Boris Saltikoff, Kauko Puustinen and Mikko Tontti

**Metallogenic zones and metallic mineral deposits in Finland**

Explanation to the Metallogenic Map of Finland

Geological Survey of Finland
Espoo 2006

This paper contains explanations to the Metallogenic Map of Finland 1 : 1 000 000 (Saltikoff et al. 2002). The aim is to provide the reader with a general description of the individual metallogenic zones and with references regarding the present knowledge of the specified metallogenic zones and individual deposits and occurrences in Finland.

A metallogenic map of a region depicts the natural metallogenic zones (linear, sub-linear), provinces and fields (isometric), i.e. the areas of mineral occurrences of certain types. The map is based on knowledge about the existing mineral occurrences and favourable geological structures. The present metallogenic map of Finland is mainly empiric, and the metallogenic groups are defined as ‘clusters of similar mineralisations’, without precise specification of the nature of the ‘similarity’. In the explanation report, the word mineralisation is used as a general term for a mineralised body. The mineralisations are divided into mineral deposits, occurrences and showings according to their volume and are classified on the map in respect to their metal content and morphological type. The metallogenic zones and provinces are classified according to the metal content of the respective mineralisations. The legend and classification of metallogenic zones and provinces and mineralisations are largely based on the principles of the Metallogenic Map of Europe of 1973, e.g. the term ‘morphological type of a deposit’ is used as the position of the deposit in relation to the hosting strata rather than as the geometric shape of the deposit. In the report, the metallogenic zones and provinces are individually described in terms of their location, geological setting, the most important or typical mineralisations and the most popular genetic concepts. At the end of the paper there are also descriptions of some important single deposits not belonging to any of the described metallogenic groups.

The geological base material for the Metallogenic Map comes from the Bedrock Map of Finland 1 : 1 000 000 of 1997 and the mineralisation data mainly from the Ore Deposit Database MALMIKANTA of the Geological Survey of Finland. The descriptions of the metallogenic zones and deposits in the report are accompanied by a wide list of references containing selected papers in widely used languages, English, German and in some instances French. Papers printed in national languages (Finnish or Swedish) are included only if they contain a substantial summary in English or German or if they have fundamental information. When published sources were not available, information was obtained via personal communications with informants also mentioned in the text.

Key words (GeoRef Thesaurus, AGI): metallogeny, metallogenic map, ore deposit, ore geology, mineral deposit, Finland, explanatory text.

Julkaisu on Suomen metallogeenisen kartan (Metallogenic Map of Finland 1 : 1 000 000, Saltikoff et al. 2002) selitys. Sen tarkoituksena on tutustuttaa lukija Suomen metallogeenisiin vyöhykkeisiin ja alueisiin, metallimalmiesiintymiin ja -aiheisiin sekä tarjota monipuolinen ja ajankohtainen kirjallisuusviiteliuettelet. 


Avainsanat (GeoRef Thesaurus, AGI): metallogeny, metallogenic map, ore deposit, ore geology, mineral deposits, Finland, explanatory text.

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METALLOGENIC ZONES AND METALLIC MINERAL DEPOSITS IN FINLAND

Boris Saltikoff, Kauko Puustinen and Mikko Tontti

INTRODUCTION

This report contains explanations to the recent edition of the Metallogenic Map of Finland 1:1 000 000 (Saltikoff et al. 2002). The purpose of the report is to provide the reader with a general description of the individual metallogenic zones and with references that are as complete as possible for becoming further acquainted with the present knowledge of the specified metallogenic zones and individual metal deposits and occurrences in Finland.

In the reference list there are selected works of use to international public, i.e. publicly available papers in widely used languages (English, German and in some instances French). Papers printed in national languages (Finnish or Swedish) are included only if they contain a substantial summary in English or German. In cases where printed sources are not available, information has commonly been obtained via personal communications, and the key persons concerned are mentioned.

Scope of the map

A metallogenic map of a region depicts the natural metallogenic groups (linear or sublinear zones and isometric provinces fields), i.e. the areas of distribution of mineral occurrences of certain types. It is based on our knowledge about the existing mineral occurrences and favourable geological structures. A metallogenic map is not a prediction map for direct exploration but rather an important tool for geological decision-makings.

Ideally, a metallogenic map should be based on a comprehensive model of the development of the Earth’s crust involving all processes (traditionally called ‘ore forming processes’) that affect the distribution and re-distribution of the chemical elements and cause accumulation of those into clusters called mineral deposits or more general mineralisations (de Launay 1913). However, we have to conclude that no such comprehensive model has been developed anywhere and the existing models of those processes (as e.g. the plate tectonic model) take into account only a part of the factors concerned. Similarly, the existing schemes of genetic classification of the mineral deposits (Smirnov 1976, Routhier & Moiseev 1983, Eckstrand 1984, Cox & Singer 1986, Laznicka 1993) still produce results contradictive to the field experience. Therefore the present metallogenic map of Finland is mainly empiric, and the metallogenic groups are defined as ‘clusters of similar mineralisations’, with no precise specification of the nature of the ‘similarity’.

Historical review

The legend and classification of the metallogenic units used in the present metallogenic map of Finland are largely based on the principles of the Metallogenic Map of Europe, Sheet No 2 (UNESCO 1973). The se-
ries of the metallogenic maps of Europe, published by the Commission for the Geological Map of the World by IUGS, have been subject to profound international discussion since the early 1960s in respect to the classification of the deposits in size and morphological type, areal metallogenic units and the background geology. Unfortunately, very little of this discussion was properly documented. The foreword by P. Laffitte in the “Explanatory memoir of the metallogenic map of Europe and neighbouring countries 1 : 2 500 000” (UNESCO 1984) constitutes the only summary of the principles approved.

Indeed, the Metallogenic Map of Europe (UNESCO 1973) was preceded by some other studies, e.g. in Finland by Eskola (1935) and Mikkola & Niimi (1968). However, they remained less known and thus brought only a little input into the subsequent debate.

The concept used in the Metallogenic Map of Europe (UNESCO 1973) was inherited by practically all metallogenic maps published in Fennoscandia thereafter, such as the Metallogenic Map of Finland (Kahma 1973) and the Metallogenetic Map of Northern Fennoscandia (Frietsch et al. 1987), and the problems embedded in this concept were met time and again. It is for that reason they are discussed here in detail.

In the Metallogenic Map of Europe (UNESCO 1973), the mineralisations (deposits, occurrences and showings) were shown as symbols classified in terms of their morphology (presented as the shape of symbols), orientation (as direction of symbols), principal metals (as colour) and size class (as size of symbols). Genetic attributes were added as little arrows or other symbols only, because of the lack of a unanimously agreed genetic classification and of the polygenetic character of many mineralisations. Still there was a continuous fermentation in the interpretation of the genesis of particular deposits, and the resulting notations hardly satisfied the geological public.

One question giving rise to serious debate has been the size classification of the deposits. This was initially defined as the metal content of deposits, with no respect to the grade. The main problem here was the comparison of deposits of various metals. It had to be decided whether a copper deposit of 10 Mt with 4 % Cu should be considered larger or smaller than a zinc deposit of 20 Mt with 3 % Zn. The problem was solved by using an authorised table of equivalent tonnages of the various mineral commodities issued by the editors (UNESCO 1984), with a fixed boundary between the ‘larges’ and the ‘smalls’ for each mineral. It was proclaimed that this threshold value would be 1/1000 of the hitherto known world reserves for each metal. Table 1 presents the boundary values for the metallic commodities in the UNESCO list. The boundary between ‘smalls’ and ‘showings’ was set as 0.01 of the upper boundary for the ‘smalls’.

Another problem arose about the size of the poly-metallic deposits. After a discussion it was decided to define the size of a deposit as a combination of the amounts of the metals concerned. Practically speaking, the ‘combined size estimate’ of a deposit was calculated as a sum of the metal equivalent tonnages and the colour of the symbol assigned according to the main metal.

Legitimacy of the equivalent limit values in Table 1 has been debated since its publication, because its basis, the known world metal resources, was re-estimated every year with very contradictory results. Consequently, in many later maps, like in the Metallogenetic Map of Northern Fennoscandia (Frietsch et al. 1987), we see the boundary values are mostly similar, only differing for a few metals.

Metallogenic zones in the Metallogenic Map of Europe (UNESCO 1973) were drawn after classification by the main metals and genetic groups. In the Metallogenetic Map of Northern Fennoscandia (Frietsch et al. 1986, Frietsch et al. 1987, Frietsch 1988), metallogenic zones were traced simply as groups of similar deposits.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Lower limit of ‘large’ deposits (metal tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>Ag 500</td>
</tr>
<tr>
<td>Gold</td>
<td>Au 50</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Co 10 000</td>
</tr>
<tr>
<td>Chromium</td>
<td>Cr 1 000 000</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu 100 000</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe 50 000 000</td>
</tr>
<tr>
<td>Manganese</td>
<td>Mn 1 000 000</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Mo 5 000</td>
</tr>
<tr>
<td>Niobium</td>
<td>Nb 20 000</td>
</tr>
<tr>
<td>Nickel</td>
<td>Ni 20 000</td>
</tr>
<tr>
<td>Lead</td>
<td>Pb 200 000</td>
</tr>
<tr>
<td>Platinum metals</td>
<td>PGE 10</td>
</tr>
<tr>
<td>Sulphur</td>
<td>S 1 000 000</td>
</tr>
<tr>
<td>Antimony</td>
<td>Sb 20 000</td>
</tr>
<tr>
<td>Tin</td>
<td>Sn 20 000</td>
</tr>
<tr>
<td>Titanium</td>
<td>Ti 500 000</td>
</tr>
<tr>
<td>Uranium</td>
<td>U 1 000</td>
</tr>
<tr>
<td>Vanadium</td>
<td>V 5 000</td>
</tr>
<tr>
<td>Tungsten</td>
<td>W 10 000</td>
</tr>
<tr>
<td>Zinc</td>
<td>Zn 200 000</td>
</tr>
</tbody>
</table>
In addition to the above-mentioned true metallogenic maps, a few related maps of Finland and Fennoscandia deserve to be mentioned. In the Ore Deposit Map of Finland (Kahma et al. 1976), the main attention was paid to the metal content and metal proportions of the deposits. These variables were shown for each deposit drawn as a sectored circle (pie chart) of a size proportional to the total equivalent metal tonnage, with no morphological or genetic attributes. In the Map of Ore Deposits in Central Fennoscandia (Tontti et al. 1996, Lundqvist et al. 2000) mineralisation classification like that in the Northern Fennoscandian map (Frietsch et al. 1987) was applied, but no metallogenic zones were drawn. The same applies to “Map sheet no 9 (Europe)” of the Mineral Atlas of the World (Juve et al. 1997). This map was intended to be accompanied by a true metallogenic map (see Turchenko et al. 1995), but according to our knowledge that map was never printed commercially. The Metallic Mineral Deposits Map of Finland of 2000 by the present authors (Puustinen et al. 2000) mainly inherited the principles used by Kahma et al. (1976), with updated knowledge on the mineralisations and their volume. The deposits are shown as pseudo-three-dimensional spheres of a volume proportional to the tonnage and a colour according to the principal metal. The Metallic Mineral Deposits Map was actually compiled from the same material as the present Metallogenic Map, and thus functions as a useful additional tool for studying the latter. The Metallic Mineral Deposits Map was intended to serve the wider public as well, and it was accompanied with an explanatory text of popular character, entirely in Finnish (Saltikoff et al. 2000).

In the Ore Deposit Map of Finland by Kahma et al. (1976), the size parameters of deposits of various metals were calculated using the same equivalent table (Table 1) as in the Metallogenic Map of Europe (UNESCO 1973). Because of the problems involved in that classification, as discussed above, and because Table 1 did not cover all metals of interest, an alternative approach was chosen in the Metallic Mineral Deposits Map of 2000 (Puustinen et al. 2000). We stated that the ‘rarity’ of the various metals is fairly well reflected by their market prices. As experience shows, metal prices do indeed fluctuate, but the absolute fluctuations and especially the fluctuations in the relations between the prices of various metals are actually rather small. Consequently, the metal prices in the London Metal Exchange (LME) at a certain moment (August 1999) were chosen as a measure of their equivalent tonnages (Table 2). An estimate of the size of a deposit was calculated simply by determining the in situ values of all potentionally exploitable metals in the deposit, then calculating a sum of them and converting the sum to a tonnage of one metal – e.g. copper – of the same value. The principle is primitive but relatively stable.

It must be stressed that the absolute values of the metals have no significance at all in these calculations. They do not reflect the gross or net value of the deposit, but simply serve as a tool for comparison of the relative size of deposits containing various metals.

The same size estimates are used in the present Metallogenic Map as the basis for size classification. On a purely empirical basis, an amount of 100 000 tonnes Cu is accepted as the basic threshold value for the ‘large deposits’ class, and then the threshold values for other metals are determined as tonnages approximately of the same value. These equivalent values are also shown in Table 2. The limit for the ‘small deposits’ class is defined as 1/100 of the former or equivalent to 1 000 tonnes Cu, and the deposits exceeding 10 000 000 tonnes Cu (in practice, only one, the Kemi Cr deposit) are classified as ‘extra large’ or ‘world class’ deposits.

Table 2. Equivalent tonnages for various metals on the basis of market prices from August 1999

<table>
<thead>
<tr>
<th>Metal</th>
<th>LME price GBP/ton</th>
<th>Amounts of metal equal to 100 000 ton Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>Ag</td>
<td>106.32</td>
</tr>
<tr>
<td>Gold</td>
<td>Au</td>
<td>5732.51</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Co</td>
<td>31.90</td>
</tr>
<tr>
<td>Chromium</td>
<td>Cr</td>
<td>0.61</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>0.96</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe</td>
<td>0.02</td>
</tr>
<tr>
<td>Manganese</td>
<td>Mn</td>
<td>0.54</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Mo</td>
<td>5.45</td>
</tr>
<tr>
<td>Niobium</td>
<td>Nb</td>
<td>1.71</td>
</tr>
<tr>
<td>Nickel</td>
<td>Ni</td>
<td>2.57</td>
</tr>
<tr>
<td>Lead</td>
<td>Pb</td>
<td>0.33</td>
</tr>
<tr>
<td>Platinum metals</td>
<td>PGE</td>
<td>7172.29</td>
</tr>
<tr>
<td>Sulphur</td>
<td>S</td>
<td>0.02</td>
</tr>
<tr>
<td>Antimony</td>
<td>Sb</td>
<td>0.80</td>
</tr>
<tr>
<td>Tin</td>
<td>Sn</td>
<td>3.37</td>
</tr>
<tr>
<td>Titanium (in ilmenite)</td>
<td>Ti</td>
<td>0.06</td>
</tr>
<tr>
<td>Uranium</td>
<td>U</td>
<td>13.26</td>
</tr>
<tr>
<td>Vanadium</td>
<td>V</td>
<td>14.59</td>
</tr>
<tr>
<td>Tungsten</td>
<td>W</td>
<td>2.56</td>
</tr>
<tr>
<td>Zinc</td>
<td>Zn</td>
<td>0.60</td>
</tr>
</tbody>
</table>
PRINCIPLES APPLIED INTO THE PRESENT METALLOGENIC MAP

Definitions

In the present work, the field of study is limited with deposits and occurrences of heavy metals, in accordance with the original meaning of the term ‘metallogeny’ (de Launay 1913). Geologically they are easier for interpretation than the deposits of non-metallic commodities, as the intensity of the ore forming process can be implicitly described by the amount of the metals concentrated, which again is determined purely by the grade of the mineralisation (percentage of the metal concerned).

Throughout this work the word mineralisation is used as a general term for a mineralised body of any size; the process or the regional phenomenon is referred to as ore forming process. The mineralisations are divided into mineral deposits, occurrences and showings according to their size, as discussed in the previous chapter; the use of these terms broadly follows the common usage.

From the metallogenic point of view, a mineralisation is a natural concentration of a chemical element or some elements (and in our case, heavy metals) to such a degree that it forms an unusual segregation of metal-rich mineralogical species, ore minerals, somewhere in the Earth’s crust (de Launay 1913). This definition includes no economic parameters at all. However, in practice the only comprehensive information available is the description of real exploration and mining objects, where non-geological parameters (like cut-off grade, harmful elements, unfavourable location) always are implicitly included e.g. in tonnage estimation, and we are dependent on that information in our metallogenic reasoning.

A metallogenic zone (if sub/linear) or provincefield (if isometric) is an area favourable for the presence of mineralisations of one (or more) particular type(s). Because such favourability is always controlled by some geological factors, the metallogenic zones roughly coincide with main geological structures. The control may be of varying character, and the relationship between a metallogenic zone and a geological structure varies correspondingly. For example, zones of stratiform mineralisations of the banded iron formation are absolutely restricted to certain stratigraphic units, while a “titanium-iron province” means an area hosting scattered mafic intrusions with titanium-iron mineralisation and thus is always somehow indefinite.

Base data

The geological material in the present Metallogenic Map, drawn as the base map and used for delineating metallogenic zones, comes from the Bedrock Map of Finland 1 : 1 000 000 (Korsman et al. 1997). Fig. 1 shows a reduction of that map and the system of main regional geographic-geological blocks named after Nironen et al. (2002). The magnetic and gravimetric maps of Finland (shown as Fig. 2 and 3) were involved as additional materials for understanding and interpretation of the sub-surface and deep geological structures.

For a comprehensive description of the geology of the bedrock of Finland, the reader is advised to the monograph “Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield” (Lehtinen et al. 2005).

In the Metallogenic Map, the legend of the bedrock geology is strongly generalised as compared with the original bedrock map. Of the stratigraphical and lithological units, only those of the highest rank are shown. A non-traditional feature pictured is the presence of two megablocks or domains: the Kola-Karelian Domain that occupies the north-eastern part of Finland and represents a craton of Archaean age partly with a Proterozoic overprint, and the Svecofennian Domain of the south-western part with a crust entirely of Lower Proterozoic age (Puustinen et al. 1995). This feature (Fig. 4) is paid special attention because of its importance from the point of metallogeny. Especially the border zone between the two domains running across Central Finland, the Raahe-Laatokka zone, has been for a long time known as a provincefield of high metallogenic potential (Kahma 1973, Kahma 1978, Ekdahl & Filipov 1999). A number of most important metallogenic zones (Rantasalmi Au zone, Juva-Puimala Ni-Cu province, Kotalahti Ni-Cu zone, Vihanti-Pyhäsalmi Zn-Cu-Pb zone) are grouped immediately at the flanks of the border line, and some others (e.g. Outokumpu Cu-Zn-Co zone, Laivakangas Au zone, Hitura Ni-Cu province) lie not far away from it. The geology of the
Main geological units:
1. Inari Area
2. Lapland Granulite Belt
3. Enontekiö Area
4. Central Lapland Area
5. Eastern Lapland Complex
6. Central Lapland Granitoid Complex
7. Peräpohja Belt
8. Kuusamo Belt
9. Pudasjärvi Complex
10. Isalmi Complex
11. Eastern Finland Complex
12. Kuhmo Belt
13. Ilomantsi Belt
14. Kainuu Belt
15. Kiiminki Belt
16. Savo Belt
17. Höytiäinen Belt
18. Outokumpu Area
19. Saimaa Area
20. Central Finland Granitoid Complex
21. Pohjanmaa Belt
22. Tampere Belt
23. Pirkanmaa Belt
24. Häme Belt
25. Uusimaa Belt

Raahe-Ladoga zone is described in several papers, the most comprehensive of them being a monograph edited by Korsman (1988).

The characteristics of the mineral deposits and occurrences presented in the Metallogenic Map and referred to in the present report are collected from the reference sources listed in connection with the description of each zone, and partly from unpublished archive materials. The primary data is also stored in the national Ore Deposit Database maintained by the Geological Survey of Finland since 1970s (Gaál et al. 1977, Saltikoff & Tarvainen 1990), now available under the name MALMIKANTA (Geological Survey of Finland/GTK, web pages, under preparation). The same characteristics are used in the Metallic Mineral Deposits Map (Puustinen et al. 2000), with exception of some few latest revisions. Particularly, the figures of the size of the deposits mentioned below are the
most recent available estimates. If not otherwise stated, they are geological in situ estimates of the (Measured + Indicated) class. Production figures for the exploited deposits are taken from the report on mining history in Finland, preliminarily described by Puustinen (1997) and now updated until 2001. The mineral deposits and occurrences cited in the present report and not indicated in the Metallogenic Map can most easily be seen in the Metallic Mineral Deposits Map (Puustinen et al. 2000).

The references belonging to particular zones and mineralisations are listed in connection with the corresponding descriptions. Besides, there are a number of general papers describing or reviewing the deposits of the entire country. Of such papers, we present the above-mentioned paper by Kahma (1973) on the metallogeny of Finland; a monograph on the exploited deposits in Finland edited by Aurola (1954); the section “Finland” by Isokangas (1978) in a monograph “Mineral Deposits of Europe”; papers by Rouhunkoski (1982), Papunen (1986) and Ketola (1986) on the exploration practices in Finland, by Frietsch et al. (1979) on the ore deposits in the entire Scandinavia, and by Puustinen (1997) on the history and statistics of mining in Finland. There are also several papers dealing with metallogeny and geology of deposits and occurrences of particular metals, such as Mikkola & Rouhunkoski (1980) and Inkinen & Hiltunen (1980) on copper deposits; Nuutilainen & Paakkola (1977) on iron deposits; Puustinen (1981), Gaál & Sundblad (1990) and Eilu et al. (2003) on the deposits and metallogeny of gold; Papunen & Gorbunov (1985) and Puustinen et al. (1995) on the deposits and metallogeny of nickel; Kulonpalo &
Marmo (1955) on molybdenum mineralisations; and IUREP (1982) on uranium deposits. Recently, on-line textual public databases describing deposits of some metals have been developed in the Geological Survey of Finland, like FINGOLD (Eilu 1999) and FINZINC (Eilu 2000).

Finally, attention should be given to reports and books on the mineral deposits and occurrences in Finland dating back as far as the 18th century. These early papers are unfortunately all written in Swedish and as such unavailable to the international public; however, a reader familiar with the language may be interested in these. The earliest one is a description of the geology and mineral deposits of southwestern Finland by Daniel Tilas (1738); then come the two books by C. O. Bremer (1824 and 1825) and then the widely known monograph called “Materialer till Finlands geognosi” by H. J. Holmberg (1858). These papers have widely been used by the later researchers as information sources on ancient mining areas, especially in the Orijärvi metallogenic zone.

Classification of the mineralisations and metallogenic zones

The mineralisations (mineral deposits and occurrences) are classified on the map in respect to their metal content (total amount of the metals and the principal metal) and morphological type. The metallogenic zones are classified according to the metal content of the respective mineralisations. No genetic parameters are shown on the map, as the genetic conceptions vary from time to time. The metallogenic models presented by various authors are mentioned in the present publication, with reference to the original sources.

The principal metals of the mineralisations are shown by the colour of the mineralisation symbols, following common practices. In a case of a multimetal mineralisation, the principal (dominating) metal is understood as the metal that yields the largest relative tonnage in the mineralisation. In the colour scheme, the only non-traditional feature is that cobalt is included in the same group with copper rather than with nickel. This reflects the fact that the cobalt-dominated ore types (e.g. Co-Au type) closely resemble the copper types, even if cobalt as a by-product submissively follows nickel. Sulphur (pyrite) ore type is discarded as an independent class; the occurrences of sterile pyrite, once anxiously explored for sulphur, are included in the iron type.

The size of a mineralisation is defined as the total amount of the metals concentrated in the mineralisation. In a metallogenic map, deposit size is a parameter of less importance. The mineralisations are simply divided into two main size classes: 1) major deposits and minor deposits plus the subgroup of “world class deposits” (extra large), and 2) the class of minute
occurrences and showings (extra small). The precise size estimates of the deposits and major occurrences in Finland are depicted in the “Metallic Mineral Deposits Map” (Puustinen et al. 2000), and the principles of their size calculation is discussed in the chapter “Historical review” of the present paper.

Morphological types

The term ‘morphological type of a deposit’ is used in the same sense as in the Metallogenic Map of Europe (UNESCO 1973). It is hereby understood as the position of the deposit in relation to the hosting strata rather than as the geometric shape of the deposit. Definition of the nomenclature used is as follows:

- Stratiform deposits: syngenic supracrustal mineralisations strictly restricted to particular layers in strata, such as black schists, palaeoplacers or banded iron formations,
- Stratabound deposits: mineralisations of possibly syngenetic initial origin but eventually concentrated by epigenetic processes in particular layers of strata, such as the volcanic hosted massive sulphide deposits,
- Stocks: nebular or irregular disseminations in intrusive rock bodies other than layered intrusions, such as intrusive-hosted nickel-copper deposits; also deposits of the porphyry copper type are included here,
- Magmatic stratiform: deposits in the sheet-like layered intrusions,
- Vein deposits: mineralisations restricted to single veins, vein swarms or shear zones with more or less distinct orientation,
- Irregular replacement bodies: stockworks (vein networks with no orientation), deposits called ‘metasomatic pipes’,
- Replacement zones: skarn bodies, silicification bodies etc. with distinct orientation controlled by other factors than the strata,
- Pipes: pipe-like intrusions, such as carbonatite pipes,
- Placers: alluvial mineralisations in recent overburden.

In practice, very few deposits represent one pure morphological type. Thus contradictions in classification of the deposits are always possible. For instance, even the stratiform mineralisations form real deposits only along with secondary concentration processes (e.g. thickening in folding) and are close to the strata-bound type; mineralised veins are always accompanied by a certain amount of ore-grade replacement zones; magmatic layering or stratification is found in many minor mafic intrusions, and the boundary between ‘magmatic stratiform’ and ‘stock’ type deposits is somewhat arbitrary. Porphyry copper deposits could be classified either in the ‘stock’ class (as here) or in the ‘stockwork’ class (as done by Juve et al. 1997).

DESCRIPTION OF THE METALLOGENIC ZONES

The individual metallogenic zones delineated in the Metallogenic Map of Finland are shown in Fig. 5. In this section, they are described in terms of their location, geological setting, the most important or typical mineralisations and the most popular genetic concepts, with reference to the original papers. At the end of the paper there are also descriptions of some important single deposits not belonging to any of the described metallogenic groups.

The Orijärvi Zn-Cu-Pb + Fe zone (1) is a zone of supracrustal Zn-Cu-Pb mineralisations hosted by skarns and Al-rich rocks (including cordierite-anthophyllite rocks), and Fe mineralisations of skarn and banded iron formation types. These deposits belong to the same type as the Zn-Cu-Pb and Fe deposits of the Bergslagen province in Central Sweden in terms of the principal metals, host rock types and also the isotopic composition of lead in galenas (M. Vaasjoki 1981; Frietsch & Papunen 1986). In fact, the entire Orijärvi zone can be regarded to as the eastern branch of the Bergslagen province. The Orijärvi zone runs in E-W direction in the southern part of the Uusimaa Belt (geological unit no. 25 in Fig. 1). This part is characterized by abundant quartz-feldspar gneisses (leptites), interpreted partly as metamorphosed felsic volcanics, beds of marbles and calc-silicate rocks (originally pure and impure limestones) and minor occurrences of banded iron formations. It has been
Fig. 5. The main metallogenic zones of Finland
called Leptite Belt (Eskola 1914, Lukkarinen 1986) or Svionian belt (Kinnunen & Saltikoff 1989). The ore-bearing horizons of the zone reverentially follow the marble and calc-silicate rock beds of the region (Fig. 6).

The Orijärvi zone is cut into parts by younger granitoid massifs (both Late Svecofennian granitoid masses and anorogenic rapakivi granite batholiths). The belonging of the mineralisations in the eastern parts of the zone, for example Pernaja (O. Vaasjoki 1953), Hyvärilä inside the Vyborg rapakivi batholith (Vorma 1975) and Salo-Issakka at the Russian border, to this zone has been subject to discussion, but a clear evidence thereupon was obtained by the lead isotopic composition of the deposits mentioned (M. Vaasjoki 1981 and pers. comm. 2003, Frietsch & Papunen 1986).

The southern flank of the Orijärvi zone is hidden below the sea. Probably the zone extends well to the south, and the iron deposits of banded iron formations (BIF) and/or skarn type discovered offshore in the Gulf of Finland, e.g. Jussarö, belong to this zone, too; however, this is impossible to definitely prove with the present data.

The Orijärvi zone is historically the best-known mineral province in Finland. Iron deposits in this zone have been subject to mining since 16th century (Tammekann 1926, von Knorring 1955) and copper deposits since 18th century, and the classical studies by Eskola (1914) on the regional metamorphism and metasomatism in Orijärvi was a description of the principle of the metamorphic facies. The most important recent works dealing with the geology of the zone are Latvalahti (1979), Mäkelä (1983, 1989), Colley & Westra (1987), Väisänen (1988) and Isomäki (1986). There are also noticeable works on detailed aspects, such as lithogeochemistry (Wennervirta & Papunen 1974), for the region.

The largest sulphide deposits are Orijärvi, Aijala and Metsämonttu in the central part of the zone and Attu in the west. Orijärvi (Varma 1954a, Isokangas 1978) has been exploited for almost 200 years (1757 – 1955), and yielded in total 0.92 Mt of ore at 1.32% Cu, 3.32% Zn and 1.07% Pb. The ore was hosted partly by cordierite-andalusite rock and partly by tremolite skarn. The main ore minerals were chalcopyrite, sphalerite and galena plus some pyrrhotite and pyrite. It is noticeable that the cordierite-hosted ore (“hard ore”) regularly was copper-dominated and the skarn-hosted ore (“soft ore”) zinc-dominated.

Aijala and Metsämonttu (Varma 1954b, Isokangas 1978) were discovered in 1940’s. Aijala was mined in 1948 to 1960 and produced 0.84 Mt of ore at 1.59% Cu and 0.66% Zn, Metsämonttu in 1951 to 1974, yielding 1.51 Mt at 3.34% Zn, 0.74% Pb, 0.28% Cu, 25 g/t Ag and 1 g/t Au. Attu, discovered in 1750ies and test mined then, was never subjected to modern mining, despite of its significant resources, estimated...
as 4.3 Mt at 1.76 % Zn and 1.05 % Pb (Pehrman 1931, Hangala 1987).

Not far away from Orijärvi there is a small deposit of a slightly other type, lilijärvi (Mäkelä 1989). It is fairly rich in gold (1.3 % Zn, 0.6 % Cu, 0.6 % Pb, 30 g/t Ag, 4 g/t Au). The ore in lilijärvi is hosted by light-coloured sericite schist and contains arsenopyrite in addition to the above-mentioned sulphide ore minerals.

The largest iron deposits are located in the southernmost chain in the zone, in the archipelago of the Gulf of Finland. Jussarö (Saksela 1939, Haggerty 1964, Mikkola 1966, Laajoki 1985) was known for centuries due to the strong magnetic anomalies harmful for navigation. It was subject to exploitation in several stages between 1834 and 1967 and produced 1.65 Mt of ore at some 28 % Fe, although the real resources count not less than 5 Mt. The ore belongs to the BIF type with magnetite as practically only ore mineral.

Nyhamn was exploited in a pilot scale as an underground mine in 1957 to 1959, and 0.08 Mt at some 20 % Fe were extracted; total estimated resources are ca. 10 Mt.

All other occurrences are very small to the present standards; in ancient times, in the 17th and 18th century, tens of mines were opened here for exploiting such minuscule objects as

- Sillböle in the Helsinki district (1744–1866; 0.035 Mt at 30 % Fe; Tammekann 1926),
- Malmberg near Orijärvi (1670–1866; 0.016 Mt at 35 % Fe; von Knorring 1915) and
- Ojamo in Lohja (1542–1838; 0.012 Mt at some 45 % Fe).

**The Kemiö Ta zone (2)** is a province with abundant granitic complex pegmatite bodies scattered in the mafic intrusives and supracrustal rocks of the Svecofennian complexes (Pehrman 1945, Lindroos et al. 1996). The main tantalum minerals are tantalite and tapiolite.

The pegmatites at Kemiö have long been subject to mining for non-metallic minerals, i.e. quartz and feldspar (Isokangas 1978). Recently their tantalum potential was re-evaluated and found to be of economic interest (R. Alviola, pers. comm. 2003). Thus they have to be regarded as a tantalum province, as well.

**The Palmottu U zone (3)** consists of a number of minor uranium disseminations in the granitic neosome of Svonian migmatites. Actually, a territory of increased radioactivity can be traced up to Turku in the west (H. Seppänen, pers. comm. 2003), but the most significant mineralisations (IUREP 1982) are limited to the marked zone. The largest of them, Palmottu (1.0 Mt at 0.11 % U; Räisänen 1989), has also been subject to extensive studies in migration of radionuclides in bedrock and groundwater (Pomies et al. 1998, Blomqvist et al. 2000, Grundfelt 2002, Ruskeeniemi et al. 2002). The minute mineralisation at Hyyrykälä is of special interest because of its native copper content (Marcos 1996, Marcos & Ahonen 1999, Marcos et al. 1999).

At the southeastern end of the zone, several mineralisations of a different type (high-grade uraninite-quartz-haematite veins) have been encountered. They display an anomalous, sub-Phanerozoic model age (Vaasjoki 1977) and have been described as possibly belonging to the so-called unconformity type of deposits (O. Äikäs, pers. comm. 2003).

**The Vammala Ni-Cu zone (4)** is one of the most important nickel mining districts in Finland with the (today closed) mines of Vammala (Stormi) and Kylmäkoski and about 60 other known deposits and occurrences (Puustinen et al. 1995). These all belong to the classical Svecofennian type (Papunen & Vorma 1985, Puustinen et al. 1995) that includes practically all of the nickel deposits of economic value so far discovered in Finland.

The deposits of the Vammala zone are hosted by synorogenic mafic-ultramafic intrusions in migmatitic gneisses of the Pirkannaa Belt (unit no. 23 in Fig. 1) that surrounds the Central Finland Granitoid Complex from the south (Peltonen 1994, 1995a, 1995b, 1995c). As such, this zone is totally analogous to the other nickel zones of the Svecofennian type like the Telkkälä, Juva-Puumala, Ilmolathi, Kotalahti, Oravainen and Hitura zones described later in the present paper. Minor differences between these zones include, e.g., the fact that most of the nickeliferous intrusions in the Vammala zone are ultramafic in composition, while the intrusions in the Kotalahti zone are predominantly mafic (noritic).

During the years, the nickel deposits and zones in Finland have been subject to a lot of studies and discussions by many authors. The most comprehensive monograph, “Nickel-copper deposits of the Baltic Shield and Scandinavian Caledonides” (Papunen & Gorbunov 1985) contains several papers on the nickel provinces in general and particularly on the Vammala zone, and on some of the most interesting individual deposits. A more recent summarising paper on the subject is a publication by the present authors on the distribution and the metallogenic types of the nickel deposits in Finland (Puustinen et al. 1995), where all the known deposits and major occurrences are listed and described in small clusters referred to by numbers (Fig. 7). These two papers are the basic references here.

Most of the authors are of the opinion that the lo-
Fig. 7. Nickel deposits in Finland, grouped by size and metallogenic types (from Puustinen et al. 1995). Metallogenic types: Svecofennian – red; Outokumpu type – yellow; black schists – black; layered intrusions – violet; Archaean komatiite type – blue; others – silver-grey. Lines – linear features linked to the particular deposit clusters. Numbers refer to the deposit clusters as discussed in Puustinen et al. (1995).
cation of the Svecofennian type nickel zones and the individual deposits within them is mainly controlled by a favourable lithological environment dominated by migmatitic mica gneiss fields and trondhjemitic plutonic massifs and by favourable tectonic structures, especially fault systems. Depending on how these two factors are emphasized, the zones are depicted as linear or sub-linear units (e.g. Gaál 1985) or field-like broad belts (e.g. Papunen & Vorma 1985). Frietsch et al. (1979) brought up the idea of a single ring-like nickel belt in the migmatite belts around the Central Finland Granite Complex covering both the Vammala zone and all other Svecofennian nickel zones mentioned above. In the paper by Puustinen et al. (1995), the Vammala zone is referred to as a high rank entity (called “Vammala Belt”) stretching from the city of Pori on the west coast (No. 50 in Fig. 7) to the Kylmäkoski deposit (No. 53 in Fig. 7), and it is divided into several lower rank clusters (called ‘zones’) controlled by shear lines.

According to the most recent views, the entire Pirkannaa Belt is considered to be of a high nickel potential. Also statistical modelling of the lithological framework (Saltikoff and Koistinen 1989, Puustinen et al. 1995) and modelling of a combination of the geological, geophysical and till geochemical factors (Tiainen & Viita 1994) assign a high nickel potential to the Pirkannaa Belt. Therefore, in the Metallogenic Map, the Vammala zone is drawn to continue east from the Kylmäkoski deposit and to include the clusters 56, 58 and 59 by Puustinen et al. (1995; see also Fig. 7). However, considering the fact that all major deposits and an overwhelming majority of minor deposits discovered hitherto are located in the stretch between Pori and Kylmäkoski, this part of the Vammala zone is delineated as the ‘core’ of the zone.

When drawn as broadly as in the Metallogenic Map, the Vammala zone comes near the Telkkälä zone (zone no. 9 in Fig. 5) in the east and near the Oravainen zone (no. 22, Fig. 5) in the northwest. It is not impossible that these zones may join, although there seems to be no direct evidence of it.

Of the individual deposits in the Vammala zone, the type locality, the Vammala deposit (also known as Stormi) is the largest and best studied (Häkli et al. 1979, Häkli & Vormisto 1985, Marshall & Mancini 1994, Marshall & Mancini 1995, Liipo et al. 1997). It was mined from 1974 to 1995 and produced 7.57 Mt of nickel ore with a grade of 0.68 % Ni and 0.42 % Cu. The deposit consists of sulphide dissemination in a differentiated ultramafite massif. The main orebodies occupy the bottom part of the massif in a subhorizontal way (Fig. 8).

The next most noteworthy deposit is Kylmäkoski at the southeastern end of the ‘core zone’ (Papunen 1974, 1977, 1980, 1985). It was the first deposit of economic value to be discovered in the zone and was mined from 1971 to 1974, producing 0.69 Mt of ore at 0.36 % Ni and 0.27 % Cu. Geologically it is very similar to Vammala, hosted by a small and shallow (less than 100 m in depth) body of ultramafic rocks. Among these a unique olivine rock with nodular and partly even orbicular texture has been detected (see e.g. Papunen 1985). The ore is mainly of the normal pentlandite-chalcopyrite-pyrrhotite dissemination type. In addition, a few massive veins containing rare

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Fig. 8. Vertical section of the Vammala Ni-Cu deposit. Ore (black) in the layered intrusion composed of various ultramafic rocks (variously rastered). From Häkli & Vormisto (1985).
sulphides and arsenides, like niccolite, maucherite, gersdorffite and PGE-minerals have been encountered (Gervilla et al. 1997a, 1997b, 1998).

The minor Hyvelä deposit near the city of Pori at the northwestern edge of the ‘core zone’ (Stenberg & Häkli 1985) has indicated reserves of 0.8 Mt of ore at 0.53 % Ni and 0.28 % Cu. Hyvelä differs from the deposit type described above in respect to host rock, which is a slab-shaped norite body.

Of the other individually studied deposits worth mentioning in the Vammala zone is Sääksjärvi, located midway between Hyvelä and Vammala (Mancini & Papunen 2000). This deposit is unexploited, and has resources estimated at 3.5 Mt at 0.24 % Ni and 0.33 % Cu. A very special case is the Korkeakoski deposit north of the city of Pori (Puustinen et al. 1995). This tiny deposit (0.2 Mt at 0.41 % Ni and 0.31 % Cu) is associated to a dolerite dike of the Subjotnian age (1650 Ma). Thus its relationship to the Vammala zone is perhaps spatial only.

The hitherto known mineralisations outside the core of the Vammala zone are rather small, and no comprehensive primary descriptions on them are available. Summary information on them, collected from the archived exploration reports, is published by Tiainen and Viita (1994) and Puustinen et al. (1995).

Recently the deposits of the Vammala zone have been subject to systematic studies on PGE elements (e.g. Gervilla et al. 1997b, Gervilla et al. 2004). In the course of these studies a new peculiar Re-Mo-Cu-Os mineral was found in the Ekojoki deposit (Peltonen et al. 1995).

The Pirkkala-Valkeakoski Au zone (5) consists of several minor mineralisations represented by gold-bearing quartz veins in synorogenic Svecofennian intermediate intrusives or more mafic inclusions in these, and in pelitic gneisses of the Pirkanmaa Migmatite Belt (unit no. 20 in Fig. 1), where several mafic to ultramafic intrusives or more mafic inclusions are represented by mafic metavolcanics, a.o. cassiterite and antimony minerals. The host rocks are mostly represented by mafic to ultramafic arc complex of Central and Western Finland (Gaál & Sundblad 1990, Rosenberg 1997, Eilu 1999, Eilu et al. 2003).

A few mineralisations of a similar character are located to the south of the zone under consideration. However, their relationship to the main group is uncertain, and it is possible they constitute a separate province. The largest of these, Jokisivu (Luukkonen 1994, Luukkonen et al. 1992, Luukkonen et al. 1997a), was recently proved to be of a commercially feasible size, estimated to be 1.47 Mt at 6.8 g/t Au (Dragon Mining NL 2005).

The Eräjärvi Ta zone (6) is a pegmatite province similar to the Kemiö province, although better known for its Li and Be minerals (Volborth 1951, 1954, 1960, Lahti 1981). Among the tantalum-bearing minerals, a new species, manganotantalite, was discovered here (Lahti et al. 1983).

The Haveri-Orivesi Au-Cu-W zone (7) is confined to the narrow volcanics-dominated Tampere Schist Belt (unit no. 22, Fig. 1) that lies between the Pirkanmaa Migmatite Belt and the Central Finland Granitoid Complex (Kähkönen 1987, Kähkönen 1989, Nironen 1989a, Nironen 1989b, Gaál & Sundblad 1990). The zone includes three mines:

- The Haveri Au-Cu mine, exploited from 1942 to 1960, with resources recently estimated at 1.6 Mt at 2.85 g/t Au and 0.39 % Cu (Stigzelius 1944, Lupander & Räsänen 1954, Isokangas 1978, Mäkelä 1980, Kähkönen et al. 1981, Karvinen 1997, Nironen 1994),
- The Ylöjärvi Cu-W-(Au) mine, which yielded 4.01 Mt at 0.75 % Cu, 0.04 g/t Au and 0.09 % W between 1943 and 1966 (Himmi 1954, Himmi et al. 1979, Isokangas 1978, Gaál et al. 1981) with its well-studied mineralogy (Clark 1964a, 1964b, 1964c, 1965a, 1965b, 1966; Clark & Clark 1968),

Some other prospects, like Ahvenlammi (Lindmark 1986, A. Luukkonen et al. 1992), Järvenpää (ibid.) and Tammijärvi (A. Luukkonen 1994, Eilu 1999) have hitherto proved uneconomic.

The mineralisations typically contain chalcopyrite as the main copper mineral, arsenopyrite, native gold and gold tellurides as gold minerals and scheelite in the tungsten bearing parts, plus a lot of minor ore minerals, a.o. cassiterite and antimony minerals. The host rocks are mostly represented by mafic metavolcanics, which typically are strongly altered by tourmalinisation (as at Ylöjärvi), silicification or sericitisation (as at Kutemajärvi).

The Peräkorpi Ti-Fe province (8) is an area in the western part of the Central Finland Granitoid Complex (unit no. 20 in Fig. 1), where several mafic to ultramafic intrusions of rather small size occur associated with Svecofennian granitoids. These intrusions carry ilmenite-magnetite mineralisations (Kärkkäinen 1999, Kärkkäinen & Appelqvist 1999, Kärkkäinen 2001) and are also notable for their rather high apatite content, which makes many of them potential sources of phosphorus as well. The resources of the Peräkorpi deposit itself are estimated at 30 Mt at 23.1 % Fe, 2.35 % Ti and 2.5 % P₂O₅.
It could also be noted that the mineralised intrusions always show distinct stratification and the mineralised bodies constitute an organic part of this. Thus they are drawn as ‘magmatic-stratified’ bodies despite the fact that intrusions do not fulfill the strict definition of ‘layered intrusions’.

A few isolated Ti-Fe minor mineralisations are also known southwards from this province, e.g. Susimäki and Riuttamaa to the south of the Vammala nickel zone (Palmunen 1925, van Lamoen 1979), Attu-Fe (van Lamoen 1977) and Heinäsuu inside the Orijärvi zinc-copper zone (von Knorring 1955). Kulonsuomäki near Karkkila was mined from 1817 to 1896 and produced 0.024 Mt at some 40% Fe and 1.8% Ti.

The Telkkälä Ni-Cu zone consists of two minor nickel deposits, Telkkälä and Ahokkala (Häkli et al. 1975, Häkli 1985), and a number of small showings all hosted by minor mafic intrusions embedded in Svecofennian gneisses in the southern corner of the Saimaa area (unit no. 19, Fig. 1). In the south and west, the zone is enclosed by younger rapakivi granites of the Vyborg batholith. Its relations to the other nickel zones of eastern Finland are not clear, and there is a possibility that rather it represents a continuation of the western Pori-Vammala zone (metallogenic zone no. 4).

At Telkkälä, another orebody was detected in 1987, soon after the first exploitation period, and the initial description of the deposit is by Häkli (1985). This new discovery was predominantly an offshoot orebody in mica gneiss just below the formerly known deposit (O.-P. Isomäki, pers. comm. 2002; Fig. 9) and yielded an amount of metal even larger than the initial discovery. This event clearly shows the exploration potential of even the minor mineralisations at least in the present zone. In total, 0.61 Mt at 1.29% Ni and 0.33% Cu were mined in Telkkälä within two periods between 1969 and 1992.

The minute deposit of Kitula (Marmo 1955) may belong to a similar type but lies isolated and surrounded by granitoid rocks some 30 km apart from Telkkälä. Therefore it is not included in this zone. The deposit was quickly mined in 1970, yielding some 0.02 Mt ore at 0.67% Ni and 0.24% Cu.

The Juva-Puumala Ni-Cu province is a region difficult to delineate in the central part of the Saimaa area (unit no. 19, Fig. 1) where minor tholeitic mafic intrusions of the Svecofennian age intrude migmatitic gneisses and carry nickel-copper deposits and occurrences (Makkonen 1996, Puustinen et al. 1995). The style of mineralisation resembles that in all other Svecofennian nickel-copper provinces, and in many reports (e.g. Frietsch et al. 1979), the Juva-Puumala province is drawn as connected to the Kotalahti zone. In the present paper it is delineated as an independent province because it lies entirely to the west of the crustal-scale Kolkonjärvi shear zone, in the Svecofennian Domain, and thus belongs to a separate geoblock (Fig. 10).

In the western parts of the Saimaa area, closer to the Central Finland Granitoid Complex, there are numerous minor remnants of analogous associations of migmatitic gneisses with mafic intrusions and nickel-copper mineralisations. They are marked on the Metallogenic Map as small unnumbered spots of the province.

The Rantasalmi Au zone, located in the northern part of Lake Saimaa (block no. 19), in the vicinity of the Kolkonmäki shear zone, consists mainly of the Pirilä and Osikonmäki gold deposits and some few minor occurrences. All of them are generally considered to be epigenetic.
The Pirilä deposit (0.15 Mt at 8 g/t Au and 30 g/t Ag; Makkonen & Ekdahl 1988, Kontoniemi 1998) is hosted by a quartz rock body in the so-called Pirilä Belt, a complex at the contact zone between volcanic rocks and metapelites including a narrow iron formation.

The Osikonmäki deposit, comprehensively described in a monograph (Kontoniemi & Nurmi 1998) with 4 detailed articles dealing with metallogeny (see under the main heading), and in several other papers (Kontoniemi 1989, Kontoniemi & Ekdahl 1990, Kontoniemi et al. 1991, Vaasjoki & Kontoniemi 1991, Kontoniemi 1997, Kontoniemi et al. 1998), is hosted by a synorogenic tonalite pluton (1887 Ma) and exhibits a strong structural control. The geological in situ ore resources at Osikonmäki have been estimated to be 2.2 Mt, averaging 3.1 g/t Au and 0.77 % As.

The most common sulphide minerals at Pirilä and Osikonmäki include pyrrhotite, arsenopyrite, löllingite and chalcopyrite. Gold occurs as native gold and electrum, as inclusions and at grain boundaries of and between arsenopyrite and silicate grains. Special studies have been published on fluid inclusions geochemistry (Poutiainen 1993) and the general geochemical characteristics of these deposits (Nurmi et al. 1991a, b).

The Virtasalmi Cu zone (12) is a chain of skarn-like bodies that contain several copper mineralisations with very little of other metals (except iron). The zone be-
longs to an isolated crustal block of high metamorphic grade (Hyvärinen 1969, Pekkarinen 2002) in the very northern corner of the Saimaa area (unit no. 19 in Fig. 1). The largest of the mineralisations, the Virtasalmi (Hällinmäki) deposit was exploited between 1966 and 1984 and yielded 4.25 Mt at 0.76 % Cu. It consists of chalcopyrite-cubanite-pyrrhotite mineralisation with some magnetite lumps, hosted by dark, iron-rich andradite-hedenbergite skarn. What is amazing, is that a bed of very pure white marble with a little wollastonite and completely iron-free diopside organically belongs to the strata and is only 100 m away from the dark skarn horizon. In fact, the marble is an essential part of the complex and has been exploited in a couple of small quarries.

A volcanic origin of the rocks in the complex has been proposed (Lawrie 1987), and consequently an affinity between the Virtasalmi zone and the Vihanti zone has been suggested (Ekdahl & Philippov 1999). On the other hand, the similarity of the complex to the Orijärvi zone is also striking, e.g. in terms of the presence of magnetite skarn, wollastonite-bearing marble and even minor iron formation horizons (Pekkarinen 2002).

The Ilmolahti Ni-Cu zone (13) is a narrow strip of mica gneiss remnants in the northern part of the Central Finland Granitoid Complex that hosts a chain of six minor nickel deposits of normal Svecofennian type. These follow a single NW-SE trending fault for a distance of about 80 km. Due to the modest size of the hosting gneiss formation, this zone has been regarded as less prospective and little interest was paid to it, despite the fact that the largest of the deposits, Ilmolahti (estimated at 0.15 Mt at 0.33 % Ni and 0.25 % Cu in the explored parts) is not so far from being commercially viable. No published first hand information on the zone and deposits is available. A short description in Puustinen et al. (1995) is based on unpublished archive reports.

The Kotalahti Ni-Cu zone (14) is perhaps the best-known metallogenic zone in Finland. It was made known by Gaål (1972) and Gaål et al. (1975), who anticipated an extremely narrow and long belt running through all of central Finland roughly at the boundary between the Svecofennian and Kola-Karelian Domains, along a single deep fracture system, and including nearly all the significant nickel deposits of the Svecofennian type. It was named after the Kotalahti deposit and mine, the then largest nickel mine not only in Finland but in the entire Western Europe in the 1960s.

Over the years, concepts on the Kotalahti Nickel Belt have been studied and discussed by many authors (e.g. Gaål et al. 1978, Tontti et al. 1979, Frietsch et al. 1979, Tontti 1981, Kuosmanen et al. 1982, Gaål 1985, Papunen & Vorma 1985, Ekdahl 1993, Ekdahl & Philippov 1999). The most recent discussion and review is to be found in a monograph by the present authors on the distribution and metallogenic types of the nickel deposits in Finland (Puustinen et al. 1995).

Investigations after 1975 showed that the structure of the Kotalahti Belt is more complicated than was initially assumed: more deposits and occurrences were discovered and that made the prospective area broader, the deposit chain was confirmed not as continuous but forming separate clusters (Tontti et al. 1979, Tontti 1981), and the deposits in individual clusters were shown to have slightly various characteristics (e.g. Papunen & Vorma 1985). The boundary between the two major domains is not a straight line either (cf. Fig. 4), and the mineralisations concerned fall partly in the Svecofennian Domain and partly in the Kola-Karelian Domain. The comprehensive data on the distribution of the nickel deposits, as presented in Puustinen et al. (1995), show that the mineralisations in the belt form up at least two parallel sets of sub-linear deposit groups of lower rank (see Fig. 7).

Consequently the outlines of the nickel belt have been drawn in many different ways in different publications. Some authors joined all the nickel mineralisation zones into a broad belt covering the entire migmatite belts east of the Central Finland Granitoid Complex (e.g. Ekdahl 1993, Ekdahl & Philippov 1999), and some sketched a ring-like nickel belt covering all Svecofennian migmatite belts surrounding the Central Finland Granitoid Complex, with no preference given to the Kotalahti system (Frietsch et al. 1979). In contrast, in the above-mentioned work by Puustinen et al. (1995), the nickel-bearing territory is described in a set of small deposit clusters, without taking much of a stand on their mutual connection.

In the present Metallogenic Map, the Kotalahti zone is delineated as an elongated province of nickel-copper deposits of Svecofennian type, hosted by mafic-ultramafic intrusion bodies in an environment dominated by migmatitic mica gneisses and running on the eastern side of the Kolkonjärvi shear zone, which is indicated by a deep trough in the gravimetric map (Fig. 10). The zone includes the large deposits of Kotalahti and Laukunkangas with their neighbouring occurrences and also the Talluskanava and Ilokangas occurrence groups, thus corresponding to clusters 21 to 25 in Figure 7. This zone is separated from the Juva-Puumala province (metallogenic zone 10, Fig. 5) by the Kolkonjärvi shear zone and is located in the Savo Belt (unit no. 16 in Fig. 1), inside or at the boundary of the Kola-Karelian Domain, unlike the Juva-Puumala province, Ilmolahti zone (metallogenic
The Hälvlä deposit was mined as a subsidiary of Lankunkangas between 1988 and 1992, and 0.25 Mt of ore was extracted at 1.41 % Ni and 0.35 % Cu. Lankunkangas is thoroughly described by Grundström (1980, 1985) and Mäkinen (1987). It is worth mentioning that at Lankunkangas the high-grade ore was contained in blind ore bodies in the lower ultramafic part of the intrusion and not in the upper, exposed parts of it.

North of Kotalahti, there are clusters of minor deposits around Ilokangas and Tulluskanaava (Ekhdal 1993). They are associated with serpentinite, peridotite and gabbro bodies included in narrow mica gneiss areas surrounded by granitoids. This part of the nickel zone overlaps the Vihanti-Pyhäsalmi zinc zone (metallogenic zone 25), and it is somewhat unclear whether these clusters really are a part of the Kotalahti zone (cf. Puustinen et al. 1995).

The Vehmersalmi U zone (15) includes several minute occurrences around Puutosmäki near Kuo-pio. Here uraninite veins have been found in layered quartz-feldspar-biotite-pyrite schists, located in the Archaean basement complex. The Puutosmäki occurrence might belong to vein-type uranium mineralisations (IUREP 1982).

The Outokumpu Cu-Co-Zn + Ni zone (16) is confined to a specific association of black schists, calc-silicate rocks, a non-clastic quartz rock and serpentinites which are all traced as a winding, discontinuous ribbon of a total length of nearly 250 km in the Outokumpu area (unit no. 16, Fig. 1) in eastern Finland. The general geological and geographical outlines of the zone are described in Haapala (1936), Väyrynen (1939), Peltola (1960), Huhma & Huhma (1970), Koistinen (1981, 1987), Park (1984, 1988, 1992), Tyni et al. (1997) (see also Fig. 11).

The metallogenic zone was named after the Outokumpu deposit, the flagship of modern mining in Finland, exploited between 1910 and 1989. This large deposit (28.5 Mt with 3.36 % Cu, 0.88 % Zn, 0.23 % Co, 22 % S, 0.12 % Ni and 0.8 g/t Au; also known as Keretti, the most recent mine unit in the deposit) was subject to intensive investigations since its discovery in 1910, and it is described in a long series of publications (e.g. Tchimichkian 1936, Mäkinen 1938, Vähätalo 1953, 1954, Disler 1953, Mikkola 1969, Mikkola & Väisänen 1972, Mäkelä 1974, Gaál et al. 1975, Koistinen 1981, Koistinen et al. 1983, Park 1984, Parkkinen 1986, Papunen 1987, Gaál & Parkkinen 1993, Laznicka 1993, Warrender et al. 1998). The proper Cu-Co deposit of Outokumpu forms a flat body of massive to densely disseminated ore in the quartz rock member of the Outokumpu Association; in addition, there is a vague zone of low-grade
Ni mineralisation in the hanging wall skarn (Fig. 12; Parkkinen & Reino 1985). The same two ore types can be found in various proportions in all the other deposits of the zone, two of which have been subject to exploitation:

- Luikonlahti, mined from 1961 to 1983 and it produced 6.9 Mt at 0.94 % Cu, 0.61 % Zn, 0.11 % Co (Koljonen 1976, Tyni in Tyni et al. 1997)
- The Vuonos Ni and Cu deposit (Peltola 1980, Parkkinnen & Reino 1985), which was mined from 1972 to 1986 and yielded in total copper and nickel ores of 11.0 Mt at 2.14 % Cu, 1.31 % Zn, 0.14 & Co, 20.7 % S and 0.16 % Ni.

Other deposits individually described are

- Kylylahti (estimated at 5 Mt at 1.55 % Cu and 0.3 % Co; Rekola & Hattula 1995, Pekkarinen in Tyni et al. 1997) and
- Riühilahti (estimated at 0.7 Mt at 0.72 % Cu; Merkle 1982).

Genesis of the ores and the entire association have been discussed for decades, and all possible concepts have been presented, from pneumatolytic origin and metamorphic remobilisation to volcanic-exhalative, black schist derivative, etc. In recent years, two alternative models have been subject to discussion, the black schist (seafloor sedimentary) origin and the

A genetic link has been suggested between the Ni-Zn-Cu deposits of the Talvivaara zone (zone no. 28) and the Outokumpu deposit (Loukola-Ruskeeniemi et al. 1991) on the grounds of the identical character of the black schists and the geochemical characteristics in the two zones. However, direct observations show that there are two separate black schist formations present in both zones, one (para-autochtonous) carrying the Talvivaara-type deposits in Kainuu and the other (allochtonous) belonging to the Outokumpu association proper (A. Kontinen, pers. comm. 2003).

On the other hand, a distinct ophiolite formation, the Jormua mafic-ultramafic complex, has been identified in the central part of the Kainuu Belt (unit no. 14, Fig. 1; Kontinen 1987) and has been associated with the Outokumpu complex (Vuollo 1994, Liipo et al. 1995). On the pretext of this, the lithological assemblage of the Jormua complex is considered to be critical for Outokumpu-type mineralisation. Hence, the Jormua area is shown as a northern continuation of the Outokumpu zone on the Metallogenic Map.

The deposits and rocks of the Outokumpu association show many unique features in respect to their mineralogy; for example, the numerous chromium-

**The Koli-Kaltimo U zone (17)** is a chain of minor deposits and occurrences of uranium in quartz-pebble conglomerates and quartzites of the Jatulian unit of the Palaeoproterozoic Höytiäinen Schist Belt (unit no. 17 in Fig. 1) of eastern Finland (Wennergård 1960, Davidson 1960, Piirainen 1968, IUREP 1982, Äikäs & Sarikka 1987). Most of them, such as Ipatti, Martinmonttu and Ruunaniemi, belong to the sandstone type, but in some places, like Paukkajänvaara (Piirainen 1968, Isokangas 1958), the only exploited uranium deposit in the zone (1958-1961, 0.04 Mt at 0.14 % U), is a considerable enrichment of ore which is epigenetic and located at the contacts of a cross-cutting metadolerite.

The Koli-Kaltimo zone is accompanied by a number of uranium-thorium vein mineralisations within the territory of the Archaean basement that underlies the Jatulian arenite formation. These show the same Proterozoic age features and may represent an unconformity type uranium mineralisation (IUREP 1982, OECD 2002, O. Äikäs, pers. comm. 2003).

**The Kyykkä-Hokka Cu zone (18)** includes several minute mineralisations consisting of big lumps of massive sulphide minerals, chiefly chalcopyrite, bornite, chalcocite, in quartz veins which cut the Jatulian metadiabases of the Höytiäinen Belt (unit no. 17 in Fig. 1; Thoreld 1891, Aurola 1954). Despite of the impressive, fist-size lumps of ore minerals, the average copper content in these deposits is low, mainly less than 0.5 % according to modern exploration (L. Pekkarinen, pers. comm. 2003), and today they are of no commercial value. In the 19th century, at the time of handicraft industries, a few of them were subject to exploitation.

**The Hattu Au zone (19)** (Fig. 13) occupies the eastern branch of the Hattu Schist Belt in the Archaean Iломantsi Greenstone Belt (unit no. 13 in Fig. 1). It is thoroughly described in 15 papers by Nurmi & Sorjonen-Ward (1993). Additional or review data about the zone can also be found in Pekkarinen (1989), Ward & Nurmi (1989), Gaál & Sundblad (1990), Ojala et al. (1990), Johanson & Koijonen (1991), Johanson et al. (1991), Koijonen et al. (1994), Rasilainen (1993, 1996), Sorjonen-Ward (1997), Stein et al. (1999), Eiulu (1999), Laine (2002), and Pouitainen & Partamies (2003). Hattu was the first gold province recognized in the Archaean of the Fennoscandian Shield, and it serves as a prototype for all similar provinces in the shield.

Of the deposits and occurrences within the zone, the most important are Pampalo or also known as Ward (test mining between 1996 and 1999 with 0.13 Mt of ore at some 14 g/t Au; estimated resources at least 0.6 Mt at 7.4 g/t Au), Hosko, Korvilansuo and Rämepeuro (Hattuvaara). They are epigenetic mesothermal gold disseminations and vein swarms of the Late Archaean age, with structurally controlled locations chiefly in the supracrustal rocks of the greenstone belt (Fig. 13).

**The Huhus Fe zone (20)** is an Archaean banded iron formation (BIF) zone, analogous to (and actually a southern continuation of) the Kostomuksha formation in Russian Karelia. Horizons of banded iron formation are common all over the Iломantsi Greenstone Belt (Laajoki 1985, 1986, Laajoki & Lavikainen 1977, Gehör & Laajoki 1987, Laajoki 1990), and some of these have been regarded as deposits. Resources in the largest of them, the Huhus deposit, add up to a few tens of millions of tonnes of iron ore (Malminetsijä Oy, unpublished data).

In the western part of the zone, a few minor deposits of pure pyrite, such as Otravaara and Karhusaari, were discovered and even mined at the beginning of the 20th century (Saxén 1923, Hausen 1934, Aurola & Vähätalo 1939, Saksela 1951). These may represent the sulphide phase of the iron formations, but at least their final enrichment processes show distinct metamorphic features and a structural control.

**The Seinäjoki Au-Sb zone (21)** in the southern corner of the Pohjamaa Schist Belt (unit no. 21, Fig. 1) was initially known for its antimony deposits, such as Törnävä (Pääkkönen 1966) and the largest one, Kalliosalo (estimated at 0.46 Mt at 0.73 % Sb and 1 g/t Au), with their native antimony and certain exotic antimony minerals (Saksela 1952, Mozgova et al. 1977, Borodav et al. 1983, Borodav et al. 1985, Appelqvist 1993, Mäkitie et al. 2001). However, these deposits and occurrences typically also contain significant gold (Nurmi et al. 1991a, b, Eiulu 1999). The mineralisations consist of ore mineral dissemination in quartz veins and in the hosting metapelites and metagreywackes plus intermediate metavolcanic rocks. The southeastern end of the zone (e.g. the Timanttimaa occurrence,
Fig. 13. General outline of the Hattu zone and the gold mineralisations. From Nurmi and Sorjonen-Ward (1993).
Kangasjärvi (Rehtijärvi 1984b, Rasilainen 1991, Mullikkoräme (Rasilainen et al. 2003); mined Ruostesuo (Roberts et al. 2003b); between 1988 sióuaed on the northeasern edge of the Svecofennian area.

Black schists are also not uncommon in schists to mica gneiss environments with some volcanic affinities. The pegmatites mainly occur in a mica gneiss environment with some volcanic affinities. Black schists are also not uncommon in the area.

The Vihanäi-Pyhäsalmi Zn-Cu-Pb zone (25), situated on the northeastern edge of the Svecofennian Domain in the northern corner of the Savo Schist Belt (unit no. 16, Fig. 1), is by far the most important zinc producing area of modern-day Finland. Its deposits belong to the classical volcanogenic massive sulphide (VMS) type of the Palaeoproterozoic age and are confined to a single volcano-sedimentary schist association, which twines rather irregularly through the district (Isokangas 1954, Mikkola 1963, Mikkola & Väisänen 1972, Pajunen 1988, Vaasjoki & Sakkoo 1988, Ekdahl 1993, Laznicka 1993, Kousa et al. 1997, Loukola-Ruskeeniemi et al. 1997b, Roberts 2002, Rasilainen et al. 2003, Roberts et al. 2003a; Fig. 14). The volcanic host rocks belong to the Palaeoproterozoic Svecofennian island arc succession near the margin of the Archaean Karelian craton. Two of the deposits, Vihanäi and Pyhäsalmi, belong to the largest metallic mineral deposits in Finland. They have been subject to mining for a long time, and Pyhäsalmi is still operating. Also a number of smaller deposits, situated in the central part of the zone around Pyhäsalmi, have been exploited as follows:

- Mullikkoräme (Rasilainen et al. 2003); mined between 1990 and 2000 yielding 1.20 Mt at 6.08 % Zn, 0.30 % Cu, 0.86 % Pb, 44 g/t Ag, 1 g/t Au and 17 % S,
- Ruostesuo (Roberts et al. 2003b); between 1988 and 1990 yielding 0.24 Mt at 2.63 % Zn, 0.30 % Cu, 9 g/t Ag, 0.3 g/t Au and 31 % S, and
- Kangasjärvi (Rehtijärvi 1984b, Rasilainen 1991, Roberts et al. 2004); between 1984 and 1985 yielding 0.91 Mt at 5.12 % Zn, 0.09 % Cu, 5 g/t Ag, 0.3 g/t Au and 38 % S.

The Vihanäi mine is situated close to the geographical centre of Finland, in the municipality of Vihanäi (Rouhunkoski 1968, Wennervirta & Rouhunkoski 1970, Rauhamäki et al. 1978, Rauhamäki et al. 1980). The first indications of the ore were pyrite-rich boulders discovered by local farmers in 1936, and the zinc orebody was located in 1946. Production started in 1954 and lasted until 1992. By that time, 27.94 Mt of ore was mined with an average grade of 5.17 % Zn, 0.46 % Cu, 0.40 % Pb, 27 g/t Ag, and 0.43 g/t Au and some 13 % S. The hosting volcano-sedimentary sequence mainly comprises rhyodacitic porphyry and calcareous rocks, with subsequent cordierite-bearing metasomatic rocks and black shales. The common host rock to the zinc ores is dolomite or skarn, although the ores are related to felsic volcanism. The whole sequence is overturned and strongly deformed in several stages. The hanging-wall contact of the ore is tectonic.

Three main generations of sulphide mineralisation
Fig. 14. Geological background, outlines of the Vihanti-Pyhäsalmi zone (red line) and the most important Zn-Cu deposits (mine symbols and stars). Note also the Rauhala deposit outside the Vihanti-Pyhäsalmi zone, described in connection with the Laivakangas Au province. Unpublished materials by the Geological Survey of Finland (GTK), by courtesy of J. Luukas, J. Kousa and J. Nikander (2005).
have been identified at Vihanti: 1) pyrite ore bodies at Hautakangas and Hauktaräme with Cu- and Zn-rich parts; 2) chalcopyrite-pyrite ore bodies in skarn lenses, mined as low-grade Cu ore; 3) the youngest Pb-Ag-Sb mineralisation hosted by coarse-grained diopside skarn and also containing notable amounts of Au. A special type of mineralisation at Vihanti is a uranium-phosphorous horizon located near the stratigraphic base of the volcano-sedimentary formation (Rehtijärvi et al. 1979, Vaasjoki et al. 1980, Åikäsi 1980, Åikäsi 1989). The U-P mineralisation is chiefly in felsic volcanic rocks, but also skarn and dolomite may host it. Uraninite forms the main host for U andapatite for P. Its total tonnage is more than 1 Mt, but the U and P grades have – so far – been too low for exploitation.

In spite of intensive exploration only very few deposits of the Vihanti-type proper have been found in the northern part of the zone (e.g. Arkimaa et al. 1985, Kuosmanen et al. 1985, Tontti et al. 1981).

The Pyhäsalmi mine, owned by Inmet Mining Co (from 2002) is the oldest metal mine in Finland still operating and at 1450 m it is the deepest in Europe. It was discovered in 1958 and operated as an open pit from 1962 to 1976 and underground from 1967. The deposit is a Zn-Cu-barite VMS type mineralisation with hydrothermally altered host rocks that were subsequently metamorphosed, deformed, recrystallised and partially remobilised under amphibolite facies conditions. The ore is hosted by felsic pyroclastic rocks and quartz porphyries. Mafic volcanic rocks in the area are coarse-grained tuff breccias and lavas, the latter containing pillow units. Mafic and felsic dykes are common. (Helovuori 1979, Huhtala 1979, Ekberg & Penttilä 1986, Mäki 1986, Eilu et al. 1988, Laznicka 1993, Bigham et al. 1994, Mäki & Luukas 2001, Imaña Osorio & Mäki 2003).

The composition of the Pyhäsalmi ore varies both horizontally and vertically. To a depth of about 1000 m, sphalerite is concentrated in the central part and chalcopyrite near the outer margins of the ore. At deeper levels, there is massive pyrite (low Cu, Zn) in the centre, which is enveloped by chalcopyrite ore and further outwards by Zn ore. The highest barite contents are generally encountered in the sphalerite-rich areas. The ore is a massive pyrite ore with 70 % sulphides. The sphalerite-rich ore is in some places finely banded, and thin pyrite-porphyritic bands are common. A pyrite dissemination, which in some places has a breccia structure, exists around the massive ore. Pyrrhotite has replaced pyrite at the southern end of the ore. By end of 2004, the ore tonnage mined from Pyhäsalmi has been 39.77 Mt at 2.37 Zn, 0.83 % Cu, 14 g/t Ag, 0.5 g/t Au and 36 % S; the reserves were estimated at 15.69 Mt at 1.16 % Cu, 2.72 % Zn and 39.9 % S and the resources as 17.1 Mt at 0.8 % Cu, 0.7 % Zn, 42.9 % S.

In the southernmost part of the zone the mineralisations seem to be more copper-dominated, as for example Säviä (Aho 1977). They also are more modest in size, and no commercially viable deposits have hitherto been detected, in spite of intensive exploration and sophisticated modelling of the deposits (Gaál, ed. 1988, Kuosmanen, ed. 1988).

South from the main zone there is a minor separate block where rocks of the Vihanti association and a minor deposit, Pukkisauri, were encountered (Vaasjoki 1981, R. Lahtinen 1989).

The Laivakangas Au province (26) (Gaál & Isohanni 1979, Nurmi 1984, Nurmi 1985, Nurmi & Haapala 1986, Gaál & Sundblad 1990, Nurmi et al. 1991a, Nurmi et al. 1991b, Sundblad et al. 1993, Kousa et al. 1997, Eilu 1999) is located in western Finland around the junction of the Pohjanmaa Schist Belt (unit no. 21), Savo Schist Belt (unit no. 16) and the Central Finland Granitoid Complex (unit no. 20, Fig. 1). The gold deposits, such as Laivakangas (estimated at 0.45 Mt at 3.9 g/t Au; Mäkelä et al. 1988a, Mäkelä et al. 1988b), Kiiimala (Kojonen et al. 1991), Kopsa (Gaál & Isohanni 1979) and some others, are mainly epigenetic and confined to shear zones in granitoidic rocks. This brings some of them into the class of orogenic gold deposits and some close to the porphyry-copper ore type, and indeed several copper or molybdenum deposits (see e.g. Nironen & Csongrádi 1984, Piispanen 1985, Nironen & Front 1988) are spatially closely related to them and included into the same province.

Inside the gold province, there is a deposit of another type, the Rauhala Zn-Cu-Pb deposit, thoroughly described by Kojonen (1989), and by Kojonen et al. (1989). The relation of this deposit to the gold province has been discussed and the interpretation leans towards syngenetic (Kojonen et al. 1990). Its resources are estimated at 1.7 Mt of ore at 4.97 % Zn, 1.33 % Cu, 0.96 % Pb, 53 g/t Ag and 0.4 g/t Au.

The Hitura Ni-Cu province (27) is at the junction of the Pohjanmaa Schist Belt (unit no. 21, Fig. 1) and the Savo Schist Belt (unit no. 16) and is entirely overlapped by the Laivakangas Au province. It includes a tight cluster of several minor deposits of the Svecofennian type around the major Hitura deposit, plus a few minor deposits and occurrences to the NW and SW of Hitura. The Hitura province lies roughly at the continuation of the line connecting the Kotalahti and Laukunkangas Ni-Cu deposits, and it was traditionally referred to as the northernmost end of the Kotalahti Belt (e.g. Gaál 1972, Kahma 1973, Gaál et al. 1975). However, many
of the crucial characteristics of the Kotalahti Belt as defined in the papers mentioned above are not applicable to the Hitura area. The Hitura province is located deep inside the Svecofennian Domain. The deep gravimetric trough, which is interpreted as a major fault system and the leading structure for the nickeliferous mafic intrusions, is flattened here into an unstructured pattern. The deposits, especially those in the Hitura cluster proper (Isohanni et al. 1985), are associated with ultramafic bodies, and they perhaps resemble better the Oravainen deposit (see the description of the zone 22 above) than the deposits of the Kotalahti type (Papunen & Vorma 1985). Geochemically Hitura most closely resembles the Vammala deposit (Mäkinen 1987). On the other hand, no nickel mineralisations have hitherto been discovered between the Hitura province and the Oravainen province, which makes the continuous ring-like nickel belt, as proposed by Frietsch et al. (1983) and Papunen & Vorma (1985), less probable. Thus, the Hitura province is here considered to be an independent province.

The Hitura province as outlined in the Metallogenic Map includes the clusters described in Puustinen et al. (1995) as the Hitura zone (20), Perkkiö zone (19) and Muurasjärvi zone (29, Fig. 7). As such, the province is not very homogenous, but because the two latter clusters only contain quite small occurrences, we concentrate on the first group only.

As mentioned above, all of the nickel deposits in the Hitura cluster are associated with minor ultramafic intrusions. With the exception of Hitura itself, they are rather small and even the largest ones contain approximately 4 000 tonnes of nickel and 1 000 tonnes of copper each, in 0.5 – 2 Mt of ore at 0.2 – 0.74 % Ni and 0.05 – 0.14 % Cu. Of these, Makola (Huhta 1954, Haapala 1969, Isohanni et al. 1985), discovered in 1937 (Saksela & Hackzell 1938), was exploited from 1941 to 1954 and yielded 0.41 Mt at 0.74 % Ni and 0.44 % Cu.

Hitura (Papunen 1970, Papunen & Mäkelä 1980, Isohanni et al. 1985, Papunen & Penttilä 1996, Kousa et al. 1997) is not typical of its own province and, in fact, altogether unique in Finland. It is hosted by a pipe-like serpentinite massif with high magnesium content and no preserved signs of the primary pre-metamorphic rocks (probably dunites); the ore bodies form a nearly cylindrical entity at the outer shell of the pipe (Fig. 15); chemically Hitura is anomalous in its

![Fig. 15. Hitura nickel mine, horizontal section +350 m. According to Kojonen & Isomäki (2005). White – serpentinite, red – ore (with stopes marked with blue grid), blue vertical ruling – mica gneiss, orange grid – tonalites and granodiorites, crosses in circles – drill holes.](image-url)
high, even if not constant, PGM content. This is also seen in its mineralogy (Papunen 1970, Vuorelainen et al. 1972, Häkli et al. 1976, Papunen 1977), as such rare nickel minerals as mackinawite and valeruite are abundant and a large number of PGM minerals have been detected. Just recently a new Cu-Re-Mo mineral species, tarkianite, was discovered at Hitura (Kojonen et al. 2004).

Hitura has been subject to exploitation since 1970. The unusual mineralogical conditions, particularly the abundance of oxysulphide minerals of the valeruite group, have made dressing of the ore complicated, and recently the ore has been used for production of nickel compounds rather than for metallurgical products. Until now (the end of 2004) some 13.1 Mt with 0.57 % Ni and 0.21 % Cu have been mined of the total resources, which have been estimated at 50 Mt at 0.50 % Ni and 0.16 % Cu (cf. Isomäki 2004). The amounts of PGM have been variable; the best PGM accumulation of 20 000 tonnes of ore yielded a mill feed with values as high as 0.034 g/t Pt, 0.041 g/t Pd and 0.015 g/t Rh (Isokanni et al. 1985).

The Talvivaara Ni-Zn-Cu zone (28) includes several low-grade sulphide deposits hosted by black schist, and they form a chain of 150 km within the Paleo-proterozoic Kainuu Schist Belt (block no. 14; Laajoki et al. 1983, Loukola-Ruskeeniemi et al. 1997b). The most prominent of these deposits, Talvivaara (Loukola-Ruskeeniemi 1989, Loukola-Ruskeeniemi et al. 1991, Loukola-Ruskeeniemi & Heino 1993, Loukola-Ruskeeniemi 1995a, Loukola-Ruskeeniemi & Heino 1996, Loukola-Ruskeeniemi et al. 1997) contains at least 300 Mt of sulphide-bearing rock, averaging 0.26 % Ni, 0.53 % Zn and 0.14 % Cu. Possible by-product uranium of 0.001 – 0.004 % U could also be encountered (OECD 2002). Anomalously high concentrations of PGE elements have also been detected here (Pasava et al. 1997). A mineralogical curiosity at Talvivaara is the presence of alabandite (Törnroos 1982). Several attempts have been made to exploit the huge reserves of Talvivaara. Recent laboratory, bench and pilot scale experiments have shown the amenability of the black schist ore to bioleaching with high metal recoveries (Riekkola-Vanhanen 2005). After Talvivaara, the next largest deposits of this zone are Pappilanmäki, Korpimäki, Alanen and Sotinpuro, all containing a few tens of Mt mineralised rock.

Concerning the genesis of the Talvivaara type deposits, it has been suggested that originally they were metalliferous organic-rich muds deposited in anoxic conditions in a basin associated with sea floor spreading (Loukola-Ruskeeniemi 1995a). A genetic link between the Kainuu Ni-Zn-Cu deposits and the Outokumpu serpentinite-associated Cu-Co-Zn-Au-Ni ore deposit has also been anticipated (Loukola-Ruskeeniemi et al. 1991) based on lithological, mineralogical and geochemical features (cf. the description of the Outokumpu zone (16) above).

Talvivaara has also been a target of extensive environmental and geomedicinal studies (Loukola-Ruskeeniemi et al. 1998, 1999b, 2003).

The Nuottijärvi-Sotkamo U zone (29) includes uraniferous phosphorites associated with sedimentary carbonates of Paleoproterozoic sequences within the Kainuu Schist Belt (block no. 14, Åikäs 1980, Vaajoki et al. 1980). The Nuottijärvi deposit is located in a carbonate-apatite horizon, between quartzites and graphite-bearing phyllites. An intraformational breccia characterises the deposit. The uranium resources of the Nuottijärvi deposit might be up to 1 000 t U with an average grade of 0.04 % U. (IUREP 1982, Åikäs 1989, OECD 2002).

The Otanmäki V-Fe-Ti province (30) is situated in a small triangular formation of Proterozoic rocks inside the Archaean gneisses, in the southernmost part of the Pudasjärvi complex (unit no. 9 in Fig. 1). The Otanmäki formation consists of mainly supracrustal rocks (mica schists and quartz-feldspar schists) plus some metadiabases in the middle, and an arch-like pattern of metamorphosed mafic plutonites, which surround the other lithological units of the formation (Paarma 1954, Pääkkönen 1956, Pöschl 1964, Isokangas 1978). The Fe-Ti deposits are confined to these mafic rocks. In addition, a massif of a slightly alkaline rock, originally defined as ‘alkali granite’ (Marmo et al. 1966), but more recently interpreted as metasomatic alkaline gneiss, intrudes the supracrustal members of the formation.

The entire formation is interpreted as a basin. The mafic rocks represent original layered intrusions that are, however, strongly metamorphosed, so the gabbroic parts are turned into amphibolites and only the anorthositic parts are recognizable as intrusivc. The mineralisations are affected by the metamorphism as well. The ore minerals are segregated into deposits and ore bodies scattered in a rather irregular way along the main mineralised horizon, which made exploitation of the Otanmäki mine complicated and a special design of magnetometric survey for locating individual ore bodies was required (cf. Paarma & Levanto 1958). On the other hand, as an advantage, the main ore minerals (magnetite and ilmenite) do not occur as lamellar ‘titanomagnetite’ patterns, but rather as independent grains. This feature, noticed already by Ramdohr (1956), is favourable for producing both good-quality ilmenite concentrate and high-grade magnetite product during exploitation.

Due to their high magnetite content, the deposits in
the province cause distinct magnetic anomalies and can be easily traced even by regional-scale airborne geophysical survey. The type deposit of the province and the largest one, Otanmäki, was discovered in 1938 and mined in 1953 to 1985. Its indicated ore resources add up to 36 Mt at 34 % Fe, 0.26 % V and 7.6 % Ti. The vanadium content in the magnetite is 0.62 %, and vanadium was the most valuable commodity in the ore. Also the next largest deposit, Vuorokas (7.8 Mt at 32.5 % Fe, 0.26 % V and 5.5 % Ti) was exploited from 1965 to 1985, as a subsidiary of the Otanmäki mine. Altogether 25.4 Mt of ore was produced from the two deposits, yielding 8.6 Mt Fe, 3.3 Mt TiO₂ and 0.12 Mt V₂O₅. In 1985, mining – and the entire vanadium industry in Finland – was stopped because of disturbances in the world vanadium market, and considerable ore reserves were left over. The other 4 known deposits of the province are much smaller, less than 1 Mt each.

The alkaline rock complex mentioned above also has a specific metallogenic appearance. Two minor Nb-REE mineralisations called Hautakangas and Kontioaho were encountered in pegmatitic veins connected to the complex. According to archive reports by the Rautaruukki Company, the volume of the mineralisations is modest, but they are interesting in their mineralogy. The main niobium mineral in them is fergusonite, i.e. an yttrium niobate.

The Moukkori-Lokkiluoto Au zone (31) is confined to the Kuhmo Greenstone Belt of Archaean age (unit no. 12, Fig. 1), like the next two metallogenic zones. It contains several minor deposits (e.g. Kuikkapuro) and occurrences of Archaean type, hosted mainly by mafic metavolcanics and analogous to the Hattu Au zone described above (Nurmi et al. 1991a, Nurmi et al. 1991b, Poutiainen & Luukkonen 1994, Eilu 1999, Halkoaho & Pietikäinen 1999, Papunen et al. 2001).

The Kauniinlampi-Arola Ni zone (32) comprises a series of Archaean nickel deposits and occurrences in the Kuhmo and Suomussalmi Greenstone Belts (unit no. 12, Fig. 1). The most important ones are Hietaharju and Peura-aho (Kojonen 1981, Ketola 1982, Kurki & Papunen 1985), Kauniinlampi (Halkoaho et al. 1999, Halkoaho & Pietikäinen 1999) and Arola (Puustinen et al. 1995). They are ascribed to the komatiite group (Halkoaho et al. 2000); however, many of them show features differing from the main komatiite type both in terms of metal ratios and the composition of the host rocks (cf. Kojonen 1981). A mineralogical peculiarity is the find of native nickel in Kauniinvaara, one of the minor deposits (Pakkonen & Luukkonen 1995).

The Tipasjärvi-Saarikylä Fe zone (33) (Laajoki 1985, Laajoki 1986, Laajoki & Gehör 1990) is a strata of banded iron formations within the Kuhmo Schist Belt (unit no. 12, Fig. 1) with a number of mineralisations. However, these are still smaller than those in the Huhus zone described above, and a lot of iron is included in the silicate phase (Gehör & Laajoki 1987). Like the Huhus zone, deposits of pure pyrite are known here, too, at Lake Tipasjärvi in the southermost part of the zone (Vartiainen 1970; Taipale 1983b).

The Pääkkö Fe zone (34) includes several Superior type iron formations around Väyryläńkylä at Puolanka, in the northern part of the Kainuu Schist Belt (unit 14 in Fig. 1). The Iso-Vuorijärvi, Pääkkö, Seppola and Körölä deposits are situated in the same 10 km long or so sedimentary structure that consists of a dolomite-phyllite unit with tuffites, dolomites, black shales, phylmites, metadiabases, quatzites and iron formations. The dominant rock of the iron formations is an amphibole-rich quartz-magnetite-banded rock representing mixed oxide-silicate facies. Also quartz-siderite-banded rock of the carbonate facies and iron-rich black schists and phyllites of the sulphide facies have been encountered (Laajoki 1975a, Laajoki 1975b, Laajoki & Saikkonen 1977, Lehto & Niiniskorpi 1977, Laajoki et al. 1983). According to a whole rock Pb-Pb isochron the age of the Pääkkö iron formation is 2080 Ma (Sakko & Laajoki 1975). However, recent zircon age determinations indicate a totally Archaean provenance for the Central Puolanka Group of the Kainuu Schist Belt (Huhma et al. 2000).

In total, up to some 20 Mt of low-grade iron ore (27 % Fe, 1.2 % P, 1.9 % S) could be located in the Väyryläńkylä area. In addition to iron formations, several preglastar kaolin deposits have been located at Pihlajavaara, Pääkkö, Iso-Vuorijärvi, Honkavaara and Poskimäki (Laajoki 1975a, Laajoki 1975b). The Pääkkö Fe zone has very similar features to the large Tuomivaara iron deposit, some 60 km to the south in Sotkamo (Laajoki et al. 1983, Gehör 1994b).

The Koillismaa PGE + Ni-Cu + V-Fe zone (35) covers a complex of Palaeoproterozoic (ca. 2450 Ma) layered intrusions in northeastern Finland. The intrusive bodies of Koillismaa form the eastern half of the large discontinuous chain of platform-type layered intrusions that crosses Finland in an E-W direction about 100 km to the south of the Polar circle (Piiroinen et al. 1974, Alapieti et al. 1982, Alapieti et al. 1990, Alapieti & Lahtinen 2002: Fig. 16). These layered intrusions were emplaced in the Archaean basement, at a level that was subsequently denuded by Palaeoproterozoic erosion, so that their hanging wall is commonly immediately covered by Proterozoic supracrustal rocks of the Jatulian series, i.e. by rocks younger than the layered intrusions themselves.
The Koillismaa intrusive complex, which lies at the junction of the Archaean Pudasjärvi complex and the Proterozoic Kuusamo Schist Belt (units no. 9 and 8, Fig. 1), consists of a group of intrusive blocks (probably, tectonically separated parts of a single intrusion) and a separate ‘tail’, Näränkävaara, stretching eastwards from the main group (Alapieti 1982, Alapieti & Kärki 2005).

Initially, the Koillismaa complex was explored for nickel-copper and iron-vanadium ores. Indeed, large
but low-grade Ni-Cu mineralisations were encountered at Porttivaara and Kuusijärvi in the western subgroup of the intrusive blocks (Piirainen et al. 1977, Alapieti et al. 1979a, Lahtinen 1985) and a V-rich Fe-Ti deposit was detected at Mustavaara in the Porttivaara section (Piirainen & Juopperi 1968, Juopperi 1977). The Mustavaara mine operated from 1974 to 1985 and yielded 13.4 Mt of ore at 0.2 % V. Considerable ore reserves, indicated as 38 Mt, were still left unexploited there.


The eastern Näränkäväara intrusion (Alapieti et al. 1979b) continues across the border into Russia. The ore potential of the intrusion is still open, as no considerable mineralisations have so far been discovered, despite many years of exploration.

The Oijärvi Au zone (36) is confined to the less known Oijärvi Greenstone Belt in the middle of the Pudasjärvi Complex (unit no. 9 in Fig. 1). The gold mineralisations of Archaean orogenic type were only discovered recently, and the only non-commercial public description available on them is in the updated versions of the FINGOLD database (cf. Eilu 1999).

The Kemi-Penikat Cr + PGE zone (37), located at the boundary between the Archaean Pudasjärvi Complex (unit no. 9) and the Proterozoic Peräpohja Belt (unit no. 7, Fig. 1), covers two western members in the 2450 Ma layered intrusions chain of northern Finland (Fig. 16). Compared to the Koillismaa zone, the Kemi-Penikat zone does not contain any sulphide accumulates of the marginal series type, but basal chromitite accumulations and chromitite reefs (cf. Lahtinen et al. 1989, Alapieti et al. 1990). Indeed, the first discovered mineralisation in this zone was the Kemi (or Elijärvi) chromium deposit, by far the largest mineral deposit in Finland with estimated reserves and resources at 162 Mt at 26 % Cr₂O₃ (Kahma et al. 1962, Kujanpää 1986, Alapieti et al. 1989a, Huhtelin 1997, Kojonen et al. 1999b). The Kemi mine, established in 1966, operates continuously and up to the present time about 30.91 Mt of ore has been extracted at an average grade of 25.7 % Cr₂O₃.


The PGE mineralisations in the Penikat intrusion are confined to four mineralised horizons or reefs all located inside or at the boundaries of one megacyclic unit of the layered series of the complex. They are referred to as the Sompujärvi Reef, Ala-Penikka and the Paasivaara Reef (Alapieti & Lahtinen 1986, Halkoaho et al. 1990a, Halkoaho et al. 1990b). A detailed description and review of the geology of the intrusion and mineralisations is presented by Alapieti & Lahtinen (2002) and will not be repeated here.

We only wish to point that the PGE reefs continue through the intrusion but are mainly thin horizons (decimetres in thickness) with local swellings up to 20 m in depression structures called potholes, at a PGE level of less than 10 g/t. As such, the total volume of mineralisation can be estimated with some uncertainty only: figures of 2 340 tonnes Pt and 4 590 tonnes Pd have been presented for the in situ resources of the total field (Vermaak 1995).

At Kirakkajuppura, at the northern edge of the Penikat intrusion, a bonanza-type pocket deposit was discovered in the Sompujärvi Reef (Barkov et al. 1999, Alapieti & Lahtinen 2002). A test mine was established there in 1988 and 2 165 tonnes of ore at about 10 g/t Pt and 20 g/t Pd was extracted.

The westernmost intrusion in the chain, the Tornio intrusion, continuing to Sweden and known there as the Kukkola intrusion (Söderholm & Inkinen 1982), has received less attention after its initial discovery, as it was deemed to be of less potential. Therefore in the Metallogenic Map it is left out of the Kemi-Penikat zone.

The Suhanko PGE zone (38) and Narkaus PGE zone (39) are hosted by intrusions of the Portimo Layered Complex (Iljina 1994), which lies halfway between the Penikat intrusions and the Koillismaa Complex described above. Although situated close to each other, the Suhanko and Narkaus intrusion groups differ in their shape and character of mineralisation. The Suhanko intrusions resemble the Koillismaa Complex, while the Narkaus intrusion occupies a position strictly at the boundary between the Archaean
Pudasjärvi complex and the Proterozoic sedimentary series of the Peräpohja Schist Belt (unit no. 7, Fig. 1), just like the Penikat intrusive complex, and is similarly cut into several blocks.

Five principal types of PGE mineralisations have been identified in the Portimo Complex. In the Suhanko zone, we see (1) PGE-bearing Cu-Ni sulphide disseminations, similar to those in Koillisma; (2) massive pyrrhotite bodies; (3) a reef called Rytkikangas Reef, comparable to the Ala-Penikka Reef. In the Narkaus zone, they are (2) massive pyrrhotite bodies identical to those at Suhanko; (4) a PGE reef (Siika-Kämä Reef) and (5) offset Cu-PGE mineralisations in the Archaean wall rocks (Vuorelainen et al. 1982, Hänninen et al. 1986, Huhelin et al. 1989a, Huhelin et al., 1989b, Iljina et al. 1989, Alapieti et al. 1989b, Iljina 1991, Lerssi et al. 1991, Iljina et al. 1992, Thalhammer et al. 1993, Andersen et al. 1999, Iljina & Hanski 2002, GTK 2005.

The resources of the largest deposits in the Suhanko zone have been estimated (Outokumpu Oy & Gold-Fields Ltd. 2002) as follows:

- Konttijärvi and Konttijärvi North: 54.0 Mt at 1.44 g/t Pd, 0.40 g/t Pt and 0.10 g/t Au;
- Ahmavaara: 99.8 Mt at 1.10 g/t Pd, 0.23 g/t Pt and 0.14 g/t Au;
- Ahmavaara East: 29.8 Mt at 0.83 g/t Pd, 0.18 g/t Pt and 0.11 g/t Au;

In total, the metal content in the Konttijärvi and Ahmavaara deposits corresponds to 9.1 Moz of (2PGE+Au). Analogously, an estimate of 5.3 Moz has been given for the ore bodies of the Siika-Kämä Reef at Narkaus (Iljina & Hanski 2002).

The Tervola Au-Cu zone (40) is in the Palaeoproterozoic Peräpohja Schist Belt (unit no. 7 in Fig. 1), which comprises a wide range of metasedimentary and -volcanic rocks with only a few intrusions aged from about 1.8 to 2.2 Ga. The Tervola zone covers a part of the Peräpohja Belt containing mafic to felsic metavolcanics, carbonate rocks, black schists and (arkose) quartzites. The regional geology is described by e.g. Perttunen (1980), Perttunen (1985), Korhonen & Säävuori (1985), Perttunen & Lappalainen (1997) and Perttunen & Vaasjoki (2001).

The Kivimaa Au-Cu deposit, discovered in 1965 (Rouhunkoski & Isokangas 1974, Niiranen & Eilu 2003), is located some 50 km southwest of Rovaniemi, in the central part of the Peräpohja Schist Belt (Nironen et al. 2002). It is a single lode comprising a major calcite-quartz vein and hosted by a tholeiitic metadolerite sill. The sill occurs apparently conformably in a sequence of mafic metavolcanic rocks. The quartz vein is E-W trending, 350 m long and 1 – 6 m wide. The continuation of the deposit is open at the depth of 60 m. The auriferous vein lies in a dip-slip fault and is enveloped by an alteration zone characterised by the mineral assemblage of calcite-chlorite-biotite-albite-pyrite. The main ore minerals are pyrite and chalcopyrite. Native gold and bismuth occur as inclusions in arsenopyrite and, possibly, as free gold. All gold appears to be in the calcite-quartz vein. The deposit was mined in 1969 yielding 18 600 tonnes of ore at 1.20 % Cu and 2.0 g/t Au.

The tiny Vinsa mineralisation, estimated at 1 000 tonnes of ore at 4 % Cu and 2.5 g/t Au, is located about 20 km west of Kivimaa. Geologically it is almost identical to Kivimaa.

The Vähäjoki iron deposit, estimated at 10 Mt of ore at 30 % Fe, is also situated in this area (Mikkola 1948, Sarala & Rossi 1998, Liipo & Laajoki 1991). It clearly belongs to the epigenetic Fe-Ox-Cu-Au type and locally contains potentially significant Au, Co and Cu (Niiranen & Eilu 2003).

The Rovaniemi-Ylitornio Mo-Cu-W zone (41), which includes several genetic types of mineralisation, is in the northern part of the Peräpohja Schist Belt (unit no. 7, Fig. 1). Here, the Paleoproterozoic Peräpohja supracrustal rocks unconformably rest on the Archaean basement complex and are bound to the Paleoproterozoic Central Lapland Granite Complex (unit no. 6, Fig. 1). The border zone is an area of polymetallic mineralisations. In the western part of the zone, in the Ylitornio area, several molybdenite occurrences are encountered. The largest of them, Kallijärvi, also called Kivilompolo (0.4 Mt, grading 0.11 % Mo), is in a migmatised granitic gneiss belt where molybdenite has been found in association with chalcopyrite in a quartz vein system (Yletyinen 1967).

The Raja-Kirakka scheelite occurrence, also in the Ylitornio area, is located in a skarn interlayer in association with an amphibolitic zone. The eastern part of the zone is characterised by a few very small Cu-, U- and Mo-occurrences in mica schist – black schist environments.

The Misi Fe zone (42) occupies a minor complex of rocks of mainly mafic composition in the extreme northeastern part of the Peräpohja Schist Belt (unit no. 7, Fig. 1), almost entirely surrounded by rocks of the Central Lapland Granite Complex (unit no. 6). The ore zone includes 13 magnetite deposits, four of which have been subject to exploitation: Kärävävaara (1959–1967; 1.0 Mt of ore at 46 % Fe), Raajärvi (1964–1975; 5.12 Mt of ore at 46 % Fe), Leveäselkä (1969–1974; 0.3 Mt of ore at 46 % Fe; total resources ca. 1.2 Mt), and Puro (1961–1964; 0.06 Mt of ore at 53 % Fe; total
resources 0.60 Mt). The other 9 deposits detected range from 0.8 to 0.1 Mt at 30 – 55 % Fe.

The Misi iron ore zone was first described in detail in a monograph by Nuutilainen (1968). According to that publication, the most common rocks in the complex are mafic massive rocks described as gabbrroids, mafic metamorphic rocks or amphibolites, further albite gabbros, albities and subordinate metamorphic rocks of sedimentary origin (quartzites, lime/dolostones and various other schists). The mafic rocks are widely alбитized, and even scapolite is not uncommon. Iron mineralisation occurs as minor ore bodies of massive magnetite or magnetite dissemination in tremolite-chlorite rock, mainly in an environment of supracrustal rocks and albities.

The dominant ore mineral in the deposits is slightly martitized magnetite, which e.g. at Kärväsvaara constitutes about 70 % of the ore. The magnetite is rather pure, with no silicate or ilmenite inclusions. All other ore minerals, chiefly pyrite, chalcopyrite and covellite, are subordinate. This reflects the fact that the content of trace elements in the ores is rather low: 0.04 – 1.2 S %, 0.03 – 0.4 P %, 0.05 – 0.3 Ti %, 0.02 – 0.14 V % and approximately 0.03 Mn %.

According to Nuutilainen (1968), the genesis of the iron ores in the Misi area was ascribed to the spilitic mafic magmatism and the deposits were interpreted as products of crystallisation from a spilitic hydromagma at relatively low temperatures. As such, these deposits were for years regarded as a stratotype of a special magmatic iron ore type with low titanium. However, recently the geology of the entire region was reviewed by Niiranen et al. (2003, 2005a). The supracrustal complex was now correlated with the Kivalo group in the main Peräpohja Schist Belt. The widespread sodic alteration, manifesting itself as albitisation and scapolitisation, was verified to be a regional feature in the whole of Central Lapland and Kuusamo (cf. the next chapter, zone no. 43); in particular, the albite gabbros and albities were found to be products of alteration of gabbros rather than derivatives of a specific magma. The serpentinites and tremolite-chlorite rocks were found to be skarnoids developed from dolomitic marbles and the ore bodies proved to be replacement skarn bodies. The specific composition of iron ore, with its very low content of sulphur and chalcophile metals, may be ascribed to the sodium- and chlorine-rich environment.

The Misi zone is suggested to be prospective for FeOx-Cu-Au type mineralisation (Niiranen & Eilu 2003); however, no significant mineralisations of this type have been discovered as yet.

In the present Metallogenic Map, the Misi province is extended to the east to cover the minor Soinanjoki deposit. The latter, described as a magnetite deposit in amphibolite, is likely to be of the same type as those in the Misi district.

The Kuusamo Au zone (43) is one of the most important gold zones of northern Finland (Fig. 17). It is situated within the intra-cratonic, rift-related Paleo-proterozoic Kuusamo Schist Belt (block no. 8 in Fig. 1) and is characterized by widespread albitized rocks that contain some thirty sulphide-bearing hydrothermal Au-Co-Cu-U occurrences (Pankka & Vanhanen 1989, Pankka & Vanhanen 1992, Pankka 1992, Vanhanen 1992, Pankka 1997, Eilu 1999, Vanhanen 2001, Eilu et al. 2005). The most prominent deposits are Kouvervaara sulphide, Apujalahti, Lemmonlampi, Säynäjävaara, Meurustuksenaho, Konttiaho, Sivakkaharju, Hangaslampi and Juomasuo. All of them share an almost similar character with pyrite and pyrrhotite as the main ore minerals and accessory cobaltite, Co-pentlandite, chalcopyrite, native gold and uraninite. Gold and cobalt are the most promising metals for exploration in the zone.

The biggest of the Kuusamo sulphide deposits, Juomasuo (estimated at 0.7 Mt with 5 g/t Au and 2 Mt with 0.2 % Co), is situated in a sericitic and silicic alteration zone. The deposit has the form of a flattened pipe. In 1992, during a test mining almost 18 000 tonnes of ore was extracted, averaging 5.9 g/t Au and 0.14 % Co.

The Konttiaho deposit comprises a set of subvertical hydrothermal breccia pipes in a fold hinge. The uranium content may locally reach up to several per cent, while gold is enriched in the matrix within uranium and sulphide minerals. The largest lode of the deposit is estimated to have a few thousand tonnes of ore.

Sivakkaharju is hosted by a quartz-sericite rock, with pyrite as the main sulphide mineral. The main commodities are represented by native gold and uraninite. The estimated ore resources are 28 000 tonnes, averaging 11.3 g/t Au, 0.03 % Co and 0.12 % Cu (Dragon Mining NL 2004).

The uranium content of the Au-Co-Cu-bearing occurrences in the zone also allows use of integrated satellite and aerogeophysical data for location of gold mineralisations (Kuosmanen et al. 1991, Arkimaa 1997).

The Kuusamo U zone (44) largely overlaps the Kuusamo Au zone. It is closely related to the latter and possibly can be regarded as a sub-type of this. Some of the small uranium occurrences could even belong rather to the Au zone, or to both. Of the noted uranium-bearing deposits, Konttiaho and Sivakkaharju also represent the sulphide type, whereas the Kouvervaara uranium occurrence is situated close but separated from the Kouvervaara sulphide Au-Co de-
posits, and represents an entirely different type (Pankka & Vanhanen 1989, Vanhanen 1989, Vanhanen 1992, Vanhanen 2001). Uranium has also been reported in some albitic diabases. Some deposits could be located by aeroradiometric surveys (Arkima 1991).

The Kouvervaara sandstone-type uranium minerali-
sation is stratabound, and more than 3 km long, but only a few centimetres to some metres thick. The mineralisation is associated with the contact between sericite schist and arkose quartzite. The uranium content of the mineralisation is low, only about 200 g/t U.

**The Suonna Fe zone (45)** consists of the small iron deposits Karijoki, Suonna, Kirintökkangas and Karipuro and belongs to the banded iron formation type in the western part of the Kuusamo Schist Belt (unit 8, Fig. 1). The iron formations occur as narrow disseminated hematite and magnetite beds in sericite schists, embedded in sericite quartzite formations (Lehto & Niiniskorpi 1977, Vanhanen 2001). In total, the zone might have about 1.5 Mt of low-grade (about 20 % Fe) iron ore.

**The Jauratsi Fe zone (46)** comprises banded iron formations at the southeastern part of the Central Lapland Greenstone Belt (unit no. 4, Fig. 1) at the Matalavaara, Reposelkä, Jauratsi and Rahkavaara iron deposits. The Jauratsi deposit itself is situated in an E-W aligned syncline, some 5 km long and 1 km wide. Quartzites, sericite schists, skarns and hornblende schists are found in the central parts of the syncline. To the north of the structure, the bedrock consists of mafic volcanic rocks, including komatites at Kummitsoiva as well, whereas intermediate volcanic rocks are prevalent to the south. Hematite-magnetite-goethite-bearing iron formations are located at the northern limb of the syncline, whereas weathered goethite-bearing formations are found at the southern limb. The average chemical composition of the former is 20 % Fe, 0.02 – 0.05 % MnO, 2.4 % P₂O₅ and 0.06 % S (Lehto & Niiniskorpi 1977). The Jauratsi deposit represents oxide facies type iron formations, whereas the other iron deposits show a higher content of sulphide-bearing minerals, and thus a tendency towards sulphide facies type iron formations. In total, the Jauratsi zone might contain up to some 30 Mt of low-grade (25 – 30 % Fe) iron ore.

**The Kylälampi Fe zone (47)** is located some 20 km to the southeast of the large Koitelainen mafic intrusion. The zone comprises the Kylälampi and Kannusjänkä layered gabbro intrusions, situated in the eastern part of the Lapland Greenstone Belt, near the Archaean basement. Low-grade vanadiferous magnetite mineralisations (18 – 24 % Fe, 0.02 – 0.08 % V) in gabbro, granophyre and albite have been encountered during diamond drillings. Results for U-Pb analyses on zircons from the Kylälampi gabbro show an age of 2114 Ma (Räisänen & Huhma 2001).

**The Kittilä Au-Cu zone (48)** forms the main metallogenic complex in the Central Lapland Greenstone Belt (unit no. 4, Fig. 1). This large greenstone belt of Palaeoproterozoic age (Frietsch et al. 1986, Frietsch et al. 1987, Frietsch 1988, Mänttäri 1995, Lehtonen et al. 1998, Hanski et al. 2001a, Vaasjoki 2001) is divided into the younger, komatite-poor Kittilä area in the west and the older, komatiite-dominated Sodankylä area in the east, separated by a major tectonic N-S trend zone, which is marked by a chain of ophiolitic nickel-bearing serpentinites (cf. Hanski 1997). Several horizons of banded iron formations run through the entire area of the zone (e.g. the Porkonen-Pahtavaara Fe-Mn zone 50). Widespread albitionisation is characteristic to the entire Central Lapland Greenstone Belt and may be a crucial factor in the character of mineralisation, too.

The Kittilä metallogenic zone is analogous to the other highly ore potential Neoarchaean and Palaeoproterozoic greenstone belts in Precambrian shields elsewhere in the world. The western part of the zone is characterized by base metal dominant mineralisations and the eastern part by gold dominant deposits (Fig. 18). It contains tens of hydrothermal Cu, Au and polymetallic base metal mineralisations in supracrustal sequences, with pyrrhotite/pyrite, chalcopyrite and sphalerite as the main typical sulphide minerals. On the other hand, the gold mineralisations are dominated by pyrite, chalcopyrite, arsenopyrite and native gold.

The core metaliferous gold-bearing subzone is the so-called the Sirkka Shear Zone (Keinänen & Holma 2001), which extends across the entire Lapland Greenstone Belt from Pahtavuoma in the west, through Saattopora and Sirkka to Tepsa in the east. The shear zone also has extensions to the south of Pahtavaara and to the southeast of Sodankylä.

The Pahtavuoma Cu-Zn deposit in the western corner of the zone (Korkalo 1977, Inkinen 1979, Korvuo 1997) is situated in an E-W trending volcano-sedimentary sequence. In all, the deposit comprises four stratabound copper ore bodies, six zinc ore mineralisations and three vein-type uranium occurrences. The copper mineralisations occur at the contact between schists and greenstones, hosted predominantly by graphite-bearing phyllite or micaceous schist. One of the copper deposits was mined during two periods between 1974 and 1993, and some 0.3 Mt copper ore was recovered with an average grade of 1.07 % Cu and 26 g/t Ag. The total copper ore reserves are estimated at 4.4 Mt at 1.04 % Cu and 23 g/t Ag, and zinc ore reserves of 17 Mt at 0.81 % Zn and 0.81 % Cu. Extensive mineral exploration and studies has been performed in the Pahtavuoma area during the 1960s and 1970s (c.f. Kokkola & Korkalo 1976, Mäkelä & Tammenmaa 1978, Ketola 1979, Hirvas & Mäkinen 1989, Hälltä & Karhu 2001).

Korvuo 1997, Eilu et al. 2005) is located in a similar environment to Pahtavuoma and is in the western part of the Sirkka Shear Zone. The ore is hosted by albítites that occur as two separate E-W trending zones. The protolith to the albítites has been an intermediate volcaniclastic rock and also felsic sediment. The highest gold grades are found in the vertical N-S trending quartz-carbonate veins. The deposit was mined from 1988 to 1995 and 2.14 Mt of gold-copper ore was recovered with an average grade of 3.25 g/t Au and 0.26 % Cu.

The Sirkka polymetallic Ni-Cu-Co-Au deposit (Inkinen 1979, Eilu et al. 2005) is one of the polymetallic nickel- and gold-bearing occurrences within the Kittilä volcano-sedimentary environment. It is associated with typical graphite-albite-biotite rocks and has a metal content of 0.32 % Ni and 0.38 % Cu. The deposit was subject to test mining from 1953 to 1956 when some
9 500 tonnes of ore was extracted. The deposit gave the name to the Sirkka Shear Zone.

The Riikonkoski Cu deposit (Puustinen 1985) is also located in the volcano-sedimentary environment, slightly to the south of the Sirkka Shear Zone. Graphite-rich black schist, sericite schist and albite host the predominantly brecciated mineralisation. The estimated resources are 2.5 Mt with an average grade of 0.68 % Cu.

Numerous gold occurrences are located within the various hydrothermally altered albite-carbonate rocks throughout the Central Lapland Greenstone Belt. These mineralisations appear to be epigenetic and are commonly hosted by breccias and quartz vein networks. The notable occurrences along the central part of the Sirkka Shear Zone include Levijärvi, Loukinen, Soretiaavuoma, Hirvilavanmaa and Kutuvuoma (Härkönen & Keinänen 1989, Ward et al. 1989, Keinänen & Holma 2001, Sorjonen-Ward et al. 2001, Holma et al. 2003, Eilu et al. 2005). A monograph on the Kittilä Greenstone Belt (Ojala, ed., in press) is under preparation at the moment. It contains 13 articles dealing with the general geology, structure and prospectivity of the region and descriptions of several individual deposits.

The largest of the gold deposits is Suurikkuusikko to the north of the Sirkka Shear Zone, along the so-called Kiistala Shear Zone (Härkönen & Keinänen 1989, Nurmi et al. 1991, Lehtonen et al. 1998, Hölttä & Karhu 2001, Patison & Oliver 2001, Eilu et al. 2005). It is associated with a tectonic breccia and located in the contact zone between mafic volcanic rocks and graphite-rich schists. The breccia is strongly silicified with fragments of albite rock and schists. Gold is mainly included within arsenopyrite and also within pyrite, and therefore specific methods have been tested for the recovery of gold (see Härkönen et al. 1999a, Härkönen et al. 1999b, Kojonen et al. 1999a). Using use a cut-off of 2 g/t Au and parameters from a variography study show that in the central part of the Suurikkuusikko deposit the measured resources are 2.5 Mt at 6.2 g/t Au, the indicated resources 9.3 Mt at 5.1 g/t Au and the inferred resources 12.5 Mt at 4.2 g/t Au (Riddarhyttan Resources AB 2005).

A significant amount of gold has also been discovered at Kuotko to the north of Suurikkuusikko, in connection with the so-called Kuotko Shear Zone. Pyroclastic tholeiitic metabasalts form the major host rock and felsic dikes host the ore (Härkönen & Keinänen 1989, Eilu et al. 2005).

The Pahtavaara Au deposit in Sodankylä, in the eastern part of the Kittilä Au-Cu Zone, is situated within the extensive Sattasvaara Komatiite Complex (Korkiakoski et al. 1989, Ward et al. 1989, Korkiakoski 1992, Korkiakoski & Kilpelä 1997, Eilu et al. 2005). The metamorphosed komatiites at Pahtavaara have been converted into amphibole-chlorite rocks, biotite schists or amphibole rocks with quartz-barite veins and pods. In the biotite schists, gold is closely associated with magnetite and talc-carbonate veins. In amphibole rocks, gold is coarse-grained and dominantly occurs in a native form towards the margins of the quartz-barite veins. The deposit was mined between 1995 and 2000 and some 1.92 Mt gold ore was recovered with an average grade of some 2.14 g/t. Mining started up again in 2003 and within two years 0.43 Mt of gold ore has been extracted.

A low-grade gold mineralisation of another, palaeoplacer type has been located in the conglomerates of the Kumpu Formation, at Kaarestunturi in Sodankylä and at Kumputunturi in Kittilä. The Kumpu quartzite formation discordantly overly the greenstone sequences, thus representing the uppermost unit of the Central Lapland Greenstone Belt (Härkönen 1984, Härkönen 1986, Härkönen & Keinänen 1989).

The Koitelainen PGE+Cr+V-Fe field (49) occupies 2440 or so Ma mafic layered intrusion, which is a flat, oval brachyanticline structure, some 26 x 29 km in size and initially about 3 km in thickness, intruded through the Archaean basement (Mutanen 1997, 1996, 1989, GTK 2005) in the central part of the Central Lapland Area (block no. 4 in Fig.1, see also Fig. 16). The Archaean gneisses (Kröner et al. 1981, Mutanen & Huhma 2001) form two domes in the area. The Koitelainen intrusion shows all the standard types of igneous layering and hosts deposits of chromite, vanadium, titanium, platinum-group elements and gold. Chromitite layers mostly occur in the uppermost layers (Upper Chromitite), but also near the basement of the intrusion (Lower Chromitite). The Upper Chromitite has a varying thickness of 0.8 – 2.2 metres and extends along the strike length up to 60 km. A vanadiferous magnetite gabbro is also located in the uppermost part of the intrusion. Based on geological analogies and on a very sparse drilling density, the potential geological in situ resources of the Upper Chromitite of the entire intrusion might be at least several tens of million tonnes of chromium ore, averaging 21 % Cr$_2$O$_3$, 0.4 % V and 1 g/t PGE. The Os and Nd isotopic systematics of the intrusion have been studied by Hanski et al. (2001b).

The Porkonen-Pahtavaara Fe-Mn zone (50) in the western part of the Central Lapland Area (block no. 4) is a Proterozoic banded iron formation (BIF) zone. It belongs to the Central Lapland Greenstone Belt and consists of volcanic rocks with closely associated pyroclastic and chemical sediments, and associated manganiferous iron formations, notably at
the N-S trending row of hills of Porkonen, Pahtavaara, Silmänpatama, Kuoreslaki and Haurespää. The iron and manganese of the iron formations, precipitated under oxide, carbonate or sulphide facies, derive from submarine volcanic emanations. Typically, the oxide facies is at the bottom of the sequence, with carbonate-silicate facies above it and the sulphide facies uppermost. The iron formations underwent low-grade metamorphism, as indicated by the prominence of typical iron sheet silicates in the mineral assemblages alongside magnetite and Fe-Mn-carbonates (Paakkola 1971, Gehör 1994a, Gehör 1994b).

The jaspilitic Fe and Mn deposits of the Porthavena zone have been known since 19th century (Thoreld 1866, Witt 1909, Berg 1916, Hackman 1927, Kaitaro 1949, Hytönen et al. 1966). Their jasper has also been used as a decorative stone (Kinnunen 1982).

The Kesänkitunturi U zone (51) in the western part of the Kittilä area includes two types of uranium mineralisation – the proper Kesänkitunturi type, and the uranium mineralisations encountered in connection with the Cu-Au deposits of the Kittilä zone, especially at Pahtavuoma (metallogenic zone no. 48).

The Kesänkitunturi sandstone-type deposit is located in a Paleoproterozoic orthoquartzite – sericite quartzite sequence. Here the Kumpu quartzites discordantly overlie deformed Kittilä greenstones. The geological in situ resources of Kesänkitunturi could be up to 950 t U, with an average grade of 0.06 % U. The only uranium-bearing mineral is uraninite (IU-REP 1982). Because the deposit is situated within a natural reserve area, it cannot be exploited under any circumstances.

The Pahtavuoma uranium vein deposit consists of three ore bodies in the southern part of the greenstone-associated graphic schists. Differing from the sulphide-bearing deposit, which is located at the contact between the schists and greenstones, the uranium ore bodies are found within separate schist horizons. Almost vertical uraninite-bearing postorogenic veins vary from some centimetres to several metres. The geological in situ uranium resources show 500 t U, with an average grade 0.19 % U. Similar types of veins constitute the Laavivuoma occurrence west of Pahtavuoma (Inkinen 1979, IUREP 1982, Korvuo 1997).

The Rautuvaara Fe-Cu-Au zone (52) comprises a large number of skarn-like iron deposits and occurrences including the Rautuvaara and Hannukainen mines (Mining Magazine 1982) in the western Finnish Lapland, in the westernmost branch of the Central Lapland Greenstone Belt (unit no. 4, Fig. 1), about 100 km north of the Arctic Circle (Hiltunen & Tontti 1976, Juopperi & Vornanen 1977, Mäkelä 1977, Hiltunen 1982, Lehtonen et al. 1985, Lehtonen 1988, Lehtonen et al. 1998, Väänänen & Lehtonen 2001). Genetically, most of the deposits of the zone seem to belong to the group of Fe-(Cu-Au) skarns, although recently these deposits have been included in the Fe-Ox-Cu-Au type (Eilu & Niiranen 2003, Niiranen et al. 2005b). Some of the deposits, e.g. Juvakaisenmaa, have been known, at least, since the early 17th century, as are the numerous marble deposits of the area. Besides the skarn-type deposits, there are also banded iron formations, e.g. Ristimella, and a peculiar hematite-baryte-mica schist at Taporova (Pertsev et al. 1988).

The iron deposits at Kolari, variably enriched in gold and copper, are located at the contact zone between supracrustal rocks of the Palaeoproterozoic Central Lapland Complex and a synorogenic monzonitic pluton. All ore bodies are apparently stratiform lenses hosted by the country rocks of the pluton (quartzite, quartz-feldspar schist, calcitic marble and amphibolite), and seem to have a structural control. At Hannukainen the hosting supracrustal sequence is 70 – 140 metres thick and dips at 15° to the W, while at Rautuvaara the dip is 80° SE. Alteration and gangue are characterised by diopside-hornblende exoskams. Minor endoskams locally hosting low-grade sulphide mineralisation are known in the (monzo)dioritic marginal unit of the pluton (Hiltunen 1982).

The principal ore mineral in the deposits is magnetite, which amounts to about 95 % of the ore minerals. The sulphur content in the ore is 1 – 5 %. It mainly occurs in pyrrhotite, although small amounts of chalcopyrite and pyrite are also present. Several ore bodies at Hannukainen (e.g. Laurinjoja and Kuervitiikko) and one orebody at Rautuvaara contain Au-bearing chalcopyrite and native gold in “ore-grade amounts” (0.3 – 0.7 % Cu and 0.5 – 3 g/t Au; Niiranen et al. 2005b).

The first indications of the presence of an iron deposit at Rautuvaara were obtained in 1956 in a high-altitude airborne magnetic survey. Rautuvaara was discovered in 1957 and the Hannukainen deposit, about 10 km NNE of Rautuvaara, in 1974. Rautuvaara was exploited by open pit and underground mining between 1962 and 1988, and produced 11.42 Mt of ore with a grade of 46.78 % Fe and 0.32 % Cu. Hannukainen was discovered by a low-altitude airborne magnetic survey, which indicated four orebodies. Mining has only been conducted in the Laurinjoja orebody and only by open-pit methods. Production took place between 1978 and 1990, and 4.56 Mt of ore was mined with grades of some 43 % Fe, 0.88 % Cu and 0.95 g/t Au. Probable reserves at depth are several tens of Mt.

The Pyhääjärvi V-Fe-Ti zone (53) is a rather poorly
known, roughly N-S oriented, zone of amphibolite with hornblendeite, mica gneiss, quartzite, gneissic granite and granite. Magnetite-ilmenite occurrences of unknown size and grade (massive veins and disseminations) occur in the sill-like amphibolites. There are no publications on the zone; the information given here is based on oral communication and internal reports of the former Otaniemäki Oy, today Rautaruukki Oy.

The Pulju Ni zone (54) is one of the high nickel potential zones in Lapland. It is a distinct narrow zone about 100 km long and 1–2 km wide, located in the northern part of the Central Lapland Area (unit no. 4, Fig. 1), and is associated with a prominent geophysical aeromagnetic high. The zone is almost N-S trending in its northern parts, but curves toward the southwest and branches in its southern part. It contains tens of small and low-grade nickel occurrences of komatiite type (Puustinen et al. 1995, cf. Fig. 7). The largest occurrences are Hotinvaara (1.3 Mt at 0.43 % Ni and less than 0.1 % Cu) and Iso-Siettelöjoki (0.5 Mt at 0.29 % Ni and 0.01 % Cu), with more potential occurrences around Kietsimä in the north (Puustinen et al. 1995). According to Papunen (1993, 1998), the Pulju zone is a rift-related volcanic-sedimentary sequence that contains lithologies typical of komatiitic greenstone belts, and both metasomatic and magmatic sulfides have been encountered there.

The Nirroselkä Ni zone (55) trends NW-SE and can be traced for some 70 km at the northern boundary of the Central Lapland Area (unit no. 4, Fig. 1), along the marginal zone of the Lapland Granulite Belt (unit no. 2). The zone is composed of an amphibolite sequence with ultramafic komatiitic rocks, mica schists, quartzites and iron formations. All of the small nickel occurrences detected so far have approximately the same size and nickel grade (0.01 Mt at 0.15 % Ni and 0.01 % Cu). The Nirroselkä and Pulju zones share many common features and the almost coalesce at their northern ends (Puustinen et al. 1995).

The Lemmenjoki placer Au area (56) is located in the basin of the river Lemmenjoki and its tributaries, in the western parts of the Lapland Granulite Belt (unit no. 2, Fig. 1). Although the first hints of the presence of gold in the overburden here date already from the year 1901, it was the Ranttila brothers who discovered actual gold in September 1945 (Stigzelius 1954, Johansson et al. 2000). Since then, numerous professional and amateur prospectors have made their trails there. Gold nuggets have also become objects of collection and as such, subject to studies for their genuineness (Kinnunen 1996, Kinnunen et al. 1997). Some platinum nuggets have also been found sporadically in gold panning (Vuorelainen & Törnroos 1986a, Vuorelainen & Törnroos 1986b, Törnroos & Vuorelainen 1987, Törnroos et al. 1998).

The Ivalojoki placer Au area (57) in the basin of the river Ivalojoki is the oldest gold field known in Finland (Stigzelius 1954, Saarnisto & Tamminen 1987, Saarnisto et al. 1991, Johansson et al. 2000). It was discovered during a government expedition in September 1868 (Fircks 1906, Sundell 1936). This started a gold rush in 1870. According to the official records of the Mining Board, some 470 kg gold was recovered between 1870 and 1916. However, the actual amount could be some 1 500 kg up to the present day. Professional and amateur prospectors also favour this area even today, and the issue of collecting nuggets and their genuineness and properties is of consequence (Kinnunen 1996, Kinnunen et al. 1997, Kinnunen 2003). The bedrock source for placer gold in Pleistocene till and gravel is unknown. It has been assumed that gold is derived ultimately from the local granulite bedrock, in which mildly auriferous retrogressive shear zones have been known (Ward et al. 1989).

The southernmost end of the Ivalojoki area, the Tankavaara field, is situated near the southern border of the Lapland Granulite Belt (Johansson et al. 2000). Also here, professional and amateur prospectors have favoured the area since 1934.

The Ruossakero Ni zone (58) in the Enontekiö area in northwestern Lapland (unit no. 3 in Fig. 1, Puustinen et al. 1995) is associated with an Archaean greenstone belt composed of mafic volcanic rocks and volcaniclastic sediments, surrounded by Archaean granodioritic basement gneisses. The two largest of the nickel deposits, Ruossakero (5.5 Mt at 0.53 % Ni and 0.02 % Cu) and Sarvisoaivti (0.7 Mt at 0.40 % Ni and 0.05 % Cu), are associated with serpentinized peridotite and dunite bodies of komatiitic composition. The zone extends to the south in Sweden, where two nickel occurrences of a similar type, Kurkovare and Keukiskero, have been located (Frietsch et al. 1987). Thus the total length of the zone could be some 75 km. Additionally, the large Tshohkkoaiiv differentiated gabbro-peridotite body, occurring close to Ruossakero, could be related to this Ni zone.

The Vätsäri Fe zone (59) counts four small occurrences of banded iron formations (Lehto & Niiniskori 1977). They are connected to skarn horizons of amphibolite units surrounded by the granite gneiss basement rocks in the Inari area (unit no. 1 in Fig. 1) of northeastern Lapland. It has been suggested that the zone could be a part of the Pechenga nickel-bearing zone.

To the west of the Vätsäri zone, banded iron formations are also encountered at Supru and Kopasaaari.
In addition to the metallogenic zones and provinces described above, there are several mineral deposits that could not be connected to any metallogenic groups or have their relatives far away. Some of them have been even important mining targets. The most important of these single deposits (Fig. 19) are described in this chapter.

**The Korsnäs Pb-REE deposit** in the westernmost Finland, inside the Oravainen Ni zone is a unique mineralisation hosted by a large calcite-diopside-baryte-allanite vein that cuts the local Svecofennian gneisses (Isokangas 1978). It was mined between 1958 and 1972 and yielded some 0.87 Mt of ore averaging 3.6 % Pb. Allanite and a couple of other REE minerals (Papunen & Lindsjö 1972) made the deposit prospective for rare-earth metals, too. During a pilot production of a REE concentrate the ore proved to contain 0.83 % Ln$_2$O$_3$.

**The Hammaslahti Zn-Cu** deposit (Hyvärinen et al. 1977, Gaál 1977, Karpanen 1986, Loukola-Ruskeeniemi et al. 1991) is halfway between the Outokumpu deposit and the occurrences of the Kyykkä-Hokka zone in eastern Finland, in the central part of the Höytiäinen Belt (unit 17 in Fig. 1), on the western limb of a local anticlinorium, at the boundary between the arkositic and phyllitic members of the turbidites of the belt. The deposit consists of several flat, “fish-shaped” ore bodies overlapping one another in en échelon manner. The ore is chalcopyrite-pyrrhotite dissemination and breccia with sphalerite prevailing in some parts of the ore bodies, hosted by local turbidites, hydrothermally altered but otherwise just identical to the other country rocks in the area. The Hammaslahti deposit was mined from 1973 to 1986 and produced 5.59 Mt of ore at 1.11 % Cu and some 1 % Zn.

The most striking feature of Hammaslahti is that it is so conventional. It was studied from the points of view of structure (Gaál 1977, Ward 1988, Loukola-Ruskeeniemi et al. 1991, 1992), geochemistry (Hyvärinen et al. 1977) and particularly the geochemistry of the adjacent black schists (Loukola-Ruskeeniemi et al. 1991), geophysics (Airo & Karell 2001) and isotope geology (Vaaajoki 1981, Huhma 1986), but no unique characteristics of the environment – like e.g. in the Outokumpu region – were found. Genetically this sediment-hosted disseminated ore deposit was compared even with massive volcanogenic sulphide deposits (Loukola-Ruskeeniemi et al. 1992). However, most authors point out that similar conditions prevail over large territories in eastern Finland and even elsewhere in the Fennoscandian Shield, and it is unclear why no other mineralisations similar to Hammaslahti have so far been discovered here.

**The Mätäsvaara Mo deposit** in the Archaean terrain of eastern Finland (northeast from the Koli-Kaltimo uranium zone) is the only molybdenum deposit in Finland that has been exploited (1.15 Mt at 0.14 % Mo from 1940 to 1947. The deposit has been described by Kranck (1945), Isokangas (1978) and Mikkola (1980). It is a stockwork of quartz veins and/or silificed shear zones of Neoarchaean age (Stein et al. 1995) hosted by Archaean microcline granite and tonalite of the Eastern Finland Basement Complex (unit no. 11, Fig. 1).

Fig. 19. The major mineral deposits not belonging to the metallogenic zones.
and Aittojärvi in the Kuhmo Greenstone Belt (unit no. 12, Fig. 1; Taipale 1983a, Kurki 1989). However, these occurrences are too scattered to be connected to any distinct metallogenic zones.

The Taivaljärvi and Ala-Luoma Ag-Zn deposits (Kopperoien & Tuokko 1988, Papunen et al. 1989,Tuokko 1989, Diez & Engel 1989, Engel & Diez 1989) are situated in the volcanic series of the Archaean Tipasjärvi and Suomussalmi Greenstone Belts, respectively, in the Kuhmo Belt (unit no. 12, Fig. 1). They are ascribed to the Moukkori-Lokkiluoto gold zone by some authors (e.g. Esipchuk et al. 1999), but actually they are chemically different and genetically interpreted as syngenetic (volcanic-exhalative; Kopperoien & Tuokko 1988). Together with a few minor similar occurrences they might constitute an individual metallogenic zone spatially overlapping with the Moukkori-Lokkiluoto gold zone (metallogenic zone 31 in Fig. 5).

The Keivitsa Ni-Cu-PGE-Au deposit consists of the western main Keivitsa and the nearby eastern Satovaara intrusions. These mafic-ultramafic bodies are situated in the northeastern part of a faulted brachysynclinal structure (Hanski et al. 1997, Mutanen 1997, Mutanen & Huhma 2001, Gervilla et al. 2005, Lamberg et al. 2005, Mutanen 2005). Both Keivitsa and Satovaara might represent two blocks of a single intrusion, separated by a zone of northeasterly faults (Satojärvi fault zone). The Satovaara block has been displaced downwards, perhaps 2 – 3 km, in relation to Keivitsa.

The igneous layering in the lower part is roughly conformable to the base contact, but upwards the dip of the layering becomes gentler and finally almost horizontal. The intrusion is formally divided into four zones: (1) The basal marginal chill zone, (2) the ultramafic zone, (3) the gabbro zone and (4) the granophyre. The intrusion chamber was filled as a single cast. No evidence of repetitive entries of magma has been found. The thickness of these layers and sub-layers range from a few centimetres up to 3 metres. Chromitites with proven metallurgical properties and substantial amounts of vanadium, also contain a range of complex PGM associations (Mutonen 1996, Mutanen 1997, Alapieti & Lahtinen 2002, Gornostayev & Mutanen 2003, Mutanen 2005). U-Pb analyses of zircons from the Akanvaara gabbroic rocks give an age of 2436 Ma, while the granophyre cap has an age of 2420 Ma (Mutonen & Huhma 2001). The Os and Nd isotopic systematics of the intrusion point to an existence of coeval, crustally contaminated komatiitic volcanism (Hanski et al. 2001b).

The Sokli Fe-Nb deposit is the westernmost carbonatite complex within the igneous alkaline rock province of the Kola Peninsula (Vartiainen 1980). It was emplaced about 370 Ma ago (Kramm et al. 1993). The main mineral deposits in the complex are the regolith phosphate deposits (Vartiainen 1989), but it has also a considerable potential of iron ore. In addition, pyrochlore mineralisations have been located as fragmentally embedded in magmatic carbonatites forming discontinuous mineralised zones. The niobium mineralisations are of low grade, 0.3 – 0.5 % Nb₂O₅, the total tonnage, however, may reach up to hundreds of millions of tonnes (Lee et al. 1999, Vartiainen 2001, Wall et al. 2001).

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