PART

11

11

FINLAND'S MINERAL RESOURCES

OPPORTUNITIES AND CHALLENGES FOR FUTURE MINING

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ABSTRACT

This chapter provides an overview of Finland's metallic mineral resources, including past production and presently identified and assumed resources. We also discuss the exploration potential and challenges for future mining in Finland.

Forty-seven metallogenic areas have been defined in Finland, and there are more than 30 different genetic types of mineral deposits. Mining in Finland focused on Fe and Cu in past centuries, and gradually also included Zn, Ni, Cr, and Au from the 1930s to the 1980s. Currently, 12 metal mines are in operation. Ore production has increased to an all-time high for Cr, Au, and Ni, and there are interesting occurrences for numerous other commodities. The ultimate resources of various mineral commodities are impossible to accurately define. Most deposits are insufficiently studied or have not been discovered, therefore forming untapped reserves for future mining. Changing needs of raw materials and improving mining and processing technologies allow new types of deposits to be excavated.

Mine development is becoming increasingly difficult because of growing competition with other land use purposes and tightening regulations. The green mining concept was developed in Finland as a tool to promote future sustainable and acceptable mining.

Keywords: ores; metals; mineral resources; mining; exploration; sustainable development; Finland.

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INTRODUCTION

A thriving modern society is based on using mineral commodities, and their consumption correlates strongly with economic growth and urbanization. Infrastructures, logistics, food production, energy technology, information and communications technology, and consumer electronics all increasingly rely on an ever-widening array of metals and minerals. More than 40 elements are needed to produce a personal computer or a smartphone.

According to the United Nations, the world population stood at 7 billion in 2012 and will reach 9 billion in 2050, most of the growth occurring in developing countries. In the same time frame, the average urbanization will rise from the current 50% to 67% (United Nations Department of Economic and Social Affairs/Population Division, 2012). This means that we will have 3 billion new urban dwellers in 2050, and see almost 70 million new people moving to cities annually. The growing world population, accelerating urbanization, and more evenly distributed wealth have created a huge and steadily increasing demand for natural resources.

An average gross domestic product (GDP) of around US$5000 per capita is regarded as the point at which people start to rapidly increase their consumption of mineral commodities (e.g., Halada et al., 2008). Copper is a good indicator of economic development, and it plays a crucial role in modern society across the world, contributing to infrastructure, technology, and lifestyles. In developed urban societies with a high GDP, such as the U.S.A., Germany, and South Korea, copper usage has expanded, along with increasing GDP to a very high level (Fig. 11.1). In less developed societies, copper consumption is low but seems to follow a uniform path of development. Therefore, there will be an enormous growth potential for copper usage with the development of populous countries such as China and India.

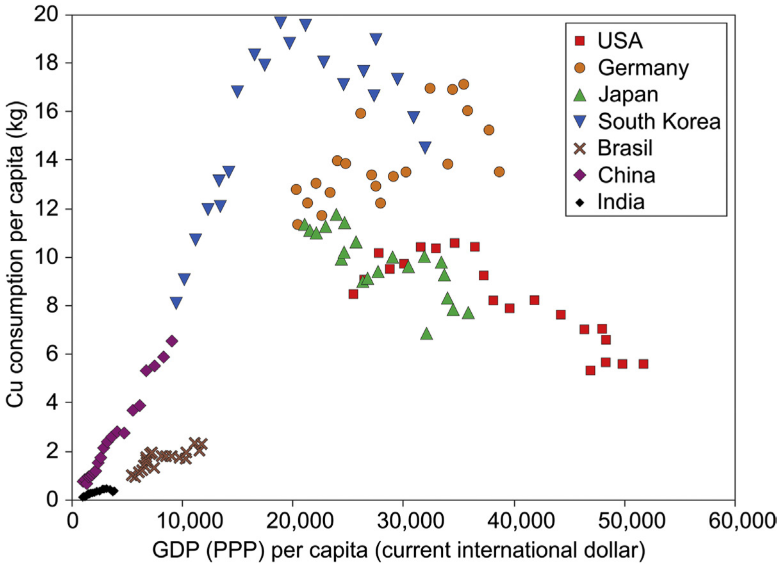

FIGURE 11.1 Copper consumption versus gross domestic product for selected countries.

Data sources: *Chilean Copper Commission (2002, 2012, 2013)*, *International Monetary Fund (2013)*, and *World Bank (2013)*.

In developed societies, the consumption of minerals seems to reach a so-called saturation level (Fig. 11.2). Consumption no longer increases, but remains at a high level or shows a slight decrease with decreasing demand, effective recycling, and substitution. Metals used for infrastructural development, such as iron and copper, are the first ones needed in the early stages of societal development, followed by a variety of other metals and minerals. The demand for so-called high-tech metals starts to increase in the most developed societies. The present world average GDP is close to US$10,000, and needs to increase several times before the saturation level of consumption is reached. This will take at least several decades, and create a long-term growth cycle for mineral demand.

China presently consumes 40% of the global metal supply, and will continue to be the largest customer for metals in the global market in the coming years (PricewaterhouseCoopers International, 2013). Although China's high economic growth may gradually weaken, rising long-term demand in India and other populous countries will ensure an economic future for mining industry products. Indeed, the combination of a growing world population and rising living standards for an expanding share of humanity will increase the demand for metal and mineral commodities for many decades to come, although mineral demand and prices are volatile and highly dependent on economic cycles.

The Fennoscandian Shield is evidently the richest area of mineral resources in Europe, and will be an important source of mineral raw materials for the future. Finland, located in the center of the shield, is composed of a variety of geological formations, from Archean gneisses and greenstone belts to Paleoproterozoic volcano-sedimentary belts, and ultramafic to granitic intrusive rocks. These geological formations also contain a wide variety of mineral deposits, as described in other chapters of this book. Many of the deposits are still poorly known, and there is an obvious potential for new mineral discoveries.

This chapter aims to provide an overview of Finland's metallic mineral resources, including past production, presently known resources, and assumed geological resources. We will also discuss the exploration potential and challenges for future mining in Finland.

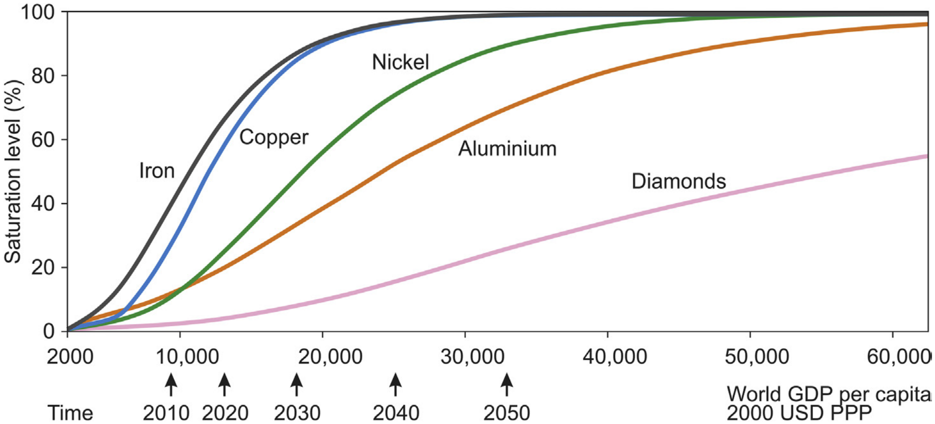

FIGURE 11.2 Saturation level of consumption for various commodities versus average world gross domestic product.

Source: *Modified from Rio Tinto (2013).*

WHAT ARE MINERAL RESOURCES?

In reporting or discussing mineral resources, confusion can arise if the terms used are undefined or have different meaning for different parties. The most important terms required for the proper understanding of this chapter are described here. A *mineral occurrence* is a concentration of any useful mineral found in bedrock in a sufficient quantity to suggest further exploration, and a *mineral deposit* is a mineral occurrence of sufficient size and grade that it might, under the most favorable circumstances, be considered to have potential for economic extraction. *Ore* is a naturally occurring material from which a mineral or minerals of economic value can be extracted at a reasonable profit (American Geosciences Institute, 2013). An *ore deposit* is a mass of material of sufficient ore content to make extraction economically feasible. Ore is therefore an economic concept tied to particular circumstances; the economic viability of a mineral deposit varies according to current needs, commodity prices, the grade and quality of useful commodities, the location of the deposit, local infrastructure, and the kinds of technology available for mining. In addition to geological, technical, and economic considerations, the mining industry is increasingly subject to the reconciliation of environmental, social, and political interests in the use of land.

Mining is a capital-intensive international commercial activity that utilizes mineral resources. Hence, it is obvious that the terms used in reporting mineral resources are regulated by national and international standards such as the JORC, CRIRSCO, NI 43-101, PERC, and UNFC codes (Joint Ore Reserves Committee of the Australasian Institute of Mining and Metallurgy, Australian Institute of Geosciences and Mineral Council of Australia, 2012; Committee for Mineral Reserves International Reporting Standards, 2013; National Instrument 43-101, 2011; Pan–European Reserves and Resources Reporting Committee, 2013; United Nations Economic Commission for Europe, 2009). All companies that are listed on the stock exchange should follow one of these standards when they report information on their mineral resources. The reports must be signed by experts who have a Qualified Person status particularly related to the deposit type reported.

A *mineral resource* is a concentration or occurrence of solid material of economic interest in or on the Earth's crust in such form, grade (or quality), and quantity that there are reasonable prospects for eventual economic extraction. The location, quantity, grade (or quality), continuity, and other geological characteristics of a mineral resource are known, estimated, or interpreted from specific geological evidence and knowledge, including sampling (Joint Ore Reserves Committee of the Australasian Institute of Mining and Metallurgy, Australian Institute of Geosciences and Mineral Council of Australia, 2012). Mineral resources are subdivided, in order of increasing geological confidence, into *inferred*, *indicated* and *measured* categories (Fig. 11.3). Mineral resources must always satisfy the requirement that there are reasonable prospects for eventual economic extraction. Geological evidence and knowledge required for the estimation of mineral resources must include appropriate sampling data; a mineral resource cannot be estimated in the absence of sampling information.

An *ore reserve* is the economically mineable part of a measured and/or indicated mineral resource. It includes diluting materials and allowances for losses that may occur when the material is mined or extracted, and is defined by studies at the prefeasibility or feasibility level, as appropriate, that include the application of modifying factors. Such studies demonstrate that, at the time of reporting, extraction could reasonably be justified (Joint Ore Reserves Committee of the Australasian Institute of Mining and Metallurgy, Australian Institute of Geosciences and Mineral Council of Australia, 2012). Ore reserves are subdivided in order of increasing confidence into *probable ore reserves* and *proved ore reserves* (Fig. 11.3). A *probable ore reserve* is the economically mineable part of an indicated, and in some circumstances a measured, mineral resource. A *proved ore reserve* is the economically mineable part of a

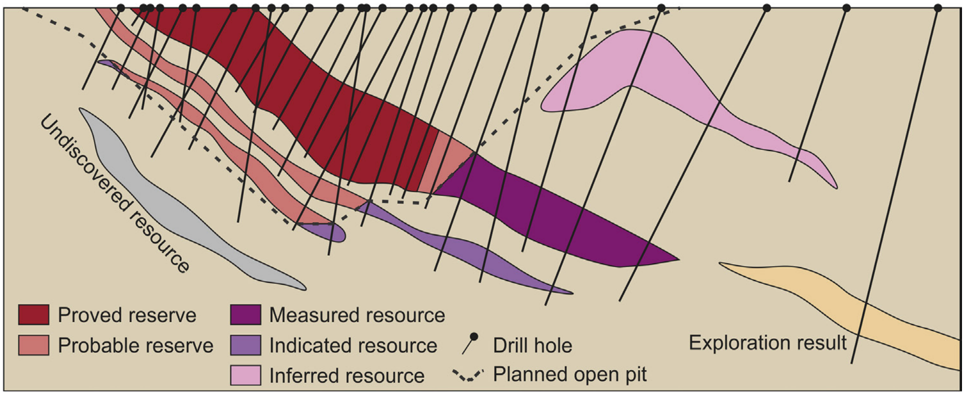

FIGURE 11.3 Schematic representation of the subdivision of mineral resources and reserves.

Representation is based on geological confidence (density of drilling data) and various modifying factors (see text).

measured mineral resource. The modifying factors mentioned are considerations used in converting mineral resources into ore reserves. They include, but are not restricted to, mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social, and governmental factors.

The mineral resources as previously defined refer to identified or known resources. Such resources can be observed and measured, and the category (inferred, indicated, measured) in which they fall depends on the amount and reliability of the observation and measurement data. In this chapter we also use the term *assumed mineral resources*. By this we mean the estimated geological resources that are not supported by large quantities of data or are not reported according to current standards, but are based on drill intersections of mineralized zones and interpretation of other geoscientific data that allow evaluation of the potential extent of mineralization. Assumed resources are less well established than inferred resources and fall outside the category of identified resources.

Considering the tonnage values presented in this chapter, it is very important to keep in mind that the reported resources are mostly geological in situ values, and in most instances the resource estimates are not based on existing industrial standards. Furthermore, the monetary values given are based on estimates of in situ mineral resources (not ore reserves), which do not take into account any modifying factors. Therefore, our estimated tonnage and monetary values must not be confused with the results of studies on the economic profitability of mining projects, carried out according to strict standards such as the JORC or NI 43-101.

MINING HISTORY IN FINLAND

The information in this chapter is largely based on the data in Puustinen (2003) and FODD (2013). It is noteworthy that the mined tonnages of metals discussed here are not the actual amounts of metals produced in smelters, but calculated values of metal contents of the excavated ore, based on reported average metal concentrations of the mill feed. In other words, these are theoretical total metal contents of the excavated ore, not taking into consideration the losses during enrichment and smelting.

The history of mining in Finland goes back at least to the 1500s. The Ojamo iron mine, discovered in 1530, is considered to be the oldest metal mine in Finland (Table 11.1). In the early stages, mining operations mostly produced modest amounts of iron and copper. At least 327 mines had been in

Table 11.1 Selected metal mines in Finland. Production is reported until the end of 2012.

Mine	Main metals	Discovered by	Discovery year	Operating years	Ore excavated (Mt)	Produced metals (Ag, Au, Pd, Pt: t; others: kt)	Value of production (M$)
Ojamo	Fe	Unknown	1530	1533–1564, 1609–1673, 1684–1694, 1826–1863	0.012	Fe 5.8	0.353
Orijärvi	Cu, Zn	Layman	1757	1758–1882, 1929–1955	0.92	Cu 10, Zn 24, Pb 7.6, Ag 8.4, Au 0.084	93
Jussarö	Fe	E.J. Westing, Bergstyrelsen	1834	1834–1861, 1898–1900, 1957–1967	1.6	Fe 450	28
Outokumpu	Cu, Co	GTK	1910	1910–1989	32	Cu 970, Co 56, Au 25, Zn 240, Ag 290	6982
Petsamo	Ni, Cu	GTK	1921	1936–1944	0.46	Ni 17, Cu 8.9	296
Mätäsvaara	Mo	Layman	1903	1910–1911, 1920–1922, 1932–1933, 1940–1947	1.2	Mo 0.98	34
Makola	Ni, Cu	GTK	1937	1941–1954	0.41	Ni 3.1, Cu 1.8	55
Haveri	Au, Cu	Oy Vuoksenniska Ab	1935	1942–1960	1.6	Au 4.4, Cu 6.1	99
Ylöjärvi	Cu, W	GTK	1938	1943–1966	4.0	Cu 30, W 1.6, Ag 50, Au 0.27	160
Aijala	Cu, Au, Zn	Suomen Malmi Oy	1945	1948–1961	0.84	Cu 13, Au 0.59, Zn 5.4, Ag 12	74
Otanmäki	V, Fe, Ti	GTK	1938	1949–1985	25	V 64, Fe 8600, Ti 1900	2399
Metsämonttu	Zn, Au	Suomen Malmi Oy	1946	1951–1974	1.5	Zn 45, Au 1.1, Pb 7.1, Cu 1.6, Ag 20	111
Vihanti	Zn, Cu	GTK	1947	1952–1992	28	Zn 1400, Cu 130, Pb 98, Ag 280, Au 3.3	3077
Kotalahti	Ni	Outokumpu Oy	1954	1957–1987	12	Ni 82, Cu 32	1410
Luikonlahti	Co, Cu	Ruskealan Marmori Oy	1944	1958–1983	6.9	Co 7.0, Cu 65, Zn 25	580
Korsnäs	Pb	GTK	1955	1958–1972	0.87	Pb 31	35
Kärväsvaara	Fe	Layman	1921	1921, 1937, 1958–1967	0.93	Fe 430	26
Pyhäsalmi	Zn, Cu	Layman	1958	1959–	51	Zn 1200, Cu 450, Au 7.3, Ag 240	3918

Rautuvaara	Fe, Cu	Suomen Malmi Oy	1956	1962–1988	12	Fe 5300, Cu 26	428
Raajärvi	V, Fe	Otanmäki Oy	1958	1962–1975	5.1	V 5.6, Fe 2100, Ti 5.7	266
Hitura	Ni	GTK	1963	1965–1985, 1988–2008, 2010–	17	Ni 96, Cu 36, Co 0.51, Pt 0.22	1674
Kemi	Cr	Layman	1959	1966–	40	Cr 7100	10,413
Hällinmäki	Cu	GTK	1964	1966–1984	4.2	Cu 32	124
Vuonos	Cu, Co, Ni, Zn	Outokumpu Oy	1965	1967–1986	11	Cu 120, Co 7.3, Ni 11, Zn 69, Ag 0.11	1149
Telkkälä	Ni	Outokumpu Oy	1961	1969–1970, 1988–1992	0.61	Ni 7.8, Cu 2.0	130
Hammaslahti	Cu	GTK	1968	1971–1986	5.6	Cu 62, Zn 3.8	250
Kylmäkoski	Ni, Cu	Outokumpu Oy	1962	1971–1974	0.69	Ni 2.5, Cu 1.9	47
Stormi	Ni, Cu	Outokumpu Oy	1961	1974–1995	4.6	Ni 51, Cu 32	931
Mustavaara	V	Otanmäki Oy	1967	1974–1985	13	V 27	679
Pahtavuoma	Cu, Ag	Outokumpu Oy	1970	1974–1976, 1989–1993	0.29	Cu 3.2, Ag 5.3	14
Hannukainen	Fe, Cu	Rautatuukki Oy	1974	1978–1990	4.6	Fe 1900, Cu 15, Au 0.21	175
Laukunkangas	Ni	Outokumpu Oy	1979	1984–1994	6.7	Ni 50, Cu 14	846
Saattopora	Au, Cu	Outokumpu Oy	1972	1988–1995	2.1	Au 7, Cu 5.7	139
Hälvälä	Ni	Outokumpu Oy	1970	1988–1992	0.25	Ni 3.5, Cu 0.88	59
Ruostesuo	Zn, Cu	Outokumpu Oy	1959	1988–1990	0.24	Zn 6.3, Cu 0.71, Au 0.081, Ag 2.1	15
Mullikkoräme	Zn, Au	Outokumpu Oy	1987	1989–2000	1.2	Zn 73, Au 0.0012, Ag 0.053, Cu 3.6, Pb 10	179
Kutemajärvi	Au	Lohja Oy	1981	1993–2004, 2006–	2.1	Au 14	240
Pahtavaara	Au	GTK	1987	1995–2000, 2003–	5.5	Au 11	178
Särkiniemi	Ni, Co	GTK	1994	2007–2008	0.12	Ni 0.71, Co 0.032, Cu 0.075	13
Talvivaara	Ni, Zn	GTK	1977	2008–	47	Ni 40, Zn 86	766
Kittilä	Au	GTK	1986	2006–	4.3	Au 16	272
Jokisivu	Au	Outokumpu Oy	1985	2009–	0.32	Au 0.86	14
Pampalo	Au	GTK	1990	1996–1999, 2007–2008, 2010–	0.59	Au 3.4	56

Continued

Table 11.1 Selected metal mines in Finland. Production is reported until the end of 2012.—cont'd

Mine	Main metals	Discovered by	Discovery year	Operating years	Ore excavated (Mt)	Produced metals (Ag, Au, Pd, Pt: t; others: kt)	Value of production (M$)
Laiva	Au	Outokumpu Oy	1980	2010–	1.5	Au 0.93	16
Kylylahti	Cu, Au, Zn	Outokumpu Oy	1984	2011–	0.37	Cu 4.7, Au 0.21, Zn 2.2, Ag 1.3	26
Kevitsa	Ni, Cu	GTK	1987	2011–	3.1	3.9, Cu 8.1, Pt 0.099, Au 0.17, Pd 0.088 Ni	99

Main metals are those responsible for at least 10% of the total value of production.
Ore excavated equals mill feed.
Value of production is in US dollars, based on average metal prices for 2000–2009.
Ore excavated and produced metals are rounded to two significant digits.
Short periods of test mining are not included in operating years.
Source data up to 2001: *Puustinen (2003)*.
Source for newer data: *Reports and news releases of mining companies.*

operation before 1900 and had produced about 140,000 t iron and 10,000 t copper (Puustinen, 2003). In the early twentieth century, copper production began to increase due to the discovery of the Outokumpu deposit and the subsequent beginning of mining there in 1910 (Fig. 11.4). Exploitation of the Outokumpu deposits can be regarded as the beginning of the modern mining industry in Finland.

Altogether, 17 metal mines were opened in Finland from 1900–1944. After the war, the pace began to increase and was at its highest between 1955 and 1975, during which period 33 new mines started operation (Fig. 11.5). The opening rate diminished after 1975, with eight mines starting their operation in the 1980s and only four from 1990–1999, possibly reflecting the economic recession in the early 1990s and low commodity prices. There was a 12-year gap between the starting of the Pahtavaara mine in 1995 and the next significant operation at the Kittilä gold mine in 2006. However, the pace seems to be increasing again, with four metal mines opened during the 2000s, another four between 2010 and 2012, and several

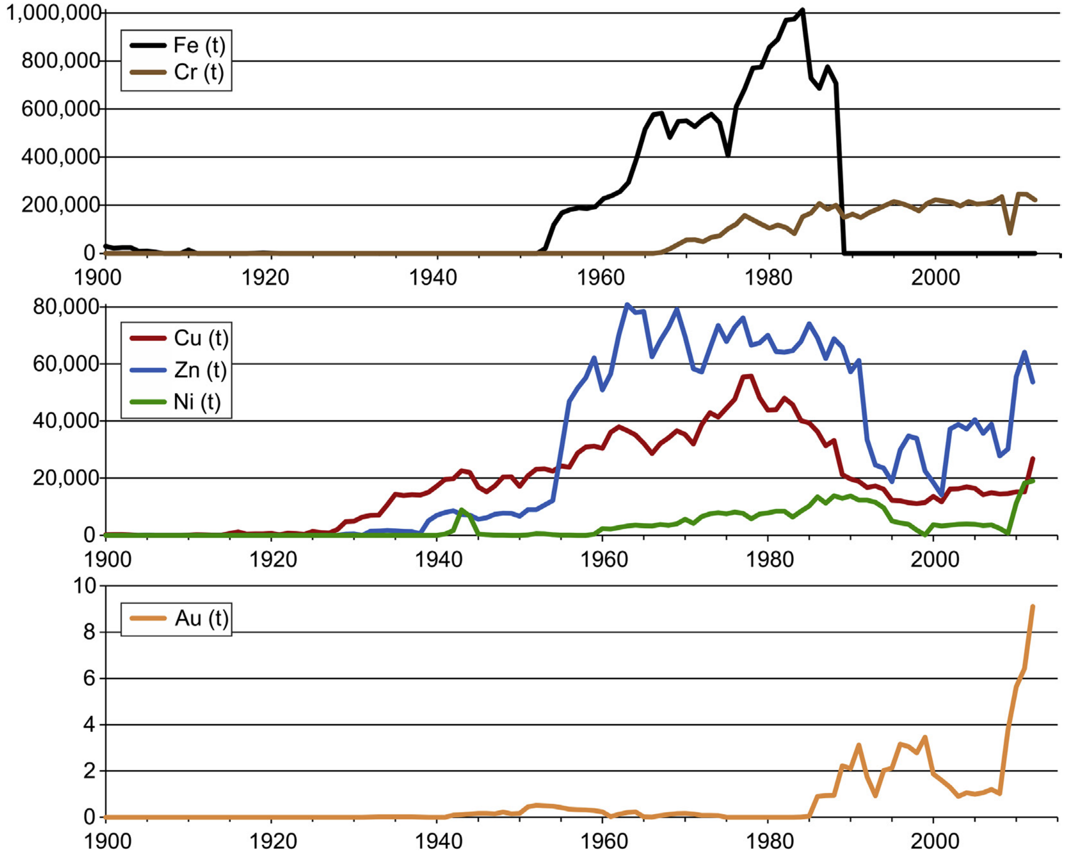

FIGURE 11.4 Annual mine production of selected metals in Finland from 1900–2012.

The figures do not represent real metal production, but are calculated total metal contents of excavated ores based on reported tonnages and average metal grades.

Source for data up to 2001: *Puustinen (2003); for newer data, see reports and news releases of mining companies.*

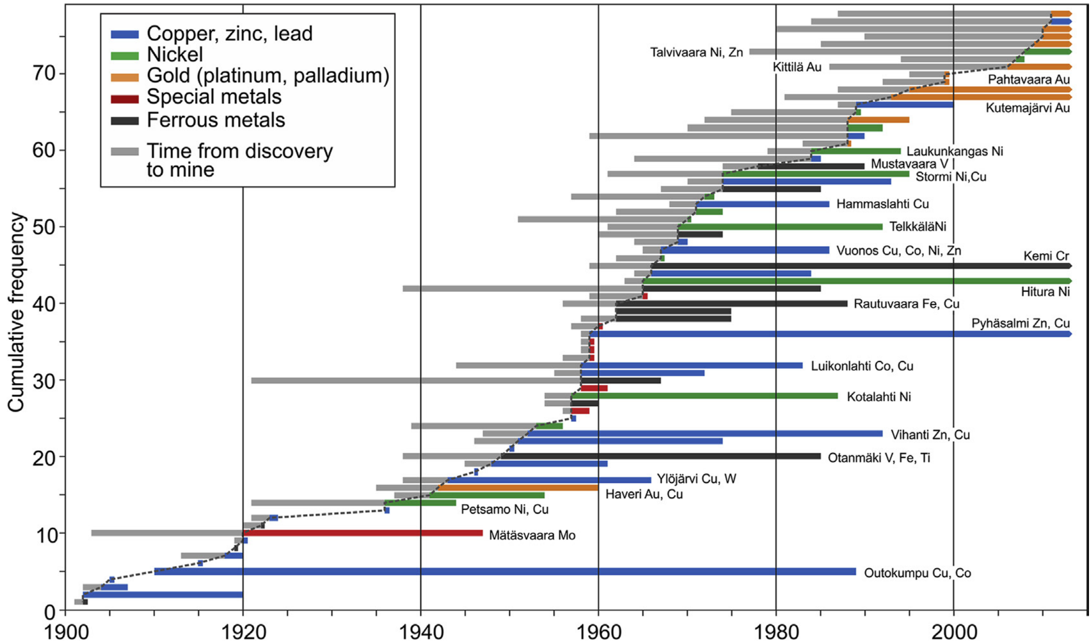

FIGURE 11.5 Mining history for metal mines in Finland from 1900–2012.

The gray bars indicate the time from discovery to the beginning of mining, while the colored bars show the duration of mining.

Data sources: *Puustinen (2003)* and *FODD (2013)*.

advanced mine projects on the way (Fig. 11.6, Table 11.2). The average time from the discovery of a deposit to the opening of a mine remained rather constant at roughly 6 years from the 1920s to the 1960s, but has considerably increased to about 24 years for mines opened in the twenty-first century.

Until the 1940s, Outokumpu was the only important Finnish mine in operation. The Mätäsvaara molybdenite deposit was operated in several phases from 1910–1947, but the total production was only about 970 t of molybdenum. However, Mätäsvaara has been the only molybdenum mine in Finland. The Petsamo nickel deposit was discovered in 1921, but the mine only produced 17,000 t nickel and 8900 t copper from 1936–1944, before the Petsamo area was ceded to the Soviet Union after the Second World War. The nickel production of Petsamo is seen as a small peak in the early 1940s in Fig. 11.4.

The Otanmäki iron mine opened after the war in the late 1940s. Production started gradually from 1949–1954 and the mine became a significant vanadium producer responsible for about 10% of the world production in the 1960s and 1970s (Illi et al., 1985). The total production of the Otanmäki mine was about 8.6 Mt iron and 64,000 t vanadium. Other important iron mines were Kärväsvaara, Rautuvaara, Raajärvi, and Hannukainen (see Table 11.1). Mine production of iron in Finland ended when the Hannukainen mine was closed in 1990 (Fig. 11.4).

The Aijala copper-zinc mine opened after the war in the late 1940s and was soon followed by the Metsämonttu zinc and Vihanti zinc-copper mines in 1951 and 1952, respectively. Several base metal mines producing both copper and zinc were opened from 1955–1975, causing a generally increasing trend in annual copper production until 1978 (see Fig. 11.4). The most important of these mines were

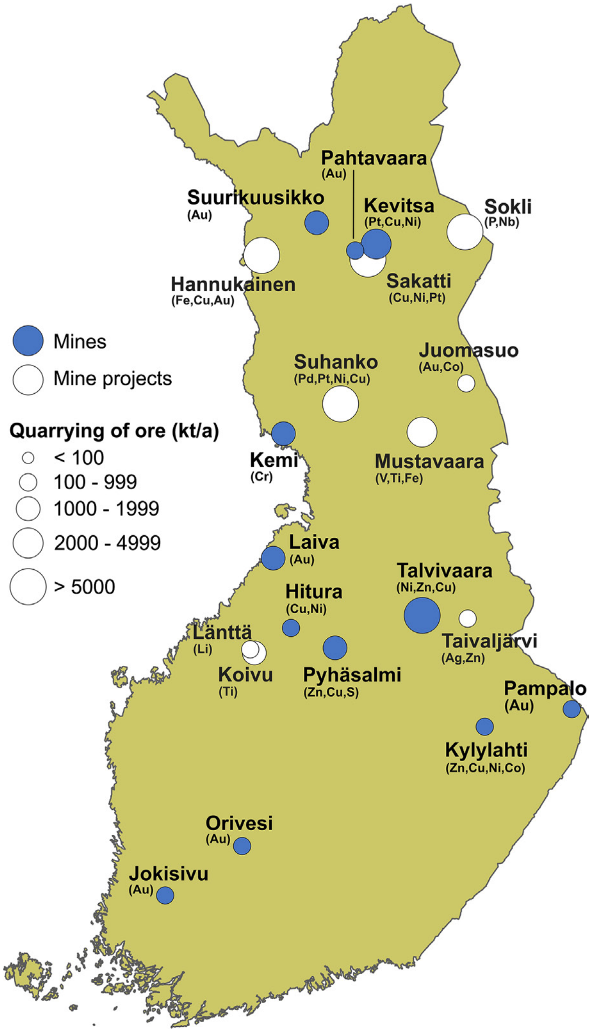

FIGURE 11.6 Mines and mine projects in Finland in 2012.

The symbol size indicates the annual amount of ore mined for operating mines and the planned annual output for mine projects.

Data source: *Pokki et al. (2014) and Geological Survey of Finland internal data.*

Pyhäsalmi and Vuonos, which, in addition to Outokumpu and Vihanti, have produced more than 100,000 t of copper (Table 11.1). The exhaustion of reserves and closure of most of the copper-producing mines led to a decrease in copper ore production from the 1980s onward, and by the beginning of the 2000s, the only mines producing copper were Pyhäsalmi and Hitura. Until the 1950s, the Orijärvi and Aijala mines were responsible for the modest zinc production in Finland. The opening of the Vihanti and Pyhäsalmi mines raised the annual mine production of zinc to the level of 60,000–80,000 t, where it remained until the closure of Vihanti in 1992. After that, Pyhäsalmi and Mullikkoräme were the only producers of zinc

Table 11.2 Operating metal mines and major deposits in Finland in 2012

Name	Main metals	Other metals	Operating years	Premining value (M$)	Premining size (Mt)	Ore excavated (Mt)
Operating mines						
Talvivaara	Ni, Co, Zn	Cu, Mo, U, Mn, Ag	2008–	124,752	2100	47
Kemi	Cr		1966–	53,490	188	40
Kevitsa	Ni, Cu, PGE	Co, Au	2011–	21,593	270	3.1
Pyhäsalmi	Zn, Cu	Au, Ag	1959–	5109	67	51
Kittilä	Au		2006–	4427	64	3.8
Hitura	Ni	Co, Cu, PGE	1965–1985, 1988–2008, 2010–	2279	21	17
Kylylahti	Co, Cu, Ni	Au, Zn	2011–	1656	8.4	0.37
Laiva	Au		2010–	801	23	1.5
Pahtavaara	Au		1995–2000, 2003–	341	7.7	5.5
Kutemajärvi	Au		1993–2004, 2006–	264	3.0	2.1
Jokisivu	Au		2009–	186	1.9	0.32
Pampalo	Au		1996–1999, 2007–2008, 2010–	127	1.8	0.59
Deposits						
Koitelainen Cr	Cr, V	Pd, Pt		23,539	72	–
Sokli Nb	Nb	Fe, U, Ta, Zr, REE		17,228	250	–
Akanvaara Cr	Cr, V	Pt, Pd		15,073	55	–
Mustavaara	V, Fe, Ti		1974–1985	7557	110	13
Suhanko	PGE, Ni, Cu	Au		6993	190	–
Hannukainen	Fe, Cu	Au	1978–1990	5549	200	4.6
Siika-Kämä	PGE, Ni	Cu, Au		3250	49	–
Konttijärvi	PGE, Ni, Cu	Au		2401	75	–
Vaaralampi	Ni, PGE, Cu	Au, Co		2494	33	–
Ruossakero Ni	Ni	Co, Cu		2009	36	–
Akanvaara V	V	Cu, Ag		1772	20	–
Sompujärvi	PGE	Au		1327	6.7	–
Kuervitikko	Fe, Cu, Au			1039	45	–
Koivu	V, Ti			921	62	–
Taivaljärvi	Ag, Zn, Au	Pb, Cu		428	13	–
Juomasuo Au	Au, Co	Cu		285	2.0	–
Juomasuo Co	Co	Au		180	3.1	–

Table 11.2 Operating metal mines and major deposits in Finland in 2012—cont'd

Name	Main metals	Other metals	Operating years	Premining value (M$)	Premining size (Mt)	Ore excavated (Mt)
Länttä	Li, Ta			55	3.0	–
Sakatti	Ni, Cu, PGE			n.a.	n.a.	–

Akanvaara Cr includes Akanvaara UC + ULC + LC.
Koitelainen Cr includes Koitelainen UL + LC.
Suhanko includes Ahmavaara + Suhanko.
Vaaralampi includes Vaaralampi + Niittylampi.
Ore excavated equals mill feed.
Premining size and ore mined are rounded to two significant digits.
Short periods of test mining are not included in operating years.
n.a.: Data not available; – : Not excavated.
Premining value is in US dollars, based on average metal prices for 2000–2009.
Source for premining size: *FODD (2013)*.
Source for ore excavated: *Reports and news releases of mining companies.*

until the opening of the Talvivaara mine in 2008. Korsnäs was the only mine in Finland producing lead as a major constituent. The mine operated from 1958–1972 and produced 31,000 t lead.

Nickel production was very small after the war, until the opening of the Kotalahti and Hitura mines in 1957 and 1965, respectively. From 1960–1990, nickel ore production gradually increased due to the opening of several mines, and peaked at a little over 10,000 t of contained nickel annually between 1985 and 1993 (Fig. 11.4). The most important nickel mines were Kotalahti, Hitura, Stormi, and Laukunkangas, each of which produced at least 50,000 t of nickel. By 1995, all the other mines had stopped operation and Hitura was the only mine producing nickel in Finland. With the opening of Talvivaara in 2008, nickel mine production in Finland has started to increase again.

Seven small uranium mines operated in Finland between 1957 and 1965. All were small short-term operations, active for only one to three years. The most important of these was Paukkajanvaara, which was active from 1958–1961 and produced about 55 t of uranium.

The Kemi mine is the only mine producing chromium in Finland. The chromite deposit was discovered in 1959 and an open-pit operation started in 1966. Chromite production gradually increased to its present level of a little over 200,000 t of contained chromium metal annually. In 2006, the mine became an entirely underground operation.

Excluding the gold-panning areas in Lapland, Haveri was the only gold mine in Finland in the twentieth century, until the late 1980s. It produced 4.4 t gold from 1942–1960. Gold was a by-product in several base metal mines, but the amounts produced were minor, usually from tens to a few hundred kilograms annually. The Saattopora gold mine was opened in 1988, followed by the Kutemajärvi (Orivesi) and Pahtavaara mines in 1993 and 1995, respectively. This caused an increase in annual gold production to 2–3 t. In the early years of the 2000s, gold production decreased to about 1 t annually, until the opening of several new gold mines caused it to strongly increase from 2009 onward (refer to Fig. 11.4). The most important of these new mines was Kittilä, opened in 2006.

The selection of metals mined in Finland has changed over time. In the early stages, from the 1500s to the beginning of the 1900s, mining was mostly concentrated on copper and iron, and the amounts produced annually were small. In the early 1900s, the amounts of metals mined annually began to

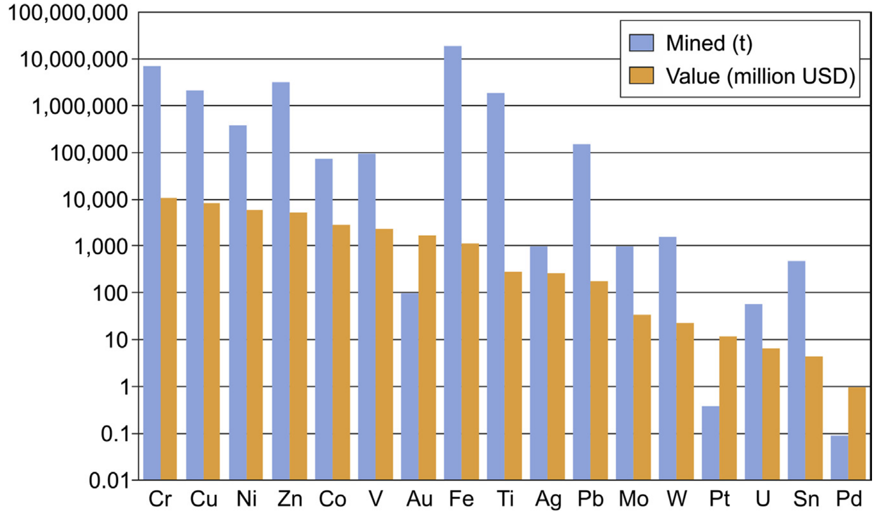

FIGURE 11.7 Total amounts of metals produced in Finland from 1501–2012.

The figures are calculated total metal contents of excavated ores based on reported tonnages and average metal grades. The nominal values (US dollars) are calculated using average metal prices for the period 2000–2009.

Source for data up to 2001: *Puustinen (2003); for newer data, see reports and news releases of mining companies.*

increase (Fig. 11.4). Copper started this trend in the late 1920s, followed by zinc in the late 1930s, nickel at the beginning of the 1960s, chromium in the late 1960s, and gold in the late 1980s. However, iron dominated the tonnages mined from the mid-1950s until the end of iron mining in Finland in 1988. By the end of the twentieth century, mining volumes of all the base metals had significantly decreased due to the closure of several major mines. Only chromium production had continued to increase steadily.

Since the beginning of the twenty-first century, the mine production of base metals in Finland has started to increase again. At the end of 2012, there were 12 operating metal mines in Finland (Tables 11.1 and 11.2). The average annual ore production from 2010–2012 had increased to an all-time high for chromium, gold, and nickel, and was at its highest in the 2000s for copper and zinc (Fig. 11.4).

Iron dominated the total tonnages of metals mined in Finland throughout history, but the calculated value of several other metals currently being mined is higher (Fig. 11.7). The total mined tonnage of ferrous metals (iron, vanadium, chromium, titanium) is 28 Mt and their calculated value is US$14 billion. Although the total mined tonnage of base metals (copper, nickel, zinc, lead, cobalt) is only 6.0 Mt, their calculated total value of US$22 billion clearly exceeds the value of the ferrous metals. The total tonnage of mined precious metals (gold, silver, platinum, palladium) is only 1.1 Mt, and the total value of this is US$2 billion.

METALLOGENY AND MINERAL RESOURCES

METALLOGENIC AREAS

Metallogeny is defined as the study of the genesis of mineral deposits, with emphasis on their relationship in space and time to regional petrographic and tectonic features of the Earth's crust. A metallogenic province, area, or belt is an area characterized by a particular assemblage of mineral deposits, or by one or more characteristic types of mineralization (American Geosciences Institute, 2013).

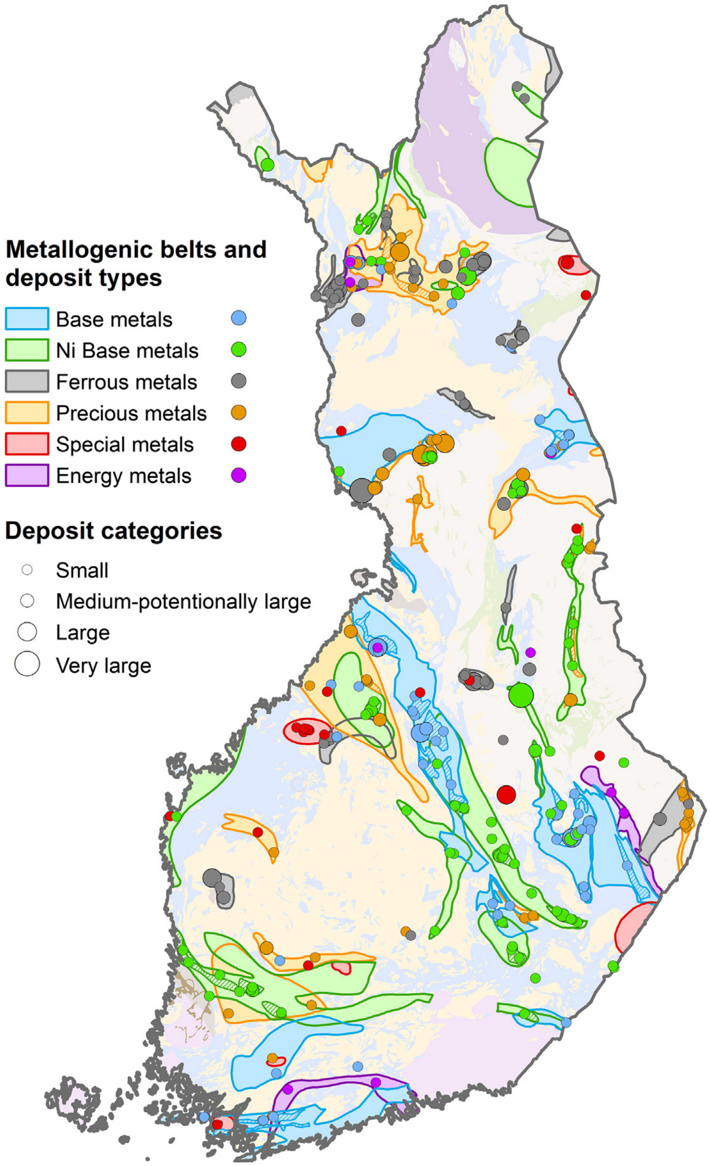

FIGURE 11.8 Metallogenic areas and known important mineral deposits and occurrences in Finland.

Source: *The metallogenic areas are modified from Eilu et al. (2009) and the deposits are based on FODD (2013).*

Altogether, 47 metallogenic areas have been delineated in Finland, and 12 additional areas extend across the Finnish border from Norway, Sweden, or Russia (Fig. 11.8). These areas are defined as domains with an indicated mining and exploration potential for one or a few genetic types of metal deposits. Metallogenic areas are delineated on the basis of the presence of metal mines, deposits, mineral occurrences, and other indications of certain types of metallic mineralization, by the local and regional bedrock geology, and by indications from geophysical and geochemical surveys (Eilu, 2012). Of the metallogenic areas in Finland, 13 are predominantly characterized by ferrous metals (iron, titanium, vanadium, chromium), 13 by precious metals (gold, platinum, palladium), 14 by nickel, 9 by other base metals (copper, zinc, lead), 7 by so-called high technology metals mostly used in advanced technologies (beryllium, lithium, niobium, rare earth metals, tantalum), and 3 by uranium. The total area of all the metallogenic belts is 103,824 km^2, which is 31% of the land area of Finland. However, the belts partially overlap (Fig. 11.8), and the area covered by at least one belt is 88,758 km^2 (26%).

More than 30 different genetic types of mineral deposits occur in the metallogenic areas, and many of the areas can contain deposits of more than one of the major groups of metals. According to the value of past production and present known and assumed resources, the most important deposit types encountered within the metallogenic areas are mafic-intrusion-hosted titanium-iron-vanadium, mafic–ultramafic-hosted chromium, iron-oxide–copper–gold, layered-intrusion-hosted nickel-copper-platinum group metals, synorogenic intrusive nickel-copper, orogenic gold, volcanogenic massive sulfide (VMS), and Outokumpu-type copper-cobalt (Eilu, 2012). The giant and unique Talvivaara nickel-zinc-copper-cobalt deposit is also highly significant.

Excluding the rather small known resources in Archean orogenic gold deposits and komatiite-hosted nickel deposits, most of the known metal resources in Finland occur in deposits formed in the Paleoproterozoic, either during multiple rifting episodes from 2.45–1.92 Ga or during the Svecofennian orogeny in 1.9–1.8 Ga. The 365 Ma Sokli niobium-rare earth element (REE) deposit is the most important post-Svecofennian metal deposit in Finland.

The metallogenic areas are described in more detail in Eilu (2012), and the reader is directed to that publication for further details.

IDENTIFIED AND ASSUMED MINERAL RESOURCES

It is no surprise that most of the known mineral resources in Finland are located within the metallogenic areas; after all, the areas are defined mainly on the basis of the known deposits and occurrences.

In addition to identified resources in operating mines and well-known and explored deposits, there are less well-defined resources in deposits that have not been thoroughly explored. These assumed resources are mostly contained in incompletely explored deposits, are not supported by large quantities of data, and have, in many cases, not been evaluated according to present standards. However, it is useful to also consider the assumed resources to acquire a better picture of the possible total endowment of metals in the Finnish bedrock. In Fig. 11.9, the remaining identified and assumed mineral resources in Finland are combined, as they are reported in the Fennoscandian Ore Deposit Database (FODD, 2013). The database contains information on all known metallic mineral deposits with a published resource estimate in the Fennoscandian Shield (Eilu et al., 2007).

The majority of the remaining zinc, copper, nickel, and cobalt resources, and a little more than half of the remaining chromium resources, reside in operating mines. Most of the remaining resources for the other metals in Fig. 11.9 are located in more or less well-known deposits that either have or have not previously been mined. Comparison with amounts mined throughout history in Finland indicates that for most of the metals, the mined amount is less than 25% of the total endowment. One must remember, however, that these figures are calculated as in situ metal contents in the deposits and calculated metal contents of the mined ore, based on reported metal grades in the ore. Although the Nb, Ta, and Be contents of the mined resources are calculated here, the metals have not actually been separated from the ore.

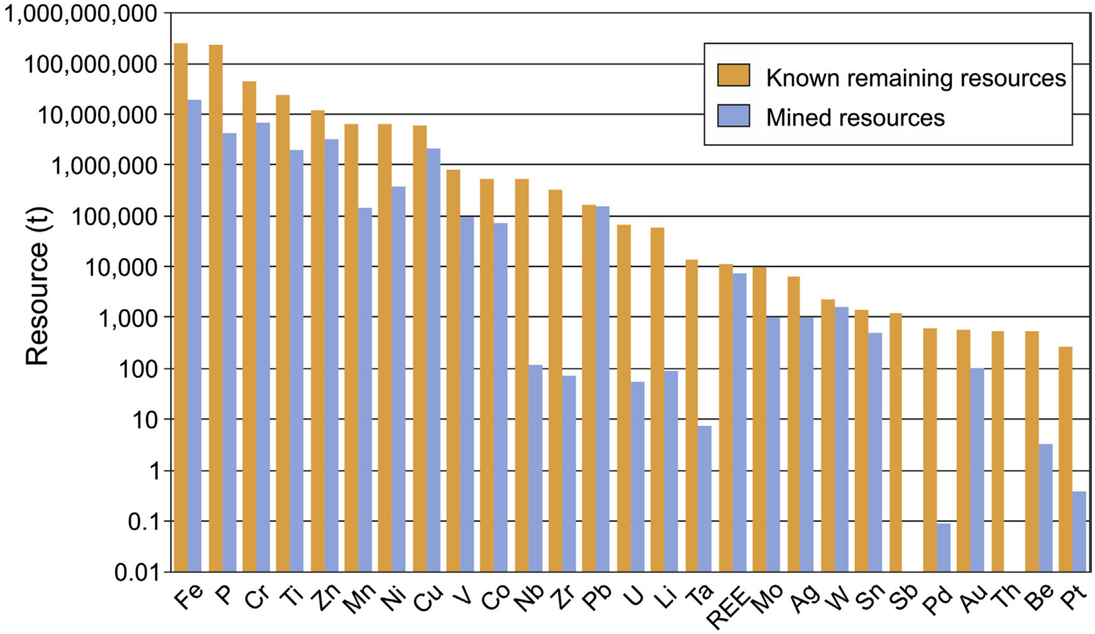

FIGURE 11.9 Remaining known and assumed in situ resources of metals in Finnish mineral deposits compared with metals contained in mined resources.

The mined resources are the calculated total metal contents of excavated ores based on reported tonnages and average metal grades.

Source: *The remaining resources, and mined resources for P, Mn, Nb, Zr, Li, Ta, REE, Sb, Th, and Be, are based on data from 351 metal deposits in Finland (FODD, 2013). The mined resources for the other metals are based on Puustinen (2003).*

UNDISCOVERED MINERAL RESOURCES

By *undiscovered resources*, we mean resources in undiscovered mineral deposits whose existence is postulated on the basis of indirect geological evidence. Unlike known resources, undiscovered resources cannot be observed or measured. They are hypothetical or speculative resources, associated with a probability of existence. The only way to verify the amount of undiscovered resources is through exhaustive exploration. However, it is possible to estimate undiscovered resources, and numerous methods have been developed and applied for this purpose over the years (e.g., Lisitsin et al., 2007, and references therein). In Finland, undiscovered resources of important metals have since 2008 been estimated by the Geological Survey of Finland (GTK) (Rasilainen et al. (2010, 2012)). The procedure selected for the GTK assessments is based on the three-part quantitative assessment method developed by the U.S. Geological Survey (USGS).

The three-part assessment method

The three-part quantitative assessment method was developed at the USGS starting in the mid-1970s (Singer and Menzie, 2010, and references therein), and has been increasingly used by the USGS and others since 1975 (e.g., Richter et al., 1975; Singer, 1975; Singer and Overshine, 1979; Drew et al., 1984; Bliss, 1989; Brew et al., 1992; Box et al., 1996; U.S. Geological Survey National Mineral Resource Assessment Team, 2000; Kilby, 2004; Lisitsin et al., 2007; Cunningham et al., 2008; Hammarstrom et al., 2010;

Sutphin et al., 2013). The method is based on statistical data analysis and integration, it treats and expresses uncertainty, it enables the use of varying amounts of objective geological data and subjective expert knowledge, and it generates reproducible assessment results. The components of the method are:

(1) Evaluation and selection or construction of descriptive models and grade-tonnage models for the deposit types under consideration.
(2) Delineation of areas according to the types of deposits permitted by the geology (permissive tracts).
(3) Estimation of the number of undiscovered deposits of each deposit type within the permissive tracts.

Deposit models designed for quantitative assessments are the cornerstone of the method. Several kinds of deposit models exist, but the two essential models that are always needed in an assessment are the descriptive model and the grade-tonnage model. A descriptive model consists of systematically arranged information describing all of the essential characteristics of a class of mineral deposits (Barton, 1993). The model describes the geological environments in which the deposits occur and lists the essential identifying characteristics by which a given deposit type might be recognized and separated from other deposit types. A grade-tonnage model consists of data on average metal grades and the total ore tonnage (past production and current resources) of well-studied and completely delineated deposits of a certain type, usually presented as frequency distributions. These distributions are used as models for grades and tonnages of undiscovered deposits of the same type in geologically similar settings.

A *permissive tract* is an area within which the geology permits the existence of mineral deposits of the type under consideration. Tract boundaries are based on geology and they should be defined so that the probability of deposits occurring outside of the tract is negligible. It is important to distinguish between areas that are favorable for the existence of deposits and permissive tracts; the former are a subset of the latter. A permissive tract does not indicate any favorability for the occurrence of deposits; neither has it anything to do with the likelihood of discovery of existing undiscovered deposits in the area.

The estimated *number of undiscovered deposits* in a permissive tract represents the probability that a certain fixed but unknown number of undiscovered deposits exist in the delineated tract. The estimates are typically made subjectively by a team of experts knowledgeable about the deposit type and the geology of the region. Uncertainty is taken into consideration and the estimates are made at several levels of confidence (typically at 90%, 50%, and 10%), from which the probability distribution of the expected number of deposits can be derived.

As the final step of the assessment, estimates of the number of deposits are combined with the grade and tonnage distributions from the grade-tonnage models, using statistical methods to achieve probability distributions of the quantities of contained metals in the undiscovered deposits. Software using Monte Carlo simulation has been developed for this purpose (Root et al., 1992; Duval, 2012).

For the assessment process to produce reliable results, it is essential that the three parts previously described are consistent with each other. The delineation of the permissive tracts should be based on criteria derived from descriptive models. The estimates of the number of undiscovered deposits must be carried out according to the deposit type and they must be consistent with the grade-tonnage models. If the consistency requirements are met, the assessment process produces reliable and repeatable probabilistic estimates of the total amount of metals in situ in undiscovered deposits. It must be emphasized that these estimates are not concordant with the present industrial standards (e.g., JORC, NI 43-101) and should never be confused with estimates of known reserves or resources. Furthermore, the modified process used in the GTK assessments does not take into account the economic, technical, social, or environmental factors that might in the future affect the potential for economic utilization of a resource. Thus, part of the estimated undiscovered resource is likely to be located in subeconomic occurrences that will never be profitable to excavate.

The undiscovered mineral resources in Finland

The undiscovered resources of the platinum group elements, nickel, copper, zinc, and gold down to the depth of 1 km in the Finnish bedrock have been estimated by the Geological Survey of Finland. The results of the platinum group element and nickel assessments have been published (Rasilainen et al., 2010, 2012) and the results for copper, zinc, and gold will be published in the GTK Report of Investigation series. As an example, the results for nickel are briefly described in the following.

The assessment was performed for: (1) Ni-Cu deposits associated with Svecofennian (~1.89–1.87 Ga) mafic–ultramafic intrusions in central and southern Finland, (2) Ni-Cu deposits associated with Archean (~2.8 Ga) komatiitic rocks in eastern and northern Finland and Paleoproterozoic (~2.05 Ga) komatiitic rocks in northern Finland, (3) Ni-Cu-PGE deposits associated with Paleoproterozoic (~2.45 Ga) mafic–ultramafic layered intrusions in northern Finland, and (4) Outokumpu-type Cu-Zn-Co deposits hosted by 1.97–1.95 Ga ophiolitic metaserpentinites, metaperidotites, and their altered derivatives in eastern Finland. The two largest known nickel deposits in Finland, Kevitsa and Talvivaara, both represent a rare and previously unknown deposit type for which not enough data are available for the construction of reliable deposit models. Hence, undiscovered nickel resources in these two deposit types could not be quantitatively estimated.

Grade-tonnage models were constructed for the deposit types using data from known deposits within the Fennoscandian Shield. Altogether, there are 40 well-known synorogenic intrusive deposits, 9 komatiitic deposits, 8 layered-intrusion-hosted deposits, and 10 Outokumpu-type deposits in the grade-tonnage models. The remaining known nickel resources in these deposits total 430,000 t of nickel (Table 11.3).

Twenty-six permissive tracts were delineated for synorogenic intrusive deposits, 30 for komatiitic deposits, 43 for layered-intrusion-hosted deposits, one for Outokumpu-type deposits, and 15 for Talvivaara-type deposits. The number of undiscovered deposits was estimated separately for each permissive tract, excluding the Talvivaara-type tracts, in a series of workshops. The mean estimate of the number of undiscovered deposits is 66 for the synorogenic intrusive type, 34 for the komatiitic type, 52 for the layered-intrusion-hosted type, and 6 for the Outokumpu type.

Metal contents of the undiscovered deposits were estimated by Monte Carlo simulation (Table 11.3). Layered intrusions are estimated to contain by far the greatest amount of undiscovered nickel, followed by orogenic intrusive and komatiitic deposit types. The estimated nickel content of

Table 11.3 Remaining known in situ resources and estimated undiscovered resources of nickel in important deposit types in Finland

Deposit type	Remaining known resources (t)	Undiscovered resources (t)
Layered intrusions	223,123	4,200,000
Orogenic intrusive Ni-Cu	128,155	480,000
Komatiitic Ni-Cu	42,003	280,000
Outokumpu	36,767	41,000
Talvivaara	4,516,160	–
Kevitsa	813,120	–
Total	5,759,328	5,001,000

– : Not estimated
Undiscovered resources are estimated at 50% probability.
Source: *Data from Rasilainen et al. (2010, 2012).*

undiscovered Outokumpu-type deposits is clearly small. Most of the undiscovered synorogenic intrusive nickel resources are located within the permissive tracts around the Central Finland Granitoid Complex, whereas the undiscovered komatiitic resources are evenly distributed between the greenstone belts of northern and eastern Finland (Fig. 11.10). The undiscovered layered intrusion-hosted resources and Outokumpu-type resources are restricted to northern Finland and the Outokumpu area,

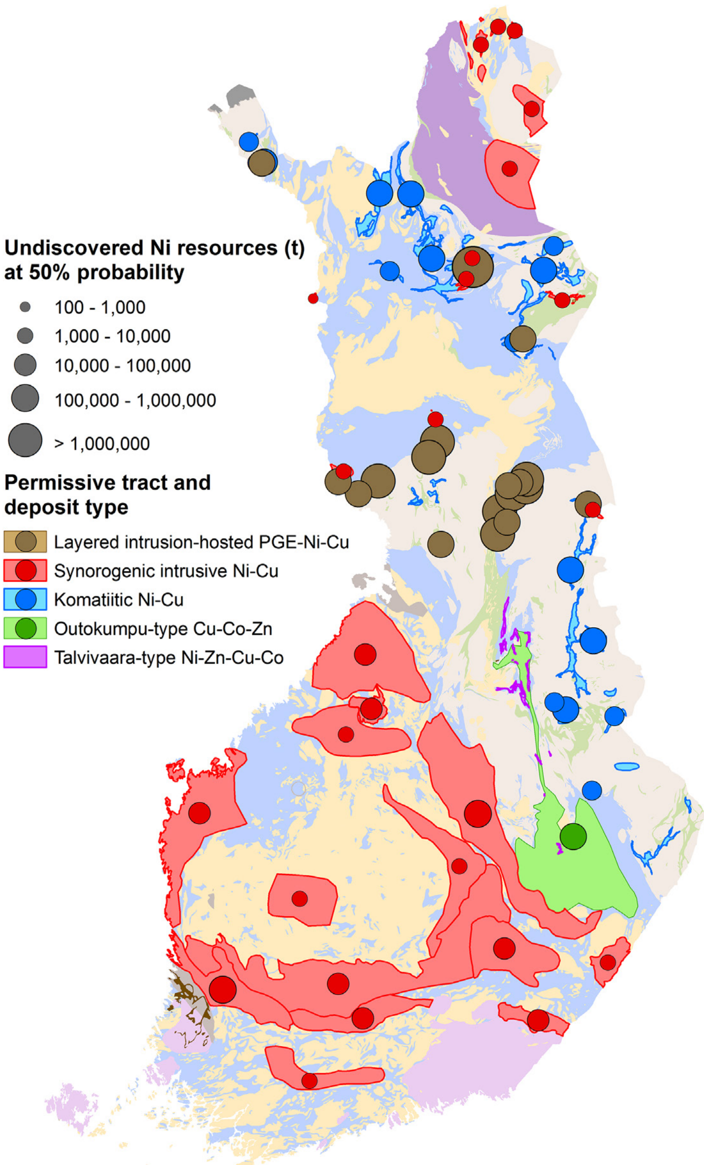

FIGURE 11.10 Permissive tracts for important nickel deposit types in Finland.

Filled circles indicate the estimated undiscovered nickel resource at the 50% probability level for each tract.

respectively. Although it is statistically not strictly correct to sum together the median estimates for the different deposit types, the results suggest that the total known remaining and estimated undiscovered nickel resources are of a roughly similar size.

CHALLENGES AND OPPORTUNITIES FOR FUTURE MINING

Mineral raw materials are unevenly distributed across the Earth and concentrated in small volumes of the crust through distinct geological processes. Mineral deposits, as such, are nonrenewable and ore reserves at existing metal mines are finite. Continuously increasing demand for mineral resources will exhaust most existing mines within the next few decades. Are we going to run out of metals, as predicted by Meadows et al. (1972) in their famous report on limits to growth for the Club of Rome? The Earth is entirely made up of minerals and there is no risk of rapid depletion of most of the raw materials. Global ore reserve data are not a good measure of remaining resources and actually give only a small fraction of the world's total mineral resources (Herrington, 2013; Mudd et al., 2013). Most mines will have a much longer lifetime than can be estimated according to present ore reserves. Drilling will move resources into reserves and new discoveries are commonly made around existing mines (see Fig. 11.3).

The Pyhäsalmi copper-zinc mine is a good example of increased mine life based on continuous and successful near-mine exploration (Fig. 11.11). Ore reserves at the start of mining in 1961 were 18 Mt. Since then, more than 50 Mt of ore have been extracted, and there are still almost 10 Mt of remaining reserves. The distinct decrease of reserves in 1982 was based on higher cutoff values related to lower commodity prices. The considerable increase of reserves in 1998 was caused by the new deep ore body.

The Kemi Cr mine is another example of extended mine life. A new estimate in 2014 increased the ore reserves by more than 50% from 33 Mt to 50.1 Mt, and the mineral resources up to 97.8 Mt (Outokumpu Oyj, 2014). The increase was based on the discovery of an extensive new ore body under one of the old open pits. Moreover, reflection seismic studies indicate the continuation of the host rocks and potential chromium deposits further downwards.

In addition to identified ore resources, a large number of subeconomic mineral deposits are known or can be assumed to contain huge resources. The subeconomic resources may become economically viable in the future, depending on their geographic location, commodity demand, and price fluctuation, and the introduction of new mining and beneficiation technologies (Tilton, 2010). Increasing demand and a more limited supply will raise commodity prices, which will make lower-grade deposits economically viable provided that environmental and social aspects are met.

New estimates of, for example, world ultimate copper resources indicate that, in spite of the growing use of copper, the assumed global resources have actually increased during the last few decades (Mudd et al., 2013). Verification of true copper ore reserves will, however, need intensive mineral exploration.

The life span of many metal products is long and metals are recyclable in most applications. Therefore, once produced, metals remain available for future generations, and sustainable societies will create effective mechanisms for recycling and decreasing the growing need for primary resources. Future manufacturing will pay special attention to product design, which will allow effective recycling of all commodities. Technological development will allow the substitution of some critical metals by other

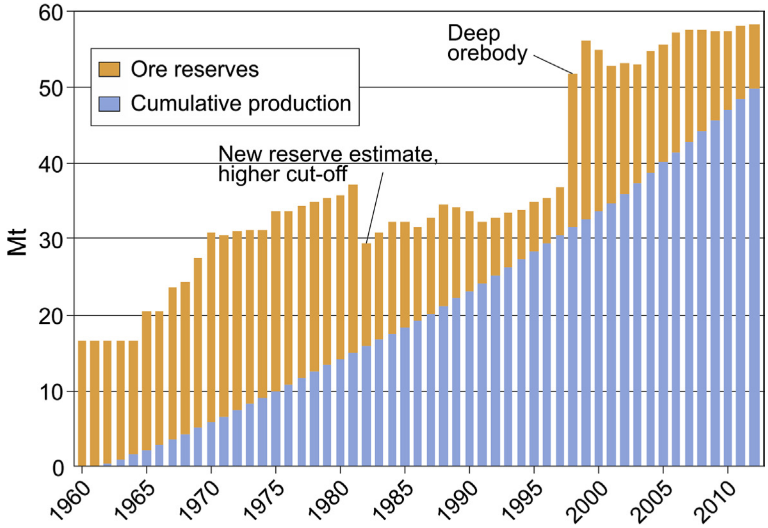

FIGURE 11.11 Development of reserves in the Pyhäsalmi mine.

Source: *Data from T. Mäki (personal communication, 2013).*

compounds. On the other hand, fast technological development and new innovations will require new raw materials for the next-generation low-carbon, high-tech society, which makes it very difficult to forecast the future critical elements (Vidal et al., 2013). Therefore, it is impossible to estimate the global need for various mineral raw materials for future generations.

Thus far, the majority of mining operations have used resources at or near the surface. A major challenge for future mineral production is the increasing difficulty of ore discovery. Deep-seated deposits remain largely unknown and it is likely that many of the remaining undiscovered deposits are located under overburden or water, or in remote or sensitive places, such as the Arctic regions. Long-term investment in geoscientific mapping and research is the basis of mineral exploration and the best way to safeguard minerals for the future. The development and effective use of deep penetrating geophysics, such as seismic, gravimetric, magnetic, electrical, and electromagnetic methods, are increasingly important. Better data and understanding of geological structures and earth processes in 3D and 4D, and the development of drilling technologies, are crucial for future discoveries. This is particularly important in countries such as Finland, where considerable resources for a wide range of commodities evidently remain undiscovered.

Mining is already technically possible today at depths of several kilometers. Underground mining can be carried out using automation, and its footprint is much more limited than that of open-pit mining. Underground mining is also environmentally and socially more acceptable, and it is evident that its role will strengthen in the future. The future smart mines will employ high-level automation, produce less waste, and be increasingly less visible.

Finland is a potential producer of a wide range of minerals. Fig. 11.12 presents the metals currently produced, those in projects under feasibility studies, and minerals that on a geological basis have an obvious potential for discoveries and future production. These commodities also include

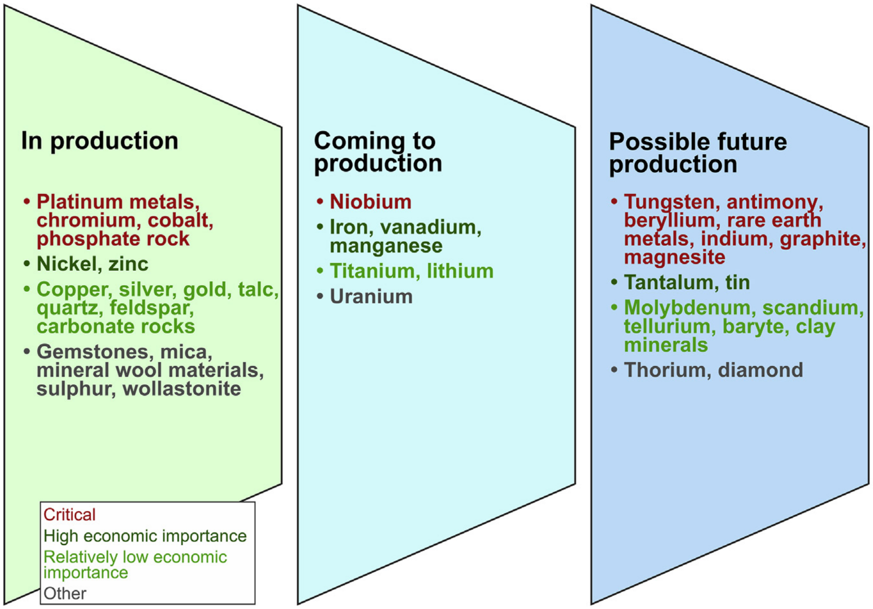

FIGURE 11.12 Commodities currently produced in Finland and those with potential for future production.

Source: *The classification of commodities is based on their criticality and economic importance at the EU level (European Commission, 2014). The group "Other" is not included in the EU classification.*

the majority of the critical and important minerals recently classified by the European Commission (2014). Technological innovations will create demand for new commodities and affect the prices of various minerals (Vidal et al., 2013). On the other hand, the development of mining and processing techniques will make new types of occurrences economically viable. Therefore, it is very difficult to forecast which commodities will be produced in Finland in the future. There are increasing efforts to recover all valuable commodities from ore mined and processed in addition to the main ore metals, and some commodities will also be produced from old mine tailings.

The ultimate resources of various mineral commodities are impossible to accurately define, because of the lack of detailed geological knowledge. In Finland, about 96% of the bedrock is covered with glacial sediments, peat bogs, and water. Although geological formations can continue to depths of several kilometers, our knowledge of geology, mineral resources, or ore potential even at depths of a few hundred meters is very limited and almost completely based on interpretations. Although the various geoscientific datasets in Finland are of high quality and we have a good understanding of regional geology, ore deposits are tiny targets and difficult to find under the cover. Therefore, even many mineral deposits reaching the bedrock surface can remain undiscovered. The recently found Sakatti Cu-Ni-PGE deposit in Sodankylä is a good example of a grass-roots discovery, and demonstrates that even huge high-grade deposits can still be discovered at the bedrock surface (Anglo American plc, 2012). Undiscovered mineral deposits, both at depth and at the bedrock surface, form untapped resources for future mining.

GREEN MINING CONCEPT

Mine development is also becoming increasingly difficult for societal and environmental reasons. There is increasing competition with other land use purposes such as nature conservation, recreation, tourism, agriculture, and infrastructural building. Tightening laws and regulations will make future mining more difficult in many countries. There is a global scarcity of mining professionals, and in some regions it is impossible to find enough energy and water.

People are not ready to radically reduce the use of mineral-based products, but increasingly oppose mining in nearby areas, within their own country or within environmentally vulnerable areas, such as the Arctic regions. The mining industry has major challenges to improve its resource efficiency, as well as its adverse environmental and social impacts, and to strengthen societal interactions and positive impacts on the mining regions.

Finland's green mining concept was developed in 2011 as a major tool to make it the front-runner in sustainable mining. This concept is based on five pillars, as demonstrated in Fig. 11.13.

Green mining promotes material and energy efficiency, which reduces the environmental footprint of mineral-based product life cycles. Methods that save energy and materials in mining and enrichment of minerals have to be developed. The purpose of these new solutions is to allow the recovery of all useful minerals and by-products and to minimize the amount of waste. Solutions for reducing raw water and energy consumption are being developed. To achieve a result that is best for the entire operation, we have to have a reliable way of measuring the material and energy efficiency and the environmental footprint during the life cycle.

Furthermore, green mining aims to ensure the availability of mineral resources for the future. Sustainable development requires that our current use of mineral resources does not endanger the ability of future generations to satisfy their needs. Mines exploit economically viable ore deposits. Although individual deposits are nonrenewable, the mineral resources in the Earth's crust are in no danger of rapidly running out. To ensure the availability of mineral resources for future needs and to fulfill the so-called mineral debt, we must continue geoscientific mapping and research, and invest in mineral exploration. The development of exploration, mining, and processing techniques is also needed to be able to discover and use new types of deposits.

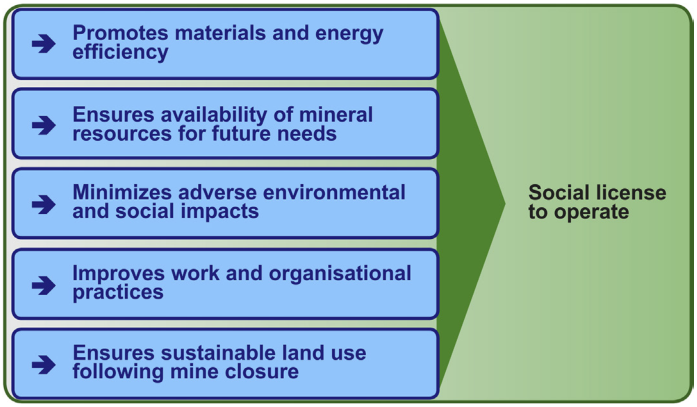

FIGURE 11.13 The green mining concept of Finland.

Mining operations always impact on the natural environment, economy, and social structure of the region. The goal of green mining is to minimize the adverse environmental and social impacts in all the stages of the operations. At the same time, the operations strive to maximize social and local benefits. Minimizing the adverse environmental impacts requires the development of better control and measurement methods that take into consideration the special characteristics of mining operations and the local natural conditions. Maximizing the beneficial societal, economic, and cultural impacts in a sustainable way requires research, communication, and methods that allow broad-based community participation. Participation is especially important on the regional level, because this allows the corporate social responsibility of the mines to be executed in the best possible way.

A wide range of technology and heavy machinery is used in mining, which increases potential safety hazards. Work must be organized in such a way that it is safe and meaningful to employees. This can be achieved by automating processes and making them more efficient, as well as by developing new practices and working methods in cooperation with the entire staff. Occupational safety aiming at zero accidents is an important starting point in all development. Operations must also be safe for local residents and the environment. Increasing automation and the development of technologies helps to reduce the need for a workforce and will improve safety. The mining organization will become lighter and most operations will be executed in mines and enrichment plants using remote control.

The operation time for individual mines can be more than 100 years, but is always limited. After this, the mining areas will be restored to make them safe and allow other kinds of land use. Planning of the controlled ending of mining operations and the proper measures for achieving this is started well before commencing mining operations, and is developed throughout the project's life cycle with the broad-based participation of local residents and other stakeholders. Closure of a mine also requires functional and tested technical and scientific methods, so that the quarries, waste areas, and other infrastructure can be restored in a way that allows further sustainable use of the area according to plans.

The actual availability of commodities is controlled not only by geological accessibility, but increasingly by availability of water and energy, and by social constraints, politics, legislation, and environmental regulations. Therefore, the mining industry needs to improve its performance in all the green mining areas to make it economically, environmentally, and socially viable and acceptable in the future.

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