MineFacts

A collection of facts about mining, the permit granting process, economy and the environment

Aitik. Photo: Boliden

MINEFACTS

A collection of facts about mines

This material has been produced as part of the project MineFacts, an EU funded project carried out during 2017 with the purpose of producing easily accessible, objective and general facts about prospecting and mining operations, which if wished can be used without restriction, above all by municipalities and regions in northern Finland, Sweden and Norway. We chose to produce this material in all three languages, and to add nation specific facts where we considered it necessary (for example the different countries have partially different steps in their permit granting processes for mining permits). The material also includes a slimmed PowerPoint presentation which may be studied and used without restriction.

The project aims to increase the general level of awareness in this area and to give municipalities and regions help, based on this material, to communicate objective and fact-based information to their inhabitants – for example in a situation where new or increased prospecting or mining operations can be expected.

In the course of the project we visited over 30 different municipalities in the three countries to gather information about what the municipal representatives in these municipalities consider extra important to include in the material. Through the year we have organised workshops, worked with reference groups and presented the project in different contexts. After the activities described, our opinion is that the need for this type of basic, objective and fact-based information is considerable.

We would like to express our gratitude to everyone who in different ways has contributed during the project and at the same time welcome those wishing to use this material. A big thank you to EIT RawMaterials which financed the project and so made our work possible.

The chief project manager has been Laura S Lauri, GTK (The Geological Survey of Finland).
Other parties working with the project have been SGU (The Geological Survey of Sweden), Luleå University of Technology, the University of Lapland, LTU Business and Sodankylä Municipality. In addition, AA Sakatti Mining, Boliden and Nussir have participated.

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EIT RawMaterials
Connecting matters

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1. Do we need metals?

What are metals? How much do we use and for what?

METALS AND SOCIETY

Since the early history of mankind we have used metals in everything from implements and buildings, to food supplements. Originally they were metals that are easily accessible, for example copper and iron.

Through smarter technology the number of metals we use has increased exponentially. Several metals are used to form alloys to make use of the properties of different metals. Others are used in technology such as touch screens, circuit boards or fibre optic cables.

With an increasing population and rising standard of living in many places, the need of metals is increasing. For example, a person uses on average 600 kg of copper and 15 t of iron, and several tons of other metals and minerals.

Metals are elements extracted from our bedrock. Metals are finite resources, that is to say there is only a certain quantity of metals. At the same time, metals are elements which in many cases can be recovered an infinite number of times without losing their properties. However, there can be technical difficulties in recovering certain metals. Our metal production comes from mines, which extract so-called primary raw materials from the bedrock, and from waste recovery. Steel, which is the most common metallic product, occurs in thousands of different varieties and sorts and can contain a number of metals which have been alloyed into steel.

Figure 1. Zinc from Sweden. Zinc is used in for example stainless steel. Photo: Boliden.

FACT:
How many elements do we use every day?

Modern technology, such as smartphones, solar cells, electric cars and airplanes, need many different materials and elements to work. Throughout the ages, the number of elements used by people in different objects has increased dramatically, from only a few to almost all in the periodic table. The figure below shows a handful of the most important, but far more elements are used today in smaller amounts.

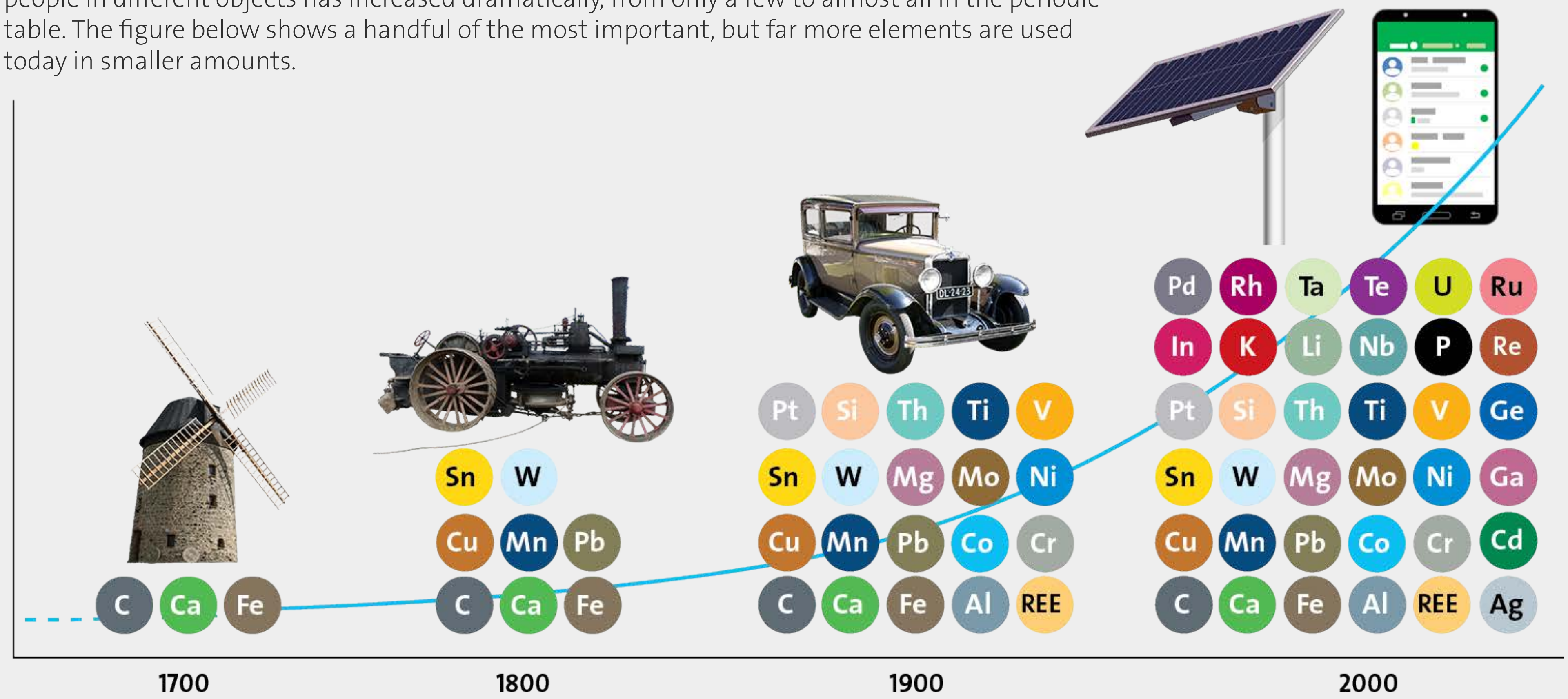


Figure 2. Illustration: SGU with inspiration from BP.

2. Is recovery sufficient?

Our modern society needs metals and minerals, but can these needs be met through recovery? What metals can be recovered, and to what extent?

RECOVERY IN SWEDEN

The world's need of metals and minerals is great and growing. Recovery and recycling are among the most energy-effective actions to limit the environmental impact of the mining and minerals industry. Our society generates huge quantities of waste. The development of among other things electronic products in the last decade has been very fast, as regards both the volume and number of products. At the same time, decreasing quantities of raw materials are used per product. This development is expected to continue, in turn making the lifecycle of the products shorter and shorter. Recovery therefore is becoming increasingly important, while becoming a growing challenge. A mobile telephone today can contain around 70 different elements, many of which are metallic elements whose recovery is of interest.

In Sweden we are good at metal recovery. Since the 1950s the recovery of precious metals and scrap containing iron, steel and base metals has drastically increased, steel scrap from 50 per cent to 92 per cent by the year 2010. As regards other less common metals, recovery is still at a modest level, but nevertheless we take care of about half of Europe's electronic waste in this country. Sweden's metal producing industry, one of our most important base industries representing high proportion of our export, largely takes its raw materials from Sweden's bedrock. But it also uses a high proportion of recovered metals. The table on the right shows the use of different metals in Sweden, and our production and how much is recycled, based on international statistics.

Table 1. Use, mining production and recovery of metals in Sweden, tons (WBMS April 2014, SGU 2014:3, UNCTAD 2013).

Metal	Use	Mine production	Recovery
Iron	4 326 000	27 285 000	2 032 000
Copper	121 800	82 760	65 300
Lead	17 000	59 466	49 300
Zinc	23 900	175 711	730
Aluminium	90 500	0	56 500
Nickel	25 000	0	14 610
Tin	70	0	0
Gold	2,6	6	10
Silver	35	340	27
Chromium	100 000	0	64 000
Magnesium	No data	0	0
REE	500	0	0

CIRCULAR ECONOMY

A circular economy means that one reduces society's need of prime raw materials through everything from better product design and new business models to improved technology, control methods and awareness, along with recovery and recycling. There are several important principles behind the circular economy:

- Waste is seen as a resource, now or in the future.
- Products are given a smarter design to simplify recovery.
- As far as possible, use recoverable and non-toxic materials to secure resource effective and toxin free cycles.
- Maximise the lifetime of products through repair, upgrade and forms for trading in products at the distributor.
- Simplify recovery through source separation and collecting materials.

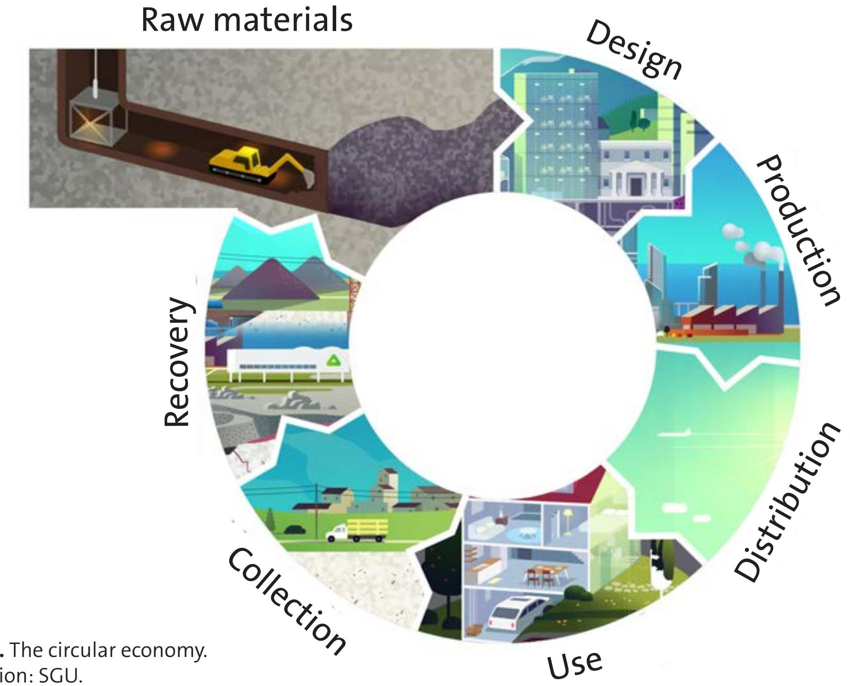


Figure 3. The circular economy.
Illustration: SGU.

WHAT METALS ARE RECOVERABLE?

Several metals, such as copper, steel and aluminium, are easy to recover. Recovery is often carried out by resmelting the metal and manufacturing new products. The process is simpler the more metal is present and if the metals do not need to be separated from each other. An aluminium can, for example, is simpler to recover than a circuit board of the same size, since the aluminium can be resmelted into new cans. The circuit board on the other hand contains many components and metals that must be separated. This can be done by crushing the circuit board into a powder and using different methods such as magnetism, density and chemicals to separate the metals and then resmelt them.

Some metals, such as rare earth metals, indium and beryllium, are difficult or impossible to recover using today's technology. This can be for several reasons, including ineffective separation, the resmelting removes desired properties or that volumes are insufficient to make recovery profitable.

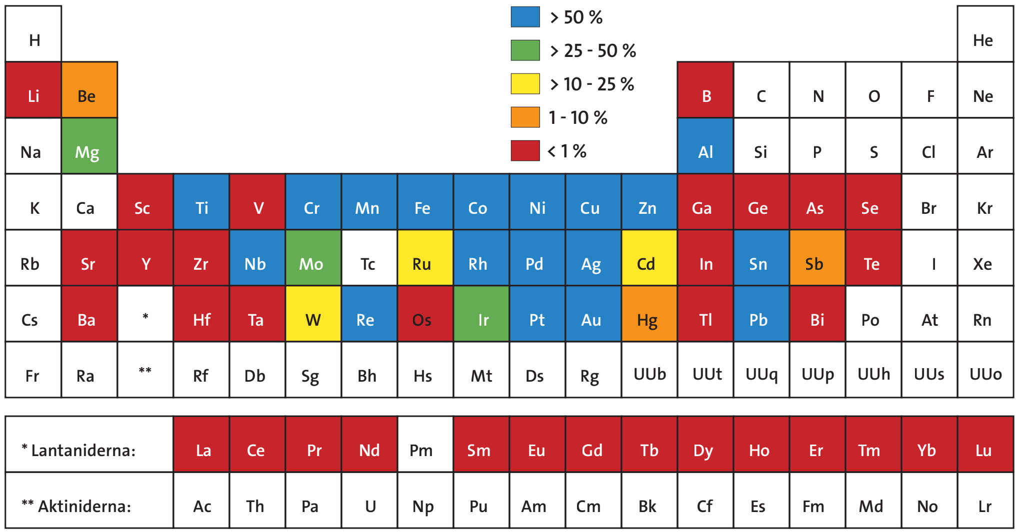


Figure 4. Degrees of recovery of 60 different metals in our society. For more than half, less than 1 per cent is recovered. Several of these metals are used in new technology and are so-called "critical materials" which are needed among other things in electric cars, mobile telephones, wind turbines and solar cells. Source: Source: UNEP 2013 (United Nations Environmental Programme).

IS RECOVERY SUFFICIENT?

The production of metals and minerals has never been as great as it is today, both from mining and recovery. At the same time, we are using more material than ever. Our increased need of new technology, means of transport, energy and food creates major challenges for raw material suppliers. Recovery is an energy effective way to produce raw materials, but is it sufficient to cover our increased needs? There are several influencing factors, above all access to waste for recovery and whether the right technology is available. Another important aspect is whether or not recovery is socio-economically and environmentally effective. It can for example be better to deposit waste, since it could release hazardous substances when recovered. Recovery might also be uneconomical if the technology is extremely energy consuming or if there is no demand within a reasonable transport radius.

Copper is one of the most recoverable metals: it retains its properties after resmelting, and is often found in large quantities without the need to separate it, for example in electricity cables. Despite this, recovery meets only around 30 per cent of the world's need every year according to ICSG*. This is perhaps because copper is used for a very long time, up to decades. Almost all the copper that has been extracted is currently being used in the community.

Steel, which is used among other things in infrastructure and vehicles, is the world's most recovered material. About 650 M t of steel came from recovered material in 2016 (Worldsteel**). By recovering steel, about 70 per cent of energy can be saved (Worldsteel) and carbon dioxide emissions are reduced by 58 per cent (BIR***). In all, about 40 per cent of the world's steel comes from recovered material every year (BIR).

Iron, base and precious metals are easier to recover than many of the other metals we use in our society, yet recovery does not meet the demand. For many less common metals, for example the rare earth metals cobalt and lithium, recovery amounts to less than 1 per cent. These are needed among other things for "green technology" such as electric cars, batteries and wind turbines. The high demand for metals and minerals means that recovery can at best only partially meet the demand.

* International Copper Study Group, www.icsg.org. ** World Steel Association, www.worldsteel.org *** Bureau of International Recycling, www.bir.org.

3. The permit granting process

What are the requirements for starting a mine in Sweden? What permits are needed? How is the environment protected? Who are affected and is there consultation with all parties?

THE PERMIT GRANTING PROCESS

Examination of permits for mining operations is a process involving a large number of players. From an operator declaring its intention to start exploration for ore to the start-up of a mine requires several different permits. The examination process is different from that for other environmentally hazardous operations in that besides the Environmental Code (1998:808) it also involves examination under the Minerals Act (1991:45). The intention of the Environmental Code is to promote sustainable development, which means that present and future generations are assured a healthy and good environment, while the purpose of Sweden's Minerals Act is to ensure that society has a supply of essential metals and minerals through the extraction of specially identified natural resources, so-called concession minerals*.

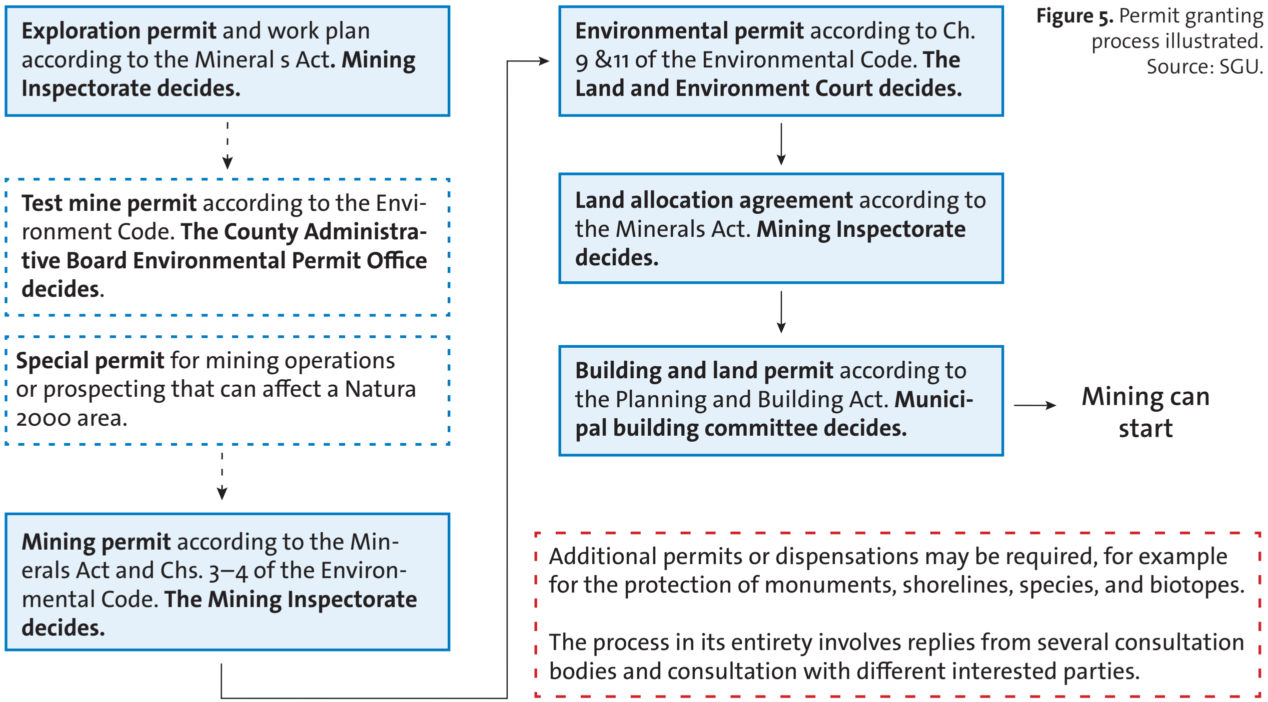


Figure 5. Permit granting process illustrated. Source: SGU.

* antimony, arsenic, beryllium, lead, caesium, gold, iridium, iron occurring in the bedrock, cobalt, copper, chrome, mercury, lanthanum and lanthanides, lithium, manganese, molybdenum, nickel, niobium, osmium, palladium, platinum, rodium, rubidium, ruthenium, silver, scandium, strontium, tantalum, tin, titanium, thorium, uranium, vanadium, bismuth, tungsten, yttrium, zinc, zirconium, andalusite, apatite, brucite, fluorite, graphite, kyanite, ceramic or refractory clays, magnesite, pyrites, nepheline syenite, sillimanite, pit coal, rock salt or other salt occurring in a similar way, iron pyrites, heavy spar, wollastonite, oil, gaseous hydrocarbons and diamond.

FACTS:
What bodies monitor mining operations?

MINING INSPECTORATE

The Mining Inspectorate plays a central role in examining mining operations and hearing applications for exploration and mining permits. Another important mission is to supervise compliance with the Minerals Act (1991:45). The Mining Inspectorate also provides information about legislation and ongoing prospecting and processing for companies, interested parties, authorities, media and the public.

The Mining Inspectorate is a separate decision-making body sorting under the Geological Survey of Sweden (SGU) but has independent status in exercising authority. The Mining Inspectorate is headed by the Chief Mining Inspector who decides on issues in accordance with the Minerals Act.

THE CAB

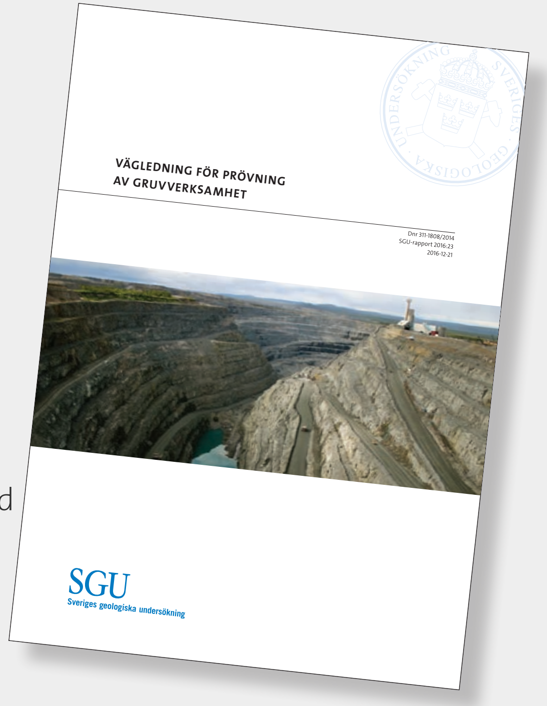
The County Administrative Board plays an important role in the examination of mining operations. It participates e.g. as a referral body in examining exploration permits. For some exploration work a permit is also needed from the County Administrative Board, for example driving offroad. When examining a mining permit, consultation also takes place with the County Administrative Board. The County Administrative Board Environmental Permit Office decides on test mining permits. Consultations are also held with the County Administrative Board on a number of occasions. Besides being an important element in examination, the County Administrative Board often also has a supervisory function in mining operations. There are 21 county administrative boards in Sweden.

LAND AND ENVIRONMENTAL COURT

The environmental permit for mining operations is one of the last stages before operations can begin. The same rules in the Environmental Code apply to mines as to other operations impacting the environment. The health and environmental effects of a mine and protective measures if the mine is granted a permit are examined by the Land and Environment Court. Here decisions are also made on the conditions for operations, for example noise, damming, dumping, limiting emissions and so on.

There are five land and environment courts in Sweden. They are located in Umeå, Östersund, Växjö, Vänersborg and Nacka district courts.

Do you want to know more?
Read *Vägledning för prövning av gruvverksamhet (in Swedish)*. SGU, 2016.
http://resource.sgu.se/produkter/sgu-rapp/s1623-rapport.pdf




The iron ore mine in Kaunisvaara, Pajala. Photo: Niclas Dahlström

FROM MINERAL EXPLORATION TO MINE

The route from an exploration permit to an active mine is long. As of 2016 there were 604 exploration permits, but only 14 active mines. Few exploration permits move onto an application for a mining permit, and even fewer become mines. The time from the start of exploration work to a mine possibly opening is difficult to estimate, but is often a question of decades.

Before an application can be made for a mining permit and environmental permit, prospecting for ore often continues for several years. If ore is found, this is followed by long studies to draft an environmental impact assessment, technical description and waste management plan, together with the design of a mine and any tailings storage facility and concentration plant.

Examination by the Mining Inspectorate for a mining permit in many cases takes about 1½ years or more. In cases that are controversial, the application can be referred to the government, which means that the case takes further time. The application time for an environmental permit often takes as long as for a mining permit before a decision can be announced. This examination too can take longer, depending among other things on whether there are any appeals.

Figure 6. Bedrock mapping and boulder tracing are common prospecting methods. These methods have a very low impact on nature. Illustration: Boliden.

WHO IS AFFECTED BY THE MINE?

During the examination process there are opportunities for the public, involved parties, organisations, municipalities and authorities to put forward opinions regarding the application. There is also a right to appeal. When the terms of the environmental permit have been made public there is also an opportunity for other players to suggest conditions.

The conditions are intended to limit environmental impact and disruption to the public and residents in the area, in the form of noise, dust and vibrations.

It is not uncommon for a mine or planned mining operation to be geographically located within a reindeer herding area and to impact the reindeer industry. In such cases, the Sámi community or communities in question own special rights. When the working plan for exploration work is put forward it is obligatory for the operator and involved parties to be in contact. The information and dialogue that needs to be pursued before an application from mining permit is based on voluntary undertakings and initiatives. Contact is important for the parties' understanding and acceptance of each other's operations.

A description of the impact on the reindeer industry shall be included in the EIA that the operator drafts. How comprehensively the reindeer industry in the area is to be addressed depends on the extent to which the reindeer industry in the area is impacted by the planned operations. In addition to a description of the impact, the operator shall also propose damage limitation. Even limited disruption from mining operations can be of major significance, for example as regards the impact on migratory routes or calving areas.

Figure 7. Marking of calfs. Photo: Niclas Dahlström.

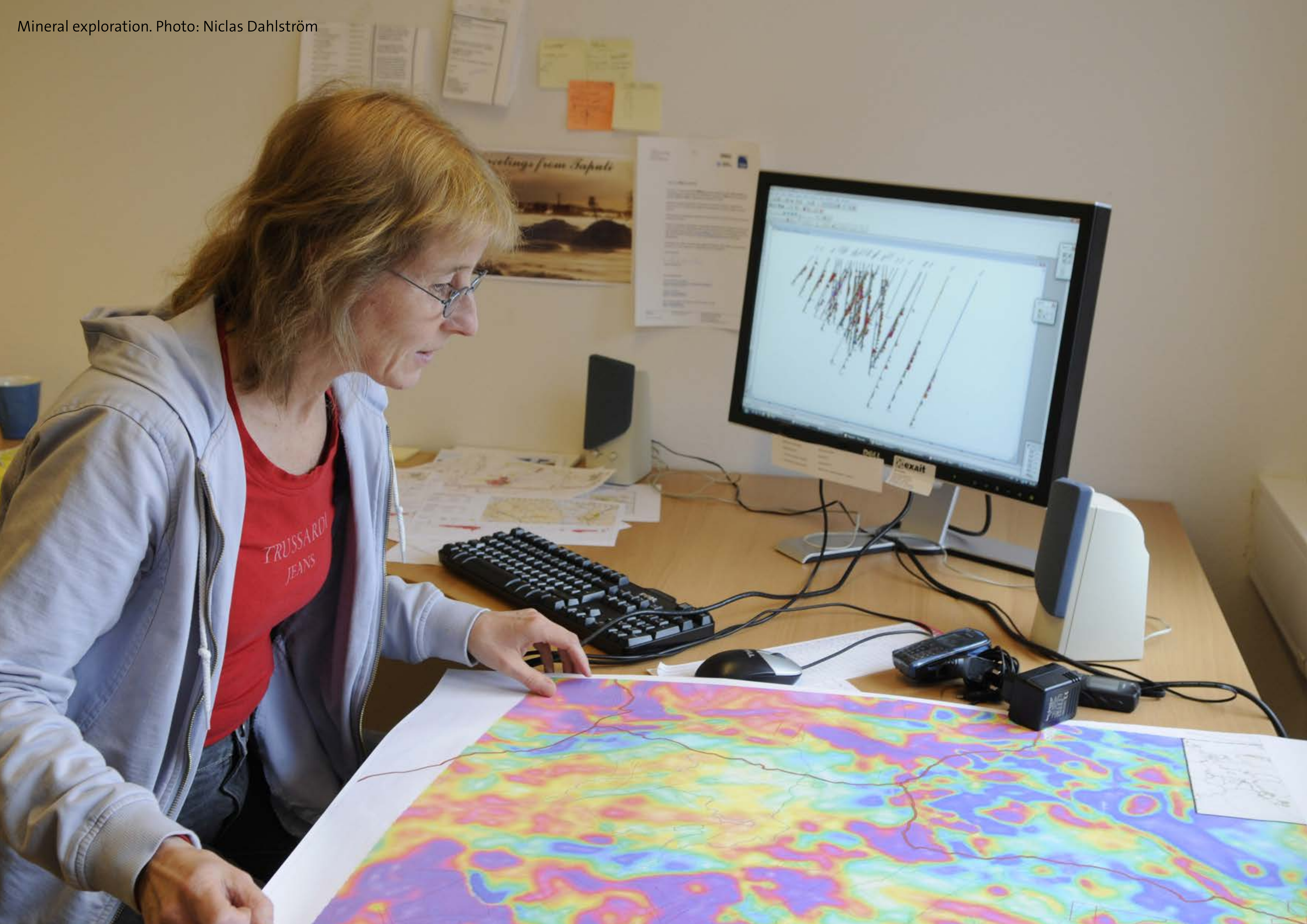
THE SÁMI, MINING POLICY AND ILO 169

The issue of mines and land claims has long been a much debated matter. Mines occupy large land areas and affect people and industries in the area. Since several ore deposits have been found in northern parts of Sweden, the impact on the Sámi has been of especial importance, above all with regard to the reindeer industry. The reindeer industry operates over large areas and is therefore affected by several different operations that occupy large land areas, including mines, forestry, wind power and tourism. The Sámi Parliament has a cross-party consensus on its approach to mines and prospecting in Sápmi (Lapland). The Sámi Parliament considers that until ILO 169 and the Nordic Sámi convention are rectified and implemented in Sweden, further mineral exploitation and prospecting shall not take place in Sápmi. They also consider that the Sámi Parliament shall have a veto right, affected Sámi people shall have a veto right, and affected Sámi communities shall have a veto right. They consider that to reach a yes vote to exploitation, everyone must be in agreement – there must be consensus for exploitation to take place*. The ILO** is one of the United Nations' so-called specialised agencies and is responsible for issues to do with working conditions, discrimination and indigenous peoples work and life conditions. Convention 169 contains a number of regulations on commitments within different areas. The governments in the countries that have ratified the convention are to ensure that the rights of indigenous peoples are protected and that their integrity is respected. This means among other things that special actions shall be taken to protect their institutions, property, land, culture and environment. As regards mines, the convention could mean in practice that where possible compensation would be payable to the Sámi for mine start-ups on the traditional lands they use. Another demand is consultation regarding setting up, partially a requirement to Danny. There are also a number of regulations which are open to interpretation, such as the rights of indigenous populations to influence the decision making process when setting up on land they traditionally use. This does not however mean a veto right. Sweden has not yet ratified ILO 169. Several of the Parliamentary parties have previously declared their positive attitude towards the convention, but that the consequences have not yet been sufficiently researched. An 1999, SOU***-published a report on ILO 169 and the measures demanded to enable ratifying the convention.

* https://www.sametinget.se/73597 hämtad 2017-07-12

** International Labour Organization

*** Statens offentliga utredningar 1999:25 Samerna - ett ursprungsfolk i Sverige. Frågan om Sveriges anslutning till ILO:s konvention nr 169.
http://www.regeringen.se/rattsdokument/statens-offentli ga-utredningar/1999/03/sou-199925/



Mineral exploration. Photo: Niclas Dahlström

4. Who benefits from the mine?

Mining is one of Sweden's most important export industries, but who benefits from mining? How many jobs does it provide and what kind of jobs are there? What happens in case of bankruptcy? Who pays?

MINING IN NORTHERN SWEDEN

This chapter focuses primarily on mining in the two northernmost counties of Sweden – Västerbotten and Norrbotten. This region had 11 active mines in 2017 and the majority of them are operated by LKAB and Boliden.

The most recent available data from Statistics Sweden on mining employment covers the year 2015 and it shows that 5 881 worked in mining* in northern Sweden. As figure 8 shows, mining is a much larger employer in Norrbotten than in Västerbotten, but the mining companies are of course important employers at the local level in both counties.

The total value added by mining in northern Sweden was 10,3 billion SEK in 2015. In 2011 when iron ore prices were at an all-time high, the regions mining industry generated a total value added of about 22,9 billion SEK. This can be understood as mining's contribution to gross regional product (GRP, sometimes called regional GDP). GRP reflects the value of all goods and services produced within the region, minus the value of inputs.

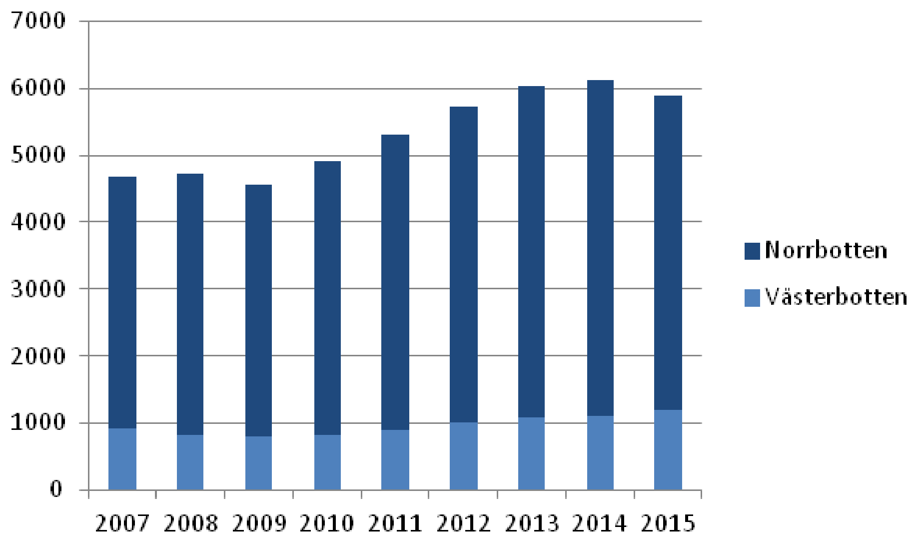
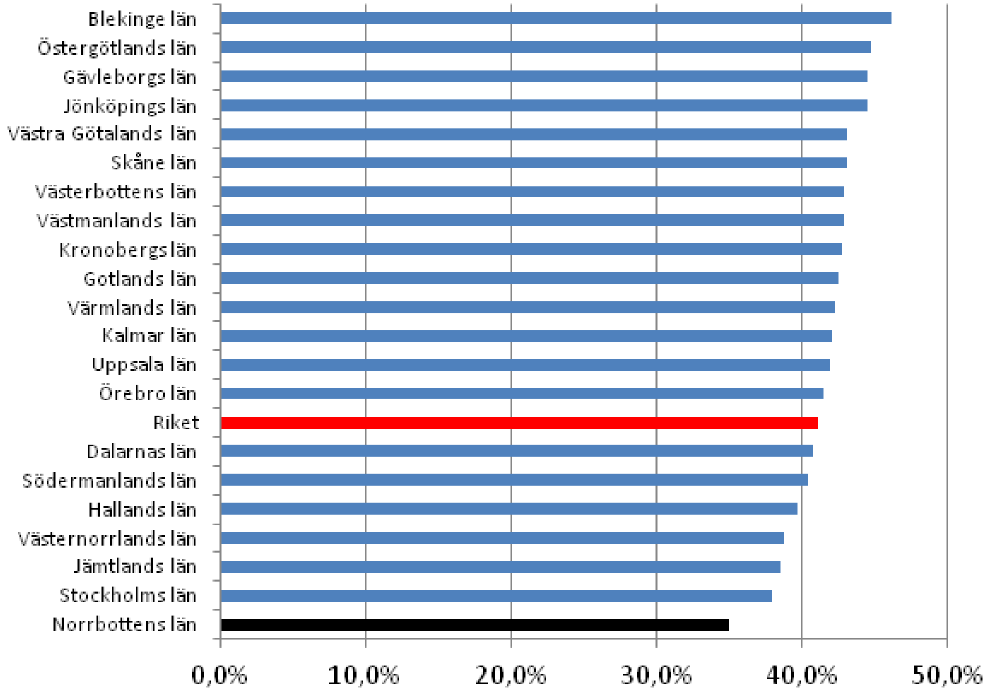


Figure 8. Employees in mining in northern Sweden.

* Defined as "extraction of minerals" in the statistics (SNI2007 classification).

Mining constitutes a particularly large share of the regional economy of Norrbotten county. In 2011, the mining industry generated approximately 20 % of GRP in Norrbotten. This can be compared with petroleum's share of Norway's GDP which was 14 % in 2017*. Norrbotten is relatively specialized on capital intensive natural resource industries. This contributes to a relatively high GRP, especially with respect to the size of the population. In the recent years, Norrbotten has consistently ranked among the top three Swedish counties in terms of GRP per capita. A drawback of this apparently productive specialization is that the regional economy has to cope with the effects of volatile commodity price cycles. Mineral resources are comparative advantages for northern Sweden, but there is limited regional or local ownership. The main direct regional income generated by mining is wages earned in the industry. GRP essentially reflects the sum of wages and profits generated in a region, which makes the sum of wages as a share of GRP an interesting comparative indicator on regional economies. Figure 9 provides a comparison of such indicators, calculated with data for the year 2011.



* http://www.norskpetroleum.no/en/economy/governments-revenues/

Figure 9. Wage sum as a share of GRP in 2011 by county

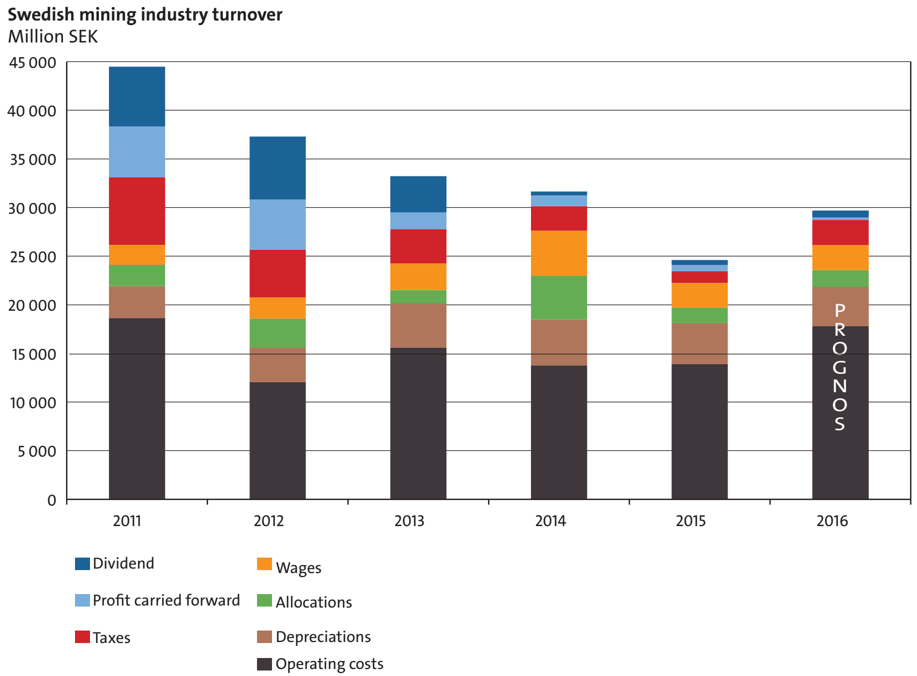
As figure 9 shows, the GRP-share of wages was lower in Norrbotten than in any other Swedish county in 2011. During the same year, Norrbotten had the second highest GRP per capita in Sweden. Large profits are clearly generated in Norrbotten and not least by mining. But who benefits from it? The next section will address that, focusing on the mining industry.

WHO BENEFITS FROM MINING?

There are many actors that may benefit financially from mining, but it is important to note that there may also be those that are negatively affected. This is addressed in a later section of this chapter. In this section, we adopt a 'gross perspective' and attempt to compile a list of different types of actors who may benefit from mining, with respect to the Swedish tax- and regulatory regime. These include:

- Owners (dividends)
- State (taxes, fees, dividends from state-owned LKAB)
- Employees (wages)
- Suppliers of a wide range of input goods and services (contracts)
- Land owners (fees)
- Other actors who benefit from increased demand (hotels, retail trade etc.)
- Municipalities and regions (income tax payments)
- Miscellaneous beneficiaries (research funding, sponsorships etc.)

SGU has compiled key figures on the Swedish mining industry which provides information on the size of profits, dividends, tax payments and wages in relation to turnover. These are provided in figure 10 and they illustrate how volatile the last few years have been. Combined profits were approximately 15 billion SEK in 2011, but the aggregated outcomes in 2014 and 2015 were losses. The main reason was bankruptcies (Dannemora and Northland Resources). Profits were up again in 2016 to approximately 1,5 billion SEK.



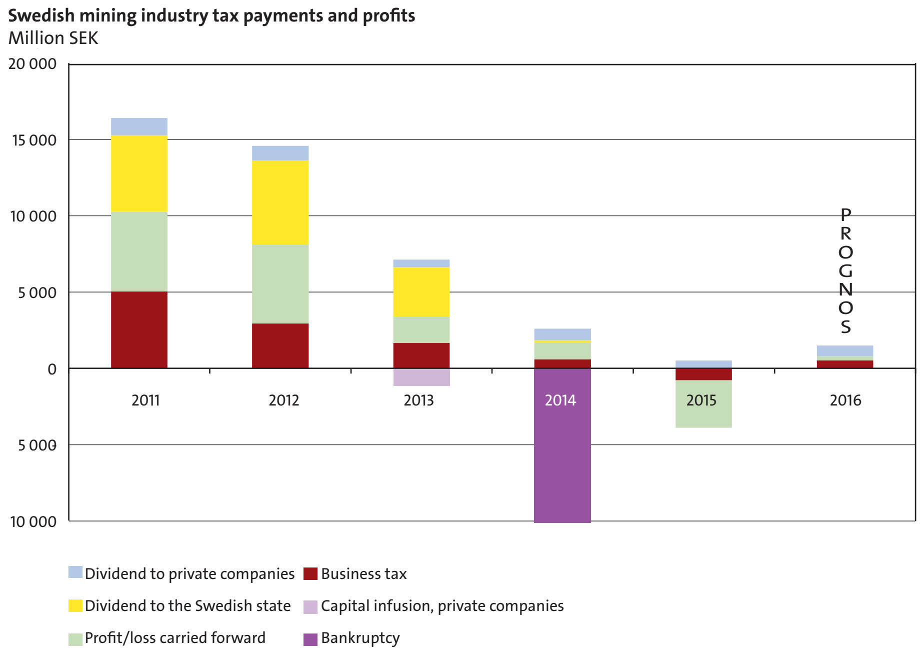


Figure 10. Key figures on the Swedish mining industry. Source: SGU, http://resource.sgu.se/produkter/pp/pp2017-1-rapport.pdf

COSTS AND BENEFITS

Mining can generate substantial profits and other positive economic impacts, but a mine always has an environmental impact and it can also affect individuals, communities and other economic activities in negative ways. In the field of economics, positive and negative impacts are often characterized as 'benefits' and 'costs'. In some contexts, researchers may attempt to value these costs and benefits. The sum of benefits, less costs, then equals net social benefit – i.e. the value for society. We will certainly not attempt to value the net social benefits of mining here, but we will provide conceptual examples of different positive and negative impacts - benefits and costs – that may be associated with a mine. Many of these benefits have also been addressed in more detail in the previous section.

Positive impacts: benefits
The most obvious positive economic impact of a mine arises when it generates profits for its owners. In the Swedish context, a firm which generates profits also pays corporate tax. In addition, a mine generates jobs, both direct and indirect (e.g. in suppliers of input goods and services) and the employees earn incomes. In the Swedish context, these employees pay regional and local income taxes which contribute to financing the welfare system. Mining companies are also required to pay a mineral fee to land owners and the state. Finally, other external benefits may arise, such as increased demand for services, consumption spending, improved infrastructure etc.

Negative impacts: costs
Developing a new mine will always incur substantial private costs (capital and operating costs) for the company and its investors. These are internalized in the investment appraisal and should be recovered through sales of the product, and hopefully with an additional profit. There may however arise a number of negative effects that are not taken into account in the price of the product. This may create burdens for actors that do not enjoy benefits of the mine in the same way as its owners. In the field of economics, such negative effects are often called 'external costs' and they comprise different negative side effects of production or other activities. Common examples

include various negative environmental impacts (pollution, dust, noise etc.) that are not paid for by the 'polluter'. A mine can also displace other forms of land use in an area, including for example reindeer herding, nature based tourism, or recreation (as well as combinations of these and other forms of land use) and cause social disruption. These are examples of negative impacts which can be difficult to value. There is also a risk that relatively large scale mining operations may crowd out other local economic activities by driving up wages and prices in general. Finally, mining communities have to live with cyclical commodity markets which means that investing in for example housing may be risky.

Net social benefit: benefits-costs

The discussion we outline above leads to the conclusion that there is an important trade-off between positive and negative impacts – benefits and costs – associated with a new mine. From a socio-economic perspective, one can argue that there should be an assessment which determines if the outcome is acceptable or not. This will of course depend on the context. The environmental impact of a new mine is an important aspect and it will depend on for instance mining technology, the type of mineralization etc. This is addressed in more detail in another chapter and it is important to note that mining in Sweden has to comply with a strong environmental legislation.

Another important aspect to consider is the localization of a new mine – will it impact a local community and/or is there competing forms of land use in the area? It should be emphasized that net social benefits of mining are practically never estimated, at least in Sweden. Such calculations are highly complex and would likely be hard to legitimize. In practice, stakeholder dialogue and expert analyses in environmental impact assessments (EIA) and social impact assessments (SIA) can provide guidance on the relevant trade-offs between positive and negative impacts and identify appropriate mitigation strategies. During the recent decades, the role of local communities has become more influential due to the mining industry's increased focus on sustainable development and social license to operate.

The underground mine in Garpenberg, Sweden.
Photo: Boliden

LOCAL/REGIONAL SOCIO-ECONOMIC EFFECTS: WHAT DOES RESEARCH TELL US?

This section summarizes lessons from research on mining and socio-economic development in northern Sweden. The text is largely based on the final report of the Interreg Nord-project SusMinNor (see Lesser et al. 2016)*. First of all, the local/regional economic impact of a mine is an important aspect of its sustainability, which is clearly interconnected to its ”social license to operate”. If a mine does not generate local benefits of any kind, the affected community will only experience its adverse impacts. Research has also emphasized that 'local vs non-local' is a key factor when it comes to labour, supplier contracts, and other benefits. The local community can absorb more of the benefits generated by the project if there are strong (or at least some) linkages between mining and the local economy. The formation of such linkages requires that sufficient capacity exists (or can be developed) in terms of skilled labour, competitive suppliers etc.

Contemporary mining companies tend to focus on core activities and outsource related functions. This provides SME opportunities in for instance various mining services, consulting, equipment development and manufacturing etc. Local SME's may struggle to compete with regional, national or even international competitors in procurement processes. One way of enhancing local capacity is by pooling SME resources to bid on contracts together, and to pursue dialogue with the mining company about potential opportunities.

Access to housing can act as a bottleneck for local development. Without sufficient housing in a mining community, there will be a greater reliance on long-distance commuting to the mine. In the Swedish tax regime, income tax is paid where a person lives and if a mine relies largely on non-local labour, the local municipality will miss out on potential tax revenues. This may be difficult to resolve, as housing investments in mining-dependent communities may be associated with risks due to the volatile nature of commodity markets. In addition, the workers may simply prefer to live elsewhere, independent of the local housing situation.

* http://ltu.diva-portal.org/smash/get/diva2:1070321/FULLTEXT01.pdf

Concerning different forms of spill-over effects of mining, research from Umeå University (see Knobblock, 2013*) has pointed out the importance of both formal and informal networks between mining companies and other actors. The existens of such networks in Västerbotten county is said to have contributed to an innovative environment with a number of new businesses in both core- and related mining activities. Furthermore, Wiberg, (2009)** has argued that successful regional cluster building processes during a mining boom can reduce the vulnerability of labour demand compared to growth in mining and exploration alone. The success of such a process is said to depend on the ability to internationalize and expand the market of the cluster; the level of entrepreneurship (i.e. having, or attracting, individuals with the necessary drive and capabilities); and sufficient access to skilled labour. This view promotes the development of skills and competencies around mining as sources of regional competitive advantage, rather than the resource itself.

There are also studies that have attempted to measure the economic effects of mining, or the economic impact of individual mines. A recent study by Tano et al. (2016)*** showed that labour incomes in northern Sweden had increased rapidly among workers in mining and also in construction, during the mining boom that emerged around 2005. The researchers also found evidence of spill-over effects on labour incomes in non-mining sectors in the mining towns.

During the mining boom, several impact studies used simulation models to estimate the impact of planned mines on local and/or regional employment. These estimates suggest that a new mine can generate between 30-120 additional jobs for every 100 direct job at the mine. The variation between these estimates can largely be explained by different assumptions about the future demographic development, ranging from modest to expansive). Can a mine reverse a declining demographic development?

A recent study by Moritz et al. 2017**** used an econometric approach to analyze mining industry employment in northern Sweden ”ex post” – i.e. the researchers examined the actual development and did not rely on simulation models. The study found that the mining industry had generated approxi-

* http://journals.brandonu.ca/jrcd/article/view/714/161
** http://www.georange.se/upl/files/10047.pdf
*** https://doi.org/10.1016/j.resourpol.2016.03.004
**** https://doi.org/10.1007/s13563-017-0103-1

mately 100 additional regional jobs for every 100 direct job in mining. If this result is accurate, one can crudely estimate that the mining industry in northern Sweden generates approximately 12 000 jobs direct, indirect and through induced effects (i.e. generated by increased demand for services, consumption spending etc.).

Figure 11. Working the ground to prepare for mining in Kaunisvaara, Pajala. Foto: Niclas Dahlström.

CASE STUDY:
THE KAUNISVAARA MINE IN PAJALA

The development of an iron ore mine in the village of Kaunisvaara outside Pajala was discussed already in the 1970s, but the plans were not realized until decades later when high iron ore prices had made the mineralization interesting again. A Canadian exploration company - Northland Resources - announced plans to develop a mining operation and the small municipality which had experienced declining development saw the potential for new jobs and positive development. The Kaunisvaara project in Pajala offers an opportunity to observe how a relatively small local economy changed during the development of a new mine. We emphasize that these observations are intended as an empirical example and should not be interpreted as a rule of thumb. The effects are context specific, at least to some degree.

The construction of the Kaunisvaara mine started in 2010 and iron ore concentrate production commenced in late 2012. The mine was producing at about 50 % capacity in 2014 when it closed due to bankruptcy, which has been attributed to a combination of capital cost overruns and falling iron ore prices. At this point, direct employment was approximately 200 at the mine and 200 at the transport sub-contractor. By calculating the change in a few common indicators on economic development between 2009 (pre-mining) and 2014 (the last active year), we can observe a strongly positive development in local employment and incomes during the mining era. Local respondents who followed this development closely in their professional roles have argued that the majority of this growth can be attributed to the mine either directly or indirectly. These indicators are reported in table 2 and figure 12. Specifically we find that:

- The growth rate of local per capita income greatly exceeded national average during the mining era.
- The local labour market participation rate was below the national average before the mining era, but had surpassed the national average in 2014.
- Nearly 800 new local jobs were created between 2009 and 2014. This crudely suggests a 1:1 ratio of direct to indirect employment.

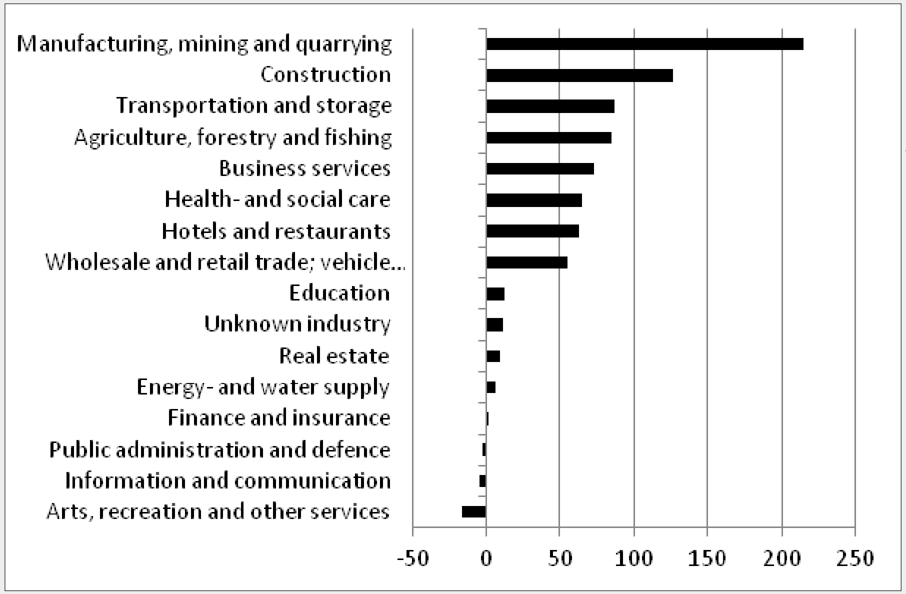


Figure 12. Change in local employment by sector: 2009 (pre-mining) to 2014 (end-year)

	Income (sum of wages) per capita*		Growth, 2009-2013	Average annual growth (%) 2009-2013	Labor market participation rate**			
					2009		2014	
	2009	2013			Men	Women	Men	Women
Pajala	98,4	121,9	23,5	6,00%	73,8%	72,4%	82,90%	81,00%
Sweden	138,6	149,2	10,6	1,90%	76,2%	73,1%	78,5%	76,0%

Table 2. Change in selected socio-economic indicators in Pajala.
* thousand SEK in constant (2013) prices
** % of people in ages 20-64

THE MINERALS MARKET

Mining operations take place all over the world, and the price of raw materials is decided by global supply and demand. Demand is governed largely by the economic cycle, our consumption of goods and investments in infrastructure and industry. Sweden is one of the biggest mining countries in the EU and is also a considerable producer of zinc and lead globally, in 10th and 9th place respectively among the world's biggest producers. As of 2016, 91 percent of the EU's iron production was in Sweden. At mid-2017 there were in all six companies extracting metallic ores at 14 places in Sweden. The industry is above all dominated by two companies: the state-owned LKAB, which produces iron ore, and the privately owned Boliden Mineral AB which produces base metals, tellurium, gold and silver. The mine cluster and its indirect effects contributed 128,000 mSEK to the GNP in 2013, corresponding to about 3.3 per cent*. Sales in the mining industry amounted to 37,300 mSEK in 2012. Dividends, provisions and state taxation amounted to over 10,000 mSEK. In Sweden it is a legal requirement that prospecting and mining operations be operated via Swedish-registered companies (AB).

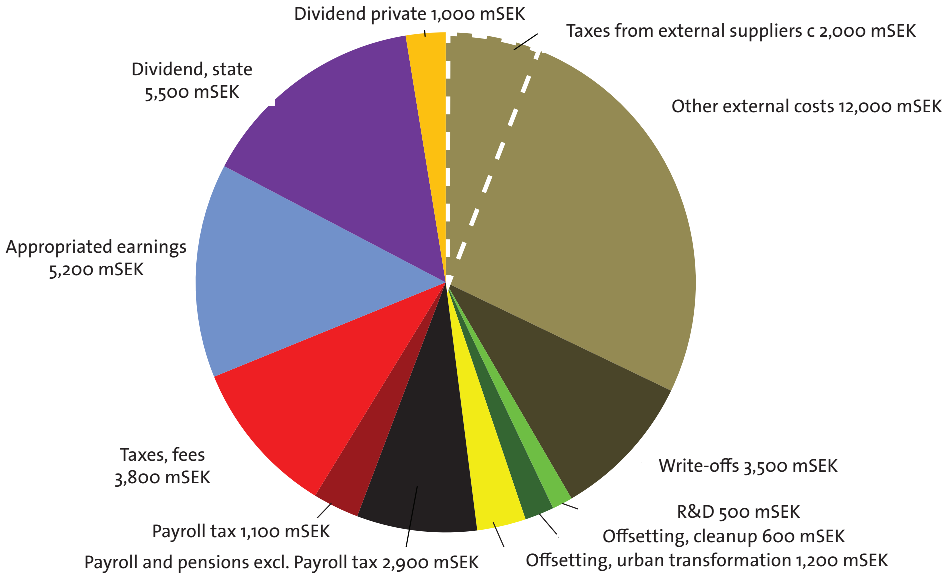


Figure 13. Sales, taxes and profits of mining industry 2012. Total 37,300 mSEK. Source: SGU.

* Tillväxtanalys. Sverige – ett attraktivt gruvland i världen? En internationell jämförelse (Rapport 2016:06).

WHAT HAPPENS AFTER BANKRUPTCY?

Companies which for different reasons cannot continue operations can apply to file for bankruptcy. In the case of mines it can among other things be a question of liquidity problems, difficulties in achieving profitability or low metal prices due to a changed market. Mines are special in that they are so-called hazardous operations. When operations stop, waste management is also closed down, which can mean increased risks to our health and the environment.

In Sweden, PPP applies (Polluter Pays Principle) which means that the polluter shall always pay for the pollution. To ensure that the community (=taxpayers), does not have to pay for restoration of mines and waste dumps, or other environmentally hazardous operations, an economic guarantee shall be put up by the company.
The economic guarantee varies depending on the operation and shall be considered ample and provide for the need of security at any time*. In a report from the Swedish National Audit Office in 2015, the total guaranteed amount was 2,700 mSEK.

Since the turn of the 21st century up until 2017, four newly started mines have become bankrupt. In these cases the economic guarantee has not been sufficient and the intentions of the law have not been fulfilled. This has led to negative environmental consequences and major restoration costs to the state. Since then, several measures have been taken, including a report from the Swedish National Audit Office** and work has been done to produce a strategy for sustainable management of mining waste***. Mining operations have taken place in Sweden for over 1,000 years, which has led to mines and waste which are not managed by anyone today. In cases where there is no responsible party for historical mines, the state takes over and pays for any needed restoration. This has occurred, among other places at Gladhammar mines in Kalmar County. Mining went on here in the 19th century which left mining waste from which metals leached into nearby lakes and watercourses. Restoration began in 2011 and has cost around 63 mSEK.

Up until the end of 2016, the total cost to the state for restoration of both bankrupt and historical mines amounted to about 710 mSEK.

* Miljöbalken (1998:808) 16 kap. 3 § ** Gruvavfall – Ekonomiska risker för staten (RiR 2015:20)
*** http://www.regeringen.se/regeringsuppdrag/2016/04/uppdrag-att-ta-fram-strategi-for-hantering-av-gruvavfall-och-gora-en-bedomning-av-kostnader-och-atgarder-for-efterbehandling/

EMPLOYMENT

A mine needs many employees, among others machine operators, truck drivers, geologists, miners, drillers and chemists, as well as accountants, legal staff and so on. As of 2016*, in all about 7,200 people were employed in the mining industry, divided among 16 mining operations (including concentration plants). The proportion of women is still low, 19 per cent, but has steadily risen since the beginning of this century.

The number employed in a mine varies greatly depending on its size. The number employed in production in the Lovisa mine is just under 20, while the open pit mine Aitik has about 700 employees. A medium-sized mine in Sweden often has between 150-400 employees.

WORKING IN A MINE

Sweden has one of the most advanced and high-tech mining industries in the world. Production is becoming automated at a high rate, and about half the jobs in a mine are above ground. About 200 different occupations can be represented in a mine, everything from geologists and environmental engineers to HR specialists and truck drivers.

Sweden has high demands on worker safety, and the mining industry is no exception. The industry works constantly to improve safety in the mines.

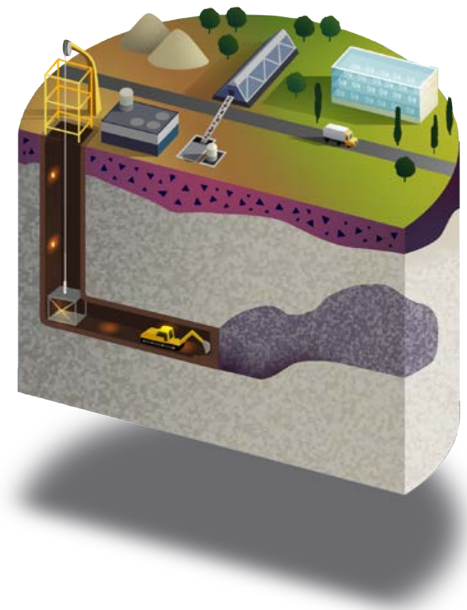


Figure 14. A mine needs a good deal of workforce and skills. Picture from the SGU school portal Geology on the interaction between geology and society. www.sgu.se/geologisk

* Source: SGU. Bergverksstatistik 2016.

5. Exploration

Why prospect and explore for minerals? What do you prospect for and how?

PROSPECTING

New deposits are found by prospecting. Geologists work to find clues as to where there are important metals such as copper, gold and nickel, and minerals such as apatite (needed in fertiliser) in large quantities. Deposits are hard to find, and prospecting takes a long time.

Ore is a naturally occurring material from which minerals of commercial value can be extracted at a reasonable cost. A deposit can contain several ores and many different metals, which need to be concentrated in quantities 100-10,000 times greater in the deposit than in the surrounding bedrock. Ore is created deep in the earth's crust through different geological processes. Prospecting activities aim to locate the ore, which can be detected by its properties. Many ore minerals are heavy, magnetic or electrically conductive, and their presence in the bedrock shows in geophysical measurements. You can often see high metal content in surrounding ground and groundwater due to the ore.

During the most recent ice age, the inland ice lifted small sections from the ores at the surface and transported them along its routes. Geologists need to find these routes and interpret them to find the ore.

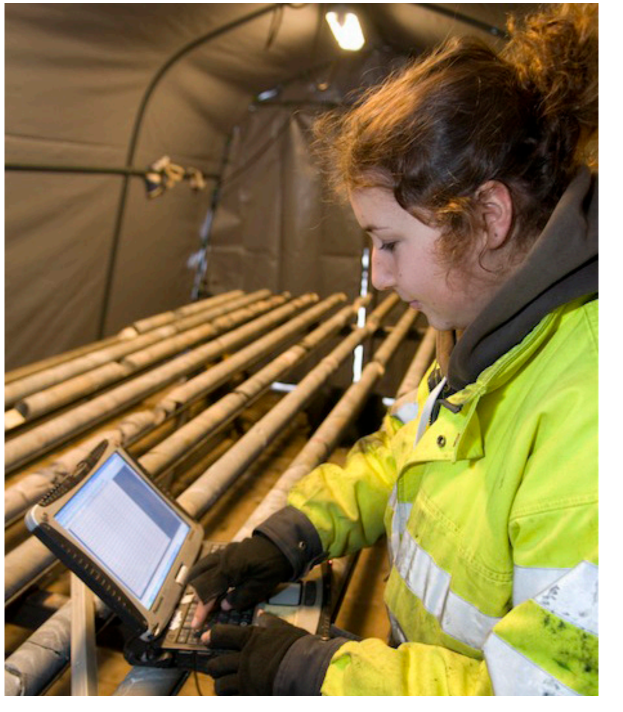


Figure 15. Drill core logging. Photo: Niclas Dahlström.

THE LONG PROCESS FROM PROSPECTING TO A MINE

Prospecting activities usually begin in an office, where all existing data on the bedrock and its chemical and physical properties are reviewed to determine whether the area is favourable to certain types of mineralisation and ore. Different types of rock concentrate different metals, so that if a company is looking for gold, it looks for rock types that are favourable to gold deposits. If the company's interest is in industrial minerals, such as calcite or dolomite, it looks for other rock types.

Field investigations in prospecting projects usually start with geological mapping and sampling to get a perception of the rock types and their composition in the area.

The investigations are carried out by geologists who walk around in the area, hammering small pieces of stone from rock surfaces. Geophysical measurements are made either by ground personnel walking with measuring instruments, or from the air from low-flying aircraft. Geophysical measurements are needed to steer mapping and sampling to the most favourable areas.
After the first mapping and sampling phase, which usually takes several years, all the collected data are analysed. If nothing interesting is found, the area is abandoned. If there are signs that something interesting can be hidden in the ground, the next phase of field investigations is initiated. Based on the collected information, the investigations usually target a more limited area with high potential for discovering ore. Heavier and more expensive methods such as diamond drilling are used to gain information from deeper down in the ground. Based on drilling results, the prospecting activities are either stopped or again steered more exactly to the area with the most favourable indications.

Out of 1,000 prospecting projects, only about one gives sufficient indications of the existence of ore in the area. The entire process from the initial field mapping stage to the start of mine planning usually takes several decades, even if there are favourable geological indications of ore in the area. Most prospecting projects fail to find ore.

FACTS:
The exploration process

Exploration takes a long time, and few projects lead to mines. The reason may be several, for example, that the find is too small or low grade, the prices are too low or there is difficulty in obtaining a permit. If everything goes as the company thinks and you manage to find a mineral resource and get all the permits, then the process can take between 20-30 years in general. The process is illustrated in a simplified manner below. Between the steps, a number of permits are required, which you can read about in Chapter 3.

0 years — **Exploration process** — 20-30 years

Project initiation
- Project start
- Selection of area
- Office work

Field investigations
- Searching for anomalies
- Mapping

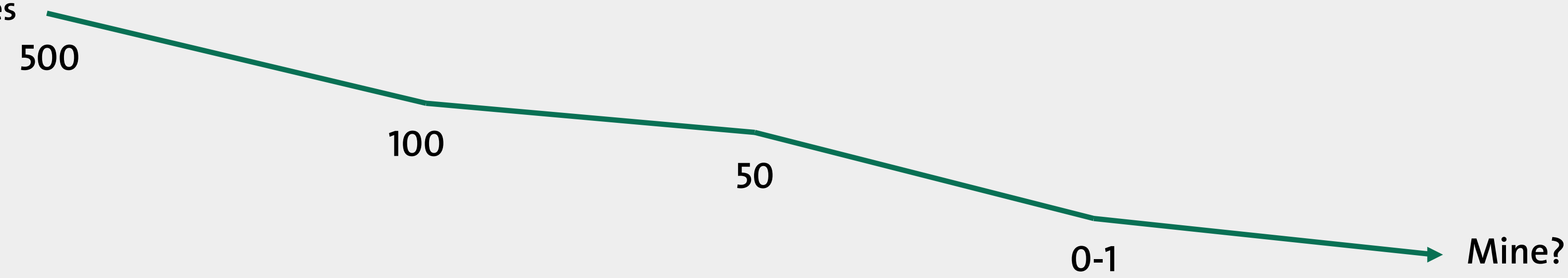
Target evaluation
- Target selection

Field work
- Drilling target
- First drilling phase

Field work
- Investigations of a potential mineral occurrence
- Second drilling phase

Resource estimation
- Mine planning initiated

Amount of projects in phases



6. Geology and mining

Geology is the study of the Earth and its component parts. What does our bedrock look like and how do we best extract metals? What does a mine look like, and what types are there?

MINERAL DEPOSITS FORM THE MINE

Our bedrock was formed several million years ago. Different processes have contributed to the formation of different types of rock in different places. Mineralisations, concentrations of valuable minerals, are formed during certain processes. If these mineralisations are considered economically viable to extract, they are called ore.

Several factors are considered when calculating the mineability of a deposit. Important factors are the cost of extracting the deposit, the metal content and its location. Copper ore with a content of 0.3 per cent is probably not worth extracting if it lies at a depth of 1000 m, but can be interesting if it is at the surface. This is because extraction costs are lower in an open pit (at the surface) than in an underground mine. In an open pit, more low-grade ore can be extracted with a lower content, while underground mines mean more expensive operation. If deposits with a higher concentration are found at great depth however, underground mines can be profitable. In Sweden there are mines reaching depths of more than 1,400 m. The location of the deposit decides which type of mine can be set up. For example, an open pit mine cannot be started if the deposit is at a depth of 1,000 m.

The quantity of ore extracted every year, the rate of extraction, differs between different types of mine. An open pit means that more ore can be extracted at a lower extraction cost. The offer also means that lower ore content can be extracted, which means that more ore must be extracted every year to achieve profitability in the mine. This is the case for example with the open pit called Aitik, where large quantities of low-grade ore are extracted. In the small underground Lovisa mine a small quantity is extracted each year, but comprises more high-grade ore.

The size of the mine depends on several factors, among other things how large the deposits are, how large the investment is, the mining method and so on.

MINES AND TYPES OF ORE

In general, ore can be divided into three types: sulphide ore, iron ore and gold ore. The types of ore differ among other things in how they are processed, their composition and their general environmental impact.

Sulphide ore consists of sulphur compounds. Sulphide mineral is mineral comprising sulphur compounds. Such compounds that are of economic interest include zinc blende, lead glance and chalcopyrite. Several base metals, such as zinc, lead, copper and nickel, are extracted from sulphide ores. Even gold and silver can be extracted from them, often as by-products. Since sulphide ore contains large quantities of sulphide minerals, they are often associated with greater environmental risks than many other ores. This is because all sulphide minerals weather or decompose quickly in contact with oxygen. Read more about sulphide mineral in the fact box on the next page.
It is often only iron that is extracted from iron ore, but there can be other metals and substances in the ore. There are several types of iron ore minerals, magnetite and haematite ore being the most important. In Sweden, most of the iron ore is extracted from so-called apatite iron ore. It takes its name from the high content of apatite mineral, which contains phosphorus. The apatite iron ores in the active mines contain about 70 per cent iron. They always have a very low content of sulphide mineral and are therefore generally less hazardous to the environment. In Sweden there are also skarn iron ores, which unlike apatite iron ores can contain large quantities of sulphide mineral.

Gold often occurs together with other metals such as silver and platinum metals, but can also occur in among other things sulphide minerals. Several of the most important gold ores are formed in gold seams in quartz or other valuable types of rock. Gold is also extracted largely from older sedimentary placer strata and sulphide ores. The content of sulphide mineral in gold ore varies. In the Björkdal mine in Sweden, waste is produced that is reused outside the mine as road building ballast and other infrastructure. Gold ores can however also produce hazardous waste.
The proportion of tailings occurring is related to the content in the ore. Iron ores, which have a high content (often over 30 per cent) generate less tailings than sulphide ores (which are often of a lower grade from 0.1 to a few percent).

FACTS:
Sulphide mineral and the environment

SULPHIDE MINERALS

Sulphide is a group of minerals whose anion is the sulphide ion S^{2-}. Common sulphide minerals include pyrite, lead glance and pyrrhotite. Several sulphide minerals contain valuable substances. These minerals are formed in reducing (oxygen deficient) environments, where sulphur and metals form a compound. Sulphide mineral is stable as long as conditions are oxygen deficient, but becomes unstable in contact with oxygen or other oxidising substances. For this reason, mining waste containing sulphide mineral is often covered in dense layers of soil or water to prevent oxygen reaching the waste.
Pyrite (FeS_2) is the most common sulphide mineral. When pyrite comes in contact with sufficient oxygen, the mineral weathers through oxidisation. That means that the bonding between sulphur and iron his broken and the iron enters an aqueous acid solution together with sulphate. The reaction also releases hydrogen ions, which lower the pH value and makes the water acidic. Similar reactions take place with most sulphide minerals, but then with other metals which enter solution.
Sulphide minerals can also continue to weather in contact with oxidisation agents other than acid, including Fe^{3+}, which can form after pyrite has already weathered. That means that if mining waste that is already heavily weathered is deposited in oxygen deficient conditions, there is a risk that weathering processes continue nevertheless. This is the reason why among other things tailings are deposited in water filled ponds soon after their appearance.

ENVIRONMENT

Several of the greatest environmental risks associated with mining waste relate to the weathering of sulphide minerals. All minerals weather, but sulphide minerals tend to weather much faster than many other minerals. They also contain large quantities of metals which can be harmful to our health and the environment, among others copper, cadmium and lead. When sulphide minerals weather, acidic metallic leach water occurs, Acid Mine Drainage, or AMD. When the pH value of the water falls, then many metals generally become more soluble and disseminate in the environment more easily. The acidic environment often also contributes to metals leaching more easily. One way to counteract the weathering and dissemination of metals is by raising the pH value. This is often done by adding lime to water and dumps. Sometimes this is done with a preventive aim at the same time as covering, when the lime is placed in different extractor. Read more about covering and environmental impact in chapter 7.

THE MINE'S ECONOMY

A crucial factor in the mine's economy is the value of the ore, which is often given in kronor per ton. The value is determined above all by the metal content of the ore, and usually amounts to between 200 and 2,000 SEK/ton. Metals of low value like iron therefore require ores with a high metal content (30-65 per cent Fe) for extraction to be economically viable. Deposits of gold and platinum which have a very high metal value on the other hand are profitable to extract even at a very low content (1 – 10 g metal/ton ore). Depending on the character of the deposit, the ore is extracted from an open pit or underground. If the ore occurs near the surface, it is usually extracted in (with large machines, giving high productivity and lower production costs. Further ore bodies are located deeper, the ore is extracted in an underground mine, which brings higher production costs and lower productivity. An underground mine also takes longer to setup, and demands considerably higher investment costs. The nature of the deposit and the choice of mining method also affect how large a proportion of the metal content in the ore body can be extracted. There is a certain loss of ore in all ore extraction, which means that between 5 and 30 percent of the ore is not extracted, just as the proportion of waste rock in mined ore reduces the metal content. Ore losses arise if for example parts of the ore must be left as a pillar to stabilise the extraction area, through irregularities of the ore boundary, so that all ore is not blasted away, or when all the blasted ore cannot be loaded up. The dilution by waste rock is caused above all by irregular ore boundaries, or poor strength of the surrounding rock.

Several different mining methods are used for underground mines, depending on the character and value of the ores. For smaller ore bodies with a high ore value, backfilling is often applied, which brings small ore losses, small waste rock dilution but higher production costs. Deposits with lower ore value require that extraction can be carried out at a lower cost through sub level caving or similar, which means a more large-scale process, which is thereby suitable only for large ore bodies. This often gives greater ore loss and greater waste rock dilution.

EXTRACTION AND THE ROUTE TO METAL VIA THE CONCENTRATION PLANT

Ore extraction can be carried out in an open pit or underground. Ore bodies are therefore often mined in open pits down to a depth of 300 – 400 m, below which normal extraction changes to underground extraction. In Sweden, it is underground extraction that dominates, but the majority of the world's extraction is in open pits. Extraction underground entails bigger costs and greater complexity, and there a richer deposit is required to achieve profitability. As an example where extraction takes place at deeper levels, the distance the ore needs to be transported to reach the surface gradually increases in length, and costs and energy needs thereby increase. Great depths often also mean increased rock stress, which lead to more stringent demands for rock reinforcement, which also increase costs. Great depth also means increased costs for and need of ventilation in the mine.

Underground extraction
In underground mines the ore is accessed by driving ramps or shafts down to the level where the ore is extracted. Many underground mines lack ramps, and people and machines must be transported in shafts. At the extraction levels, production areas are prepared, i.e. drifts (tunnels) are driven to the ore face. A development tunnel can be up to 200 m long. Where necessary, the walls and roof of the tunnel are reinforced with bolts, nets and shotcreting. The choice of mining method is made after consideration of a number of parameters, such as the placing of the ore body, the geology, geometry, rock mechanical conditions and the environment and surroundings. The form and appearance of the ore, which becomes apparent through prospecting, is of vital importance when selecting a mining method. A large compact or body can often be extracted cheaper and more effectively than a small irregular ore body, since one can then use more large-scale methods such as sub level caving. Sub level caving means that you create a cavity in the ore body by drilling and blasting, then the blasted material collapses of its own accord, the ore is driven away from underneath and the rocks surrounding the ore body is allowed to fill the cavity created. All infrastructure in the form of roads, shafts, ventilation etc. is placed in the rock alongside the ore body.
For smaller and more irregular or bodies, other mining methods are used, for example backfilling.

The mining operation in Garpenberg. Underground mining usually takes up less space than open pits. Photo: Boliden

For large ore bodies, and flat ore bodies, the room and pillar mining method is used.

Regardless of the mining method, extraction is through a process that involves a number of basic operations, a so-called blasting cycle.

The blasting cycle for the mining method called sub level caving is as follows:
After making a drift to reach the ore in the rock, so-called development, caving is carried out, where long vertical upward holes are drilled through the ore body in a fan shaped pattern. When the whole drift has been drilled, blasting agent is injected into the drill holes, which is called charging. After that, often once a day and at night when the mine is empty, blasting takes place. When the blasting has been done, the explosion gas is ventilated out, and in the morning, loading begins. In the LKAB mines in Kiruna and Malmberget the ore is removed from the drifts with loaders using buckets having a capacity of 17-30 tons. The ore is then dropped into a steep shaft, a so-called ore pass. The ore falls through the shaft and is collected in rock pockets just above the main level.

From the rock pockets the ore is transported in large trucks (Malmberget) or by train (Kiruna) and tipped into large rock pockets above the crushers (transport). In the crushers, the ore is ground down to 10 cm and then transported on long belt conveyors to the ore hoists or skips, which lift the ore to the surface. The ore is loaded automatically into the skips. Each skip can transport about 40 t of ore and travels at a speed of 17 m/s.

Open pit mining
One precondition for open pit extraction is that the ore body extends up to the surface or is not covered by an excessively thick layer of soil or rock. In most open pit mines, ore is extracted by so-called benching. The mining method is based on the ore being extracted in "benches" at successively lower levels. These benches give the open pit a characteristic stepped appearance.
Extraction in open pits is done in a number of productions stages. First the soil and rock layer lying over the ore is transported away, and then the ore is extracted in horizontal discs called stopes. Blasting holes are drilled by downward drilling, and when the blasted ore has been unloaded, production is successively moved to greater depths. The blasted rock is loaded on to tracks by loaders, and waste rock is transported by truck to a waste

rock dump, while the ore is transported to a crusher, either in the open pit or on the surface. After crushing, the ore is transported to a concentration plant for grinding, flotation, thickening and drying.

Figure 16. The open pit in Kevitsa, Finland. Photo: Boliden.

THE ROUTE THROUGH THE CONCENTRATION PLANT

The ore extracted in the mine needs to be treated to separate economically valuable mineral from mineral with little or no economic value. This is done in a concentration plant. How large a proportion of the material extracted has commercial value varies from mine to mine, but as an example, iron mines contain around 50 per cent iron bearing mineral, while a copper mine perhaps contains only 0.5-1.5 per cent copper minerals (e.g. chalcopyrite). A goldmine can be profitable with as little as one or a few grams of gold per ton of ore, i.e. in the order of 0.0001 per cent. Whatever is not commercially valuable mineral is separated out from the process as "waste rock". Dressing, or the concentration process, normally begins with crushing and grinding. In certain cases, pre-dressing is done, which means that coarse waste particles are separated from the ore flow at an early stage of the process. In iron mines this can be done by dry magnetic separation and in other cases there are also optical separation processes. Separating, which is normally done after crushing but before grinding, has both economic and environmental advantages. The production capacity of the plant increases in following stages so that the need of energy, water and chemicals per ton of extracted ore decreases, at the same time as coarser waste is more inert than if it were fine-grained, and additionally causes fewer problems with e.g. damming. Pre-dressing is not always possible, however, for example if the commercial mineral has small-sized grains. Generally, pre-dressing also leads to some loss of commercially valuable minerals. The goal when crushing and grinding is to reduce the ore to a particle size where commercially valuable mineral can be separated from the waste in subsequent separation processes. The most common separation processes are based on differences in the density, magnetic or surface properties of different minerals. There are also methods based on differences in electrical conductivity or optical properties. For iron bearing minerals, the magnetic separation method is chosen, depending on the mineral type, between high- or low-magnetic methods. Magnetite ores react strongly to magnetic fields and can be separated by low magnetic methods, while haematite is magnetically weaker and therefore needs high magnetic methods. Gravity based methods can be used when there are great differences in density between the minerals to be separated. For

Crushing ore. Photo: Niclas Dahlström

example, gold, tin, lead and tungsten-bearing minerals are usually heavy in relation to waste rock and can be separated using such methods. For the base metals copper, zinc and lead, the methods used are often based on surface properties. This is done through selectively adsorbing chemicals (called collectors) on specific mineral surfaces to make them hydrophobic, or water repellent. In flotation cells, the mineral suspension is mixed with air bubbles which attach themselves to the hydrophobic particle surfaces and lift the particles up to the froth phase, while waste mineral is not lifted by the bubbles and instead sinks to the bottom of the cell. There are also processes based on so-called reverse flotation, where instead the waste mineral is floated away from the commercial mineral. The process flows from the concentration plant which constitute waste are transported to tailings storage or mixed with cement and used in underground mines to fill mine tunnels, so-called backfilling. The commercial minerals concentrated (or dressed) through different separation processes need to be dewatered in the last stage of the concentration process. This is often done in several different stages, first through sediment based methods and later through pressure or vacuum filtration. The end product after concentration is then transported in powder form to smelting plants.

Figure 17. Early exploration in Finland, investigating soil samples. The geologist dug the samples and carried the till samples and Reino the dog carried geochemical samples and drinking water.

Restoration at the Svärtträsk mine. Photo: SGU

7. Life of mine and the environment

Mines can have a major effect on the environment, both the appearance of the landscape and the chemical environment. How long is a mine operational, and how is its environmental impact during and after operations?

THE LIFE OF THE MINE

Mining operations are generally continued as long as extraction is profitable and there are deposits left to extract. Profitability is largely steered by raw material prices. It is common for the mining company to prospect while the mine is operational. During operations, knowledge is gathered about the geology of the area and around the deposits. It is not unusual for further information about the deposits and the immediate area to bring the discovery of more ore near the mine. The number of years the mine will be in operation is usually decided by the mine's ore base. The ore base is the known deposits of ore, often expressed in millions of tonnes. The ore base divided by ore extracted per year gives the mine's life at the time of calculation.

As an example, a mine with 100 M t of ore and extraction rate of 5 M t per year has a life of 20 years. If prospecting near the mine leads to the discovery of a further 50 M t, the life of the mine will increase by 10 years if the production rate stays the same. For a newly started mine it is often stated how long it will be in operation, but that is not necessarily correct, since it only reflects the ore base the company has at the time. In several places in Sweden, there have been mining operations for a very long time even though it was previously thought that there was no ore left. With changed raw material prices, also rock previously considered an interesting becomes interesting to extract. New technology also contributes to this. Several open pits have gradually developed into underground mines as more ore was found at depth.

Figure 18. Garpenberg is Sweden's oldest mining area and has been extracting since the 14th century, probably longer. Today it is one of the world's most modern mines! Image: Boliden.

THE LIFE OF THE MINE

Ores are finite resources and eventually even the largest deposits become exhausted. When a new mine becomes operational, through drilling and analysing, an ore body will have been defined that is sufficiently well-known to present an ore base with a given content and volume. The ore base is then used to make a production plan for the best economic outcome, where the life of the mine becomes a function of the total known number of tonnes and the annual extraction rate.

In many cases at the time of starting up the ore body has not been completely defined – but a sufficient large quantity of ore has been found to ensure a sufficiently positive economic outcome and lifespan to begin operations. In most cases the life of the mine changes, which usually means extending operations. The reason is that new ore is added through further investigations in the known extensions of the ore body. Through prospecting near the mine, there can also be discoveries of previously unknown but nearby ore bodies, or ore bodies at greater depth which extend the life of the mine. Other factors can be increased productivity which reduces extraction costs and thereby makes deposits previously too low-grade profitable to extract. There is a similar effect from increased metal prices.

It is less common for the life of a mine to become shorter than planned. The reason is then often falling metal prices which mean that certain lower grade parts of the ore body become unprofitable to extract, thereby shortening the life. Other negative factors which can reduce the life are incorrect economic calculations, unsuitable mining methods which create ore losses or high waste rock dilution, problems with rock strength, difficulties to produce concentrate of sufficiently high quality, increased operational costs, etc.

TERMINATED OPERATIONS AND RESTORATION

When the mine is to be closed for different reasons, often because the ore base is exhausted or the operations can no longer be profitable, then by law* it must be restored and remediated. Remediation of a mine is often carried out to a so-called remediation plan. It describes how different types of waste are to be deposited, covered or in some other way handled to ensure optimum restoration. It also describes how the mine is to be remediated. Waste management differs depending on the hazard level. This is often governed by the content of sulphide mineral in the waste. Sulphide mineral weathers easily in contact with oxygen and must therefore be covered with other material to create oxygen free conditions. Read more about sulphide mineral in chapter 6.
Covering waste is often done using one of two main methods: dry covering ore water covering. Both methods aim to reduce the supply of oxygen to the waste.

Dry covering is done both with hazardous and less hazardous waste. In the case of less hazardous waste a so-called simple dry covering is done, and comprises a layer of till. In the case of more hazardous waste, among other things waste with a higher concentration of sulphide mineral, qualified dry covering is required. This contains different layers to ensure that conditions are oxygen free. A surface containment layer is dumped closest to the waste that comprises clay or clayey till, but different kinds of ash, slurry or liner products have also proven effective. Above the surface containment layer there are drainage layers to lead water away from the waste. This material is often more coarse grained. To secure the surface containment layer, a protective layer is also placed above the drainage layer. This is designed to protect from frost action and mechanical effects from among other things root penetration. The protective layer often comprises a thicker layer of till. Finally, vegetation is added to prevent erosion of the layers.

Water covering means that an artificial lake is constructed above the mining waste. The water should be stagnant to avoid oxydation. This method is common when covering tailings or filling an open pit where the waste can be deposited. The waste is often also covered by a layer of till and other material before water covering.

* 10 kap 5 § miljöbalken, 71 § utvinningsavfallsförordningen.

** Among other things bentonite mats or geomembranes of dense rubber sheeting.

FACTS:
Types of mining waste

WASTE ROCK

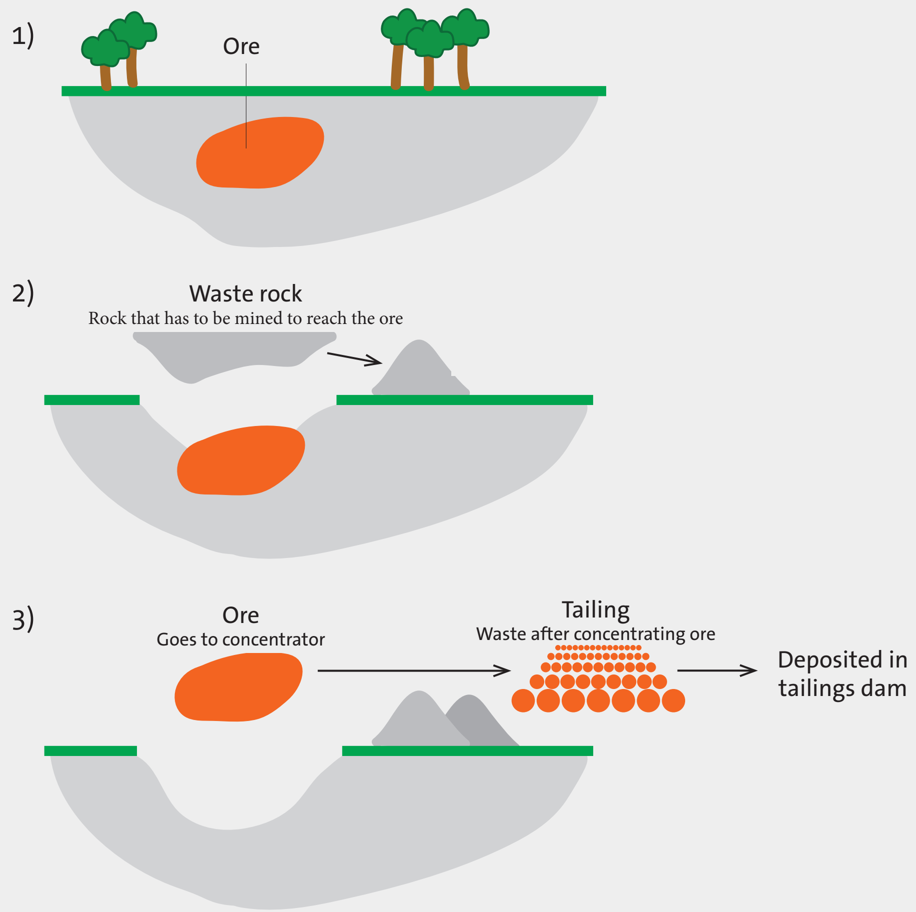
Waste rock is the rock that is removed to access the ore. Waste rock is produced in both open pit and underground mines.

The environmental hazard from waste rock varies. In some cases, waste rock can contain sulphide mineral (Read more on [sida]. It is then called acid producing waste rock and must be covered in order not to weather. Waste rock also be non-hazardous and contain only small quantities of harmful substances. In many cases, waste rock is used as material for building roads and dams in mine areas. In certain cases, the waste rock can also be used outside the mine area as ballast. Waste rock is also used to backfill mines and cavities.

TAILINGS

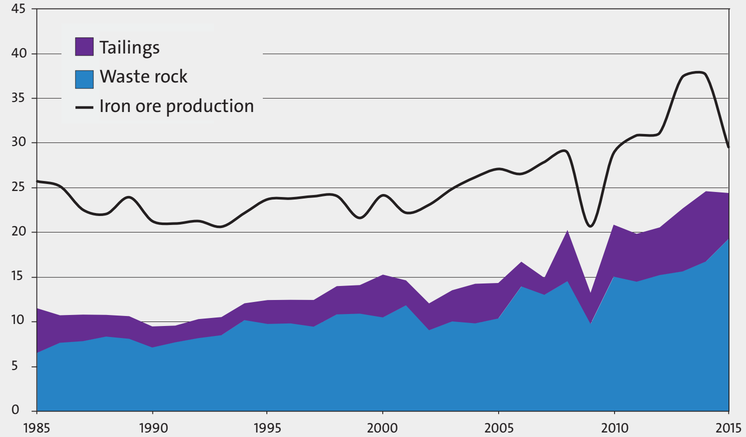
Tailings are produced after the ore is crushed and processed into mineral concentrate. What remains is called tailings. This material, like mineral concentrate, is very fine-grained. Since all minerals and metals cannot be extracted from the ore, tailings often contain small amounts of valuable minerals. Tailings from sulphide ore contain sulphide and must be covered to prevent weathering. In certain cases, tailings can be used to backfill cavities. The amount of tailings that occurs is related to the contents of the ore. Higher content, like in iron ore mines (often over 60 per cent), results in less tailings.

Figure 19. Illustration of the different mine wastes. Source: SGU.

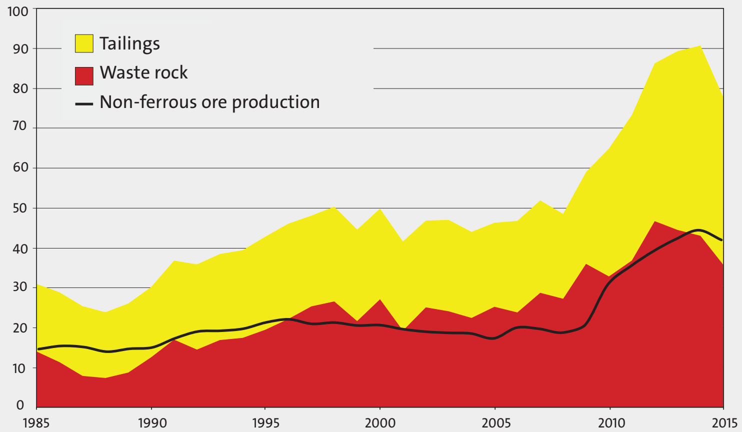


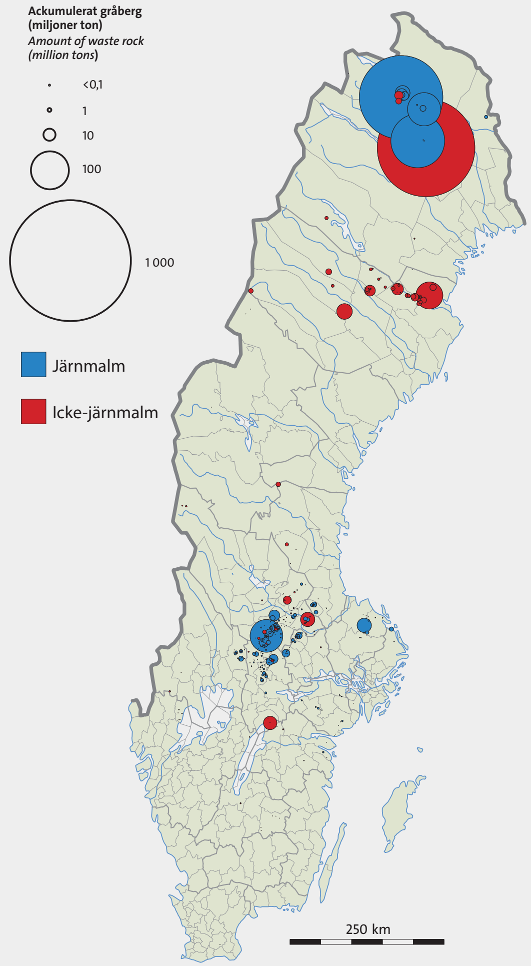
FACTS:
Mine waste in Sweden

Produced iron ore, waste rock and tailings per year in million tonnes.



Produced non-ferrous ore, waste rock and tailings per year in million tonnes.





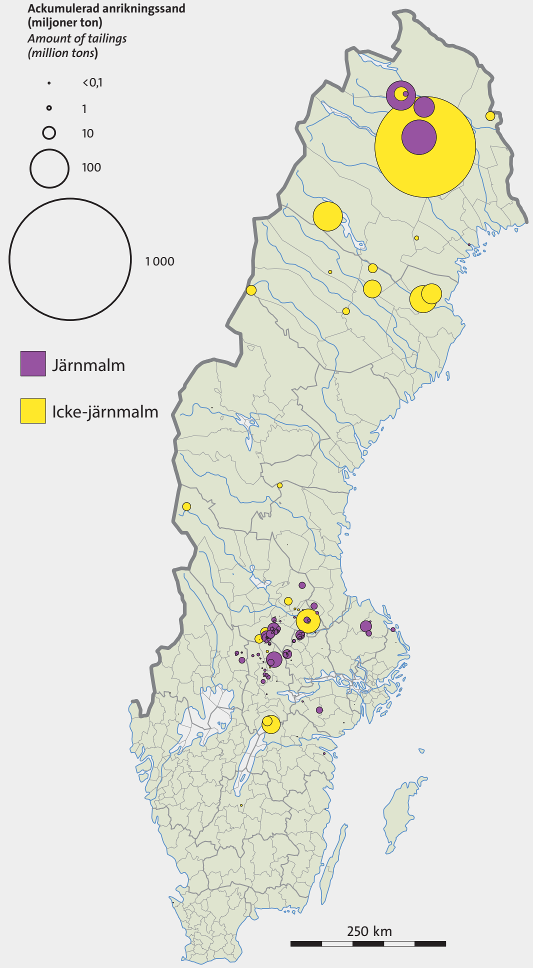


Figure 20. Figures from the annual SGU publication Bergverksstatistik (2016). The diagrams show ore, waste rock and tailings produced per year. The maps show accumulated waste in Sweden.

THE ENVIRONMENTAL IMPACT OF MINES

Mines are environmentally hazardous operations according to Swedish law. Mines can affect our environment and health in different ways, primarily through the discharge of metals and other substances into water, but also through noise, vibrations and dust, which can disturb people living nearby. A mining operation also takes up land and changes the landscape. There are several factors that steer how much the impact is from a mining operation, where the most significant factor is how waste is handled. Other factors can be topography, climate, geology and the sensitivity of lakes, watercourses and the water table. How much may be emitted by the operation, what noise levels, vibrations or other things the operation may and may not do are regulated by the conditions set in the environmental permit (see Chapter 3). The company and the supervisory authority are responsible for ensuring that the conditions are complied with and that there is no harm to the environment. The most significant environmental impact mines have is the discharge of metals and other substances into water and the ground. The impact from the emission of metals and substances varies from substance to substance. Certain substances are needed for example for the existence of life, but at excessive content levels the substances can be toxic in the short-term or long-term. Acute* and chronic* effects vary by substance, content and time of exposure. Metals are elements and do not weather, but stay in the environment for a long time. Their mobility and capacity for dissemination can however often be counteracted, among other things by raising the pH level. At a high pH level, most metals are bonded in fairly insoluble compounds or adsorbed into other minerals. It is the redox potential (reducing v. oxidising environment) and pH (concentration of hydrogen ions) that largely governs the solubility of metals and their dissemination in the environment. This is the reason why mining waste is often treated with lime, which raises the pH level. Weathering can also be counteracted by creating oxygen deficient environments that prevent oxidation. Modern mine operations work ongoing with decontamination of waste during operations. This is to secure the environment, but also for improved profitability, since weathered material is more difficult and expensive to handle. If an operation breaches the regulations of the Environmental Code the supervisory authority is obliged to file a complaint.

*Acute effects concern short exposure, often a few days, depending on the organism. It is often a matter of direct mortality, but other effects can also arise.
**Chronic effects concern more long-term exposure. In these cases it is often a question of impact upon behaviour, growth or reproduction.

METALS, ENVIRONMENT AND HEALTH

Metals are elements that occur naturally in all bedrock, soil and water. Weathering of rock occurs all the time, and metals are constantly emitted into lakes and watercourses. When rock is extracted and crushed, a greater area per grain is exposed to air and water, weather and wind. This means that the weathering processes continue much faster and that metals are more easily emitted into nature. Since metals are elements, they do not decompose, but stay in our environment or in our bodies long-term. Most substances have a negative effect on health in high concentrations. What concentrations are dangerous to humans depends on the substances and are often governed by limit values. Exposure to certain metals can be carcinogenic, cause damage to the nervous system or affect kidney functions. You can read more about metals and our health on the National Food Agency website*.

The impact on our ecosystem and our environment from metals occurs both through natural emissions and emissions from the general public and industry. Mining operations are often regulated according to emission conditions set in the environmental permit. The handling of mining waste brings an impact on nearby land and water. How great the impact is, and whether it can be considered harmful, is often assessed on the basis of environmental quality norms. Environmental quality norms for surface water can be read about on HaV**. Metals and their different effects on our environment can be read about on the Environmental Protection Agency website***.

Figur 21. Water sampling. Photo: SGU.

* https://www.livsmedelsverket.se/livsmedel-och-innehall/oonskade-amnen/metaller1
** https://www.havochvatten.se/hav/vagledning--lagar/vagledningar/vattenforvaltning/om-vattenforvaltning/miljokvalitetsnormer-for-ytvatten.html
*** http://www.naturvardsverket.se/Sa-mar-miljon/Manniska/Miljogifter/Metaller/

MINEFACTS
Do you want to know more?

MineFacts is a collection of facts about mines. In the material there are several links to more information linked to the facts and topics raised. Via the links below you will find further information from the geological surveys in Sweden, Finland and Norway:

• Geological Survey of Sweden	Sveriges geologiska undersökning	sgu.se
• Geological Survey of Finland	Geologian tutkimuskeskus GTK	gtk.fi
• Geological Survey of Norway	Norges geologiske undersøkelse	ngu.no

MINEFACTS
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Connecting matters