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# STRUCTURAL POSITION OF ORE-BEARING AREAS IN FINLAND

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ABSTRACT

The Finnish ore deposits of the economically most important metals — mainly Cu, Fe, Ni, Pb, Ti and Zn — are grouped according to their metal content. This grouping closely follows the genetic classification of the ore deposits. Areally the ore deposits in Finland are concentrated into four elongated zones, each of which probably contains several metallogenic provinces. The location of the zones shows a close relationship to structural features, especially fault zones and to the location of basic intrusive rocks. There seems to be a negative correlation between the zones and the areas of granitic rocks. This is explained as meaning that the concentration of the ore material has followed deap-seated and extensive fault zones.

CONTENTS



## Introduction

Minerals containing economically important metals are distributed rather unevenly in bed-rock due to their geochemical character and their behaviour in the geological processes. Their economic importance depends on the fact that they form concentrations in the crust — ore deposits — from which they are rather easily obtainable for the benefit of mankind. Even the ore deposits, though they irregularly distributed, form areally conspicuous concentrations.

A geographical region with ore deposits to be found more frequently than in the neighbouring regions is called an ore province or an ore zone. A region with ore deposits containing a certain metal or several metals occurring together forms a metal province. Also the so-called metallogenic (-genetic) provinces are often referred to in the literature. In Turneaure's (1955) definition »the metallogenetic province refers to strongly mineralized areas or regions containing ore deposits of a specific type or groups of deposits that possess features suggesting a genetic relationship». A similar definition is also given by Petraschek (1965). In conjunction with the metallogenic provinces, the metallogenic epochs are often mentioned. In Lindgren's (1933) terminology they mean geologic time intervals favourable to the deposition of certain useful substances.

It is obvious that in an ore zone there can be several metallogenic provinces and that a certain province can represent more than one metallogenic epoch. For instance, in the Lake Superior area there are Fe, Cu and Ni Provinces. The whole Cordilleran region is an ore province representing several metallogenic epochs. In the western United States there are Cu and Au deposits of Precambrian, Mesozoic and Tertiary age *(e.g.* Landwehr, 1967). Also several metallogenic provinces may belong to the same epoch. The Tertiary Cu and Mo provinces in Arizona, Utah and Colorado are examples of this. Thus it is necessary to draw attention to the age as well as the composition of the deposit when studying ore regions and metallogenic provinces.

In Finland, there are certain difficulties concerning the age of the deposits. All deposits belong to the Precambrian. This period is longer than all the other eras together, but as yet there is no generally accepted subdivision *(e.g.* Welin, 1966). According to Bogdanov (1967), the following Precambrian tectonic epochs are presented: Belomorian 2 600 m.y., Pre-Svecofennian—Karelian 2 100 ± 100 m.y., Svecofennian—Karelian 1 750 ± 50 m.y., Gothian 1 200 m.y., and Dalslandian 850 m.y. Semenenko (1964) has divided the Precambrian into four metallogenic periods according to radiometric dating. These are as follows: 3 500—3 400 m.y., 2 700—2 600 m.y., 1 900—1 800 m.y., and 1 200—1 100 m.y. According to him *(op. cit.)* the ore deposits in the Scandinavian shield belong to the third metallogenic period, *i.e.* they were deposited during the Svecofennian—Karelian tectonic epoch. The lead ages in many Finnish ore deposits, especially in the Svecofennian territory, accord well with this being 1 800 ± 100 m.y. However, ore deposits in Karelian rocks show lead ages of 2 100 m.y. In the Karelian basement, ages of 2 300—2 500 m.y. (Kouvo and Kulp, 1961) and even of 2 600—3 000 m.y. (Kouvo, oral communication) have been obtained thus indicating two or more mineralization periods during the Pre-Svecofennian—Karelian tectonic epoch. Similar results have been also obtained from the Precambrian deposits in Sweden (Wickman *et al.*, 1962) and elsewhere in the Baltic shield (Winogradow *et al.*, 1961). The radiometric age determinations in Finland, even if they are quite numerous, do not allow us to follow any subdivision in this context. Therefore, in the following the Precambrian is dealt with as one era.

Turneaure (1955) has classified the metallogenic provinces according to the main tectonic units as follows: Precambrian terrane, mountain belts, and stable regions. Vokes (1958) has applied the same classification in Norway, where there are easily distinguishable tectonic units.

The aim of the present study is to find out, first, the nature of the distribution and grouping of the ore deposits in Finland and, secondly, to what degree a classification of the ore districts based on the tectonic or structural units of the bedrock is applicable even in the Finnish Precambrian. The basic data for the study, especially of the smaller and poorly known deposits, were collected between the years 1963 and 1965. A preliminary report of the study has been published earlier (Mikkola & Niini, 1966).

## Grouping and relative abundance of the deposits

There are several ways of grouping ore deposits systematically. Geologically, a classification based on the genesis of the deposits is the most important. Well known and generally accepted classifications of ore deposits have been introduced by geologists such as Lindgren (1933), Schneiderhöhn (1941), Niggli (1941), and Maucher (1964). But, with regard to the Precambrian deposits, it is often difficult to apply the genetic classification reliably, since many of these deposits are highly deformed and the decisive criterions of the origin have disappeared. Moreover, in many cases the knowledge obtainable from small deposits is insufficient to allow the reaching of a conclusion as to the genesis.

Another basis upon which ore deposits are classified is their metal content, this being always critically determined during exploration. It seems that, geochemically, this kind of classification does not differ greatly from the genetic classification. In addition, it is more objective and better adapted to economic and technologic aspects than the genetic one. In table 1 the known Finnish ore deposits are grouped according to their content of valuable metals.

Table 1. Classification and relative abundance of Finnish ore deposits according to their most valuable elements. Uranium ores are not included. The S refers only to the sulfur content in iron sulfides. Total number of ore deposits taken into consideration is 230.

| | | |
|---|---|---|
| 1. Ni-Cu-Fe-Cr | | 11 % |
| Ni-Cu | 5 % | |
| Cu-Fe(-Co) | 5 % | |
| Cr-Fe | 0.5 % | |
| 2. S | | 11 % |
| 3. Cu-Zn-Pb-S | | 18 % |
| Cu-S(-Zn-Pb) | 9 % | |
| Zn-Cu(-S) | 6 % | |
| Pb(-S-Zn) | 3 % | |
| 4. Fe-Ti-Mn | | 49 % |
| Fe-Mn | 3 % | |
| Fe-Ti | 13 % | |
| Fe | 33 % | |
| 5. Au | | 7 % |
| Au(-Ag) | 4 % | |
| Au(-Fe) | 3 % | |
| 6. Mo | | 3 % |
| 7. Sb | | 1 % |
| | | $\Sigma = 100$ % |

The relative size of the groups in the table is based on the number of known deposits in each group, not on the size of the ore reserves or the metal content. This is because the size and the content of the deposits are not always known with sufficient accuracy. In large deposits, however, different and clearly separated bodies are considered as independent deposits.

The grouping includes all the known ore deposits in the bedrock of Finland except the deposits of uranium, pegmatite, and industrial minerals. Tin deposits would have been taken into account as an important factor but none were known. Information was collected from as many ore deposits as possible. Most of the deposits dealt with in this paper are, however, so small that they do not have economic importance. Those deposits whose ore reserves are exhausted or which are being exploited are so few that their number does not form a basis for statistical treatment. Therefore, the limit of the ore reserves in a deposit included in this paper is as low as 10 000 tons, which of course is not a minable quantity. It is also evident that deposits of this order are not shown in the generally used small-scale metallogenic maps (Reh, 1965). Thus the number of deposits treated here became so high (230) that the conclusions drawn in this paper are of some statistical significance.

Several ore deposits are included of which the authors do not have accurate figures of the explored ore reserves. The minimum size of such deposits was calculated by the authors from maps or descriptions. Therefore, and because we are convinced that many new deposits will be found in the near future in certain areas, we did not calculate the metal content per square kilometre, which is often used as a measure of a metallogenic province (Petraschek, 1965, p. 1631).

The classification of the deposits was carried out in the following way. The deposits were first grouped according to their content of usable metals. The following contents were used as the minimum grades: Cu 0.5 %, Ni 0.3 %, Cr 10 %, Zn 1 %, Pb 1 %, Fe 20 %, S 10 %, Ti 10 %, Mn 2 %, Mo 0.1 %, Au 2 g/t, and Ag 50 g/t. These figures are in many instances lower than the present cut-off grade, but they still mean a perceivable concentration of these elements in the crust. The above-mentioned contents were held to be equivalent to each other. Therefore, the order of the precedence of the components in a deposit was determined according to the ratio between the actual content of each metal and the above figures respectively. In the preliminary groups of deposits formed in this way there was either one single »abundant» metal or several metals. The number of different groups thus obtained exceeded 70. Therefore, it was necessary to combine some of them to achieve more expedient grouping. Hence, those preliminary groups were united which comprised the same most abundant metals but in a different order. On the other hand, also those groups having the same metal as the only »important» one were easily linked together. In the final groups the presented sequence of the metals is the same as that of the majority of the deposits in each group.

Obviously, the fact that we cannot know how evenly the material happens to be collected from different types of deposits has an influence upon the number of deposits in each group. For instance, the number of the iron ore deposits (group Fe-Ti-Mn and sub-group Fe) might be too great compared with the number of other deposits, because the easily detected magnetic anomalies have favoured iron deposits while the other indications (electric, gravimetric, geochemical, etc.) do not especially favour any other type.

As mentioned before, the grouping presented here does not differ essentially from the genetic classification *(e.g.*, Schneiderhöhn, 1941). The first group (Ni-Cu-Fe-Cr) and the Fe-Ti subgroup in the fourth group belong to early magmatic ores which are connected with the basic igneous rocks. The molybdenum deposits and the iron deposits in the last subgroup of the fourth group are mainly of pegmatitic-pneumatolytic origin. The deposits of the second (S), third (Cu-Zn-Pb-S) and fifth (Au) group originate from or have at least deformed under hydrothermal conditions. The subgroup Fe-Mn most obviously represents sedimentary iron ores. Excluding the mentioned subgroup Fe, all the others are genetically and geochemically rather homogeneous. The latter also includes deposits of various origin such as quartz-banded, skarn, and sedimentary magnetite and hematite ores.

## Areal distribution of the deposits

### *General*

The location of the known ore deposits in Finland is shown in Fig. 1. The deposit concentration in certain areas can easily be seen. But before drawing any further conclusions, the extent to which the observed deposit concentrations do in fact correspond to the actual conditions in Finland must be settled. This is because the greatest part of the bedrock is covered by water and glacial drift and must therefore be regarded as only slightly known. It may still contain many undiscovered ore deposits in some parts of the country.

When considering the effect of the regional geological and geophysical survey in relation to the location of the known deposits, it must be pointed out that the general geological maps on a scale of 1 : 200 000 or 1 : 400 000 covering almost the whole country have existed since the 1930's. The nothernmost part of Lapland is an exception, but it is not included in this study. New mapping was started straight after the

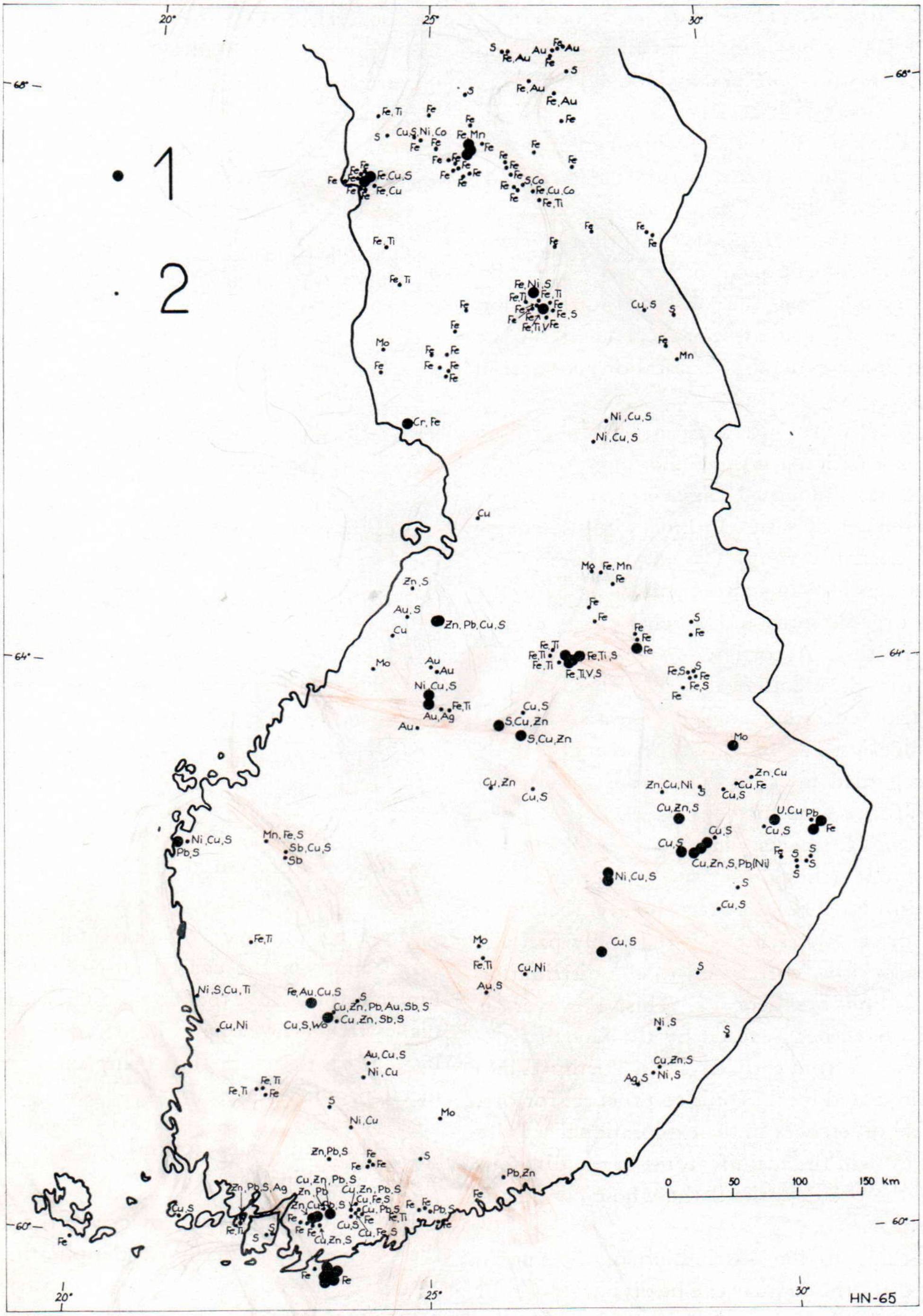


Fig. 1. Location of the ore deposits in Finland.
Key: 1 = minable or major deposit, 2 = minor deposit.

second world war. These map sheets on a scale of 1 : 100 000 cover limited areas in South and Central Finland, both on and outside the ore zones shown in Fig. 2. The aeromagnetic maps on a scale of 1 : 20 000 already covered a large part of the country early in the 1960's (Geological Survey, 1964, p. 101). Some of the areas aeromagnetically unmapped at that time coincide with the forementioned ore zones. Thus we may conclude that the observed distribution of the ore deposits is not dependent on the location of the general geological or geophysical mapping.

It is also worth investigating the degree to which explorational activity moving from place to place has influenced the distribution of the discovered ore deposits. In Finland, this activity may be described roughly as the number of ore samples sent by unprofessional people to the mining organisations and which have given rise to prospecting. According to the statistics obtained from the Geological Survey, these samples are distributed rather unevenly on a small scale (communes used as units) but surprisingly evenly when regarded in large dimensions. Southwest Finland forms a minor negative exception and a zone from North Karelia to Central Bothnia a positive one (the local names mentioned are shown in Fig. 6, p. 31). Accordingly, the distribution of samples sent by people only partially shows a positive correlation to the distribution of the found ore deposits. This, however, is likely to have been caused by the fact that deposits known from early days and existing mines have stimulated local people to prospect for ore. The areal differences in the explorational activity cannot explain the main features in the distribution of the ore deposits if the whole country is included.

According to the distribution of the known ore deposits, the country can be divided into four ore zones. Each of these zones consists of smaller metal provinces (Fig. 2). The boundaries of these provinces are based on the content of the respective metals in each deposit. The authors believe that several of these provinces are real metallogenic provinces, though their boundaries do not necessarily match exactly those presented in the map.

*Ore zones and metal provinces*

The following ore zones and metal provinces are distinguished (Fig. 2):

I The Ladoga—Central Bothnia zone, which probably continues in both directions over the boundaries of the country. The zone merges fairly accurately with a great fracture belt as will be shown later on (p. 29). It is bordered in NE. by the gneiss basement blocks of E. Finland and North Bothnia and in SW. by the granite block of Central Finland (Eskola, 1963). In this zone there are three metal provinces:

a) The Fe-Ti province partly extending into the gneiss basement area in the NE.,

b) The S-Cu-Zn province in the schist area close to the gneiss basement,

c) The Ni-Cu-S province bordering on the granite block of Central Finland.

II The zone of southernmost Finland in the coastal area of the Gulf of Finland following the east-westerly Svecofennian strike. The zone is bordered in the south by the sea, its width thus being unknown. The metal provinces are:

a) The Fe province covering the coastal area and the archipelago,

b) The Cu-Zn-Pb-S province to the north of the foregoing and partly overlapping it.

III The Tampere—South Bothnia zone, which borders on the granite block of Central Finland like an arch. There are two nearly overlapping metal provinces:

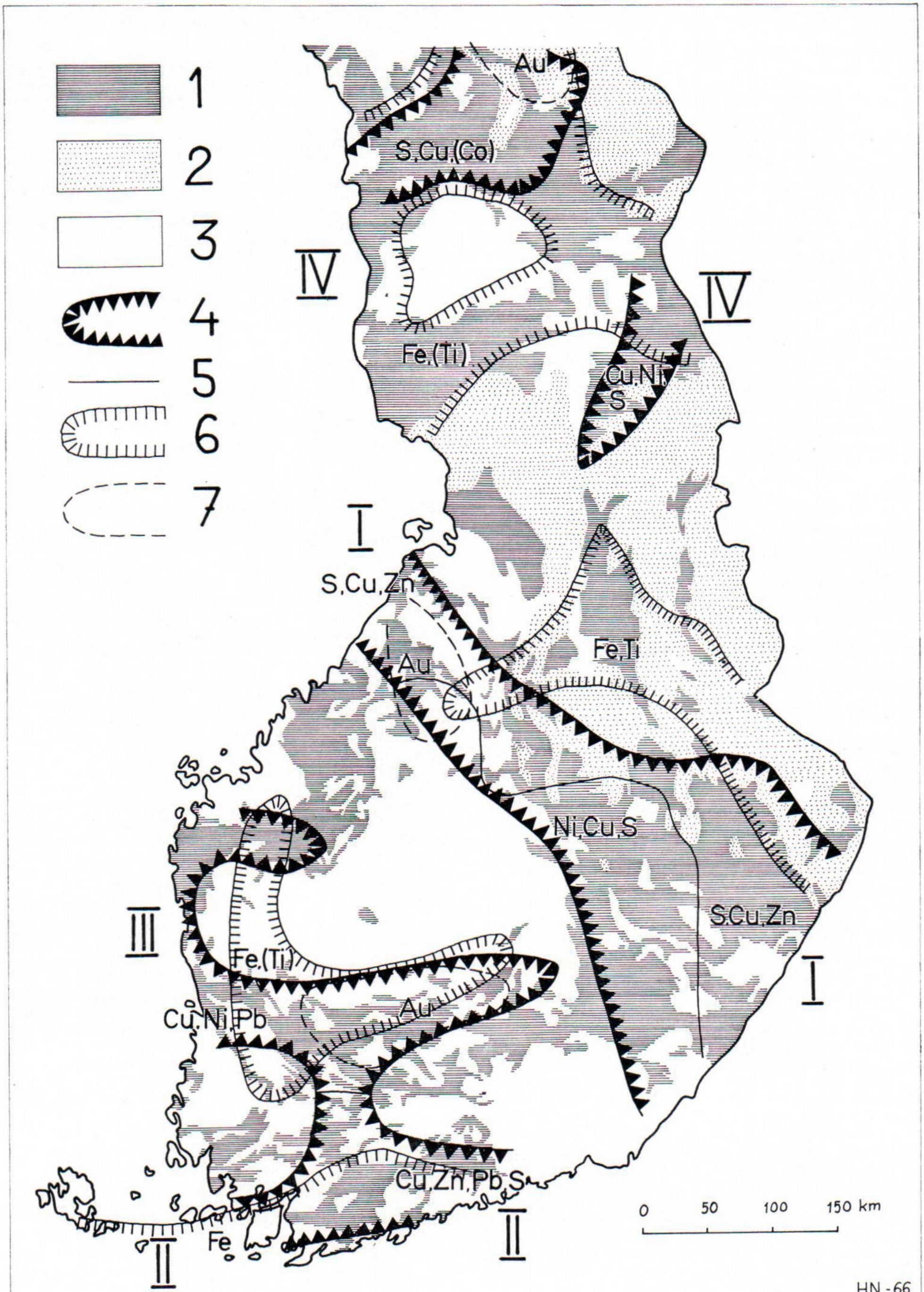


Fig. 2. Ore zones and metal provinces of Finland in relation to the main structural features of the bedrock. Key: 1 = schist and gneiss belts, 2 = gneissic basement, 3 = mostly granitic rocks, 4 = metal provinces mainly of Cu, Ni, Zn, Pb, and sulfidic Fe (= S), 5 = internal border of the above-mentioned provinces, 6 = iron ore provinces, 7 = possible Au provinces. Ore zones I—IV: see text, pp. 22—24.

a) The Cu-Ni-Pb province in the outer part,
b) The Fe (-Ti) province in the inner part.

Zones II and III are connected by an isthmus and thus they might be even considered to represent a single zone.

IV The Lapland zone, which surrounds the large granite area in Central Lapland. This ore zone includes a NW—SE striking fracture belt to be discussed in more detail in the following (p. 27). There are three metal provinces:

a) The S-Cu(-Co) province,
b) The Cu-Ni-S province,
c) The Fe(-Ti) province.

A possible Au concentration exists in all the ore zones except that of southernmost Finland. These would be called Au provinces, but because altogether there are only a limited number of known Au occurrences, these possible concentrations cannot be compared to the metal provinces presented in the foregoing. Even the known Mo deposits are so scattered that particular Mo provinces cannot be considered. There are a few Sb occurrences in a limited area of zone III, but even these are not enough for an independent Sb province.

The forementioned grouping into ore zones and metal procinces accords well with the classification used in the Soviet Union (Momdzhi & Pastushenko, 1965). So the present ore zones correspond conceptually and areally with the metallogenic zone. Data regarding the metallogenic zone are gathered by regional survey and represented on maps on scales from 1 : 1 000 000 to 1 : 5 000 000. The smaller units called here metal provinces are known as ore regions or ore zones in the Soviet Union. They are portrayed by maps on scales from 1 : 50 000 to 1 : 200 000. The smallest unit in the USSR, which is called ore field, and which is mapped in detail (1 : 1 000—1 : 25 000), does not belong to the topic of this paper.

## Structural distribution of the deposits

In the study of ore-bearing areas characterized by endogenous mineralization, special attention must be paid to the tectonic or structural features which, according to Shatalov (1964, p. 2122), primarily include structural conditions and magmatic activities as well as mineralization. The most important factors controlling the location of individual ore deposits are generally lithology in the vicinity of the deposits and certain structures connected with the folding and faulting, above all the joints and fracture zones. However, similar factors also occur outside the ore fields. Thus, factors controlling the location of larger ore and metal districts are evidently different from those of the individual deposits or at least they are of different order of magnitude.

### *Fracture-tectonics*

The greatest part of the Finnish ore occurences may be regarded as clearly intrusive or as having been mobilized in metamorphism to such an extent that they now seem to be intrusive in relation to their country rocks. The ore materials, which moved later than their country rocks, needed space in order to form concentrations. They are considered to have used permeable zones especially joints and other mechanical weakness zones of bedrock as their flow passages and final depositing sites. In order to test the statement, we have endeavoured to compare the distribution of the Finnish ore deposits with the fractures and fracture zones of the bedrock (Fig. 3). The attempt is based on the assumption that old fractures easily regenerate in later, even slight, tectonic movements, and so the present distribution of fractures as observed mainly from the bedrock topography may well reflect the ancient fracture tectonics prevalent during the final movements of the ore materials. This opinion is held among others by Russian and American geologists in their recent metallogenic studies (see Beyer 1964, Landwehr 1967).

It is obvious that the interpretation of this type of tectonic map (Fig. 3) encounters certain difficulties. Disregarding the reasons, areas with especially dense fracturing and those nearly totally lacking in fracture lines can be distinguished on the map. Fractures seem to be sparse particularly in Bothnia (except the coast of South Bothnia). This might be caused by the fact that, because of the bedrock topography, the area is very flat and therefore mostly covered by extensive and heavy clay and peat layers. In such an area, even frequent fractures would be concealed from a surficial observer. Thus, the lack of fractures in this area cannot be considered as proved, indeed hardly even as probable.

The following six areas with especially dense fracturing can be seen in the map:

— Kuusamo
— Savo—Northern Karelia
— the southwestern archipelago
— the Tampere region
— Western Lapland
— the coast of South Bothnia

While studying whether these fracture-line concentrations are true and whether they have some consequence from the point of view of the ore provinces, it is interesting to observe that, excluding Western Lapland, the densely fractured areas are the same as the areas most active in recent seismicity (Fig. 4).

Both earthquakes and bedrock fractures are results of abrupt breaking taking place in rigid bedrock. Thus it is natural that areas of recent seismic activity and of fracture concentrations caused by earlier seismic activity nearly merge. Strong support for this idea has been obtained by recent statistical earthquake and fracture studies *e.g.* in Japan (Mogi 1967). In this connection it might be necessary to point out that the compilation of the fracture-tectonic map was done without any comparison to the seismic map (Fig. 4) or the earlier fracture-tectonic maps such as the small-scale maps of Sederholm (1913, p. 10) and Härme (1961). The latter maps only show the directions of the most marked fracture or fault lines, but not their frequency. Our map, which among other things endeavours to indicate the areal variability of the fracture-line frequency in Finland, seems to be in good accordance with the forementioned seismic evidence.

The fracture lines very often cut each other, appearing in the same way as the ordinary joints seen in bedrock outcrops but in a different order of magnitude. Most of the fracture lines seen on the map represent the intersection lines of the more or less vertical ancient fracture planes and a certain deep level of the ancient earth crust. Thus, it is very likely that the largest fractures or fracture zones shown on the map do even reach considerable depths. They split up the crust into blocks of various size and shape.

This block-tectonic mosaic structure might also be indicated by the aeromagnetic maps on a scale of 1 : 400 000, according to which a new compiled map has been constructed (Fig. 5). This map does not show the anomalies themselves but those border lines which detach areas of different magnetic total intensity fairly sharply from each other and those longish dissection lines which run straight and sharp across areas otherwise rather homogeneous magnetically. In places there are plenty of these magnetic dissection lines, the pattern of which indicates a fracture-tectonic block structure of the bedrock similar to that concluded from the fracture map.

This type of tectonic structure has been accurately described and explained in the Orijärvi region of southern Finland by Tuominen (1957, 1962). It seems to be rather typical of large areas in the worn-down niveau of the Finnish Precambrian. A large part of the deep block structure elsewhere is old (*e.g.* Landwehr 1967), most likely Precambrian in age, even partly controlling the metamorphism of the rocks (Tuominen 1966). As the Russians have pointed out (see Beyer 1964), the large and deep old fracture zones might easily have functioned as the flow routes and sites of the final crystallization of

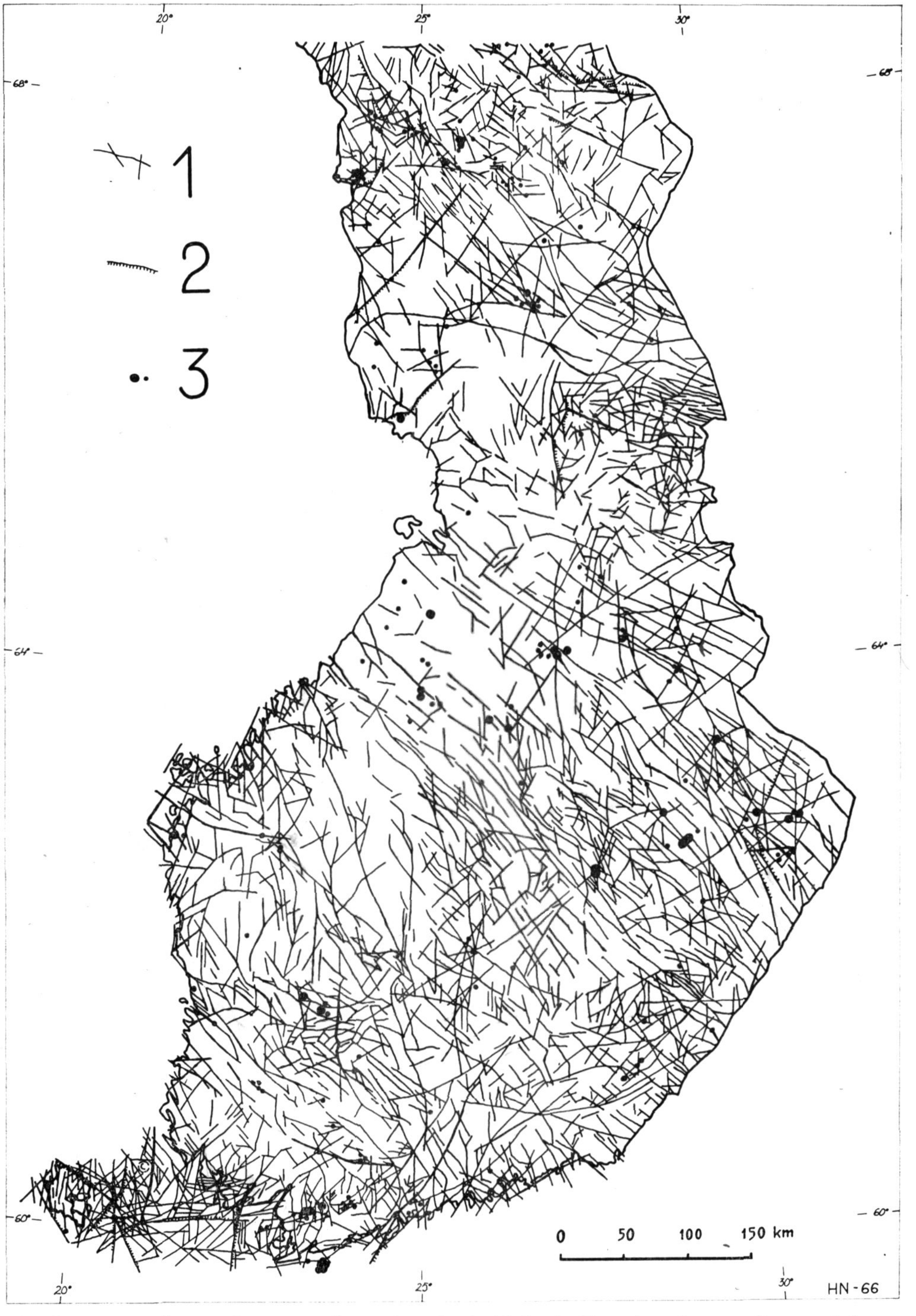


Fig. 3. Fracture lines and zones and ore deposits in Finland. Key: 1 = fracture lines and zones, 2 = probable vertical fault (the teeth on the elevated side), 3 = ore deposits.


Fig. 4. Epicentres of the earthquakes in Finland (Penttilä, 1963).

different magmas and ore-bearing materials especially under the occasional tensile stress.

The fracture lines (Figs. 3 and 5) favour the following directions: NW—SE, NE—SW, N—S, and in places W—E. In the greatest part of Finland, the most marked direction, NW—SE, is the same as the most common movement direction of the Quaternary continental ice sheet. This fact obviously augments the apparent frequency of the NW—SE fracture direction in the first-mentioned map (Fig. 3). Fractures oriented in this direction have been naturally most easily hollowed out by the moving ice sheet. However, fractures in a NW—SE direction are so prevalent in two broadish parallel belts running obliquely across Finland, the one even in areas of different directions of ice movement, that these belts might represent certain greater fracture-tectonic units. The two areas are the broad belt directed from Lake Ladoga to the northwest and the other one north of it running from Kuusamo to the northwest. The former can be seen especially clearly also on the gravimetric map of Finland (Honkasalo, 1962). Between these two belts, there are the basement blocks of East Finland and Bothnia, where, as well as outside the two fracture belts, the different fracture directions are more evenly represented, although the local fracture frequency varies considerably.

In the two large NW—SE oriented fracture belts, the consistency of the fracture trends might have been caused by the especially frequent parallel shear movements which have taken place along the fracture lines. Because, in these belts, there are many individual long fractures even exceeding 100 kilometres in length, the fault movements in these belts can be presumed to have reached considerable depths.

If the general location of the ore deposits is compared with the fracture tectonics, it can be observed that a great number of the ore deposits are situated in the two NW—SE oriented fracture belts mentioned above (see also Paarma and Marmo, 1961). — A similar coincidence has been recently described in the Western United States by Landwehr (1967). — We might conclude that these belts represent a large old mobile belt that, precisely because of its mobility, has been favourable for the mobilization and concentration of ore material.

The mobile belts clearly stretch outside Finland. Indeed, similar large ore-bearing weakness zones of bedrock bordering on great stable blocks have been established to run across all the continents. According to Konstantinow (1963), an ore belt measuring approximately 200 kilometres in width stretches from the Black Sea through Krivoi Rog, Kursk, and Lake Ladoga to Kiruna in northern Sweden. This large belt, consisting of Fe-Cu, Ni and Co deposits and

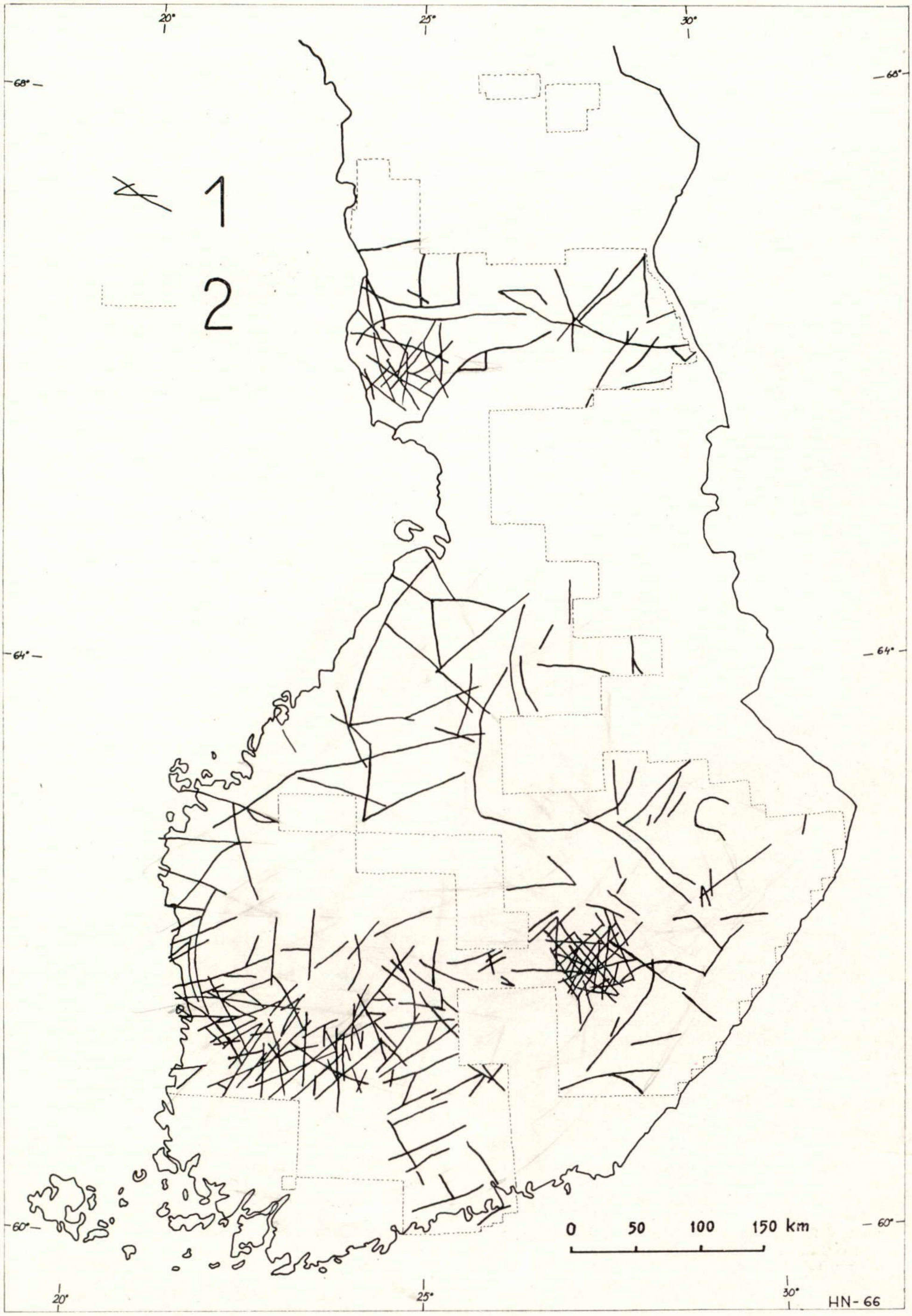


Fig. 5. Block structure of the bedrock revealed by aeromagnetic anomalies. Key: 1 = lines of discontinuity of the anomalies, 2 = boundaries of the areas mapped and interpreted.

explained as a deep mobile belt, is obviously represented in Finland by the two NW—SE oriented fracture belts, which fairly accurately merge with the Lake Ladoga—Central Bothnia and Lapland ore zones. Also these ore zones consist of Fe, Cu, and Ni deposits, sometimes with a noticeable Co content. Considering the large dimensions of this Black Sea—Kiruna mobile zone, it might even be supposed that all the Finnish ore zones belong to this single mobile belt which has zones of smaller magnitude and different directions between the granitic parts.

The ore deposits (Fig. 3) are often situated on or near the sites of intersection or concentration of the fracture lines. Naturally, this may be due partly to the fact that the constructor of the fracture map already knew roughly the location of most of the ore deposits, and thus their surroundings might subconsciously have been studied in slightly too much detail as compared with other areas. According to the map, the sites of the ore deposits seem to be, on an average more favourable to fracturing than other places. Many similar observations have been made elsewhere. So these fracture-tectonic features of Finland (Fig. 3) seem to accord with the general conclusions of Nevskiy (1967, p. 131) that horizontal zoning in the distribution of fissures in connection with ore deposits is manifest both within the limits of single ore fields and also on a regional scale. This kind of distribution of the present fractures in Finland would originally have resulted from an earlier fracturing, after which ore mineralization and the later regeneration of the same fractures would have taken place. However, the complete proving of this hypothesis and its eventual utilization in ore prospecting obviously needs a still more detailed fracture investigation of the whole country based on field studies.

*Large-dimensional structures*

Structurally, the bedrock in Finland can be divided into three main stratigraphic-tectonic units, although these units, according to many investigators, may be composed of elements of quite different ages. In the appended map (Fig. 2), the main units are presented chiefly according to Simonen (1960) and Eskola (1963). In eastern and northern Finland there is a large gneissic complex that forms the basement for the sedimentary rocks. To the southwest of this basement lies the second unit, the Karelian and Svecofennian schist and gneiss belts with a quantity of basic intrusions. These belts also contain black schists, which are often considered as the source of ore material (*e.g.* Marmo & Mikkola, 1951). The belts obviously represent the most mobile parts in the Finnish crust. They are dissected by large plutonite areas whose rocks are chiefly orogenic (migmatitic) and partly anorogenic (rapakivi) granites. These areas form the third unit.

The ore zones presented in Fig. 2 are situated quite regularly in relation to these large-dimensional structural units of Finland. They are mainly located in the schist and gneiss belts either as long straight-lined chains or as curved arches surrounding granite or granite gneiss areas. Only a few ore deposits have been found in the area of the gneissic basement, the first unit. Even the third unit, the migmatitic areas, are almost devoid of ore deposits. These areas can be interpreted as blocks of cratonic uplifts (see Wilson 1967, p. 462) thus offering only small chances of noticeable ore mineralization. The schist and gneiss belts have remained as deep zones of weakness throughout much of geologic time (Wilson op. cit., p. 464). The ore material as well as the basic intrusions derived from the mantle have had good opportunities to move just in these zones.

*Lithology*

The conception of a close relationship between the ore zones and the deep fracture belts presented above might lead one to the expectation that, in addition to the ore materials, even the silicate magmas derived from great depths could have used the same fracture belts as their flow routes and final deposition sites. It would be natural that in the deep shear movements also silicate magmas from the more basic sections of the crust would have arisen, and, as the ore material, in much greater amounts than elsewhere. There is a fairly obvious connection in many areas between the endogenous ore belts and certain intrusive or volcanic belts (Shcherba 1966, p. 1434). Thus, the study of the areal distribution of the basic intrusions in Finland might even be able to prove the close relationship between the concentration of the ore deposits and the location of the fracture zones regardless of the origin of the ore material.

The distribution of the basic intrusions in Finland is shown in Fig. 6. The compilation is mainly based on geological maps on a scale of 1 : 400 000. Only those rocks have been taken into account which, according to the explanations of the maps, can be classified as basic intrusions. However, the hypabyssic diabase and the metamorphic amphibolite are not included in the map. Sometimes diorite has been taken into account, since in the original map, it was not distinguished from the gabbro. For convenience, ultrabasic rocks have always been included, although a fairly great part of them are strongly metamorphic serpentinites and even some of the remainder have been explained as products of metamorphic differentiation. Small occurences have not been rejected, with the result that their dimensions on the map had to be slightly exaggerated. Small occurrences of ultrabasic rocks have been marked as short lines while small deposits of rocks of the gabbro class are shown as small dots.

Because the original map sheets forming the basis for the overall view of the basic intrusions were mapped at different times and by different persons and their rock classifications may be quite different, there is no sense in paying attention to the details of the map. But in large dimensions, the distribution of the basic intrusions surely indicates true areal differences. When comparing this map (Fig. 6) with the map showing the distribution of the ore zones (Fig. 2), one can note that the ore zones and the areas densely occupied by basic intrusions merge fairly accurately. The positive correlation between them clearly strengthens the idea that most of the Finnish ore deposits are associated with the deep mobile belts from which also the old basic, still unmetamorphosed intrusive rocks are derived.

## Conclusions

The ore deposits of Finland have been grouped according to their metal content. Those deposits have been included in the treatment, which exceed fixed grades and reserves. These minimum limits are well under the respective cut-off grades. The relative size of the groups is based on the number of deposits in each group. The groups with their subgroups are shown in Table I. This grouping accords rather closely with the genetical classification of the ore deposits. The known deposits are concentrated in certain areas called ore zones. Each zone is composed of two or more metal provinces, where deposits belonging to certain groups are predominant. In this respect some of the metal provinces are real metallogenic provinces. The ore zones and metal provinces are presented in Fig. 2.

By analyzing and comparing the distribution of the ore deposits and certain geological structures, it may be concluded that most of the Finnish ore deposits are located in the old deep mobile belts composed of strongly metamorphic schists or gneisses between uplifted craton-like granitic blocks. The rocks of these zones have often been very much altered by the folding and shear movements between the rather solid, chiefly granitic blocks. These ore-bearing zones continued to be tectonically active even after the orogenic movements proper. Thus, in all phases, the zones have offered good chances not only for basic intrusions deriving from the depth but

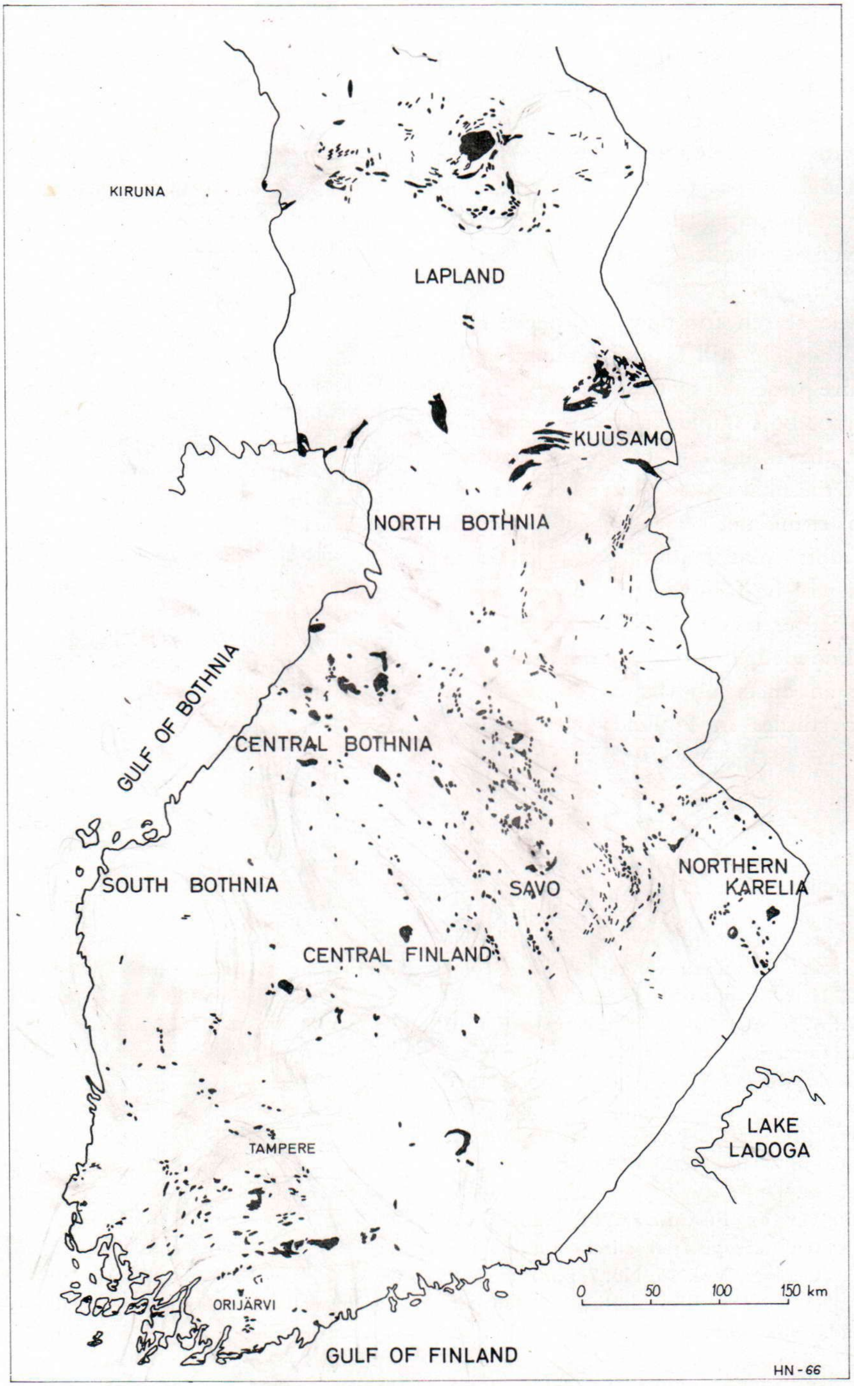


Fig. 6. Distribution of basic intrusives in Finland.

also for ore materials to move and become concentrated. These large-dimensioned tectonic belts are also indicated by the distribution and orientation features of the continuous slow fracture deformation occuring in these zones as a frequent regeneration of the old fractures. This is seen in the topographical features of the bedrock, and even as seismic activity at the present time.

Because the search for new ore deposits is intense and they are still found frequently, the general picture presented by the currently known deposits cannot be complete. The investigation presented in the foregoing thus does not endeavour to be the final report but rather a review intended to stimulate ore prospectors. It is hoped that this investigation of the Finnish ore deposits will be followed by reports based on new and larger material. As compared with the present knowledge of our ore deposits, they would have an effect on the development of metallogenic studies in Finland and the usefulness of the instructions for prospectors based on them.

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