains levels of mineral that are too low to make extraction profitable.

- **Tailings slurry** – The slurry that is left once the minerals have been extracted during the enrichment process.

- **Leaching waste** – Bedrock, rock and soil that has been used in a leaching plant. (Mining, Minerals and Sustainable Development, 2002)

The most inexpensive alternative is to handle waste close to the mine, or to place the waste management site so that the waste can be conveyed there by gravity. The climate has a major influence on the way waste is managed. If the climate is dry, there is a risk of dust dispersal. In areas of where precipitation is heavy, there is risk of leaching, which can spread various toxic waste elements into the immediate surroundings. The following factors must also be considered when planning waste management: topography, hydrology, geology, risk of earthquakes, local communities, existing land use, protected areas and biodiversity. It is difficult for a company to acquire and analyse data on all these factors, which normally makes close collaboration with local government and the local community essential. (Mining, Minerals and Sustainable Development, 2002)

2.6.1 Land disposal

Mine waste is almost always stored on land. There are a number of different ways of doing this, as well as different methods for different types of mine waste. The method chosen depends on the physical and chemical properties of the minerals contained in the waste (European Commission Research Centre, 2004). In some cases, mine waste may be used as a construction material, as in road construction, but this must be approached with a certain amount of caution. It is also worth noting that the supply of mine waste is significantly greater than demand, which means that large quantities of mine waste still have to be dealt with, even though some of this waste may serve as construction material. (Mining, Minerals and Sustainable Development, 2002)

The overburden/gangue are broken up sufficiently to be transported to a disposal site or used as backfill in the mine. It is important that the waste is tightly packed (for stability), and that the flow of water in and around the waste is controlled, to prevent erosion. If there is too much or too little rainfall, this must normally be compensated for in some way, either to prevent the heap of waste from collapsing or to contain the spread of waste dust. In strictly physical terms, filling an open pit or underground mine with mine waste can provide a storage alternative. The obvious benefit of this method is the reduced space requirement for waste management. However, because mine waste swells, the original mine will be able to accommodate no more than about 60 percent of the total waste generated. Environmental problems can nevertheless arise during the temporary storage of mine waste, or when the waste is stored in an open pit. (Mining, Minerals and Sustainable Development, 2002)

Tailings slurry is normally at least 50 percent water and can therefore be transported via pipeline. As detailed in the next section, tailings slurry is often stored in tailings dams or held behind dikes. (Mining, Minerals and Sustainable Development, 2002) Tailings slurry of low water content can also be stored in heaps or used as backfill for mines or, in certain cases, be sold as a commercial product (European Commission Research Centre, 2004).

Leaching waste is rinsed to remove residual chemicals after leaching, although heightened levels of heavy metals or chemicals may remain even after the rinsing process has been completed. For this reason, the leaching waste facility must be designed to permit control of drainage and erosion and to prevent seepage. Leaching waste can then subsequently be stored in the same manner as overburden, gangue or tailings slurry (Mining, Minerals and Sustainable Development, 2002). An alternative approach is waste disposal, where overburden/gangue and tailings slurry are stored together. Using this approach, tailings slurry can be used to fill the space formed between the larger waste fragments. Consequently, the overburden/gangue comes less into contact with air and the risk of acid drainage is reduced. Furthermore, less land is needed for waste disposal, less water is used and the waste is more appropriate for agriculture. However, it is extremely important that the ratio between overburden/gangue and tailings slurry is correct. Too much tailings slurry and the waste becomes physically unstable. Too little tailings slurry, and air and water can penetrate the waste and cause acid drainage. (Mining, Minerals and Sustainable Development, 2002)

2.6.2 Tailings slurry in tailings dams

Tailings slurry and process water combine to form a sludge that can be transported via pipeline to a tailings dam, constructed of tailings slurry, other mine waste and stone or earth. The solid particles fall to the bottom and form sediment. This means that it is therefore often possible to drain off or recycle the process water. Tailings slurry contains residues from chemical treatments and heightened levels of heavy metals. There is a considerable risk that seepage from tailings slurry can pollute groundwater and watercourses. It is good if a lot of water can be recycled as early as the actual enrichment process, thereby reducing the amount of water in the tailings slurry and the risk of seepage. Given the fact that tailings slurry consists of very fine particles, there is also a substantial risk that it can be spread over a wide area in the form of dust. (Mining, Minerals and Sustainable Development, 2002)

Tailings dams are constructed to survive over a very long time. The definition of ‘a very long time’ can vary, of course. In theory, this may refer to a period stretching to the next ice age, at which point no current structures are expected to remain standing. Adopting a more scientific stance, ‘a very long time’ may be considered to involve thousands of years. When a tailings dam is planned, it is important to ensure that it is sited in an area of limited precipitation and that the dike is broad enough to prevent seepage and to enable monitoring of the permeability of the different elements in the bottom of the dam. (Bjelkevik, 2005)

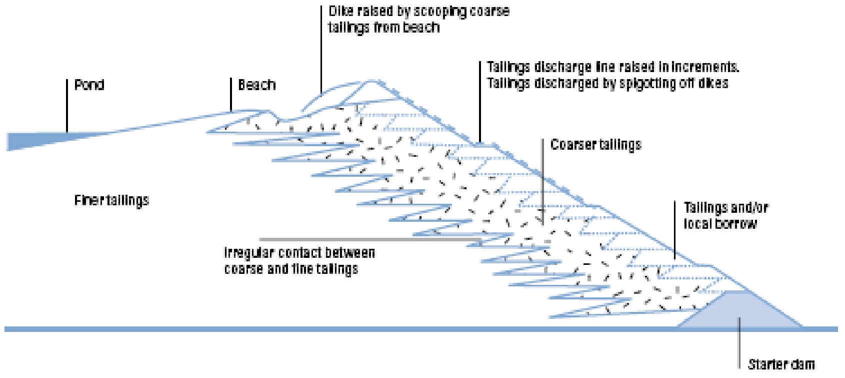
Generally speaking, there are three different types of tailings dam:

• **Upstream method** – When the upstream method is used, a starter dam is constructed, and tailings slurry is then discharged from its crest. The tailings slurry runs into the settling pond, and a beach is created between the pond and the crest of the dike, where the solid fraction settles. When the settling pond is almost full, a new dike is constructed on top of the first and more tailings slurry can be added to the pond (fig. 2.6). The benefits of this method are that it is relatively inexpensive and simple to manage, the dikes can be built out of tailings and the hydraulic gradient is low, because of the gradually shelving embankment. The drawbacks of this method are the need to monitor the hydraulic gradient, its poor ability to store water, its vulnerability to seismic activity and the difficulty of preventing dust from spreading in high winds. (Bjelkevik, 2005)

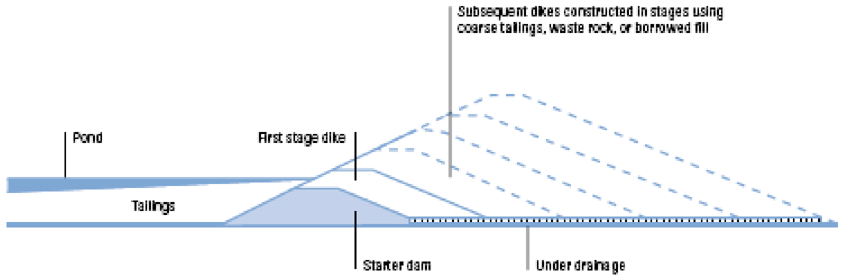
• **Downstream method** – the downstream method also involves construction of a starter dam. As tailings are discharged into the settling pond, the solid fraction is used to build on top of the starter dam (fig. 2.6). This type of tailings dam is reminiscent of traditional dams. The benefits of this method are that a large quantity of water can be stored in the pond, it is suitable for all types of tailings and it is more resistant to seismic activity. The drawback is the huge amount of material required to build the dam, which is very costly. (Bjelkevik, 2005)

• **Centreline method** – The centreline method refers to a type where the starter dam is built out both from the beach side and from the exterior embankment (fig. 2.6). This type of tailings dam is combination of the two types described above, exploiting the benefits and reducing the drawbacks of both. It requires less material than the downstream method, which reduces costs. Resistance to seismic activity is acceptable. All three are considered to offer a similar degree of safety, assuming that the necessary permits have been secured and that the conditions, behaviour and site-specific properties have been correctly determined for each specific dam. (Bjelkevik, 2005)

Upstream Method of Tailings Dam Construction



Downstream Method of Tailings Dam Construction



Centreline Method of Tailings Dam Construction

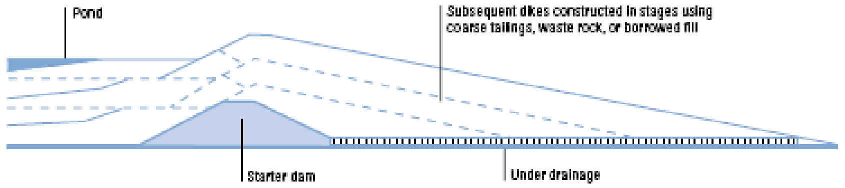


Fig. 2.6 Three different tailings dam models. Above: upstream method; middle: downstream method; below: centreline method. Source: Mining, Minerals and Sustainable Development, 2002.

2.6.3 Marine disposal

In certain cases, overburden, gangue or tailings can be discharged into the sea. Shallow-water disposal normally implies depths of between 30 and several hundred metres, while deep-sea tailings disposal involves depositing waste below the maximum depth of the surface mix layer. Tailings slurry is discharged into the sea from submerged pipelines. With deep-sea disposal, waste is pumped continuously from pipelines at a predetermined depth, continuing its descent until eventually settling on the sea floor. The advantage of deep-sea disposal is that it protects the waste from bacterial attack, and from reacting with oxygen, which can lead to the dispersal of acidified leachate and heavy metals. Even so, this type of disposal can have a severe impact on the environment. The most dramatic environmental consequences appear to stem from shoreline or shallow-water discharge of waste rock or tailings into the sea. In such cases, waste is discharged into the zone of highest biological productivity, having a correspondingly severe impact on the environment. The waste increases water turbidity and smothers the organisms that live on the seabed. The sediment may also get washed up on the shore. (Mining, Minerals and Sustainable Development, 2002)

With deep-sea disposal, the waste is expected to stay where deposited, and not rise to the surface again. Opinions differ, however. Some industry studies suggest that the risks are minimal and that within several years of closure the sea floor can be recolonized by benthic fauna. Other research suggests that deep-sea ecosystems might be more complex and biodiverse than comparable terrestrial fauna. It seems that relatively little is known about deep-sea ecosystems and the interaction among marine species at these depths. In some circumstances, deep-sea marine disposal might be an option deserving serious consideration – as when the mineral deposits are on islands that have little spare land, when available space is at risk of flooding, or when the stability of land disposal facilities is uncertain because of high rainfall or seismicity. (Mining, Minerals and Sustainable Development, 2002)

2.6.4 Riverine disposal

Riverine disposal of mine waste involves the discharge of overburden, gangue or tailings straight into a river. The method has been used since time immemorial, the main advantage being that it is cheap and convenient. The method, which is known to have a whole range of adverse environmental effects however, is currently employed by only three international mining corporations, with operations in Indonesia and Papua New Guinea, by many small-scale and artisanal miners around the world, by a number of small or medium companies, and at an unknown number of sites in Russia and China. In Papua New Guinea, the government accepted this option because the only alternative was no mine at all. (Mining, Minerals and Sustainable Development, 2002)

Riverine disposal affects the flora, fauna and physical character of rivers. Effects include increased risk of flooding, resulting in the die-back of vegetation and damage to the aquatic ecosystems, as well as risking an increase in the incidence of diseases like malaria. This naturally impacts on the potential to cultivate land near the river, or to fish it. Discharged waste also elevates the levels of different minerals and metals in the water. (Mining, Minerals and Sustainable Development, 2002) The 70 million tons of tailings and gangue released into the Ok Tedi River on Papua New Guinea, over a period of two decades, provides a classic example of just how devastating this type of waste storage can be. The release of all this waste into the river has led to the die-back of 2 000 square kilometres of forest, a 70-90 percent decline in fish stocks and has adversely affected 50 000 inhabitants in 120 villages (Miranda et al., World Resources Institute, 2003). In its 2002 report, '*Breaking New Ground,* Mining, Minerals and Sustainable Development writes that both governments and industry feel that this mine waste storage method should be avoided.

2.6.5 Potential environmental impact of waste management

Waste management and its potential environmental impact varies according to the type of waste and is influenced by the complex relationships between chemical, physical, biological and mechanical processes (Fröberg and Höglund, 2004). To be able to make a correct assessment of how waste may best be managed, the nature of such waste must be determined individually, for each mine. The environmental impact of waste management may derive from deficiencies in the operations process or from accidents. The greatest potential environmental hazard posed by the mining industry in general, and the waste management process in particular, is seepage of acidifying leachate and a rise in the incidence of heavy metals, collectively more commonly referred to as 'acid drainage'(see next section).

Waste management lays claim to huge areas of land, which can impact the habitat of different species and affect biodiversity (Aswathanarayana, 2003). Building or moving heaps of waste can contaminate land and water. Heaps of tailings and their transportation to the storage facility can generate dust and noise. Reagents from the enrichment process, such as cyanide, chloride, acids and bases, which are present in tailings, can migrate into local watercourses. The actual scale of the impact this type of seepage has on the environment naturally depends on the nature of the seeping elements. However, it also depends on the pH levels of water and land, the temperature and the hardness of the water. (European Commission Research Centre, 2004) Tailings that find their way into watercourses can also lead to sedimentation, changes in the flow of watercourses, increased turbidity and the smothering of organisms, due to increased particulate levels in the water. (Aswathanarayana, 2003)

Accidents involving the failure or collapse of tailings dams can cause considerable damage to the environment. Tailings dams can vary in size from several million cubic metres to something no bigger than a swimming pool. If it fails, there is a risk that the greater part of a dam's contents will run out and contaminate both land and water. More than one major tailings dam disaster occurs every year. The most common causes are a failure to monitor the water balance and dam structure efficiently, as well as a lack of understanding about what is meant by 'safe processes'. A tailings-dam failure can in the short term lead to flooding, the smothering of plants and animals in tailings slurry, the destruction of terrain and infrastructure and general contamination. In the long term, the results of a dam failure can cause levels of heavy metals to accumulate in plants and animals, as well as contaminating the landscape and reducing biological diversity. (European Commission Research Centre, 2004)

2.6.6 Seepage of acidifying leachate and metals

A serious environmental problem associated with waste management is the seepage of acidifying leachate and heavy metals from sulphidic ores, more commonly referred to as 'acid rock drainage'. The problem arises when the sulphide ions in sulphidic ores react to air and water. These reactions also occur quite naturally, but the extraction and decomposition of sulphidic ore dramatically increases the volume of sulphide ions exposed to air. The reaction can also be catalysed by the *Thiobacillus ferrooxidans* bacteria (Marcus, 1997). Two problems arise when this decomposition reaction begins. The first is the formation of sulphuric acid, which possesses a low pH value and can cause acidification; the second is sulphuric acid's considerable talent for releasing metal ions, such as zinc, cadmium, iron, copper, aluminium and lead.

Once this decomposition process has started, it is difficult to stop: the environmental consequences can therefore be extensive and lasting. The combination of low pH and dissolved metal ions kills all marine life and makes the water unfit for human consumption. (Mining, Minerals and Sustainable Development, 2002) For a more detailed description of acidification and other environmental problems, please turn to Appendix B. Table 2.3 provides examples of how enhanced incidences of heavy metals can affect health and the environment.

Table 2.3 Health and environmental effects of the enhanced incidence of heavy metals. Source: Ripley et al., 1996; European Commission Research Centre, 2004.

Material	**Effect on health**	**Environmental effects**
Arsenic	Cancer	Highly toxic, even fatal, can accumulate in nature.
Lead	Brain damage, convulsions, behaviour disorders, death, children especially susceptible to lead poisoning.	Toxic to humans and livestock, accumulates in the body.
Cadmium	Heart and vascular disorders, high blood pressure, brittleness of the bones, kidney disease, fibrosis of the lung, probably cancer.	Slows growth of certain plants, accumulates in tissue and plants. Humans can be poisoned by eating fish with enhanced levels of cadmium.
Copper	Nausea, liver damage	Toxic to fish and other marine life, even at low concentrations.
Mercury	Nerve damage, death	Highly toxic, causing damage to the nervous systems of many organisms.
Manganese	Can affect the taste of water and discolour washing.	Toxic to animals in high concentrations.
Nickel	Allergies, lung cancer	-
Zinc	Non-toxic, can affect the taste of water.	Toxic to certain plants and fish.

Seepage of acidifying leachate and heavy metals in nature can be avoided by preventing tailings from coming into contact with air. In the tailings pond, tailings are covered by water, reducing the rate of decomposition to a controllable level. During rehabilitation of a mine, continued coverage by water or boulder clay can be used to prevent tailings coming into contact with air. (Fröberg and Höglund, 2004) The buffering effect of the surrounding terrain determines the impact such acid drainage has on the environment. (Mining, Minerals and Sustainable Development, 2002)

Even if the tailings do not come into contact with air, the decomposition process can begin if the dam fails and tailings slurry runs out. Since the mid-1970s, tailings dam failures have accounted for 75 percent of all major environmental accidents caused by the mining industry. The risk of tailings dam failures does not cease simply because mining operations have terminated. If the tailings dam possesses construction or design weaknesses, an earthquake, rain or flooding can cause failures even long after mining operations have been completed. (Mining, Minerals and Sustainable Development, 2002) Dam failures caused by seismic activity tend to be associated with the upstream method, rather than the downstream centreline method (Miranda et al., World Resources Institute, 2003).

It is not easy to monitor the quality of tailings dams, given that they are built over a long period, and often of the tailings themselves. The fact that a tailings dam is used over a long period means that there are many changes of operating personnel, as well as the fact that the composition of the tailings themselves can change, if new finds are exploited. It is not uncommon that those responsible for managing the tailings dam are unaware of what the correct levels for the readings they are supposed to monitor should be. (Mining, Minerals and Sustainable Development, 2002) The Mining, Minerals and Sustainable Development (2002) report considers that the best way to manage safety at a tailings dam is to implement monitoring functions at three distinct levels. The first and most important level at which monitoring should be implemented is internally, within the company itself. It is vital to ensure that the best methods and techniques are used right from the start, when the facility is designed and constructed. Monitoring should also be conducted at a second but higher level within the company, possibly in the form of a geotechnical committee. The third monitoring function should be external, involving the government, the local communities and insurance companies.

2.7 Rehabilitation

Some ore bodies provide enough for five years of mining, others for fifty. New technology and rising raw material prices can extend a mine’s normal operating ‘life’, but all ore bodies run out in the end and mines, process facilities and tailings dams have to be managed to preclude future environmental problems (Ripley et al., 1996). The mine itself must be refilled and sealed but, in some cases, former mines can find new uses – such as secure storage facilities or as sites for cultivating mushrooms (Aswathanarayana, 2003). Buildings have to be demolished, waste stored or recycled, dangerous areas have to be fenced in and, finally, emissions have to be monitored. (Mining, Minerals and Sustainable Development, 2002)

The greatest impact on the environment arises when waste containing metal sulphides comes into contact with the air and starts to oxidize. To prevent this from happening, sulphide-rich mine waste must be insulated from the air by covering it with water or boulder clay. This must produce a degree of stability high enough to ensure that it will hold for a very long time. Rehabilitation of mine waste can be managed both actively and passively. Active rehabilitation normally involves the ongoing addition of lime to the waste. It is both expensive and difficult to maintain over the long term, but initially or in the event of acute emergencies it may be necessary and can function as a complement to passive rehabilitation. Passive rehabilitation means insulating the waste from the air by covering it with clay or water. The waste can be covered by water even during normal mine operations, and the storage facility can be filled with more waste. The idea is that the contents of the tailings dam, the tailings storage pond, can in the long term be developed into a lake or wetlands. The two key factors to be addressed are to secure the water balance in the long-term (i.e. the waste must always be covered by water) and to ensure that the dam’s construction is stable, unless natural wetlands or a natural lake are used. Clay coverage means that the tailings pond is drained of water and the tailings sediment is covered in several layers of clay of varying coarseness. It is important to maintain a high level of saturation, to prevent air from reacting with the waste and to promote growth of vegetation, to combat erosion. Coverage by water is often the most cost efficient alternative. There are also many variants that involve a combination of clay and water. (Fröberg and Höglund, 2004)

Irrespective of whether mine waste is covered with water or clay, it is desirable to ensure that the area is covered by vegetation again, to stabilize the ground, prevent the formation of more acid and to reduce water flow-through. Reestablishing vegetation can be a complex process, and may require several lime treatments to neutralize the pH-level of the surface soil. Even after vegetation has been established, this is no guarantee against acid drainage. It is therefore important to continue to take readings and monitor the area, even after vegetation has been re-established. (Ripley et al., 1996)

There are two ways to reduce the eventual need of rehabilitation. One way is to attempt to minimize the amount of waste generated during mining operations, reducing the quantities that have to be dealt with on closure. This can however be difficult to achieve as the levels of mineral deposits in the find fall. The other method is to separate reactive waste from harmless waste, cutting the amount of waste that requires expensive processing. (Fröberg and Höglund, 2004)

If the rehabilitation of the mine is to be a success, a plan is needed early on, when the mine is being developed, that embraces a vision of the final result. This vision of the final result should feature concrete objectives and a timetable, providing a blueprint as to how the various mine operations should be directed during its life cycle. These objectives should address both physical and socioeconomic factors concerning the rehabilitation of the entire mine site. This plan shall clearly demonstrate that the closure of the mine will pose no risk to public health and safety, that the environment will not be subjected to the dangers of physical or chemical decomposition, and that the rehabilitated site will be restored to a healthy state, enabling its use in the long term. (Mining, Minerals and Sustainable Development, 2002)

The closure of a mine is a costly business. For example, it involves the cost of meeting the demands of former mineworkers, the cost of actual closure of the mine and the cost of the activities that must be continued after the mine has been closed, such as the post-treatment of mine waste. Unless the mine closure is thoroughly planned, there is a risk that the costs will be unnecessarily inflated, dramatically reducing state revenues and potentially leading to a local recession. There are plenty of examples of mines that continue to operate, although no longer profitable, simply to avoid causing major unemployment and the inevitable political fallout.

These mines often receive state grants to keep them going. Hopes of rising raw material prices, audit pressures and expectations of being able to reverse an already negative trend can also keep operations afloat, even when the mining company is no longer profitable. Previously, many mines kept the timing of their planned closure secret, considering it to be confidential. It is now becoming increasingly common for companies to make this date public, so that the government, the local community and various organizations will be able to plan accordingly and thereby facilitate the closure process. (Mining, Minerals and Sustainable Development, 2002)

2.7.1 Potential environmental impact of rehabilitation

Sooner or later, acidifying leachate will seep from the waste storage facility. This is because of the large quantity of waste and the difficulty of controlling the flow of water through the waste, irrespective of rehabilitation method. The degree to which this acid drainage impacts on the immediate environment depends on the volume and rate of seepage and the buffering qualities of the surrounding area. (Fröberg and Höglund, 2004) To minimize the long-term environmental impact of a waste storage facility, it is important to ensure that the facility is constructed to withstand the actual physical, chemical and biological stresses to which it is and will be subjected, as well extreme events such as earthquakes, landslides, torrential rainfall and drought. The extent to which climate change impacts on waste storage facilities is relatively unknown, but could well prove to be highly significant. (European Commission Research Centre, 2004)

2.8 Summary of mine life cycle and environmental impact

Table 2.4 summarizes the processes and potential environmental impact of each phase of the mine cycle, and for waste management. It also presents a broad timetable and cost evaluation, to prove a perspective on these different phases.

Table 2.4 Summary of mine life cycle and environmental impact of each phase. Source of timetable and costs: Hartman and Mutmansky, 2002. Source of environmental impact data: Miranda et al., World Resources Institute, 2003, * Cost data missing since this phase is not included in Hartman and Mutmansky's table (2002).

Mine life cycle	Process	Potential impact on environment	Time	Cost
		Prior to exploration		
Prospec-ting	Search for ore a) Locate suitable site b) Aerial surveys c) Terrestrial surveys d) Analysis and evaluation of site anomalies	• Undisturbed areas exploited and roads built, which facilitates in-migration • Disturbance of local communities/indigenous population • Destruction or fragmentation of habitat for different species • Hunting and fishing lead to extinction of some species • Risk of waste and fuel leaks	1-3 years	USD 0.20 - 10 m or USD 0.05 - 1/ton
Explora-tion	Determine scope and value of ore a) Test drilling b) Determine number of tons and quality c) Evaluate find d) Feasibility study and decision whether to abandon or develop	• Undisturbed areas exploited and roads built, which facilitates in-migration • Disturbance of local communities/indigenous population • Destruction or fragmentation of habitat for different species • Hunting and fishing lead to extinction of some species	2-5 years	USD 1 - 15 m or USD 0.20 - 1.50/ ton

		• Risk of waste and fuel leaks		
Mine operation				
Develop-ment	Open find for production: a) Secure rights to mine the find b) Organize Environmental Impact Assessment (EIA), technological analysis and permits c) Construct roads and transportation system d) Siting of service facilities e) Excavate soil and rock to expose the find to extraction	• Area increasingly populated in pace with growth in number of roads and establishment of larger communities • Disturbance of local communities/indigenous population • Increased demand for water and electricity • Terrain is changed and deforested • Generation of mine waste • Dispersal of dust and particles • Subsidence and altered water flows • Chemical pollutants contaminate surface and groundwater • Reduction in biodiversity and of specific species	2-5 years	USD 10 - 500 m or USD 0.25 -10.00/ ton
Exploita-tion	Industrial scale production a) Surface or under-ground mining operations b) Monitoring of costs and return on investment	• Altered landscape • Generation of mine waste • Subsidence and altered water flows • High energy consumption leads to emission of greenhouse gases that cause climate change • Environmentally harmful chemicals pollute air and water • Terrestrial and aquatic organisms affected by toxic pollutants • Dispersal of dust • Noise and vibration	10-30 years	USD 5 - 75 m or USD 2.00 - 150/ton
Enrich-ment	Enrichment of extracted ore to form concentrate (parallel with extraction of ore) a) Pulverizing b) Concentration	• High energy consumption leads to emission of greenhouse gases that cause climate change • Environmentally harmful chemicals pollute surface	10-30 years	*

		water • Generation of tailings • Dispersal of dust		
Waste manage-ment	Different types of waste from different processes a) Overburden/Gangue b) Tailings c) Leachate	• Acid drainage and heightened levels of heavy metals, reducing water quality and creating toxic pollutants that affect terrestrial and aquatic organisms • Sedimentation, changes to water flows and increased turbidity, which can cause organisms to be smothered • Biodiversity and the decline of certain species • Dispersal of dust	10-30 years	*
On termination of mining operations				
Rehabi-litation	Restoration of mine area a) Disassembly of mining facility and other buildings and restoration of vegetation b) Waste storage and recycling c) Fencing in of hazardous areas d) Monitoring of emissions	• Acid drainage and heightened levels of heavy metals, reducing water quality and creating toxic pollutants that affect terrestrial and aquatic organisms • Earthquakes, landslides and other extreme events can cause otherwise stable waste storage facilities to fail • Impact on biodiversity	1-10 years	USD 1 - 20 m or USD 0.20 - 4.40/ ton

3 Production and environmental impact of minerals

A mineral is a natural element, alloy or other chemical compound, with a specific chemical composition and crystal structure. A mineral comprises one or more elements and rock, in its turn, consists of one or more minerals. There are some 4 400 known minerals, most of which are extremely rare. Compounds of silicon and oxygen, known as silicates, are the most common minerals. (Swedish Museum of Natural History, 2008) About 99 percent of the Earth's crust consists of eight different elements: 47 percent oxygen, 20 percent silicon, eight percent aluminium, four percent iron and smaller quantities of calcium, sodium, magnesium and potassium. The remaining one percent comprises approximately 90 different elements. Coal, iron, quartz, silicon oxide and limestone are relatively evenly distributed in geographical terms. Other minerals are concentrated in specific locations. (Mining, Minerals and Sustainable Development, 2002)

This chapter provides a brief description of extraction, enrichment and the potential environmental impact of the minerals addressed in the Report. It is difficult, however, to generalise about production processes and environmental impact for different minerals. These are to a large extent determined by local factors, such as geography, the natural environment and the specific characteristics of the find. Table 3.1 presents the approximate global output, price and turnover of the respective minerals and metals. Please note that it is difficult to provide precise and directly comparable figures. Table 3.2 presents a brief review of the application areas for the respective minerals included in the Report.

Table 3.1 Global output and market prices during 2006. Source: Raw Material Group 2006, *Source: Wikipedia c, 2008 (data for 2007), ** Source: USGS, 2008, *** Source: http://www.lme.co.uk/led.asp, 2007 **** Source: Geological Survey of Sweden, 2003.

Mineral	Global output 2006 (thousands of tons)	Approx. price 2006 (USD/ton)	Sales 2006 (USD million)
Coal	6 200 000	100	620 000
Copper	17 400	6 700	116 580
Iron	1 475 000	60	88 500
Aluminium	33 700	2 600	87 620
Gold	2,47	20 000 000	49 400
Nickel	1 500	24 000	36 000
Zinc	10 300	3 300	33 990
Molybdenum	178	65 000*	11 570
Lead	3550**	3100***	11005
Platinum	0,22	37 000 000	8 288
Uranium	36****	80000****	2 880

Table 3.2 The list of applications for which minerals are used is almost endless. The aerospace, automotive and electronics industries, the generation and transmission of power and the largest construction projects are just some key applications. Below is a presentation of the most common applications for the minerals in question.

Mineral	**Application**
Aluminium	Aluminium is used in the production of aerospace components, automotive components, building components, railcars, boats and ships, packaging and electronics, as well as within the pharmaceuticals and water treatment industries. (Mining, Minerals and Sustainable Development, 2002)
Lead	Applications for lead include batteries, lead crystals, cable insulation, petrol, ammunition, solder and as a shield when welding or working with radiation. (Mining, Minerals and Sustainable Development, 2002)
Gold	Gold is used for decoration, in electronics, dentistry, coins, to guild jewellery, watch chains, pens, spectacle arms, bathroom fittings and in the decoration of porcelain and glass. (Mining, Minerals and Sustainable Development, 2002)
ron and steel	Iron is used mainly in the production of steel and alloys. Steel is used in the construction of buildings (metal sheet roofing, steel girders, reinforcement rods, mounting brackets) and vehicles (cars, trucks, trains), as well as bridges and railtracks. Steel is also used for manufacturing machinery, tools, jewellery and a range of industrial applications including rollers, pipes, spigots and drill bits. Steel is also used in the pharmaceuticals industry, as in the manufacture of medical instruments and implants, such as artificial hip s. Steel is also found in countless everyday objects, from scissors and paperclips to computers and fire escapes. (Jernkontoret, 2008)
Coal	Coal is used mostly for generating electricity (mainly lignite/brown coal), but also for the production of steel (pit coal), the manufacture of chemicals, the production of liquid fuels, plastics and polymers. (Mining, Minerals and Sustainable Development, 2002)
Copper	Copper is used in the construction industry, for aerospace components and automotive components, as well as for industrial applications and equipment. Copper is an excellent conductor, used for conducting electricity and in piping. Copper is also used in furniture, coins, boats, clothing, jewellery, works of art, musical instruments and kitchen fittings. (Mining, Minerals and Sustainable

	Development, 2002)
Molybdenum	Molybdenum can be used in alloys, thermal elements, lubricating oils, missiles, aircraft components and for a number of electrical applications. Molybdenum also has a number of applications in the nuclear power industry, and functions as a catalyst in the oil refining process. (Mining, Minerals and Sustainable Development, 2002)
Nickel	Nickel is used in the production of stainless steel, corrosion resistant alloys, gas turbines, rocket engines, coins, batteries, electroplating. It is also used as a catalyst and in the manufacture of burglar-proof vaults. (Mining, Minerals and Sustainable Development, 2002)
Platinum	Platinum is used in jewellery, coins, vehicle catalysers, electronics, glass, dentistry, chemicals, electrochemicals, oil, laboratory equipment and cancer medications. (Mining, Minerals and Sustainable Development, 2002)
Uranium	Uranium is used as fuel in nuclear power plants, in X-ray equipment and in nuclear weapons. (Mining, Minerals and Sustainable Development, 2002)
Zinc	Zinc is used in electroplating and alloys such as brass, which contains zinc, copper, lead and tin. The metal is also used in batteries, water treatment, coins, paint manufacture, cosmetics, flooring and roofing, plastics, detergents, textiles and electronics. (Mining, Minerals and Sustainable Development, 2002)

3.1 Aluminium

Aluminium, denoted by the chemical symbol ‘Al’, is a light, formable metal that possesses good electrical and thermal conductivity. Aluminium resists corrosion due to the formation of a thin layer of alumina on its surface, thereby preventing further corrosion. Although the third most abundant element in the Earth’s crust, aluminium is seldom found in its pure state, but in combination with other minerals, most often bauxite. The metal has no known function in living cells, but can cause a number of physical disorders. WHO recommends that water sources should contain no more than 0.2 milligrams of aluminium per litre. Although extracted for commercial use for no more than about the past 100 years, aluminium and a range of aluminium alloys are now widely used. (International Aluminium Institute, 2008)

3.1.1 Where is aluminium produced?

Brazil, Australia, Jamaica and Guinea account for the world’s largest production of bauxite. Production in North America, Europe and Africa is relatively limited. The smelting plants for extracting alumina from bauxite are either in countries with access to large quantities of cheap electricity or where there is major demand for aluminium.

For these reasons, bauxite and alumina are both traded internationally. (Mining, Minerals and Sustainable Development, 2002) China is the largest aluminium producer in the world, followed by South Africa, New Zealand, Australia, the Middle East, Russia, Canada and Iceland: see fig. 3.1 (Wikipedia a, 2008).

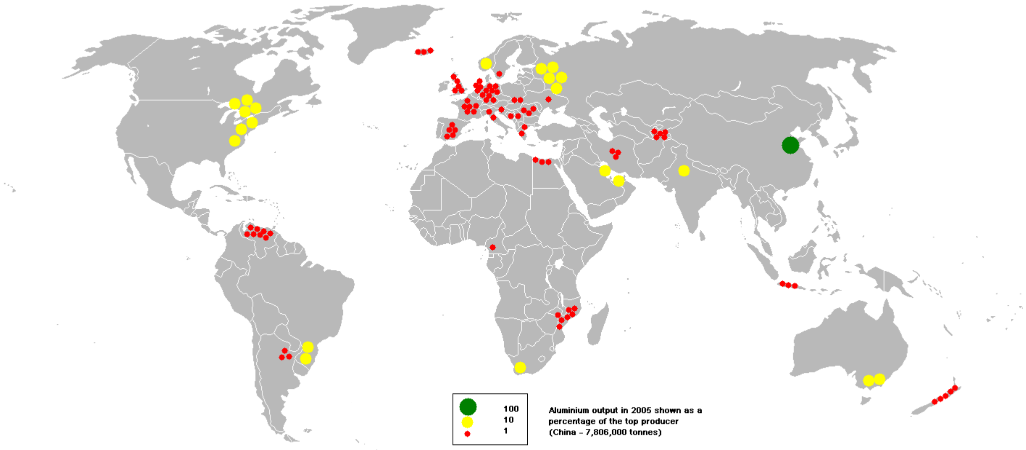


Fig. 3.1 Aluminium output in 2005. Source: http://en.wikipedia.org/wiki/Aluminium

3.1.2 How is aluminium produced?

Aluminium is extracted from bauxite, the collective term for several types of ore rich in alumina trihydrate, commonly referred to as alumina (International Aluminium Institute, 2008). Bauxite deposits are normally close to the surface, which is why some 80 percent of aluminium is extracted from open pit mines (Aswathanarayana, 2003; International Aluminium Institute, 2008). Bauxite often has a 50 - 65 percent alumina content, which translates into a metal content of about 25 – 30 percent. Alumina can also be found in other ores, but at present nothing can compete with bauxite. (Aluminiumriket Sverige, 2008) Unlike the base metal ores, bauxite does not require complex processing, because most of the bauxite mined is of an acceptable grade (International Aluminium Institute, 2008).

Alumina is extracted from bauxite using the Bayer process. The extracted ore is washed, crushed and dissolved in caustic soda (sodium hydroxide) in a digester. Pressure, temperature and caustic soda concentration is optimised for extracting the metal. The resulting liquor contains a solution of sodium aluminate and undissolved bauxite residues, known colloquially as red mud, which sink gradually to the bottom of the tank and are removed. Fine particles of alumina are added to seed the precipitation of pure alumina particles as the liquor cools. The particles sink to the bottom of the tank, are removed, and are then passed through a rotary or fluidised calciner at high temperature to drive off the chemically combined water. The result is a white powder, pure alumina. (International Aluminium Institute, 2008)

3.1.3 Environmental impact of aluminium production

The greatest environmental problem associated with the extraction of aluminium is the ‘red mud’ generated when aluminium is extracted from bauxite. This red mud contains aluminas, iron, titanium, silicon and traces of elements such as vanadium and gallium. On average, two tons of red mud is generated for every ton of alumina extracted. Studies have shown that iron, titanium and alum could be extracted from this red mud.

Furthermore, the rising price and use of vanadium and gallium indicate that it might be profitable to extract these elements. The red mud can be stored in dams, although this creates other problems: these dams take up a lot of space; they generate large quantities of dust when they dry out, and flooding and seepage can contaminate watercourses and groundwater. Some companies choose to dry the red mud and then store it in this form in heaps. (Aswathanarayana, 2003)

The production of aluminium consumes extremely large amounts energy, as well as generating greenhouse gas emissions equivalent to one percent of the total anthropogenic emission of such gases. These emissions are in turn likely to contribute to climate change. The electrical power consumed when extracting aluminium from bauxite in the refining process cannot be replaced by any other energy carrier (Aluminiumriket Sverige, 2008; Jackson and Jackson, 2000). It takes 13.3 kilowatt-hours of electrical energy to produce one kilogram of aluminium, approximately equivalent to the power generated by 19 car batteries, although this does include additional processes that fall outside the scope of this Report and which are not described above. On the plus side, aluminium’s light weight limits the energy requirement for transportation when compared to heavier products, such as glass. If the aluminium is recycled, energy consumption is slashed by 95 percent, compared to consumption for primary production. (Aluminiumriket Sverige, 2008) In 2006, a total of 16.4 million tons of aluminium were produced from recycled material (International Aluminium Institute, 2008).

3.2 Lead

Lead (chemical symbol Pb) is a soft, heavy, highly volatile and ductile metal. It is corrosion-resistant, with low thermal and electrical conductivity. Although found in plants, it does not appear to fulfil any vital function. At high concentrations, lead adversely affects both photosynthesis and mitosis. Lead is toxic for humans even at low concentrations. It can cause nausea, anaemia, kidney disease and death. In animals, it can cause convulsions, oesophageal stenosis and anaemia. Eagles, for example, have suffered lead poisoning after ingesting lead pellets from animals that have been shot. Man has known of the existence of lead over the past 6000 to 9000 years. Lead mining started in a big way some 5000 years ago, when it was discovered that silver could be extracted in conjunction with lead. (Geological Survey of Sweden, 2006)

3.2.1 Where is lead produced?

In 2005, in descending order, the largest lead producers were China, Australia, the USA, Peru and Mexico (Geological Survey of Sweden, 2006). See fig. 3.2.

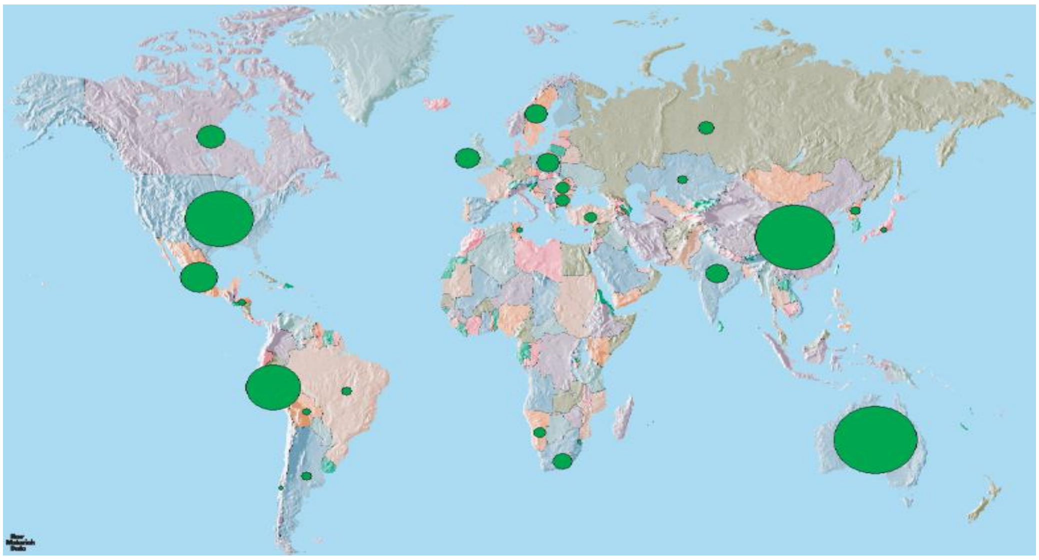


Fig. 3.2 Lead output in 2005. From the SGU report 'The Mineral Market 2006'.
© Geological Survey of Sweden (SGU). Consent: 30-1134/2008.

3.2.2 How is lead produced?

The lead concentration in lead ore is between three and eight percent (Ripley et al., 1996). The ore of greatest significance for lead production is galenite, which is the most abundant sulphidic ore in the Earth's crust. Lead is commonly found in combination with copper, zinc, silver and gold. (Geological Survey of Sweden, 2006) Lead is mined in both underground and open-pit mines. The lead-rich ore is crushed, ground and separated by gravimetric enrichment or flotation. (Ayres et al., 2003) The flotation process is adjusted according to the metals found in the ore and those to be extracted, and may involve several consecutive stages. Tailings are often stored in tailings dams. (European Commission Research Centre, 2004)

3.2.3 Environmental impact of lead production

In lead production, as with other metals extracted from sulphidic ores, seepage of acidified leachate and metals from tailings slurry poses the greatest environmental threat (Ayres et al., 2003). The global extraction of sulphidic ores accounts for almost all sulphur emissions from mining operations (Ripley et al., 1996).

Lead production is highly energy-intensive but, first and foremost, the most energy-intensive of all are smelting plants, which fall outside the scope of this Report. The production of lead from ore consumes 1 600 kilowatt hours of energy per ton. Where recycled material is used, energy consumption is cut to 500 kilowatt hours per ton (Geological Survey of Sweden, 2006). High energy consumption can lead to significant greenhouse gas emissions, which cause climate change (Jackson and Jackson, 2000). Production of pure lead in smelting plants poses the risk of substantial sulphur, lead, dust and particulate emissions (Ripley et al., 1996). In Kabew, Zambia, almost a century of mining, enrichment and refining of lead and zinc has contaminated large areas. Within a radius of 20 kilometres, lead, cadmium, copper and zinc levels are higher than those recommended by WHO, and 255 000 people are thought to be affected. (Blacksmith Institute, 2008)

3.3 Gold

Gold (chemical symbol Au) is a highly valued metal. Gold is dense, ductile, with good thermal and electrical conductivity. Gold is resistant to most reagents, but can be dissolved in aqua regia, chlorine gas, halogenhydroacids and alkalimetalcyanides, where an oxidizing agent is present. Gold is used in alloys to enhance the hardness of various metals. (National Encyclopaedia b, 2008) Pure gold is not toxic and can in some cases be used to decorate food and drink. Gold has been used since prehistoric times and is probably one of the metals that has been used over the longest time. (Wikipedia b, 2008)

3.3.1 Where is gold produced?

South Africa has been the world's largest gold producer for more than a century and, as shown in the 2005 global output chart (fig. 3.3), still was at that time. In 2007, however, South Africa was overtaken by China as the world's number one producer of gold. Other major producers are the USA, Russia, Australia and Peru. About a quarter of global gold output comes from small-scale mining operations. (Wikipedia b, 2008)

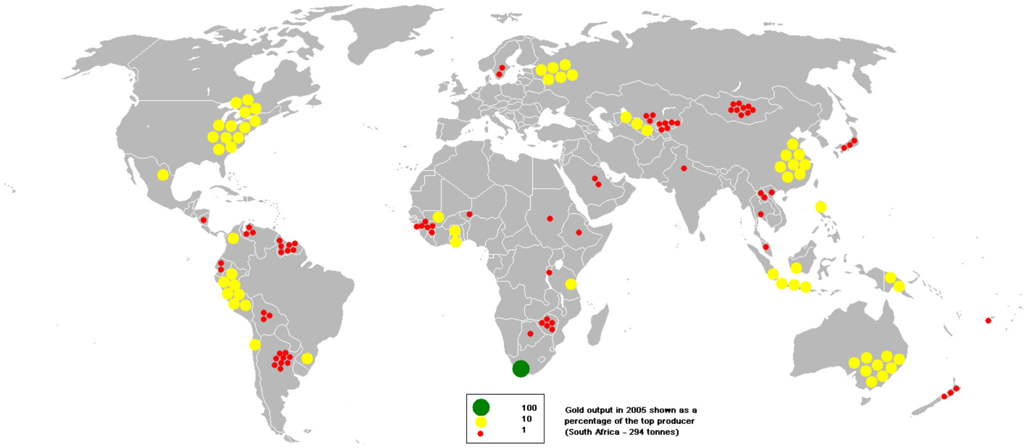


Fig. 3.3 Gold output in 2005. Source: http://en.wikipedia.org/wiki/Gold

3.3.2 How is gold produced?

Gold exists in very small quantities in different types of ore in the Earth's crust. Gold is often extracted as a by-product of copper mining. Open pit is the most commonly used method for mining gold on an industrial scale, but gold can also be extracted from underground mines, using block caving or cut and fill stoping. Gold can also be mined using hydraulic methods. (World Gold Council, 2008; Ripley et al., 1996)

Ore with a high gold content can be enriched using industrial-scale panning, the so-called 'shaking table' technique (European Commission Research Centre, 2004). Low gold-content ores can be enriched by leaching, where three different process alternatives can be chosen. The process selected is determined by the ore's metallurgical properties. The first process alternative, used for ore that contains carbon, involves calcinating the ore at a high temperature, to burn away the carbon and sulphur. This produces an oxidized ore that is treated in a leaching process, in which the gold is separated from the ore with the help of cyanide. If the ore is already oxidized, this leaching process can be started immediately. This constitutes the second process alternative. The third process alternative is used for sulphidic ores, which contain no carbon. These are oxidized in an autoclave, after which they are subjected to cyanide leaching. The gold is then adsorbed from the liquor with activated carbon and the cyanide is reused. The gold is then chemically separated from the carbon and the carbon is reused. The gold is precipitated out of the liquor with an electrolyte or by chemical substitution. The gold is melted into ingots, with a purity of about 90 percent. (National Mining Association, 2008) The extraction of gold using cyanide is known as the Merril Crowe or MacArthur-Forrest process and, since its introduction towards the close of the 19th century, it has replaced earlier gold extraction methods such as amalgamation, where gold was extracted with the help of mercury. For ore that contains copper as well as gold, flotation is the chosen extraction method, due to the fact that cyanide also has an affinity for copper. In some cases, extraction is more effective when several different enrichment methods are combined. (World Gold Council, 2008)

Tailings from the production of gold often contain cyanide. In certain cases, the cyanide is destroyed before the tailings are stored in tailings dams or used as backfill. The ‘destruction’ of cyanide refers to its transformation into an insoluble compound which cannot be ingested by organisms. This can be achieved using a number of different approaches, involving sulphur dioxide/air, hydrogen peroxide and alkaline chlorination. (Ripley et al., 1996) The cyanide may also undergo natural decomposition in the tailings dam, although this requires careful monitoring to prevent seepage. (European Commission Research Centre, 2004)

Ore-forming gold compounds are easily broken down, which enables the gold to be flushed out with water for subsequent enrichment in gold-sand (National Encyclopaedia b, 2008). This makes small-scale mining operations possible, which require only the simplest methods. The enrichment process used is mercury amalgamation, which has a major impact on the environment (Aswathanarayana, 2003). At time of writing, some 13 million people are engaged in small-scale gold extraction in more than 30 countries, while a further 80 - 100 million people are dependent on this type of activity for their income (World Gold Councils, 2008).

3.3.3 Environmental impact of gold production

The hydraulic methods sometimes used to extract gold can transform the landscape, leading to erosion, the increased turbidity of watercourses and alterations to the way water flows (Ripley et al., 1996). The gold content of the ore is very low, which means that large quantities of waste are generated whatever the mining method chosen, so that almost the entire mass extracted becomes waste. The extraction of gold from sulphidic ores can cause acid drainage which can in turn lead to the release of many heavy metals. (World Gold Council, 2008)

Using cyanide for the enrichment of gold creates environmental and health problems, due to its toxicity. In its gaseous form, cyanide is lethal to humans in concentrations exceeding 100-300 ppm. Cyanide, even in very low concentrations, is also extremely toxic for mammals, birds and fish, but does not accumulate in a biological sense. If it seeps into soil or water in conjunction with gold mining activities, an entire ecosystem can be flooded with toxic levels of cyanide, causing considerable harm. If this is to be prevented, waste containing cyanide must be stored until the cyanide has been broken down. (World Gold Council, 2008) Mining companies that use cyanide in their gold production process can operate according to the recommendations of the Cyanide Management Code, a voluntary international agreement that governs the industrial use of cyanide (Cyanide Management Code, 2008).

Mercury amalgamation is used in the small-scale extraction of gold, a process which has a major impact on human health and the ecosystem. To extract a single kilogram of gold requires between six and eight kilograms of mercury. Approximately one and a half kilograms of mercury cannot be recycled but is released straight into the surrounding natural environment, contaminating the soil, riverbeds, water and plant life. Sensitivity to mercury varies greatly from species to species. Organic mercury, especially in the form of methyl mercury, is absorbed more easily by a range of organisms. (Aswathanarayana, 2003)

3.4 Iron

Iron (chemical symbol Fe) is a heavy metal with magnetic properties. Iron and nickel are among the most abundant elements in the Earth’s core, and iron is also the fourth most common element in the Earth’s crust. In the crust, iron is often in the form of oxides, such as magnetite and hematite. Steel is an alloy of iron and carbon, containing about two percent carbon by weight. Because of its low price and high strength, iron is the most commonly used metal, measured in tons. (Jernkontoret, 2008) Iron fulfils many important biological functions for almost all living organisms, apart from certain lactic acid bacteria. Iron often helps with the transport of various elements in the body, such as electrons and oxygen. Mining iron from the Earth’s crust started around 1500 B.C. (National Encyclopaedia c, 2008)

3.4.1 Where is iron produced?

Australia, Brazil, China and Russia are the largest producers of iron ore. Much of the ore mined in Australia and Brazil is exported, while most of what is mined in China and Russia is for domestic consumption (fig. 3.4). In Africa, the production of iron ore is limited to Mauretania and South Africa. In Southeast Asia, production of iron ore is limited mainly to India. Sweden is the largest European producer. Steel is often produced in the same country as that in which the ore is mined. (Mining, Minerals and Sustainable Development, 2002)

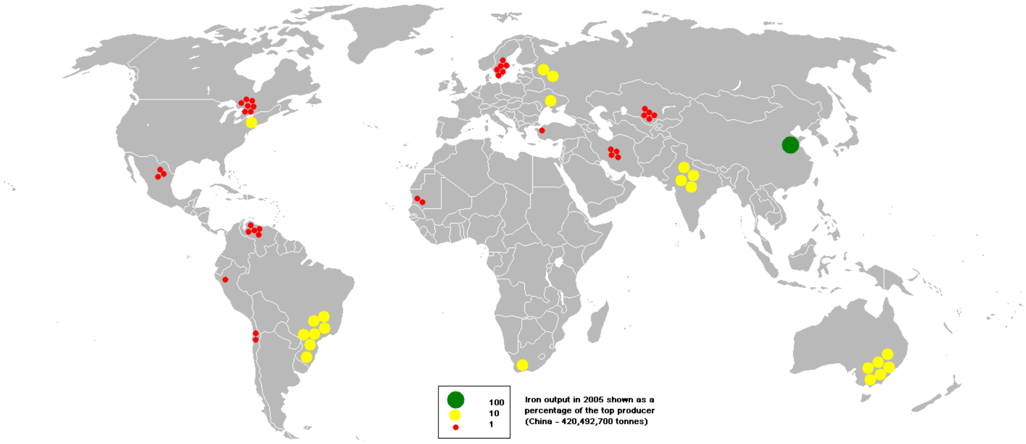


Fig. 3.4 Iron output in 2005. Source: http://en.wikipedia.org/wiki/Iron

3.4.2 How is iron produced?

Iron is normally extracted from the oxide ores magnetite or hematite, which often feature a high iron content of around 50 percent. Iron ore is extracted from open pit mines, apart from LKAB’s underground mines in Sweden. (Aswathanarayana, 2003) The extracted ore is crushed and ground, after which the gangue is separated from the ore using magnetic separation (if magnetite) or flotation (if hematite). Some ores possess such a high iron content that they can be sent direct for refining without requiring any enrichment at all. The ore is then processed into some suitable form, such as sinter or pellets, for subsequent processing into steel. (Ripley et al., 1996)

3.4.3 Environmental impact of iron production

The open pits that are often employed when mining iron ore can result in major transformations of the landscape and generate huge amounts of waste in the form of overburden Iron production often involves high water consumption, although much of it can be recycled. If the non-recycled water is released into neighbouring watercourses, it may transport particles of iron and other metals. Iron is an essential nutrient for most organisms, yet excessive concentrations can be harmful. (Ripley et al., 1996) Iron mines definitely cause dust and particulate emissions. Small particles can be transported great distances when airborne, creating health and environmental problems (Aswathanarayana, 2003). In Sweden, developments in air-cleaning technology, filters and ventilation systems have achieved a radical reduction in particle emissions. In fact, these types of emission are no longer considered to present a major environmental problem in Sweden. However, increases in air-cleaning capability also increase the energy requirement. Compared to pellet production, the production of sinter raises particle, nitric oxide and sulphur dioxide emissions. (Jernkontoret, 2008) The environmental impact of overburden, gangue and tailings is considered to be low, given the fact that the waste contains no metal sulphides (Fröberg and Höglund, 2004). This means that the overburden and gangue may be stored in heaps and tailings in dams (European Commission Research Centre, 2004).

Refining is outside the scope of this Report, but it is nevertheless worth noting that the iron and steel industry is extremely energy-intensive, due to the fact that many processes involve very high temperatures. It is also essential that the energy carriers are high grade, such as coal, oil, gas or electricity. Biofuel is low grade and cannot meet the energy requirements or the demands made with respect to combustion and ash content. This said, ore-based steel mills are more energy-efficient than scrap-based steel mills, since the coke added to the pig iron is included in the energy balance for ore-based steel mills. (Jernkontoret, 2008)

3.5 Coal

Coal is a black or brownish black sedimentary rock. Although coal consists largely of carbon (chemical symbol C), it also contains other elements such as oxygen and hydrogen. Coal is formed when organic material is covered by water and thereby protected from oxidation during the decomposition process, as in the case of peatland, marshland and river deltas. Another important factor is that the decomposition process has occurred under high pressure and at a rising temperature. There are several types of coal, used for different applications, including lignite/brown coal, pit coal and anthracite. Coal is an extremely important source of energy in many countries and has been in use since the Stone Age. It was not until the industrial revolution, when steam power replaced the water wheel, that coal started to be used on an industrial scale. (National Encyclopaedia d, 2008)

3.5.1 Where is coal produced?

The largest coal producers are China, the USA, India, South Africa and Australia (fig. 3.5). In recent years, coal output in Europe has declined, while simultaneously increasing in Asia. The coal is often used in the countries in which it is produced: a mere 18 percent of global coal output is traded on international commodities markets. (World Coal Institute, 2008)

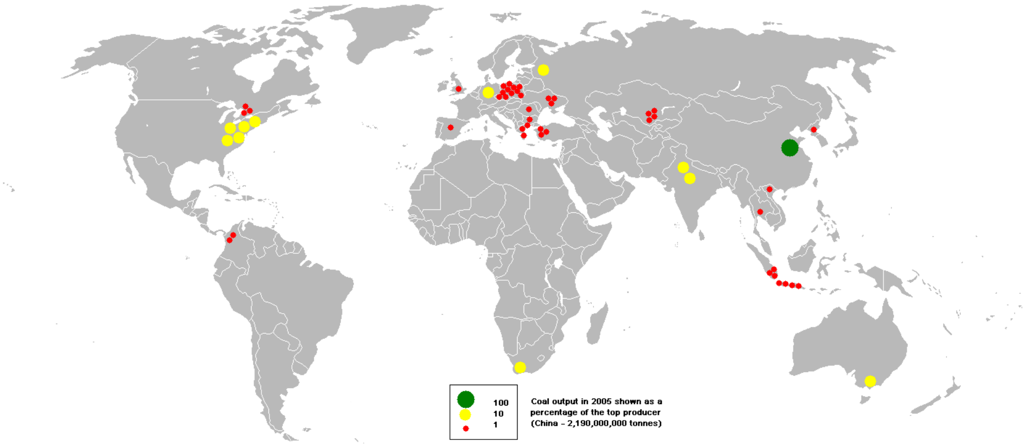


Fig. 3.5 Coal output in 2005. Source: http://en.wikipedia.org/wiki/Coal

3.5.2 How is coal produced?

Coal is extracted both from open pit and underground mines, the latter normally being either room-and-pillar or longwall mines. Depending on its purity and the quality required by consumers, the extracted coal is subjected to a number of different cleaning processes. This can vary from no more than crushing to the need for a number of advanced purification processes. Pit coal and anthracite are normally enriched, but not brown coal (European Commission Research Centre, 2004). Flotation can be used to cleanse large coal fractions from heavier rocks and metals. Small coal fractions can be cleansed using a centrifugal process or flotation. Once cleaned of impurities, the coal is transported to consumers, via conveyor, truck, train or boat. Coal can also be mixed with water and transported via a pipeline (World Coal Institute, 2008). The waste from the mining process can be stored in heaps or used to restore the landscape once mining operations have terminated. Tailings are stored in tailings dams or filtered and stored in heaps. (European Commission Research Centre, 2004)

3.5.3 Environmental impact of coal production

Underground mines involve the risk of ground subsidence and subject mineworkers to a major safety risk, as is the case in small coal mines in China. Open pit mines pose the risk of erosion, when large land masses are excavated. Coalfields often contain methane, which is released as a result of mining activities. Methane is a greenhouse gas with high carbon dioxide equivalence, and total methane emissions are estimated to account for 18 percent of all greenhouse gas emissions generated by human activities. Methane is highly explosive and underground mines must be thoroughly ventilated to eliminate the risk of explosion. Exploiting the potential of this methane can offer mine companies a profitable means of reducing impact on the environment. (World Coal Institute, 2008)

Coal mining generates dust that contains a number of different particles. The extraction of a million tons of coal produces a ton of toxic particles, including arsenic, beryllium, cadmium, fluorine, lead and mercury. Pulverized coal, in the form of very small particles, which can be dispersed over great distances, is a major health and environmental problem in itself. The problems associated with dust are even more severe in dry and tropical areas. (Aswathanarayana, 2003) Acid drainage can often arise in conjunction with coal extraction, when sulphur in the ore reacts with air and water (World Coal Institute, 2008). Pretreatment of coal, different cleansing techniques and other advanced techniques, such as the Low Nox Concentric Firing System, help reduce coal production emissions (Aswathanarayana, 2003).

3.6 Copper

Copper (chemical symbol Cu) is a ductile metal, offering good electrical and thermal conductivity. Copper occurs as a trace element in plants and animals, but is toxic and can even be lethal in large doses. Too much copper in the water can have a catastrophic effect on marine life, affecting the gills, livers, kidneys and nervous systems of marine species (Aswathanarayana, 2003). At room temperature, if in contact with air, copper oxidizes. However, the oxidized copper film protects the substrate from further oxidation. This can often be seen, for example, as a green film on copper roofing. Copper and a number of copper alloys have played a significant role in human history for many thousands of years, and continue to do so today. (Ayres et al., 2003)

3.6.1 Where is copper produced?

Chile is the largest producer of copper in the world, followed by the USA and Indonesia (fig. 3.6). Most copper is refined in the country where it is mined, but a certain amount of international trade in copper concentrate exists. Germany, Italy and South Korea are examples of countries that refine copper, although mining no copper of their own. (Mining, Minerals and Sustainable§ Development, 2002)

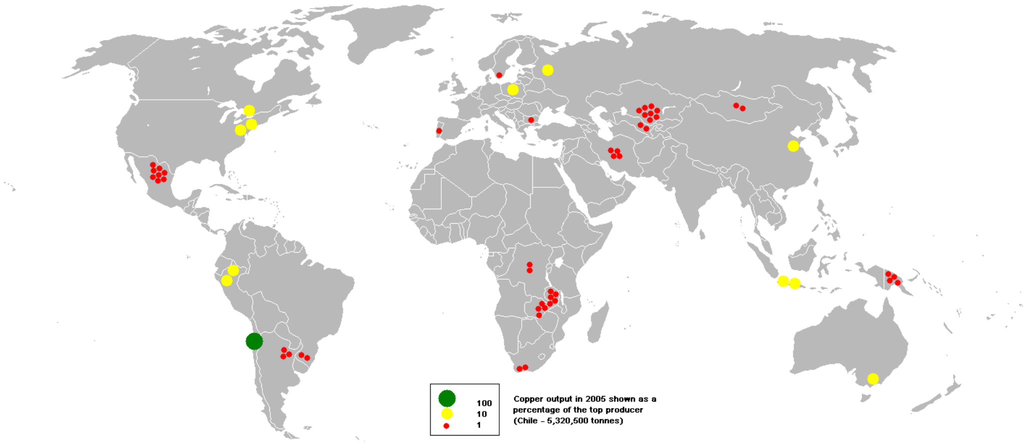


Fig. 3.6 Copper output in 2005. Source: http://en.wikipedia.org/wiki/Copper

3.6.2 How is copper produced?

The Earth’s crust contains 0.059 percent copper, but the concentration in the ore extracted from copper finds is about 0.8 percent. Copper was mined exclusively underground until the 20th century. Nowadays, however, the majority of copper mining is conducted in open pits. (Ayres et al., 2003) Copper is usually extracted from chalcopyrite, a sulphide ore, although it is also found in other sulphidic and oxidic ores. The copper in the ore is concentrated by flotation and, sometimes, by gravimetric enrichment. After enrichment, copper concentration is about 15 percent (Copper Development Association a, 2008). Electrochemical flotation methods, which are both cheap and environmentally harmless, can also be used to extract copper (Aswathanarayana, 2003).

3.6.3 Environmental impact of copper production

In common with other metals extracted from sulphidic ores, the greatest potential environmental impact of copper production is acid drainage from tailings. The mining of sulphidic ores accounts for almost all sulphur emissions generated by mining operations worldwide (Ripley et al., 1996). Mining operations and enrichment processes also cause the dispersal of dust and atmospheric emissions in the form of copper, sulphur dioxide, nitric oxide, hydrocarbons, carbon dioxide and carbon monoxide (Ayres et al., 2003).

Even though the refining process is beyond the scope of this Report, it is interesting to note that energy consumption in the case of copper production, when compared with the production of other metals, is low (c. 30 megawatt-hours per ton of copper). When the raw material is scrap, the energy requirement falls to anything from one to 20 megawatt-hours per ton of copper, depending on the purity of the scrap. (Copper Development Association b, 2008) Previously, copper production resulted in substantial emissions of sulphur dioxide, heavy metals and so on. However, the more closed processes used in present day ‘flash’ smelters have significantly reduced such emissions, which is why the method is so widely used. (Ayres et al., 2003)

3.7 Molybdenum

Molybdenum (chemical symbol Mo) is the element that has the sixth highest melting point. It is a hard metal that reacts neither to air or water at room temperature. Because of its high melting point, it is often used in alloys. Molybdenum is also an important trace element in humans, animals and plants. Even so, high concentrations of molybdenum in the body can be harmful. The metal was first isolated at the close of the 18th century, but has probably been in use for very much longer. There has been a marked increase in its use since the end of the Second World War. (International Molybdenum Association, 2008)

3.7.1 Where is molybdenum produced?

The USA, Canada, China and Chile (fig. 3.7) are the largest producers of molybdenum in the world (International Molybdenum Associations, 2008). Molybdenum is most often produced as a by-product of the copper production process. In China, the high degree of molybdenum production probably derives from the fact that the metal is produced in conjunction with tungsten. Molybdenum output has long exceeded demand. (Walterson, 1999)

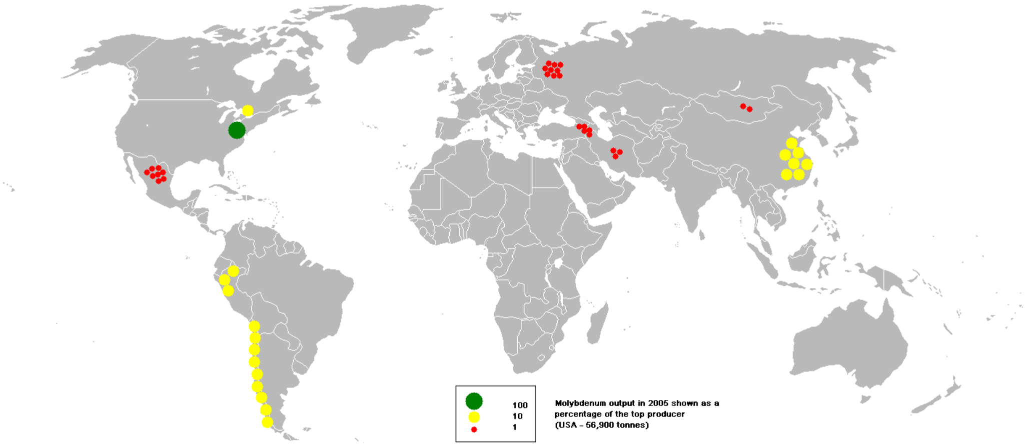


Fig. 3.7 Molybdenum output in 2005. Source: http://en.wikipedia.org/wiki/Molybdenumum

3.7.2 How is molybdenum produced?

Molybdenum is normally extracted from the mineral molybdenite or molybdenum disulphide, but can also be obtained as a by-product in the extraction of copper and tungsten. The average concentration in a molybdenum ore is between 0.01 and 0.25 percent. It can be extracted from both open pit and underground mines, block caving being used in the latter case. The ore is crushed and ground into fine particles. The molybdenum is then separated from the gangue by flotation, which may involve several stages if the ore contains several metals. If the molybdenum is in a sulphide ore, the ore may need to undergo leaching after the flotation process. (International Molybdenum Association, 2008)

3.7.3 Environmental impact of molybdenum production

In common with other metals extracted from sulphidic ores, the greatest potential environmental impact of molybdenum production is acid drainage from tailings (Ayres et al., 2003). The mining of sulphidic ores accounts for almost all sulphur emissions generated by mining operations worldwide (Ripley et al., 1996).

3.8 Nickel

Nickel (chemical symbol Ni) is a magnetic, hard but ductile metal. Thanks to its excellent properties, nickel is often used in alloys, such as stainless steel. Nickel is important to several biological functions in plants and microorganisms, yet can also be toxic. Some people are allergic, for example, and can react from mere contact with nickel. Nickel has been a known element since the 18th century, but has probably been used for much longer. (Geological Survey of Sweden, 2007)

3.8.1 Where is nickel produced?

Russia, Canada, Australia, Indonesia, New Caledonia and Colombia (fig. 3.8) have major nickel deposits, accounting for the greater part of global output (Geological Survey of Sweden, 2007).

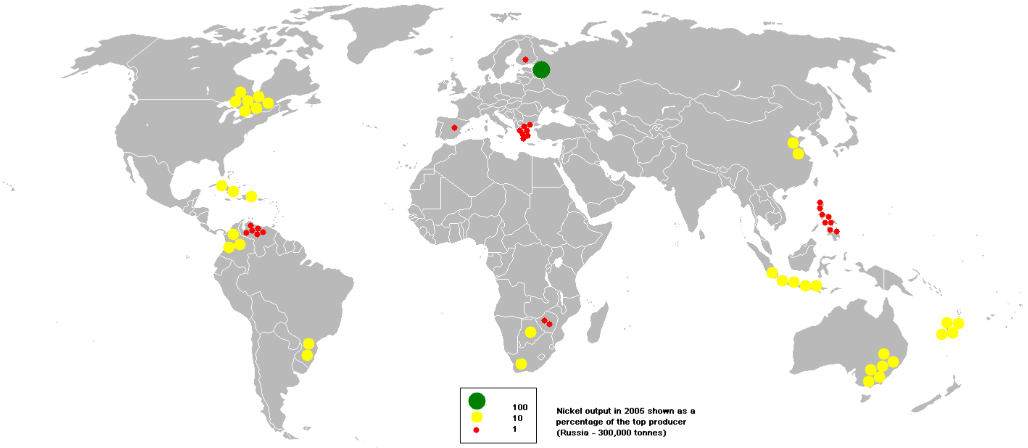


Fig. 3.8 Nickel output in 2005. Source: http://en.wikipedia.org/wiki/Nickel

3.8.2 How is nickel produced?

Nickel accounts for 0.08 percent of the Earth's crust, although concentration in the ores mined varies from1.5 to several percent (Ayres et al., 2003; Geological Survey of Sweden, 2007). Nickel is extracted from both open pit and underground mines (Jackson and Jackson, 2000). It is normally extracted from the sulphide ores pentlandite and millerite, or the oxide ore laterite. Nickel in sulphidic ores is enriched at the mine, using flotation or magnetic separation (Aswathanarayana, 2003). After flotation, nickel concentration is about ten percent (Ripley et al., 1996). Flotation cannot be used for laterite ores, however. This type of ore must instead be transported direct to a leaching mill or smelting plant. It is then smelted, and gypsum, coke and slag former is added. Once this process has been completed, the nickel attains the sulphide phase and the subsequent enrichment stage is the same as for sulphide ores. (Geological Survey of Sweden, 2007)

3.8.3 Environmental impact of nickel production

The greatest potential environmental impact of nickel production from sulphidic ores is acid drainage from tailings. The mining of sulphidic ores accounts for almost all sulphur emissions generated by mining operations worldwide. (Ripley et al., 1996) The high energy consumption associated with the production of nickel causes the emission of greenhouse gases, which in turn are believed to contribute to climate change (Jackson and Jackson, 2000).

Although the refining phase is not within the scope of this Report, it should be noted that the production of nickel from sulphide ore releases unusually large quantities of sulphur during this phase. For purposes of comparison, note that the production of one ton of copper generates one ton of sulphur during the smelting process, whereas production of one ton of nickel generates eight tons of sulphur (Geological Survey of Sweden, 2007). The area around Norilsk in Russia, which accounts for a fifth of the world's nickel output, provides an example of the potential severity of the environmental consequences. Some 1.9 million tons of sulphur dioxide and 10 800 tons of heavy metals, mainly nickel, are released into the environment from the smelting plant every year. Nickel fallout is so heavy that it has now become profitable to extract nickel from the sediment in some watercourses, introducing a new form of mining. It is considered to be one of the ten most severely contaminated sites on the planet. An area of forest covering 48 000 hectares has died, and many of the local population are suffering from lung cancer and various allergies. (Kramer, 2007)

3.9 Platinum

Platinum (chemical symbol Pt) is a heavy, ductile metal that is resistant to most chemical solutions. It is also highly resistant to corrosion and oxidation. Platinum's properties make it the ideal choice for the manufacture of jewellery and, since it is also highly valuable, it commands a higher price than gold. Platinum has been known for a very long time, having been discovered in Egyptian archaeological sites dating back to 700 B.C. and in Ecuadorian Indian sites dating back just a few centuries after the birth of Christ. This unusual metal was conveyed from South America to Europe in the 18th century. (National Encyclopaedia e, 2008)

3.9.1 Where was platinum produced?

South Africa is the world's largest producer of platinum (fig. 3.9), followed by Russia, Canada and the USA (National Encyclopaedia e, 2008).

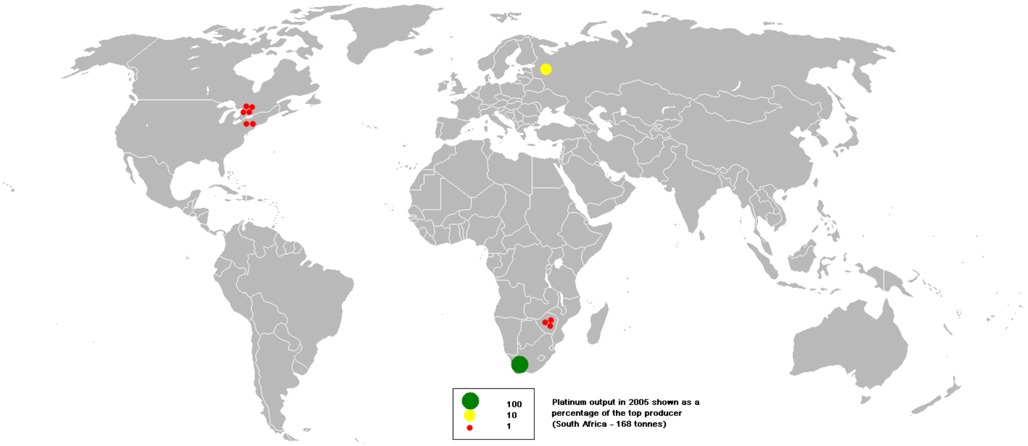


Fig. 3.9 Platinum output in 2005. Source: http://en.wikipedia.org/wiki/Platinum

3.9.2 How is platinum produced?

Sperrylite, geversite, cooperite and braggite are important platinum minerals, but the concentration of platinum metals is normally very low. These minerals tend to occur in sulphidic ores and platinum is therefore often extracted in conjunction with nickel or copper. In South Africa and Canada, most of the platinum is mined underground, although extraction in open pit mines is common in other parts of the world. Since the metal is mined together with copper and nickel, enrichment is by flotation. After the copper and nickel have been leached out, the residue features a platinum concentration of about 15 percent. Where gravimetric enrichment is carried out prior to flotation, product concentration may be as high as 50 percent, and smelting becomes superfluous. (Gold and Silver Mine, 2008)

3.9.3 Environmental impact of platinum production

In common with other metals extracted from sulphidic ores, the greatest potential environmental impact of platinum production is acid drainage from tailings (Ayres et al., 2003). Apart from the potential environmental risks associated with the mining and enrichment of sulphidic ores, the potential environmental impact of platinum production is low (Ripley et al., 1996).

3.10 Uranium

Uranium (chemical symbol U) is a radioactive element. There are three natural isotopes of uranium, none of which are stable, which means that all the isotopes decay slowly. Uranium reacts easily with water and can ignite spontaneously in air. By bombarding the uranium nuclei with neutrons, it is possible to split them, releasing energy, as utilized in nuclear power plants. Because uranium generates ionizing radiation, handling uranium involves certain health risks. Uranium was discovered at the end of the 18th century. (Geological Survey of Sweden, 2003)

3.10.1 Where is uranium produced?

Canada, Australia, Nigeria, Kazakhstan, Namibia and Uzbekistan (fig. 3.10) are the largest producers of uranium (Geological Survey of Sweden, 2003).

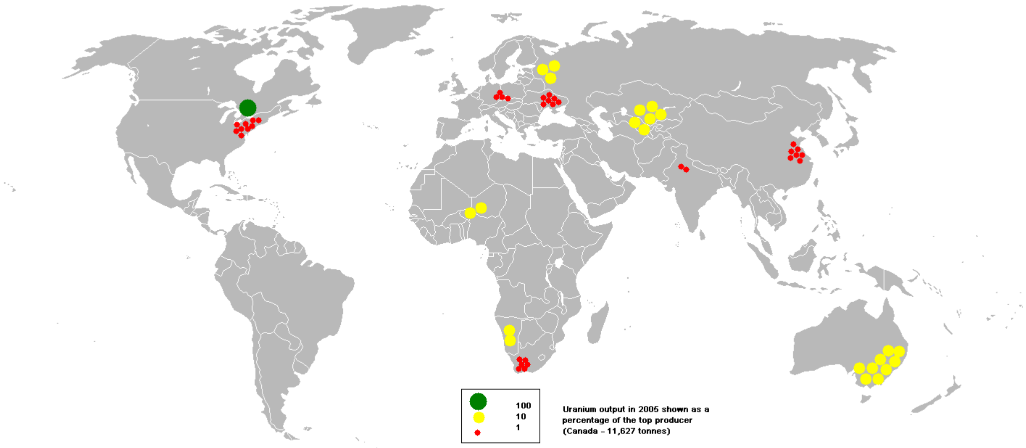


Fig. 3.10 Uranium output in 2005. Source: http://en.wikipedia.org/wiki/uranium

3.10.2 How is uranium produced?

An average of 2.3 grams of uranium per ton is found in several types of ore in the Earth's crust. The oxide ore pitchblende is the most common of these ores, but uranium can also be found in sulphidic ores, either alone or in combination with nickel or cobalt ores (Ripley et al., 1996). Uranium is mined both on the surface and below ground, using a variety of different methods. Uranium is sometimes extracted in situ by leaching direct from the ore. The mined ore is crushed, ground and then leached with sulphuric acid. The leaching liquor is first subjected to liquid-liquid-extraction, then treated with ammonia and thereafter heated to form uranium oxide. It is this product that is sold by the mines, under the name 'yellowcake'. (Geological Survey of Sweden, 2003)

3.10.3 Environmental impact of uranium production

Uranium is radioactive, which is why mining uranium incurs special risks. Radioactive radiation can damage the tissues of those engaged in the extraction and enrichment of uranium. Radioactive radiation can also be generated by waste, tailings, atmospheric emissions and effluents that have been in contact with the ore and process water from the enrichment process. Since the enrichment processes only extract the uranium from the ore, the levels of other radioactive elements in tailings will generally be as high as in the original ore. Radium, thorium and radon are examples of radioactive elements that are formed when uranium decays and which can cause problems when it comes to waste management. For instance, radon and its decay products may exist in gaseous form and can be dispersed by the wind. Radioactive radiation can be harmful to people, animals and plants living in proximity to the mine. Both terrestrial and marine plants can absorb radioactive elements direct from the medium in which they live, or via their roots. Absorption capacity varies according to species. Higher life forms can inhale radioactive elements or be exposed to radioactive elements that have accumulated in the food chain. Some of these radioactive emissions can be controlled using relative simple equipment, such as filters. Tailings can be treated to remove some radioactive and other dangerous elements. The tailings can then be stored in stringently monitored tailings dams. (Ripley et al., 1996)

If the uranium is extracted from sulphidic ores, it creates the same potential environmental impact as when other metals are extracted from this type of ore, in the form of acid drainage from the tailings. Low pH means that additional radioactive elements, metals and other toxic substances are released, increasing the problem of radioactive radiation. The problem is greatest in the case of abandoned magazines containing untreated yellow pyrite tailings. As stated above, tailings are treated to ensure that, for example, radon and sulphur are removed prior to storage. The potential environment problems that can arise from the production of uranium are minor compared to those associated with the production of copper, for instance, since the amount of uranium extracted is relatively small. (Ripley et al., 1996)

3.11 Zinc

Zinc (chemical symbol Zn) is a fairly reactive metal, reacting with acids, alkalis and other nonmetals. Zinc plays a major role in all life forms. Zinc is thought to be in some 3000 different enzymes in the human body alone. Free zinc ions can still be harmful, however, and can even cause death, especially in the case of marine animals and plants. Zinc concentrations in organisms can be several hundred times higher than those in the soil, due to the fact that the metal diffuses spontaneously though cell walls. (Aswathanarayana, 2003; Ayres et al., 2003) Zinc has been used since time immemorial: the ancient Greeks and the Romans, for example, used zinc for medical purposes (Geological Survey of Sweden, 2004).

3.11.1 Where is zinc produced?

China, Australia, Peru, Canada, the USA and Mexico (fig. 3.11) account for the greater part of world output of zinc (Geological Survey of Sweden, 2004).

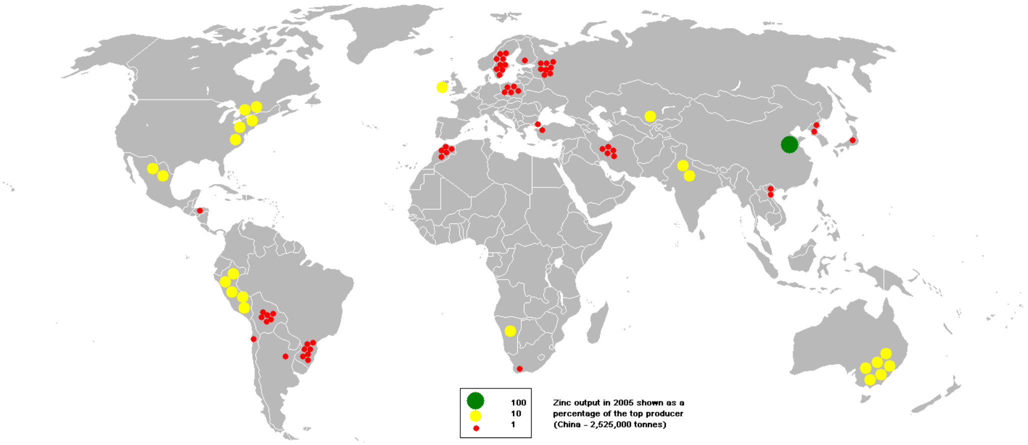


Fig.3.11 Zinc output in 2005. Source: http://en.wikipedia.org/wiki/Zinc

3.11.2 How is zinc produced?

Approximately 0.132 percent of the Earth's crust consists of zinc, the most abundant ore being the sulphide ore zincblende (Ayres et al., 2003). Concentrations of zinc in the ore vary from three to ten percent. Minerals containing copper, zinc and lead are often found together and are therefore often extracted together (Ripley et al., 1996). Zinc is extracted both from open pit and underground mines (Jackson and Jackson, 2000). The enrichment processes employed for zinc are very similar to those for copper and lead, involving both gravimetric enrichment and flotation (Aswathanarayana, 2003). After enrichment by flotation, zinc concentration is about 50 percent (Ripley et al., 1996).

3.11.3 Environmental impact of zinc production

The greatest potential environmental hazard associated with the production of zinc from sulphide ore is acid drainage from tailings. When mining zinc, there is naturally a risk that zinc escapes into the surrounding environment. Zinc's solubility is highly pH-dependant and increases as the pH level declines. High concentrations can be toxic, although at the same time, zinc is crucial to the survival of most organisms. Zinc poisoning from drinking water is uncommon and requires extremely high levels of zinc. Inhalation of zinc chloride dust can, however, easily cause potentially fatal lung damage. Zinc has the ability to replace non-essential metals, such as cadmium, lead and mercury, which occur in the same environment. One example is the fact that mercury levels in fish tend to be lower in areas where zinc is being mined, although all aspects of the role played by zinc in this respect are not known. (Geological Survey of Sweden, 2004) The mining of sulphidic ores accounts for almost all sulphur emissions generated by mining operations worldwide (Ripley et al., 1996).

3.12 Summary of production and environmental impact of minerals

The environmental impact of mining varies from mine to mine, but the extraction and enrichment of different minerals involves increased risk of various types of environmental impact. Table 3.3 summarises the environmental impact most likely in conjunction with the extraction of a particular mineral.

Table 3.3 Summary of production methods and potential environmental impact of respective minerals.

Mineral	Summary of production and potential environmental impact
Aluminium	Extraction from open pits produces major changes in the landscape, as well as creating large quantities of waste and problems with dust dispersal. Energy consumption during production is extremely high, which can lead to major emissions of greenhouse gases and promote climate change. Red mud, created during enrichment, can lead to major problems with dust dispersal and seepage of different metals into watercourses.
Base metals (lead, copper, molybdenum, nickel, zinc)	Both surface and underground mines may be used, with different environmental consequences. These minerals are often extracted from sulphidic ores, creating the risk of acid drainage. Once this seepage has started, it is difficult to stop the chemical reactions that cause this, and the environmental consequences are extensive. Tailings must be stored to prevent them coming into contact with air for a very long time, thus preventing any reactions.
Gold	Both surface and underground mines may be used, with different environmental consequences. Sometimes, the hydraulic method is used for gold extraction, altering the landscape and causing erosion, increased turbidity of local watercourses and the alteration of water flows. Enrichment often involves the use of cyanide, posing the risk of escape into nearby watercourses or land. Cyanide is toxic for humans and animals and can cause untold damage if released into the ecosystem. Gold can be extracted from sulphidic ores, involving the risk of acid drainage from tailings. Once seepage has started, it is difficult to arrest the chemical reactions that fuel this process, and the environmental consequences are extensive. Tailings must be stored to prevent them coming into contact with air for a very long time, thus preventing any reactions.
Iron	Extraction from open pits produces major changes in the landscape, as well as creating large quantities of waste and problems with dust dispersal. The extraction of iron ore can also lead to the escape of emissions to the air, land and water.
Coal	Both surface and underground mines may be used, with different environmental consequences. Extraction often leads to dust dispersal, with a considerable impact on health and the environment. Coal mining often leads to the release of methane, posing the risk of explosion, contributing to the emission of greenhouse gases and promoting climate change. Coal may be extracted from sulphidic ores, with the risk of acid drainage from tailings. Once seepage has started, it is difficult to arrest the chemical reactions that fuel this process, and the environmental consequences are extensive. Tailings must be stored to prevent them coming into contact with air for a very long time, thus preventing any reactions.

Platinum	Both surface and underground mines may be used, with different environmental consequences. Platinum may be extracted from sulphidic ores, with the risk of acid drainage from tailings. Once seepage has started, it is difficult to arrest the chemical reactions that fuel this process, and the environmental consequences are extensive. Tailings must be stored to prevent them coming into contact with air for a very long time, thus preventing any reactions.
Uranium	Both surface and underground mines may be used, with different environmental consequences. The greatest environmental hazard posed by uranium mining is the radioactive nature of uranium's decay products, which can harm humans, animals and plants that come into contact with them. Uranium may be extracted from sulphidic ores, with the risk of acid drainage from tailings. Once seepage has started, it is difficult to arrest the chemical reactions that fuel this process, and the environmental consequences are extensive. Tailings must be stored to prevent them coming into contact with air for a very long time, thus preventing any reactions.

4 Determining the environmental impact of a mine

Many aspects need to be taken into account when determining the environmental impact of a mine. The following cites those aspects that during the preparation of this Report have shown themselves to be of greatest significance. The geographical location of the mine has crucial significance. If located in a previously undisturbed area, the mine's development is likely to have contributed to changes in the ecosystem, probably having an adverse impact on biodiversity and the indigenous population. The high water consumption associated with the mining industry can lead to conflict, alterations in the flow of water and drought, possibly leading to increased desertification. Challenging topographical features, seismic activity, extreme drought and heavy rainfall can produce major problems in managing reactive waste products, leading to extensive environmental consequences.

All mining methods produce some form of environmental impact. The mining method selected is largely determined by the position and form of the ore body. Open-pit mining causes radical transformation of the landscape, generates huge amounts of waste and disperses large volumes of dust. The leaching process creates leaching waste, risking the contamination of watercourses. It can also be difficult to rehabilitate the site after the leaching process has been terminated. Underground mines involve the risk of subsidence, erosion and alterations in the flow of water.

The type of ore mined determines the enrichment method employed and the nature of the environmental threat posed by tailings. When tailings from sulphide ore come into contact with air and water, this triggers a decomposition process that causes the formation of sulphuric acid, leading to the risk of acid drainage and the release of heavy metals. Once this process has started, it is difficult to stop and the environmental consequences are extremely extensive and long lasting. To avoid triggering this chain of events, tailings must be stored so that they cannot come into contact with air. This is normally achieved by storing the tailings in a tailings dam, covering them with clay or water. Since tailings must be stored in this manner over a period of up to thousands of years, it is essential to ensure that the design of these tailings dams is stable. The amount of tailings generated depends on the concentration of desired minerals in the ore and market demand. Enrichment usually involves the use of different chemicals. These chemicals may often be recycled, but if not, they can seep into the natural environment and cause severe damage. The enrichment of gold often involves the use of cyanide, which has extremely serious environmental and health consequences if released into nearby ecosystems. Even in very small concentrations, cyanide is toxic for humans, animals, birds and plants. For example, cyanide in its gaseous form is lethal to humans in concentrations exceeding 100-300 ppm. High energy and water consumption during enrichment and other mine processes can have an adverse impact on the environment, given the fact that energy consumption often involves the emission of greenhouse gases, which in all probability contribute to climate change.

Even if stringent measures have been implemented to prevent the mine from having an adverse environmental impact, accidents can still have a massive environmental impact. Mine companies should therefore adopt a preventive approach, by identifying critical aspects of their activities and implementing crisis management systems. To ensure that the environmental impact of a mine is as minimal as possible in the long term, it is important that a plan outlining how the site is to be managed after the mine's eventual closure be drafted right from the start. This plan should also state how the closure of the mine and the site's rehabilitation is to be financed. Probably, the greatest potential environmental impact of mine closures is the risk that sulphide ore tailings come into contact with the air, triggering a decomposition process that results in acid drainage and contamination of the surrounding environment.

There are many international initiatives relating to ways in which the mining industry should act to minimise environmental impact and which may be of assistance when a mine is to be assessed from an environmental perspective. The report from the UN World Summit on Sustainable Development, held in Johannesburg in 2002, describes how sustainable development can be attained on a global basis and addresses the issue of ways in which the mining industry must cooperate to achieve this. The report proposes increased transparency and liability, greater participation on the part of interested parties and more economic, technical and capacity-building support for developing countries (World Summit on Sustainable Development, 2002). The International Finance Corporation (IFC) is part of the World Bank, which is engaged in providing advice and funding to the private sector in developing countries, with a view to combating poverty. The IFC challenges national governments to address the following areas when drafting legislation and agreements with the mining industry: land and water use, waste management, chemicals and pollutants, tailings management, health hazards and potential environmental hazards, as well as the drafting action plans to deal with these issues (International Finance Corporation, 2008).

The industry organisation ICMM has established ten principles of sustainability, which embrace ethics, corporate governance, sustainable development, human rights, risk management, biodiversity, product development and transparent auditing. The ICMM requires that its members openly declare their performance according to these ten principles, as per the Global Reporting Initiative (GRI). Furthermore, an external audit of this report is obligatory, as well as a report on the extent to which these ten principles have been implemented, in terms of various action plans and management systems (International Council on Mining and Metals, 2008). As stated in the report, the IUCN is involved in the issue of 'no-go areas' for the mining industry: discussions are currently in progress between the ICMM and the IUCM. The UN Convention on Biological Diversity is an important tool in addressing issues concerning the mining industry and biodiversity. There are also many mineral-and-land-specific initiatives. An example of the former is the Cyanide Management Code, which contains recommendations as to how industrial companies should manage cyanide. An example of a land-specific initiative is the Mining Association of Canada's "Towards Sustainable Mining" initiative (Mining Association of Canada, 2008).

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Appendix A – Mining methods

This appendix presents different mining methods in greater detail. Table 1 provides a review of the most common mining methods employed by industrial-scale mining operations.

Table 1 The most common mining methods employed by industrial-scale mining operations. Source: Hartman and Mutmansky, 2002.

Location	Group	Method	Deposit
Surface	Mechanical methods	Open pit/opencast mining	Metal, nonmetal, coal
	Hydraulic methods	Leaching	Metal
Under-ground	Methods not employing backfill	Room-and-pillar mining	Almost exclusively coal, occasionally nonmetals
		Stope-and-pillar mining	Metals, nonmetals
		Sublevel stoping	Metals, nonmetals
	Methods employing backfill	Cut-and-fill stoping	Metal
	Caving	Longwall mining	Coal
		Sublevel caving	Metal
		Block caving	Metal

Open pit

The mechanical extraction of ore at the surface is conducted in open pits. An open pit mine is one in which the layer of soil and rock (overburden) covering the deposit is excavated to expose the ore for subsequent extraction. This method employs a high degree of mechanisation and mass production technology. The method is capital intensive but labour efficient. Productivity is high, the cost is relatively low and the method avoids the health and safety risks associated with underground mines.

Practical application of the method is limited to a depth of about 1000 metres, and the extraction of ores featuring concentrations of less than 0.8 - 0.4 cubic metres per ton is not commercially feasible. This type of mine is highly dependent on the weather, and extreme weather can stop mining operations completely. Exploitation of such a great area means that a similarly great area must be rehabilitated, and large quantities of waste must be managed (Hartman and Mutmansky, 2002). Another type of open pit mining is strip or opencast mining, the big difference being that the loosened layer of rock and soil above the body of ore is not dumped as waste but is immediately used to refill sections of the mine where excavation of the ore has been completed. The material handling process is thus limited to a single unit and is normally managed by a single machine. This means that mining activities are concentrated to a more limited area, and rehabilitation can be conducted in parallel with mining operations. This method is commonly used for the extraction of coal (Hartman and Mutmansky, 2002). There are a number of other examples of mechanical mining techniques, but they are employed to a much lesser extent than the open pit method.

Leaching and other methods of hydraulic extraction

Hydraulic extraction methods involve the extraction of minerals using water or other liquids. Leaching is most commonly used of these methods, but other hydraulic methods are also employed. Some of these methods involve major environmental risks and are therefore described here, even though their use is extremely limited (Hartman and Mutmansky, 2002).

Leaching refers to the chemical extraction of minerals with water or other liquids, in which a leaching solution for catalysing precipitation of the desired mineral is injected into the ore through a borehole. The dissolved ore is pumped up again and the desired mineral is extracted. The method can be applied to the ore direct in the rock (‘in-situ leaching’) or to ore that has been extracted by other methods and subsequently crushed, ground and piled in heaps, referred to as heap leaching. The advantages of this method are low cost, a minimal labour requirement, the method can be applied to relatively small deposits, and it can also complement other extraction techniques. The method is also advantageous from a health and risk viewpoint. The drawbacks are the need for a considerable area of land where waste products from the leaching process can be tipped, as well as the fact that such products may also contain chemical residues and pose a hazard to plants and birds. It can prove difficult to rehabilitate the site and the environment may be damaged. There is a particularly strong risk that groundwater may be contaminated (Hartman and Mutmansky, 2002). In environmental terms, it is critically important that all of the solution is collected, to preclude any seepage into the surrounding natural environment. It is therefore also important to take into account how much extra water is added in the form of rain, and to ensure that this is also recovered for cleaning (Mining, Minerals and Sustainable Development, 2002).

Extraction can also be achieved by hydraulic mining or hydraulicking, in which metals are extracted from a bank of ore by directing a powerful jet of water under high pressure, to dislodge the rock and soil. Water, sand, soil and the desired metals are flushed into a channel from which the metals can be washed. This technique is used to mine gold, diamonds, titanium and platinum, for example. The benefits of this method are high productivity, relatively low cost, fairly simple equipment and the fact that only a few mineworkers are needed. The drawbacks are that this method can have a dramatic impact on the environment unless stringent precautionary measures are applied (Hartman and Mutmansky, 2002). Water consumption is huge and it can be difficult to control the way the bank is broken down. Extraction can even be carried out underwater, by dredging. There are many different methods within this group of mining techniques.

Room-and-pillar mining

Room-and-pillar mining is a non-backfill mining technique that is applied to horizontal deposits. The mined material is extracted at regular intervals across a horizontal plane, leaving four-sided ‘pillars’ of untouched material to support the overburden, leaving open areas or ‘rooms’ between them. Afterwards, the ore in the pillars is also mined.

This method is often used to mine coal. The benefits of the method are relatively high productivity, relatively low costs, the relative ease of rehabilitation and that it lends itself to mechanization. The drawbacks are possible subsidence when mining the pillars and the fact that post-closure rehabilitation is a laborious process. It is also inflexible, costly to mechanize and involves possible health-and-safety risks (Hartman and Mutmansky, 2002).

Stope-and-pillar mining

Stope-and-pillar mining is very similar to room-and-pillar mining, differing mainly in the fact that the intervals between pillars are less regular, causing the pillars to be irregularly located, either where the ore is low grade or simply on a random basis. Unlike room-and-pillar mining, this method is used not for coal but for metals and nonmetals. Benefits include flexibility, relatively high productivity, relatively low costs, relative ease of rehabilitation and it lends itself to mechanization. Drawbacks are a need for regular monitoring and maintenance of the pillars, to ensure that the pressure on them does not become excessive, the method is costly to mechanize, some of the deposit is lost because the pillars are virtually impossible to mine and the potential health and safety risks (Hartman and Mutmansky, 2002).

Sublevel stoping

In sublevel stoping, a large vertical mining space is excavated in the deposit, although it is not this that is mined. Instead, all drilling and blasting are carried out from below. The benefits are relatively high productivity, relatively low operating costs, it can be mechanized and is not especially labour-intensive. It is also simple to ventilate and can be rehabilitated when the mine is closed. The drawbacks are that the method is expensive and complex to develop, the extraction plan is inflexible and blasting can cause vibration, violent air currents and structural damage. Vertical Crater Retreat (VCR) is a variant of sublevel stoping that has been patented by a Canadian explosives company. The VCR technique employs a special blasting pattern, the idea being that the amount of explosives used is tailored precisely to the amount of ore to be blasted (Hartman and Mutmansky, 2002).

Cut-and-fill stoping

Cut-and-fill stoping is a mining method that involves backfill. There are several backfill techniques, but cut-and-fill stoping is the most widely used, because of its versatility.

There are no less than eight different cut-and-fill stoping variants, but generally speaking, mining is conducted in horizontal shafts that are backfilled on an ongoing basis as the work progresses. The material used as backfill can be gangue (left over from the mining process), tailings, or material with a greater bearing capacity, if so required. Mine companies often try to use backfill with as high a density as possible. The pillars serve to support the mining room during the work, prior to backfilling.

The advantages of cut-and-fill stoping are that the method offers relatively high productivity, offers great flexibility in choosing what to mine, development costs are low and the possibility of being able to rehabilitate the entire mine is considerable. Furthermore, the surplus material from mining operations can be used as backfill, and it offers a relatively high level of safety. The drawbacks are high operating costs, the fact that backfill management can absorb 50 percent of operating costs, that it also disrupts mining activities, that the method is labour intensive and demands a high degree of professional skill and good management and, finally, that the compacted material used as backfill can cause ground subsidence (Hartman and Mutmansky, 2002).

Longwall mining

Longwall mining is one of a group of mining methods collectively referred to as ‘caving’, and means that all the ore is mined and once this is done, the cut or ‘goaf’ that is left is allowed to collapse. Longwall mining is used with horizontal, flat sided and relatively thin deposits, mainly coal. The ore is extracted in long drifts and a durable and powerful system of powered roof supports hold up the roof of the drift as mining operations progress. This method offers the highest productivity for coalmines and can be mechanized and automated. Costs are relatively low, it is fairly feasible to restore the mine once mining operations are concluded and the health and safety risk is small. Negatives include the fact that mining operations cover a large area, the method is inflexible and mining can only be conducted in one location at a time. Consequently, if problems arise, the entire project can be delayed. It is also costly to move the powered roof support system (Hartman and Mutmansky, 2002).

Sublevel caving

Sublevel caving is used to mine vertical, massive deposits, mainly metals and nonmetals. In sublevel caving, the main mining process involves top slicing, although the ore is mined from below from the various subdrifts. As the ore is mined by drilling and blasting, a ‘cave’ is created in the gangue at each subdrift (see fig.1). The benefits of this method are that it can be largely mechanized, it is appropriate for commercial-scale operations, productivity is relatively high, the mine can be rehabilitated and health and safety risks are low. The drawbacks are a relatively high dilution of gangue in the ore, the risk of subsidence and high development costs (Hartman and Mutmansky, 2002).

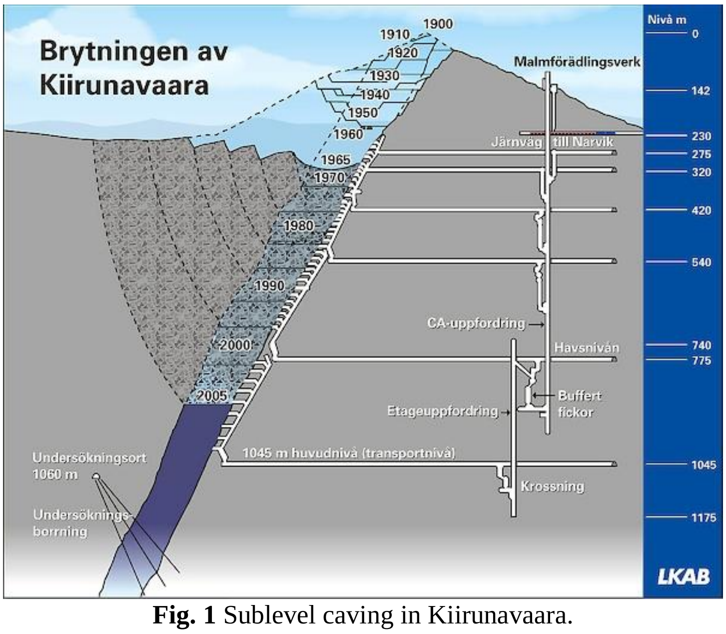

Fig. 1 Sublevel caving in Kiirunavaara.
Source: http://www.lkab.com/?openform&id=2DB6

Block caving

Block caving is the one underground mining method that can compete with surface mines in production capacity and costs. The method involves undercutting a body, pillar or block of the ore, so that the rest of the ore can be mined from below. Normally, both the ore and the surrounding rock are mined. The benefits of block caving are high productivity, relatively low cost, the mine can be largely rehabilitated and caving is achieved through cuts, eliminating the need for drilling and blasting. Furthermore, the health and safety risk is small. The drawbacks are that mining operations embrace a wide area, stringent monitoring is required for success, development costs are considerable and the development itself stretches over a long time. The method is also inflexible and shock waves pose a risk (Hartman and Mutmansky, 2002).

Appendix B – Environmental problems

This appendix describes a number of environmental problems, named in the Report, in greater detail.

Acidification

Before humanity started to cause acidification, rain possessed a pH of 5.5. The fact that this value was not neutral, i.e. pH 7, was a consequence of the transformation of atmospheric carbon dioxide into carbonic acid (Fröberg and Höglund, 2004). Acid rain and acid drainage (AD) from the mining industry are the two main reasons for acidification. Acid rain is the consequence of emitting sulphur dioxide or nitrous oxides into the atmosphere. Combustion of coal and the refining of metals from sulphidic ores are the primary sources of sulphur dioxide emissions. Nitrous oxides are generated by power stations and vehicle exhausts. These compounds react with air and water in the atmosphere, forming acids that are subsequently deposited as rain. If the pH value of rain falls below 5, the rain is considered to be acid. Acid drainage occurs when sulphide ions are present in the ore or waste, reacting with air and water to form acids. This is a common problem when mining coal, uranium, base metals and the by-products of these minerals. The extent to which acidification impacts on water and land where it occurs depends on the buffering capacity of the rock and soil in the area in question. The buffering capacity of granite, for example, is poor, while limestone's ability to compensate for acidification is considerable. The combination of minerals in mine waste has a decisive role in determining the relative acidity of leachate: silicates and carbonates are often able to raise the pH-value (Fröberg and Höglund, 2004). Fish are generally highly sensitive to changes in the pH-value and may die as a result of even very small variations. An additional effect of acidification is to enhance the concentration of metal ions in the water, which can also be highly damaging to fish stocks. Acid drainage leads to a further problem if mine waste is released into rivers, where ferric(III)hydroxide can form a film of rust over many algae, with adverse consequences for these species and those that feed on them. Watercourses that have been subjected to acid drainage from the mining industry are often noted for supporting only a few species of fish, and in very small numbers (Jackson and Jackson, 2000).

Climate change

The combustion of fossil fuels, production of oil and gas and methane emissions from agricultural activities are some of the main sources of greenhouse gas emissions, which are considered to be a highly likely cause of climate change (Mining, Minerals and Sustainable Development, 2002). There are many different types of greenhouse gas. The Kyoto Protocol to the United Nations Framework Convention on Climate Change lists the following greenhouse gases: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride. Research scientists believe that the rate at which the average temperature of the Earth will change in this century will exceed that of the past 10 000 years. The probable consequences are that melting glaciers and the thermal expansion of seawater will cause a rise in sea level, which could lead to major flooding.

Increased evaporation will accelerate the hydrological cycle, producing increased rainfall and the risk of flooding. Some areas will experience rising temperatures or more frequent extremes of weather, in the form of storms and phenomena such as El Niño (Jackson and Jackson, 2000).

Discharge of heavy metals

Metals are released as a consequence of natural processes such as weathering and erosion. The natural concentrations of different metals vary from place to place, but are mainly dependent on the nature of the metals present in the bedrock (Fröberg and Höglund, 2004). The operations of the mining industry and associated industries lead to the unnatural discharge of lead, mercury, cadmium, zinc, tin and other metals. The extent of the environmental impact of such discharges depends on the chemical form these metals take. In certain chemical forms, these metals can be directly absorbed by marine organisms, leading to their subsequent accumulation in the food chain. One such example is mercury. It poses no environmental hazard in its inorganic form, but when released into the natural environment, the action of microorganisms transforms it into monomethylmercury. This compound is water soluble and acts as a powerful neurotoxin, both on fish and humans (Jackson and Jackson, 2000).