MINING HISTORY OF FENNOSCANDIA

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The earliest indications of mining in Fennoscandia are from Sweden and Norway where exploitation of bog and bedrock iron deposits started more than 2000 years ago. Signs of prehistoric mining have been detected also from Finland. Sweden and Norway also record the first underground mining in the region, at about 11th and 12th centuries. Mining grew extensively in the 16th and 17th centuries in Sweden and Norway, both in the number of operations and in metals mined. In addition to iron, copper and silver, later also nickel, zinc and cobalt become significant products. Underground mining probably started in the 17th century in Finland and in the 18th century in NW Russia. Mining in modern industrial scales started in the region about 100 years ago with the extension of old mines and opening of new mines. This also resulted in globally substantial development in mining and ore processing technology in the whole region. A large number of mines were closed during the 20th century. On the other hand, there has been a huge increase in the size of individual operations in Fennoscandia since the end of the Second World War. Presently, mining is in increase with extension and reopening of old mines and with opening of new, dominantly very large mines. The present metals production is dominated by iron, titanium, copper, nickel and zinc, but also production of gold, cobalt, vanadium, uranium, lithium, and the REE are projected to significantly increase in the near future.

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INTRODUCTION

Fennoscandia has a long history of mining and exploration. For example, archaeological evidences shows that sponge iron was produced in Sweden in Bloomery furnaces using magnetite ore during the second century AD (Kresten 1993). Archaeological evidence shows that early copper produc-

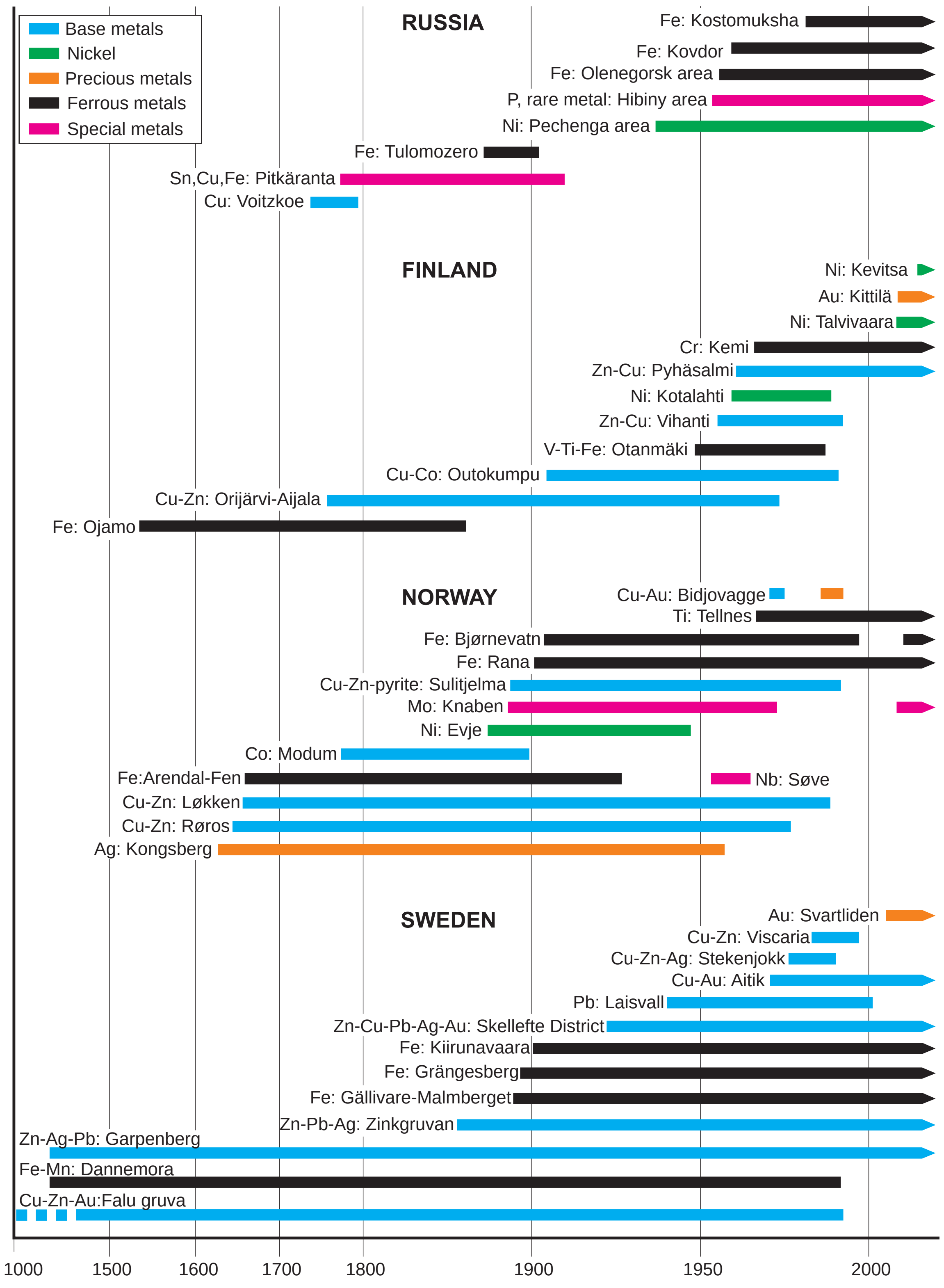

Figure 1. Milestones of the mining history of Fennoscandia: life of the most significant mines and mining camps. Lines ending as arrows indicate presently active mines. Note the non-linear time scale.

tion at the Falu mine took place during the 8th century (Eriksson & Qvarfort 1996). Statistics on copper production at Falun are available from the mid-16th century and until the closure of the mine in 1992. A similar historical background can be shown for the other countries of Fennoscandia.

Metal mining and production has constantly been significant across the region. Hence, the history of mining in Fennoscandia is briefly reviewed in this report. Below, the major developments, 'milestones', mines and mining camps important in their time are presented for each country, as individual subsections, by local experts. Furthermore, some of the immediate effects of these mines on the metals industry are discussed. The main mines and mining camps important in their time in Fennoscandia are listed in Figure 1 and their locations indicated in Figure 2.

Figure 2. Location of the most significant mines and mining camps of their time in Fennoscandia. Geological map based on Koistinen et al. (2001).

NORWAY

Pre-1500

Bog iron ores were exploited in Norway as long ago as 400 BC, and according to C^{14} dating, 28 deposits had been exploited in the Trøndelag counties (in central Norway) alone prior to 200 AD (Stenvik 2005). The oldest record of underground mining is from the late 12th century: it relates to the Akersberg silver deposit in Oslo (Berg 2000) and indicates that operations had by then been closed due to flooding. These deposits were again mined in the period 1520–1537. Small-scale copper mining in the Kongsberg district commenced before 1490. Other types of mineral resource have a much more continuous record of use – especially soapstone for household articles and building, and various types of rock used as millstone.

16th – 17th Centuries

Copper ores were discovered at Ytterøy in Trondheimsfjord at least as early as 1516 (Falck-Muus 1924), but sources disagree as to whether these were exploited at that time. King Frederik I issued a permit to the Bishop of Hamar in 1524 for mining of the Guldnes copper and silver deposits at Seljord in Telemark: these deposits were mined until 1537. Frederik's eldest son, the new king, Christian III, was responsible in 1538–1539 for the introduction of mining laws modelled on those of Saxony and including elements that are still found in the current mining law – a system of claims administered by mining inspectors. Christian III also encouraged prospecting, but with little success. His grandson, Christian IV, who reigned from 1588 to 1648, had greater fortune – in his case also with the aid of miners from Saxony. The first of the silver mines at **Kongsberg** was opened in 1623 (Fig. 1); the king himself visited the mine and founded the city in the following year (Berg 2000). Mining and smelting activities continued, with shorter periods of closure, until 1958. At the most, in 1770, 4200 people were employed in the mines.

Long-term copper mining developed in the following thirty years, first at Kvikne (1630) and then at **Røros** (1644) and **Løkken** (1654), all in deposits in the central Norwegian Caledonides (Table 1). Mining at Røros and Løkken continued until 1977 and 1987, respectively. Numerous iron mines were also opened in the 16th century, primarily in southernmost Norway, but few of these survived to recent times.

18th – 19th Centuries

The Kongsberg Mining Academy ("Bergseminaret") was established in 1757 as the first centre of higher education in Norway, to provide professional training for mining engineers: it was closed in 1814, its role to be taken over by the newly-established University of Oslo.

The established copper mines were joined by another long-term operation at **Folldal** in 1748 and new, though more short-lived, iron mines opened on the southern coast of Norway. New types of metallic ore and minerals were also exploited in addition to the established copper, silver and iron.

Cobalt was discovered at **Modum** in 1772, leading to the establishment of Blaafarveværket as a royal company for the production of the dye "cobalt blue". Mining continued after 1820 in private ownership, but closed in 1898 after periods in British and German ownership, mainly due to competition from alternative types of dye. At its peak, in the 1820s and 1830s, the company was Norway's largest industrial corporation and produced 80 % of the world's cobalt blue.

Nickel was discovered in **Espedalen** in 1837 and mining operations commenced there in 1846 and at **Ertelien** in 1849, the nickel being used in alloys with copper and zinc (Nordsteien 2000). There followed a period of almost 100 years of semi-continuous nickel mining in Norway, including a period in the early 1870s during which Norway was the world's major supplier (a position supplanted by New Caledonia after the discovery of nickel laterite ores).

Mining of pyrite for sulphuric acid production began in the mid-19th century, for example at Vigsnes and Stord and later, in 1888 at **Sulitjelma** (also a major copper producer) and at other new deposits, as well as production from the established copper mines at Røros, Løkken and Folldal. Molybdenum deposits were also discovered in the late 1800s, including the Knaben deposits, which were mined from 1885 (until 1973).

Several new, large deposits of iron ore had been discovered before the end of the 19th century. The Dunderland (**Rana**) deposits were discovered in the 18th C and those at **Bjørnevatn** in Sydvaranger in 1865.

Foreign investment was important in prospecting and mine development in the late 1800s and early 1900s, especially in northernmost Norway. The most long-lived evidence of this is the town of Longyearbyen on Svalbard, named after the founder of the Arctic Coal Company. Established in 1906, this company was the forerunner of Store Norske Spitsbergen Kullkompani, which still operates two coal mines on Svalbard (Vik 2000).

20th Century

Mining commenced at three major iron ore deposits within the first decade of the new century – at Sydvaranger (1906), **Fosdalen** (1906) and Rødsand (1910). Operations also began at Dunderland, but were sporadic until 1937. The first steps that ultimately led to Norway's major role as a producer of titanium pigments were also taken in the early 1900s, with the establishment of a company to exploit a patent for the manufacture of titanium pigment from titanium dioxide. Titania A/S opened mining operations on the Storgangen deposit in Rogaland in 1916. Titania was taken over by an American company, National Lead (NL), in 1927, and is now part of the NL subsidiary, Kronos. In 1957, the **Tellnes** deposit, one of the first in Norway to be discovered with the aid of airborne geophysical methods, was opened. Tellnes is one of the largest ilmenite deposits in the world, currently providing about 6 % of world production of Ti minerals. Other new ore types to be exploited included Zn-Pb-Cu ores such as that at **Mofjell**, just south of Mo i Rana, which was opened in 1928 and was mined until 1987.

The occupation of Norway during World War II had an important impact on mining in the country due to the strategic importance of certain types of ore that were not readily obtainable in Germany. Deposits of several types were intensively exploited and at least two, the nickel deposits at Hosanger and Flåt, were mined out. Considerable emphasis was placed on exploration for new deposits, but no significant new metal mines were opened.

Table 1. Selected mines in Norway (Fig. 2). The most important mines of their time are also shown in Figure 1.

Mine	Main commodities	Production Period (s)	Ore mined (Mt)	Produced metals (kt)
Kongsberg	Ag	1623–1958	7	1.35 Ag
Røros[1,2]	Cu, Zn	1644–1977	6.5	175 Cu; 275 Zn
Løkken[2]	Cu, Zn	1654–1987	24	552 Cu; 432 Zn
Fen	Fe	1657–1927	1	500 Fe
Folldal[1,2]	Cu, Zn, pyrite	1748–1970	4.45	60.9 Cu; 115.2 Zn
Modum	Co	1773–1898	1	20 Co
Evje	Ni, Cu	1872–1946	2.7	20.2 Ni; 13 Cu
Knaben	Mo	1885–1973	8	160 Mo
Sulitjelma[1,2]	Cu, Zn, pyrite	1887–1991	25	469 Cu; 214 Zn
Rana	Fe	1902–	100	25000 Fe
Fosdalen	Fe	1906–1997	35	11600 Fe
Bjørnevatn	Fe	1908–	140	43400 Fe
Mofjell	Zn, Pb, (Cu)	1928–1987	4.35	157 Zn; 31 Pb; 13.5 Cu
Skorovas	Cu, Zn	1952–1984	5.6	64 Cu; 152 Zn
Søve	Nb	1953–1965	1.15	4.1 Nb_2O_5
Bleikvassli	Pb, Zn	1957–1997	4.9	200 Zn; 100 Pb 7.5 Cu
Tverrfjell	Cu, Zn, pyrite	1968–1993	15	150 Cu; 180 Zn; 30 Pb
Tellnes	Ilmenite	1965–	112	21250 TiO_2
Bidjovagge	Cu, Au	1971–1991	2.38	30 Cu; 0.006 Au
Joma	Cu, Zn	1972–1998	11.453	171 Cu; 166 Zn
Bruvann	Ni, Cu	1989–2002	8.5	32.5 Ni; 9.1 Cu; 1.5 Co

1 Combined figures for several mines in a district.

2 In historical times, zinc was not exploited, and the Zn figures represent estimates based on average ore grades and not actually produced.

The period of reconstruction and industrial development following WW II saw the opening of numerous new sulphide mines, partly based on known deposits but also on deposits found using new geophysical exploration methods and intensive exploration. These included **Bleikvassli** (Zn-Pb-Cu), **Skorovas** (Zn-Cu-pyrite), **Tverrfjell** (Cu-Zn-pyrite), **Joma** (Cu-Zn), **Bidjovagge** (Cu-Au), Ulveryggen (Cu), **Bruvann** (Ni-Cu) and new deposits in the Røros province (Cu-Zn). More exotic ores were exploited at **Søve**, in the **Fen** carbonatite, where niobium was mined from 1953–1965, and iron had previously been produced (1657–1929). Outokumpu, the Finnish mining giant, developed an important role in mining in Norway in the period from 1983–2003 with ownership or part-ownership in operations at Løkken, Tverrfjell, Joma, Bruvann and Bidjovagge.

Exhaustion of a number of deposits, erratic metal prices and competition from large, easily-mined deposits in other parts of the world led to the closure of most of the remaining sulphide deposits in the last quarter of the 20th century: the only sulphide mine to survive past 2000, Bruvann, closed in 2003, as Outokumpu withdrew from mining operations in general. Norway had, by then, become an important producer of many industrial minerals. Now, early in the 21st century, demand for metals in Asia, higher metal prices and the paucity of resources in much of Europe are driving a new search for mineable ores in Norway and its Nordic neighbours.

SWEDEN

Pre-1600

According to a legend, the **Falu** deposit in the Bergslagen area of south-central Sweden was discovered by a white goat named Kåre who, one day, came back to his owner with horns and hair dyed red from weathered sulphides. ^{14}C dating of charcoal-bearing Cu-rich sediments from a lake in the vicinity of the current mine site indicated that mining (by men or goats) commenced sometime during early Viking times, ca. 700 AD (Eriksson & Qvarfort 1996). The deposit was worked continuously until the closure of the mine in 1992 (Figs. 1 and 2). The first written document mentioning the mine is from 1288 and deals with shares in the mining activity, thus making the Falu mine one of the oldest, if not the oldest, extant companies in the world (Rydberg 1979). The current incarnation of the company is Swedish-Finnish forestry company Stora Enso. The Falu mine site (Fig. 3) was registered as a World Heritage site in 2001.

Archaeological evidence shows that hard-rock iron ore mining began in Sweden even earlier, during Roman Iron age (0-400AD). Bloomery furnaces, dated to around 100 AD, with fragments of magnetite ore have been excavated north of Uppsala and it is suggested that the iron ore came from the nearby Stenby-Lenaberg deposit (FODD ID: S1450) some 8 kilometres up the Fyris river (Kresten 1993). Archaeological excavations and ^{14}C dating of the Lapphyttan blast furnace in the

Figure 3. Panoramic view of the open pit at the Falu mine. Photo: Torbjörn Bergman, SGU.

Norberg area indicates that iron was produced with more modern techniques during the 12th century (Almevik et al. 1992). The first written documents on Fe ore mining come from the mid-14th century (Rydberg 1981).

17th – 19th Centuries

During the end of the 16th century and the beginning of the 17th century the demand for iron and steel increased and paved the way for technological improvements in the mines, blast furnaces and smelters. From being small-scale operations operated by local farmers, the mines became larger industrial units. The industrial revolution, which took place during the late 19th century, brought steam engines, efficient pumps, railways, explosives, methods to process P rich (apatite-bearing) Fe ore and the use of coal instead of charcoal in the blast furnaces completely changing the industrial landscape of Sweden. The innovations, in particular the development of a Swedish railway network, made it possible to start large-scale mining of ores from outside of the Bergslagen district.

20th Century

The Fe ores in Norrbotten County, northernmost Sweden, were already known in the 17th century but it was not until a railway was built that they became economic. In 1888, the railway between **Malmberget** at Gällivare and Luleå by the Baltic Sea coast was completed and production rose from 60 to 600 000 tons of ore annually. In 1902 a railway to Narvik on the Atlantic coast was completed and in 1903 the production from the ores in Malmberget and **Kiruna** made up more than 50 % of all iron ore produced in Sweden. The mines in the north have held a leading position ever since, and today all iron ore produced in Sweden comes from these two mines.

The improved infrastructure in northern Sweden also opened the region for exploration for other commodities. In 1930 boulders from what was to become the large **Aitik** Cu-deposit were found (Malmqvist & Parasnis 1972). Several years of exploration work by Boliden AB eventually led to the opening of the mine in 1968. Initial production was 2 Mt per year and several phases of expansion, the latest approved in 2010, will lead to an annual production of 36 Mt per year by 2015. In 1973, a Cu-mineralised area was found 4 km west of the Kiruna Fe ore deposit (Godin 1976). The initial exploration method was the recognition of the "copper plant", *Viscaria Alpina*, and the mine, which was named after the flower, was in production from 1982 to 1997. Today there are advanced plans to re-open the **Viscaria** mine.

During the first decades of the 20th century, several small holding companies called "emissionsbolag" were created by Swedish banks. One of these was Centralgruppens Emissionsbolag with the mission to acquire stakes in new mining companies and to develop mines, thus it was a kind of early junior exploration company. In 1924, at a time when the company was nearly bankrupt, the **Boliden** Au-Cu-As deposit was found, and was put into production two years later. During the following years several new massive sulphide deposits was found west of Boliden. Today these deposits and their host rocks form the **Skellefte District**, one of the most important ore-districts in Sweden. Discoveries are still being made in the district. For example, the **Björkdal** Au deposit was found by geochemical methods (till sampling) in 1985 by Terra Mining AB and went into production in 1988. It is still in production but with a new owner. The **Åkerberg** Au deposit was found in 1988 by Boliden Mineral AB and was in production from 1989 to 2001. One of the most Cu- and Zn-rich deposits ever found in the district, the **Storliden** deposit, was discovered in 1997 by North Atlantic Natural Resources (NAN) and was in production 2002 to 2008.

The **Caledonian mountains** are another important mineralised region whose metal potential has been known for a long time. Although the lack of infrastructure and, more recently, environmental protection policies has limited exploitation, several mining attempts have nevertheless been made over the centuries. The best known and most "mythical" mine is the Nasafjäll Ag deposit close to the Norwegian border (Bromé 1923, Du Rietz 1949). The deposit was mined for a few years in the mid 17th century but was never profitable. The Fröå Cu deposit was found in the mid 18th century and was intermittently mined during several periods, the latest being from 1910 to 1919. Ore production reached a peak in 1917-1918 but less than 100 000 tons of ore was produced during the mine's lifetime (Helfrich 1967).

More significant deposits in the Caledonides were found and put into production during the

1940s. Galena-bearing sandstone boulders found in 1938 led to the discovery of the **Laisvall** Pb-Zn deposit. Exploitation started in 1943, mainly as a measure to secure domestic supplies of Pb during World War II, but turned out to be economic in peace time as well, and mining lasted until 2001 (Rickard et al. 1979). Exploration for sandstone-hosted Pb-Zn led to several discoveries of similar mineralisation along the Caledonian front, and the Vassbo and Guttusjö deposits 500 km to the south-southwest of Laisvall have also been in production. Exploration by the Geological Survey in the 1970s also led to the discovery of several massive sulphide deposits in the Caledonides (Zachrisson 1969) however the only deposit that has been in production is **Stekenjokk** which was mined for Cu between 1976 and 1988.

The most recent mining district to be recognised in Sweden is the so-called **Gold Line** in Västerbotten County. The Gold Line refers to a southeast-trending Au anomaly detected by the State Mining Property Commission (NSG) during a till geochemistry survey in the late 1980s. The anomaly attracted exploration to this new district, and the first deposit to be found and later put into production by Dragon Mining Ltd. was the **Svartliden** Au deposit. Several other Au deposits are waiting to be opened.

Parallel to, and in interaction with the expansion of the exploration and mining industry there was a tremendous development of the Swedish engineering industry which supplied materials to these enterprises for more than a century. In 1893, ASEA built Sweden's first three-phase power transmission system for the **Grängesberg** Fe mine. About a hundred years later, in 1987, ASEA merged with the Swiss company BrownBoveri to form ABB, a global leader in power and automation technologies. Atlas Copco was established in 1873 with the objective to manufacture and sell equipment for railway construction and operation. At the turn of the century, compressed air machinery and later pneumatic rock-drill equipment became important. Today Atlas Copco tools are found in mines around the world. Sandvik was founded in 1862 and from the very start, the company delivered rock-drilling equipment to the exploration and mining industries. Through mergers and acquisitions the Swedish and Finnish engineering industries have amalgamated to form multinational companies that today are market leaders as suppliers to the world's exploration and mining industries.

Table 2. Selected mines in Sweden (Fig. 2). The most important mines of their time are also shown in Figure 1.

Mine	Main metals	Production Period (s)	Ore mined (Mt)	Produced metals (kt)	Remaining resource (Mt)
Falu mine	Cu, Zn, Au	<800–1992	11.4*	3432 Cu; 456 Zn; 0.034 Au	-
Dannemora distrcit	Fe, Mn	<1200–1992	27.6*	10719 Fe; 536 Mn	59.4
Garpenberg district	Zn, Ag, Pb	<1200–	35.1*	1757 Zn; 4.9 Ag; 808 Pb	54.3
Zinkgruvan	Zn, Pb	1857–	32.4	2847 Zn; 1294 Pb	30.5
Malmberget	Fe	1888–	509.8	260425 Fe	423
Grängesberg	Fe	1892–1989	132.6	79946 Fe	120
Kirunavaara	Fe	1903–	940.3	505155 Fe	1003
Skellefte district (>30 deposits)	Cu, Zn, Au	1924–	105.6	992 Cu; 4856 Zn; 0.25 Au	108
Boliden (Skellefte district)	Au, Cu	1926–1967	8.3	0.13 Au; 119 Cu	-
Laisvall	Pb	1943–2001	64.5	2450 Pb	-
Aitik	Cu, Au	1968–	502.2	1055 Cu; 0.085 Au	2248
Stekenjokk	Cu, Zn, Ag	1976–1988	7.0	94 Cu; 225 Zn; 0.38 Ag	10.1
Viscaria	Cu, Zn	1982–1997	12.5	179 Cu; 88 Zn	57.2
Svartliden	Au	2005–	1.6	0.006 Au	2.7

* Documented production from 1860 to the closure of the mines. Estimated total productionfor the Falu mine probably > 25 Mt, for the other deposits pre-1860 production unknown.

FINLAND

16th – 19th Centuries

The **Ojamo** iron ore mine, which started production in 1530, can be regarded as the first metal mine in Finland (Fig. 1, Table 3). Following this, over 350 metal mines has been in operation before the Second World War. The scale of production in these mines was modest, although mining played an important role in the slowly developing society. Before the 1920s, the mines mainly produced iron ore for iron works in southern Finland. Sulphide ore production was mostly from one mine, **Orijärvi** (Cu-Zn) in SW Finland. During the first 400 years (1530–1945), ore production totalled 10.5 Mt, of which sulphide mines comprised 9.7 Mt (most of which was produced during the 1920s to 1930s) and iron mines 0.8 Mt (Puustinen 2003).

20th Century

In Finland, the modern mining industry started to form along with the **Outokumpu** mine. The deposit was discovered in 1910 (Kuisma 1985) and gradually developed into the first major sulphide ore mine in the country. Small-scale production started in 1910, production gradually increased in the 1930s, and total ore output was almost 6 Mt between 1930 and 1945. During its lifetime, from 1910–1989, about 28 Mt of ore was mined and 1 Mt copper produced (Puustinen 2003). The **Petsamo** (Pechenga) nickel deposit was found in 1921, in the then northeasternmost corner of Finland (Autere & Liede 1989). The development of a mine at Petsamo was complicated, but eventually, during 1936–1944, about 0.5 Mt of ore was mined, first as a Finnish-Canadian cooperation, and during WWII by Germany. The war between Finland and the Soviet Union ended in September 1944, and the Petsamo region was subsequently ceded to the Soviet Union.

Soon after the war, in the late 1940s, the **Aijala** (Cu) and **Otanmäki** (Fe-Ti-V) mines were opened (Table 3). Otanmäki gradually developed into a globally significant vanadium mine responsible for about 10 % of the world's vanadium production during the 1960s and 1970s (Illi et al. 1985). Seven metal mines were opened in the 1950s, including **Vihanti** (Zn) and **Kotalahti** (Ni) mines. The most active mine development period thus far in Finnish mining history was from 1960–1980, when more than twenty metal mines started production. The most important were the still operating Kemi Cr and Pyhäsalmi Zn-Cu mines. As a consequence, total metal ore output peaked in 1979 at slightly over 10 Mt. A few small mines were opened in the 1980s, but at the same time a number of major mines were closed, and total production gradually declined to about 3 Mt in the early 2000s (Puustinen 2003).

Before the opening of the Talvivaara mine in 2008, the most important sulphide mine in Finland was **Pyhäsalmi**. The deposit was discovered in 1958 when a local farmer dug a well through the overburden till into a subcrop of the massive ore (Helovuori 1979). By the end of 2010, over 40 Mt of ore had been mined and the remaining ore has secured a further 10 years of production.

The **Kemi** chromite deposit was found 1959 by a local layman (Alapieti et al. 2005). Open-pit chromite mining began in 1966 and ferrochrome production in 1967 at nearby Tornio, at the far northern end of the Gulf of Bothnia. Stainless steel production at Tornio commenced in 1976. In 2006, the underground mine became the sole source of ore. Its design capacity is 2.7 Mt/y of ore. The known ore reserves will enable mining to continue for several decades, and a recent seismic reflection survey suggested further large resources at depth (Outokumpu 2010).

Currently, we are living in a new era in Finnish mining history. Two major mines, **Kittilä** (Suurikuusikko) gold and **Talvivaara** nickel, were opened in 2008, and the development of the **Kevitsa** Ni-Cu-PGE deposit has started. These three mines will multiply Finnish metal ore output to over 20 Mt/y. In addition to these major deposits, a number of smaller projects have recently started; for example, the **Jokisivu** mine produced its first gold in 2008, and production at the **Pampalo** gold mine started in early 2011. The **Laiva** (Laivakangas) gold mine in western Finland started production in mid-2011, and the mine is expected to yield 118 000 ounces or around 3700 kg of gold per year (Nordic Mines 2010). At the **Kylylahti** Outokumpu-type Cu-Co-Ni-Zn deposit, mine construction has commenced with first production envisaged during 2012 (Universal Resources 2010).

The Talvivaara Ni-Zn-Cu-Co deposit was discovered in 1977 (Loukola-Ruskeeniemi & Heino 1996). The resource was found to be large but of relatively low grade, and it was concluded at the time that exploitation was not economically viable using conventional metal extraction techniques. Bio-heap leaching was later found to be a suitable method to operate this sulphide deposit. The mine successfully produced the first metals in October 2008, and Talvivaara has been in full production since 2010. With a planned annual production of approximately 50 000 tonnes of nickel, Talvivaara has the potential to provide 2.3 % of the world's annual production of primary nickel. In October 2010, the company announced an upgrade of the mineral resources to 1550 Mt (Talvivaara Mining 2010). The mine is anticipated to produce metals for a minimum of 60 years.

Geological Survey of Finland discovered gold in the Suurikuusikko area of the Central Lapland greenstone belt in 1986 (Patison et al. 2007). A preliminary estimate of inferred resources in 2000 amounted to 8.3 Mt, with an average grade of 6.1 grams of gold per tonne. In 2011, proven and probable gold reserves amount to 4.0 million ounces (26 million tonnes at 4.8 g/t). Construction of the mine began in June 2006, and mine was named after the local municipality of **Kittilä**. The first gold was poured on 14 January 2009. The processing plant achieved commercial production in May 2009. Life-of-mine annual gold production was then expected to average 150 000 ounces from 2009 for at least 15 years (Agnico-Eagle 2009).

The **Kevitsa** Ni-Cu-PGE deposit was found 1987 (Mutanen 1997). The property has estimated global resources of 208 million tonnes of ore at grades listed in Table 3, at 0.1 % Ni cut-off. Process facilities are under construction for a starting production of 5 Mt/y ore, with built-in expansion capabilities. The average annual production is planned at 10 000 tonnes of nickel and 20 000 tonnes of copper. Commercial production is expected to start in mid-2012. The estimated mine life is over 20 years (First Quantum Minerals 2009).

Table 3. Significant deposits in Finnish mining history (Fig. 2). Ore and metal production by the end of 2010. Data sources are given in text and in Fennoscandian Ore Deposit Database (2011). The most important mines of their time are also indicated in Figure 1.

Mine	Discovery year	Discovery by	Production Period	Ore mined (Mt)	Produced metals (kt)
Ojamo	<1530	Not known	1542–1863	0.0118	5.3 Fe
Orijärvi	1757	Layman	1758–1954	0.925	12 Cu; 12 Zn; 9.5 Pb
Outokumpu	1910	GTK	1910–1989	28.5	957 Cu; 54 Co; 227 Zn; 34 Ni; 23 Au
Petsamo	1921	GTK	1936–1944	0.462*	16.7 Ni; 8.9 Cu*
Aijala	1945	Suomen Malmi	1948–1960	0.839	13 Cu; 5.5 Zn
Otanmäki	1938	GTK	1949–1985	25.4	8616 Fe; 1 923 Ti; 66 V
Vihanti	1946	GTK	1954–1992	27.9	1445 Zn; 129 Cu; 98 Pb
Kotalahti	1954	Outokumpu	1959–1987	12.36	82 Ni; 32 Cu; 3.7 Co
Pyhäsalmi	1958	Layman	1962–	44.9	988 Zn; 359 Cu; 0.013 Au; 0.63 Ag
Kemi	1959	Layman	1966–	35.8	6 802 Cr
Talvivaara	1977	GTK	2008–	27	11 Ni; 29 Zn; 0.1 Co
Kittilä	1986	GTK	2008–	2.2	0.006 Au
Kevitsa	1987	GTK	2012 –	-	-

* Production when the area was part of Finland

RUSSIAN PART OF THE FENNOSCANDIAN SHIELD

18th – 19th Centuries

The mining history of Karelia began from the first half of the 18th century for the purpose of establishing a resource base for the Olonets mining factories. During the 18th and 19th centuries, up to 200 mine workings were in operation. The main products of that time were gold and copper at **Voitzkoe**, copper at **Voronov Bor**, copper, tin and iron at **Pitkäranta**, and iron at **Tulomozero** and **Velimäki** (Fig. 1, Table 4).

20th Century

In the 1940s, all the territory of Karelia was covered by an aeromagnetic survey at the scale 1:200 000. This resulted in the detection of a number of magnetic anomalies of high intensity. After the verification of these anomalies by drilling, three banded iron formation deposits were discovered: **Kostomuksha**, Gimoly-I and Mezhozerskoye. At Kostomuksha, detailed exploration was followed by resource estimation in the 1970s. Slightly later, similar work was performed on the **Korpanga** and Juzhno-Korpanga deposits located a few kilometres to the north of Kostomuksha, and on several other, smaller occurrences close to Kostomuksha. As a result, a reliable raw material base for the Kostomukshaore dressing complex (Karelsky Okatysh) was created. Commercial production of the Kostomuksha deposit began in 1982 and continues at the present time. The marketable products of the company Karelsky Okatysh are non-fluxed iron ore pellets with an iron content of 65.5 %. Their main consumers are the Severstal metallurgical complex and the countries of Western Europe (2.7 Mt/a), including Finland (Rautaruukki Co – 0.9 Mt/a). The known remaining resources of iron ore at Kostomuksha cover 42 years of production at the present rate. The small **Maiskoe** gold deposit, 200 km north of the Kostomuksha region, was exploited in 1995–1997 by Vuosna Ltd.

Exploitation of bedrock resources of the Kola Peninsula only started in the 20th century. During 1932–1933, all the iron deposits of the Olenegorsk Group were discovered. In 1965–1967, the Olenegorskoye, Komsomolskoye and Kurkenpahk deposits were explored, and in 1971–1975, the Kirovogorskoye, Professor Bauman and Yuzhno-Kokhozerskoye deposits were discovered. Five deposits, **Olenegorskoe**, **Kirovogorskoe**, **Professor Bauman**, **XV Oktjabrskoy Revolutsii** and **Komsomolskoe** (Table 4), are presently mined by the Olcon company, while others in the area are in reserve. The ore production supplies the Severstal steel company.

The **Kovdor** iron deposit was discovered in 1933. It has been exploited by the Kovdorsky ore-dressing complex since 1961. In 1963–1971, the complex features of the baddeleyite-apatite-magnetite ores were determined. At present, a magnetite concentrate with 64.0–64.2 % Fe is being produced from the ore; the main user is the Severstal company. Apatite and baddeleyite are sold on the foreign markets. At full exploitation capacity, the explored reserves at Kovdor will last for 34–35 years.

In the 1920s, the first deposits of the Pechenga nickel region were discovered by the Geological Survey of Finland. In 1937–1940, the Canadian company INCO performed detailed exploration of the **Kaula** deposit with estimation of reserves (6 Mt of ore at 3.68 % Ni and 1.82 % Cu). The mine, the metallurgical plant and the settlement of Petsamonickel were constructed. During the Second World War, the deposits of Kaula and Kammikivi were exploited by Germany, and 460 000 t of ore were mined (16 000 t Ni and 8000 t Cu produced). In 1945, after the annexation of the Pechenga region to the USSR, the mining of ore was recommenced. During intense exploration in 1946–1960, the **Zdanovskoe**, **Semiletka**, Sputnik, **Zapolyarnoe**, and many other deposits were discovered in the area. At present, the company Kolskaya GMK is conducting underground mining at **Kotselvaara**, Semiletka, Sputnik and Zapolyarnoe. In addition, open pit and underground mining are taking place at Severny and Severny-Gluboky mines of the Zdanovskoe deposit. The mined ore (Table 4) is processed at dressing plants in the towns of Nickel and Zapolyarny. The derived nickel sulphide matte ('fineshtain') is sent to the company Severonickel for further processing.

In 1931, the Monchegorsk group of copper-nickel deposits was discovered. On the basis of this discovery, the Severonickel mining and smelting complex and the city of Monchegorsk were constructed. Mining of these deposits lasted until 1968. In 1957–1961, the deposits of the Allarechka copper-nickel ore region were discovered. Mining of the **Allarechka** and **Vostok** deposits took

Table 4. The data from all metal mines in the Russian part of the Fennoscandian shield (Fig. 2). The most important mines of their time are also indicated in Figure 1.

Name	**Main commodities**	**Production Period (s)**	**Produced metals (kt)**	**Metal contents**	**Mined ore (Mt)**	**Remaining resource (Mt)**
Voitzkoe	Cu	1737–1794	0.7 Cu, 0.0001 Au	1.3 % Cu 1.9 g/t Au	0.088	0.047
Pitkäranta	Cu, Sn, Fe	1772–1920	7.6 Cu, 0.5 Sn, 102 Fe	1.5 % Cu 0.1 % Sn 40 % Fe	1.1128	38.93
Voronov Bor	Cu	1887–1914	0.1 Cu	1.3 % Cu	0.008	0.769
Tulomozero	Fe	1872–1902	Not reported	35.2 % Fe	Not reported	3.27
Velimäki	Fe	1889–1909	58 Fe	15.46 % Fe	0.4	130
Kostomuksha	Fe	1982–	127 792 Fe	30.55 % Fe	396.87	2454.5
Korpanga	Fe	2006–	Not reported	29.5 % Fe	Not reported	693.122
Maiskoe	Au	1995–1997	0.00005 Au	7.6 g/t Au	0.006	0.033
Olenegorskoe	Fe	1954–	22 967 Fe	30.6% Fe	75.057	412.92
Kirovogorskoe	Fe	1978–	1939 Fe	30.3 % Fe	6.4	259.92
Komsomolskoe	Fe	1989–	1635 Fe	29.2 % Fe	5.6	160.52
XV Oktjabrskoy Revolutzii	Fe	1986–	2228 Fe	29.7 % Fe	7.5	56.94
Professor Bauman	Fe	1986–	13 718 Fe	30.6 % Fe	44.83	16.17
Kovdor	Fe, Zr	1961–	187 495 Fe	24.4 % Fe 0.16 % ZrO_2	768.42	486.9
Nittis-Kunuzhja-Travjanaja	Ni, Co, Cu	1935–1975	56.8 Cu, 100 Ni	2.5 % Cu 5.1 % Ni	1.96	3.098
Zapoljarnoe	Ni	1973–	214 Ni, 113 Cu	2.19 % Ni 1.16 % Cu	9.77	10.958
Kaula	Ni, Co, Cu	1937–1944 1949–1999	Not reported	2.6 % Ni 1.4 % Cu	Not reported	14.6
Kootselvaara-Kammikivi	Ni, Cu	1952–	323 Ni, 172 Cu	1.2 % Ni 0.6 % Cu	26.92	7.45
Semiletka	Ni, Co	1968–2006	63 Ni, 30 Cu	0.73 % Ni 0.35 % Cu	8.63	7.52
Zhdanovskoe	Ni, Cu	1959–	419 Ni, 184 Cu	0.57 % Ni 0.25 % Cu	73.51	619.24
Allarechka	Ni, Cu	1962–1972	Not reported	3.59 % Ni 1.77 % Cu	Not reported	2.23
Vostok	Ni	1969–2000	Not reported	2.1 % Ni 0.95 % Cu	Not reported	2.34
Karnasurt	REE, Nb, Ta	1951–	Not reported	1.33 % REE 0.2 % Nb_2O_5 0.02 % Ta_2O_5	Not reported	23.759
Umbozero	REE, Nb, Ta	1984–	Not reported	0.95 % REE 0.2 % Nb_2O_5 0.01 % Ta_2O_5	Not reported	180.469
Juksorskoe	REE, Sr	1957–	Not reported	0.38 % REE 1.38 % SrO	Not reported	542.2
Rasvuchorr	REE, Sr	1963–	Not reported	0.34 % REE 1.14 % SrO	Not reported	35.4
Koashvinskoe	REE, Sr	1978–	Not reported	0.4 % REE 1.58 % SrO	Not reported	856.6

place in 1962–1972 and 1969–1974, respectively.

In 1921–1927, mining of the apatite-nepheline deposits of the **Khibiny** massive started. At present, such deposits are considered to be major world reserves of strontium and rare metals (87 % and 70 % of the entire Russian reserves, respectively). The average grade of strontium in these deposits varies from 1.13 % up to 1.58 %. The Khibiny deposits are mined by the company OOO Apatit. Presently, strontium production from the apatite-nepheline concentrate is taking place at a rather limited volume, and rare metals are not produced at all. The Lovozero mines of loparitic ores were opened in the 1920s and 1930s. Such ores are the source of tantalum, niobium and rare metals. At the moment, two mines are in production: **Karnasurt** (started from 1951) and **Umbozero** (started from 1984). They are mined by ZAO Lovozero ore-dressing and processing company. Their reserves are estimated to last 40–50 years.

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