This paper is dedicated to Professor Juhani Seitsaari on his 60th birthday

ON THE GEOTECTONICS AND ORE FORMING PROCESSES IN THE BASIC INTRUSIVE BELTS OF KEMI-SUHANKO, AND SYÖTE-NÄRÄNKÄ-VAARA, NORTHERN FINLAND

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The intrusive belts from Kemi to Suhanko and from Syöte to Näränkävaara incluse the ore deposit of chromite near Kemi and that of vanadium-bearing magnetite-ilmenite at Mustavaara. In addition to these deposits, there are in many parts of the belts, disseminations of pyrrhotite, chalcopyrite and pentlandite. The intrusives containing the abovementioned ore deposits were formed by the initial igneous activity of the Svecokarelian orogeny. At this stage the emerging magma formed layered intrusions between the old basement and the younger Karelian volcanic and sedimentary formations in the zones between the culmination and depression areas. In the lower areas where clastic sediments were present the magma was characterized by a high water content, which allowed the crystallization of spinel at an early stage, leading to the deposition of chromite ores. It is to be noted that no sulfide or magnetite-ilmenite ores are found in the lower areas. On the contrary, they lie in the higher areas, where magma crystallized in dry conditions. Here the fugacity of oxygen necessary for the formation of spinel was only reached at the final stage of crystallization and thus the crystallizing spinel was titanomagnetite. The layered intrusions are now visible as basic belts on the edges of the depression areas.

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Introduction

One of the most important goals of recent research in the field of ore geology has been to establish the relationships between the genesis of ores and the principal structures in the earth's crust, *i.e.* how the ores are formed in connection with the orogenic cycle. The foundation of this kind of research was in part established as early as the 1930's. At that time Stille (1940) created a model of the miogeosyncline-eugeosyncline system based mainly on the magmatic development of this system. At the same time, Väyrynen, (1933) in his investigations of the Karelides in Finland, came to the conclusion that the character of sedimentation also depends up on geotectonics, *i.e.* whether sedimentation has taken place under evolutionary or revolutionary circumstances. However, it was the work of Kay (1951) and Pettijohn (1957) which brought into usage the idea of sedimentary facies, and their relationship to geotectonics. The ideas of Pettijohn in particular have been successfully applied to research on Finnish bedrock. Finally Aubouin (1965), in his study on geosynclines, combined the ideas of Stille and Kay, and indicated that in geosynclines sedimentation and magmatism are logically connected with each other. Results of the latest research on ocean floors also add significantly to our knowledge of the concept of geotectonics. The geotectonic model thus obtained serves as a basis for the interpretation of the metallogenesis of ore deposits.

Metallogenesis in relation to geotectonics opens up a wide field for research. In the following, only a part of this problematical field will be considered, namely the basic plutonism and the associated ore deposits as based on observations made in the Kemi—Suhanko, and Syöte—Näränkävaara belts (Fig. 1). The Syöte—Näränkävaara belt is being examined by members of the Koillismaa Research Project based at the University of Oulu, Finland. This belt, together with the already well known Kemi—Suhanko belt, comprises a unit which gives sufficient data for the examination of initial magmatism and the related ore forming processes within the Svecokarelian orogenic cycle.

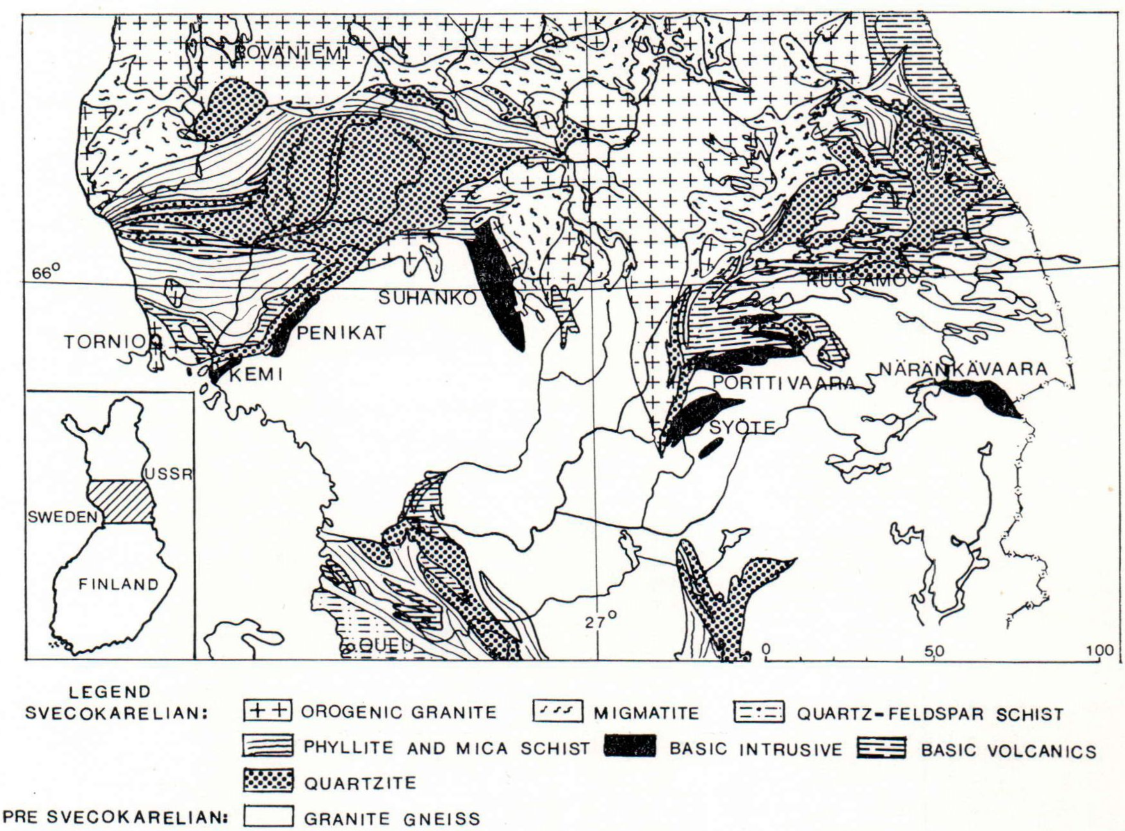

Fig. 1. Area of Study: location and geology (Simonen 1960).

The Kemi—Suhanko belt

The Kemi—Suhanko belt is situated in the SE border zone of the Kemi—Rovaniemi, or Peräpohjola schist belt. This zone has been the target of geological research for a long period of time. This can be seen from the number of publications on the belt, *e.g.* Hackman (1910, 1914) geological map sheet at 1 : 400 000 scale, and Hausen (1936), Härme (1949), Mikkola (1949), Näykki (1964), Kujanpää (1964), Isohanni (1971), and Perttunen's (1971) recently published geological map sheets at 1 : 100 000 scale. On the basis of these publications it is possible to obtain a clear image of the geological evolution of the area.

The bedrock of the area is composed of a granite gneiss basement complex appr. 2.8 billion years old, and of Svecokarelian orthoquartzite-dolomite, and phyllite-mica schist associations. Of these associations the first has traditionally been regarded as Jatulian, and the second as Kalevian. In the Jatulian formations the products of the basic magmatism are represented in great numbers. In the upper parts there are several beds of volcanics, while the lower parts are cut by hypabyssic dykes, and at the discordance between the basement complex and the Jatulian formations there are basic layered intrusions. These layered intrusions are also cut by hypabyssic dykes which indicates that the layered intrusions were emplaced during the early stages of development. The present study concerns the basic layered intrusions of which the Kemi, the Penikat, and the Suhanko intrusions are described in more detail.

The Kemi intrusion

The Kemi intrusion is a lens approximately 10 km long, and 2 km thick that strikes roughly N45°E, and dips 70°NW. The foot wall of the intrusion is composed of albitized rocks of the basement complex (an albite-quartz rock), and the hanging wall is formed from an albite diabase that has intruded between the basic intrusion and the quartzites above. The basic intrusion itself is layered and, in places, displays a banded structure. The direction of the layering and banding matches that of the bedding of the quartzites, which indicates that the intrusion was emplaced when the quartzites were still in a horizontal position. Within the layered intrusion there are the following separate zones from the bottom upwards (Fig. 2): A carbonized and talcose border zone, an ultrabasic zone and a gabbro zone. The primary rock types of the ultrabasic zone have been dunite, peridotite, and pyroxenite. At the bottom of the ultrabasic zone there is a chromium ore horizon which is characterized by a banded structure, and idiomorphic chromite crystals. The gabbros above the ultrabasic zone were, in their original form, orthopyroxene gabbros, clinopyroxene gabbros,

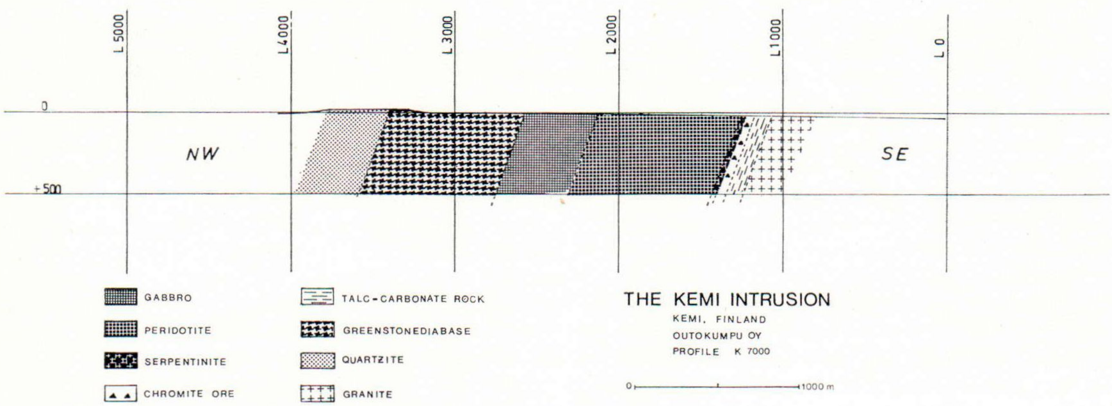

Fig. 2. Cross section of the Kemi intrusion.

and anorthositic gabbros. The cumulus crystals of the intrusion are olivine, orthopyroxene, and chromian spinel, and the intercumulus phases are represented by clinopyroxene and plagioclase. In the uppermost parts of the intrusion idiomorphic plagioclase is found which points to its cumulative origin. However, the amount of plagioclase in the cumulus phase is relatively small. It is worth observing that both the vanadium bearing titanium iron ores and the sulphide ores are missing from the Kemi intrusion.

The Penikat intrusion

The Penikat intrusion is located approximately 10 km NE of the Kemi intrusion. Its length is about 20 km, and its thickness about 2 km, and its stratigraphical position is exactly the same as that of the Kemi intrusion. The foot wall of the Penikat intrusion is composed of an albite-quartz rock, and the hanging wall of an albite diabase.

The order of layering is, however, different from that of the Kemi intrusion (Fig. 3). The lowermost unit is a gabbroic border zone. Above it there is an ultrabasic zone of pyroxenite and peridotite followed by an orthopyroxene gabbro horizon. Above this horizon there is another ultrabasic zone composed of peridotites. This second ultrabasic zone is topped by a series of gabbros comparable with those in the Kemi intrusion, or the orthopyroxene, the clinopyroxene, and the anorthositic gabbros. Above

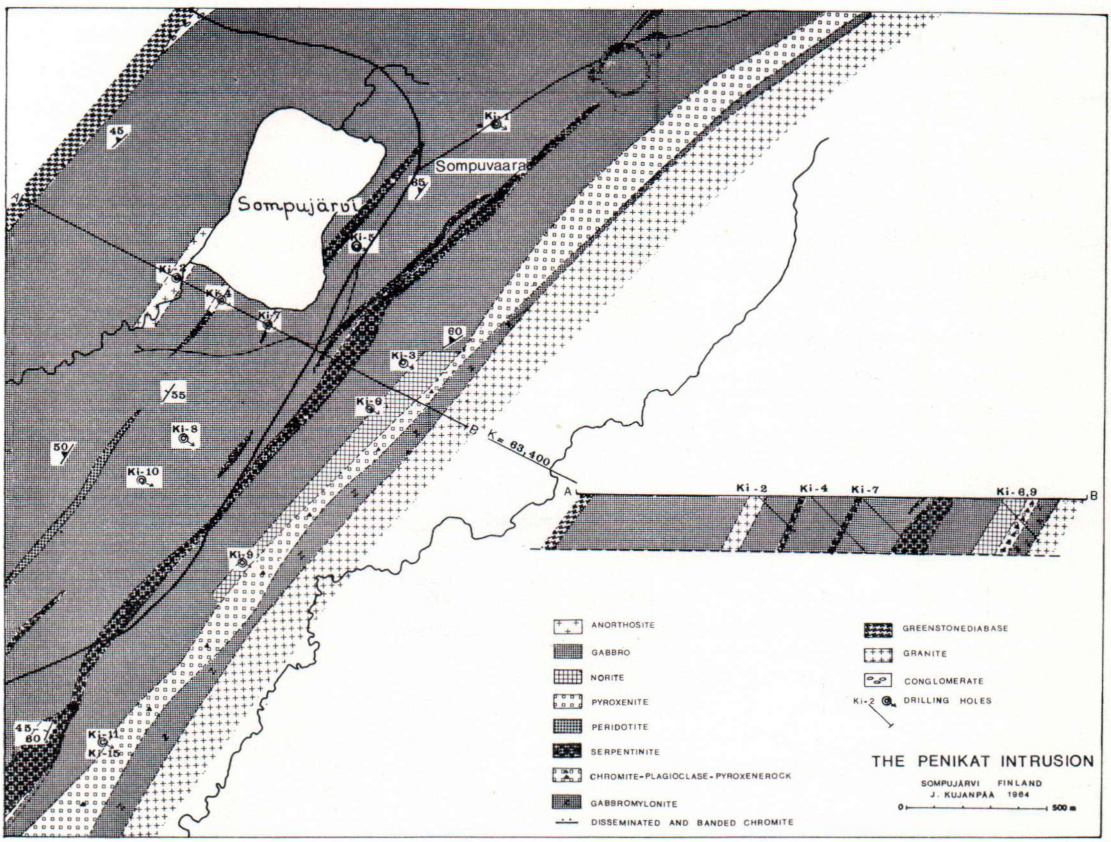

Fig. 3. Geological map of the Penikat intrusion.

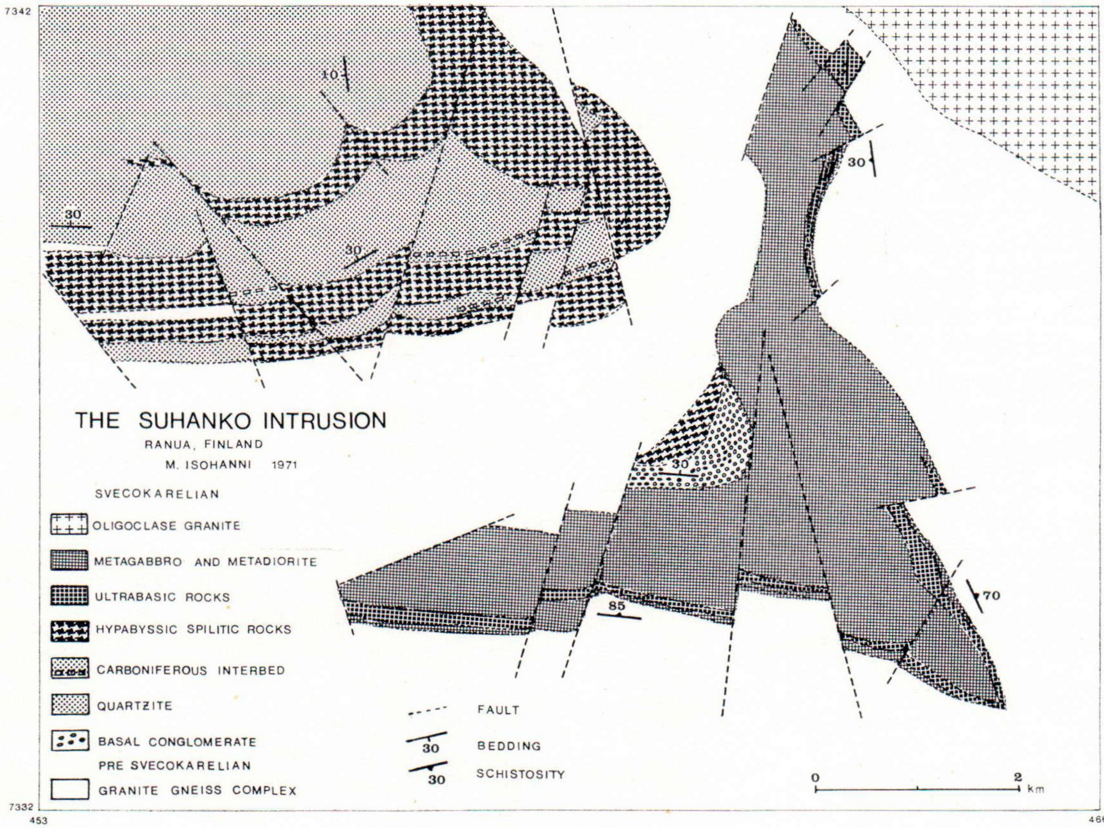

Fig. 4. Geological map of the Suhanko intrusion.

the anorthositic gabbro there is another orthopyroxene gabbro; the same rock type that is found between the two ultrabasic zones.

At least two separate intrusive pulses are represented in the Penikat intrusion in both of which the most important cumulus crystals are olivine and orthopyroxene. The amount of chromite decreases in the cumulus phase so that no actual chromium ore deposits are found in this intrusion. The vanadium bearing titanium iron ores and the sulphide ores are also missing.

The Suhanko intrusion

The Suhanko intrusion is situated approximately 50 km NE of the Penikat intrusion, and comprises an intrusive arc approximately 10 km long and 1 km thick (Fig. 4). It too has intruded between the basement complex and the Svecokarelian sediments. The foot wall of the intrusion is made of altered granite gneiss, and the hanging wall of conglomerate, quartzite, and hypabyssic basic dykes.

The intrusion is layered, and in places banded. Its lower part is built of gabbro which is topped by a 50—200 m thick ultrabasic zone. The primary rock types of the ultrabasic zone are pyroxenites and peridotite, or the same rock types that are found in the lower ultrabasic horizon of the Penikat intrusion. In the Suhanko intrusion the differentiation has, however, proceeded in a different direction so that in addition to the gabbros diorite is also found. The spinel is missing in both the cumulus and the intercumulus phases. Instead, there is a sulphide mineral paragenesis of pyrrhotite-chalcopyrite-pentlandite which has enriched the bottom of the intrusion.

The Syöte—Näränkävaara belt

To the NE of Suhanko there is a granite projection which extends southwards from the granite area of Central Lapland and cuts off the Kemi—Suhanko intrusive belt (Fig. 1). To the east of this granite tongue are found basic rocks which form a belt beginning at Syöte, and continuing further east to Näränkävaara. At first glance the bedrock here looks quite different from the Kemi—Suhanko belt, but a closer examination reveals that the differences are not so great. The Koillismaa Research Project has been undertaking these examinations for the past 3 years.

In the Syöte—Näränkävaara belt the same stratigraphical units are found as in the Kemi—Suhanko belt, that is the Pre-Svecokarelian granite gneiss complex, and the Svecokarelian quartzite-carbonate rock association with basic volcanics (Fig. 5). The main difference is that here the Svecokarelian formations do not begin with the ortho-quartzite, but with volcanics. This indicates that when the volcanic activity began the area had risen relative to the Kemi—Suhanko area. Otherwise the basic intrusions occur in the same way; they have intruded at the discordance or, in this case, between the granite gneiss and the volcanics.

The Syöte—Näränkävaara belt is divided into two parts: the western, and the eastern, which are connected by a positive gravity anomaly (Fig. 6). The western part has been intensely investigated by the Koillismaa Research Project, while the geological information for the eastern

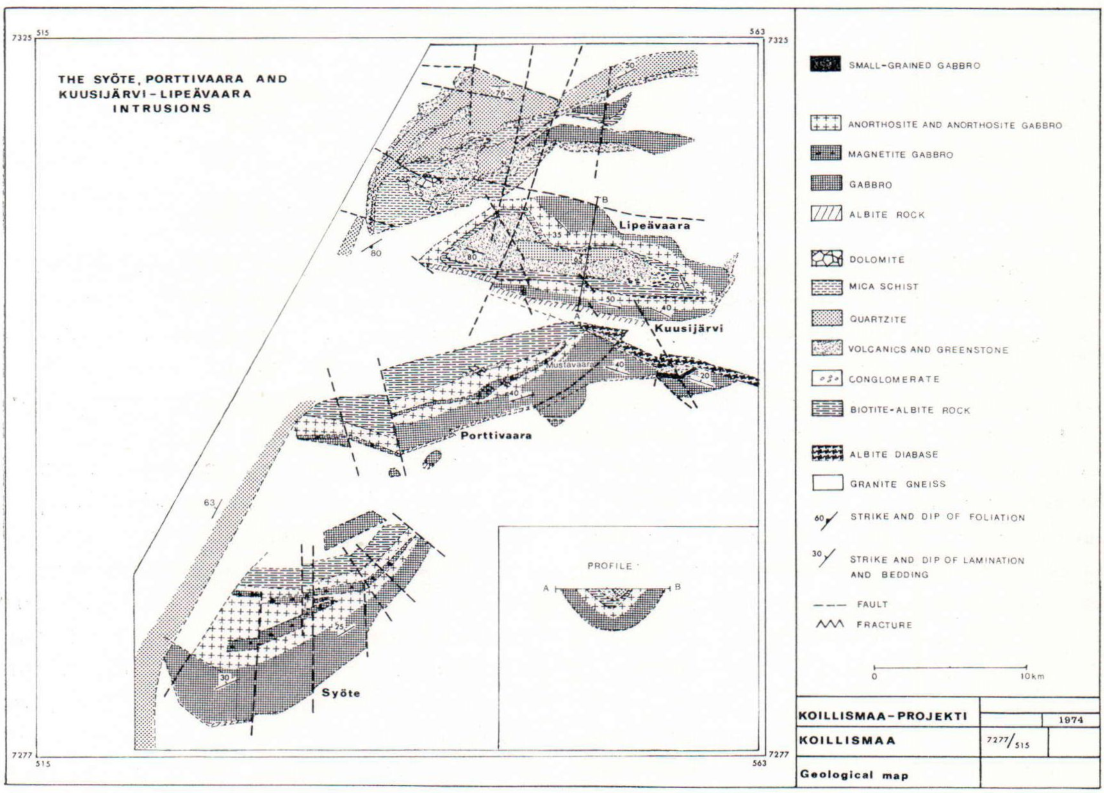

Fig. 5. Geological map of the Syöte. Porttivaara and Kuusijärvi—Lipeävaara intrus ions.

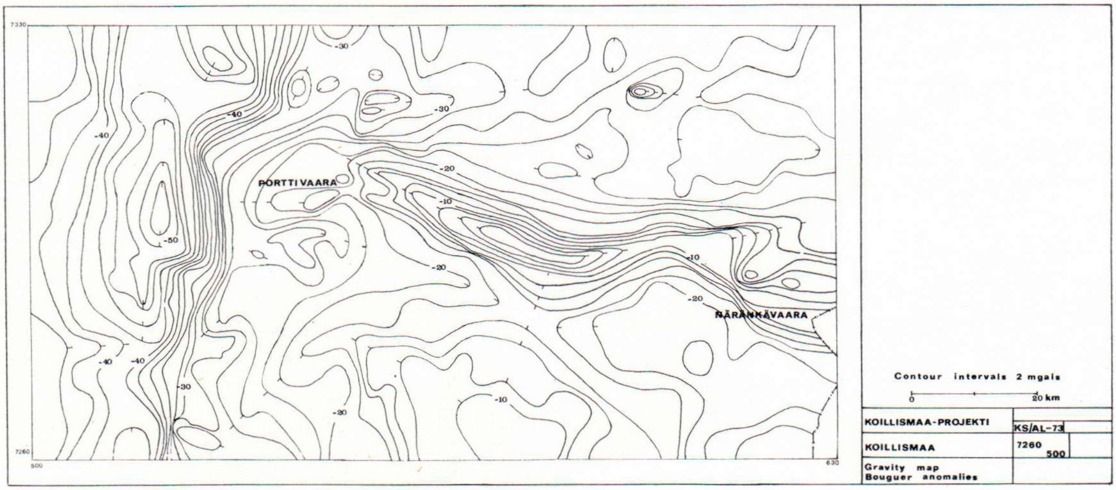

Fig. 6 Gravity map (Bouguer anomalies) of the Porttivaara—Näränkävaara area.

part, the Näränkävaara intrusion, is provided by the unpublished Master's thesis of Auranen (1969).

The intrusions of the Western part

In the western part of the Syöte—Näränkävaara belt basic rocks are found as several separate intrusions of which the biggest are the Syöte, the Porttivaara, and the Kuusijärvi—Lipeävaara intrusions. The layering in the Syöte and the Porttivaara intrusions dips 25°—45° to the NW. The Kuusijärvi—Lipeävaara intrusion forms an east-west oriented basin.

All these intrusions are basically similar. Their foot wall is composed of an albite-quartz rock, and the hanging wall of volcanics. Each of these three intrusion is layered and, in places, banded. The volumetric amount of ultrabasic rocks is small, and gabbros, anorthositic gabbros and anorthosites are the dominant rock types. The plagioclase is idiomorphic, and forms the most important cumulate at the top of the intrusion. The xenomorphic crystals of pyroxenes between the idiomorphic plagioclase crystals have, for the most part, changed to uralite. In the upper parts of the Syöte and Porttivaara intrusions vanadium bearing titanomagnetite has crystallized out in addition to the plagioclase and pyroxenes thus forming a magnetite gabbro horizon beneath the anorthosite. The titanomagnetite is xenomorphic between the crystals of plagioclase and uralite. At Mustavaara the amount of titanomagnetite is so great that the deposit is of economic value. In addition to the titanium iron ores, the sulphide ore paragenesis of pyrrhotite-chalcopyrite-pentlandite is also present in these intrusions. The sulphide mineralization has concentrated at the bottom of the intrusions, and at the hanging horizons in the lower parts of the intrusions. These hanging horizons are located close to the foot walls of the ultrabasic sills.

The Näränkävaara intrusion

The eastern end of the Porttivaara intrusion is built up of an olivine gabbro. To the east this gabbro dives into the basement complex and causes the aforementioned gravity anomaly between Porttivaara and Näränkävaara. The Näränkävaara intrusion exists as a separate lens outcropping in the granite gneiss complex.

According to Auranen (1969) the Näränkä-

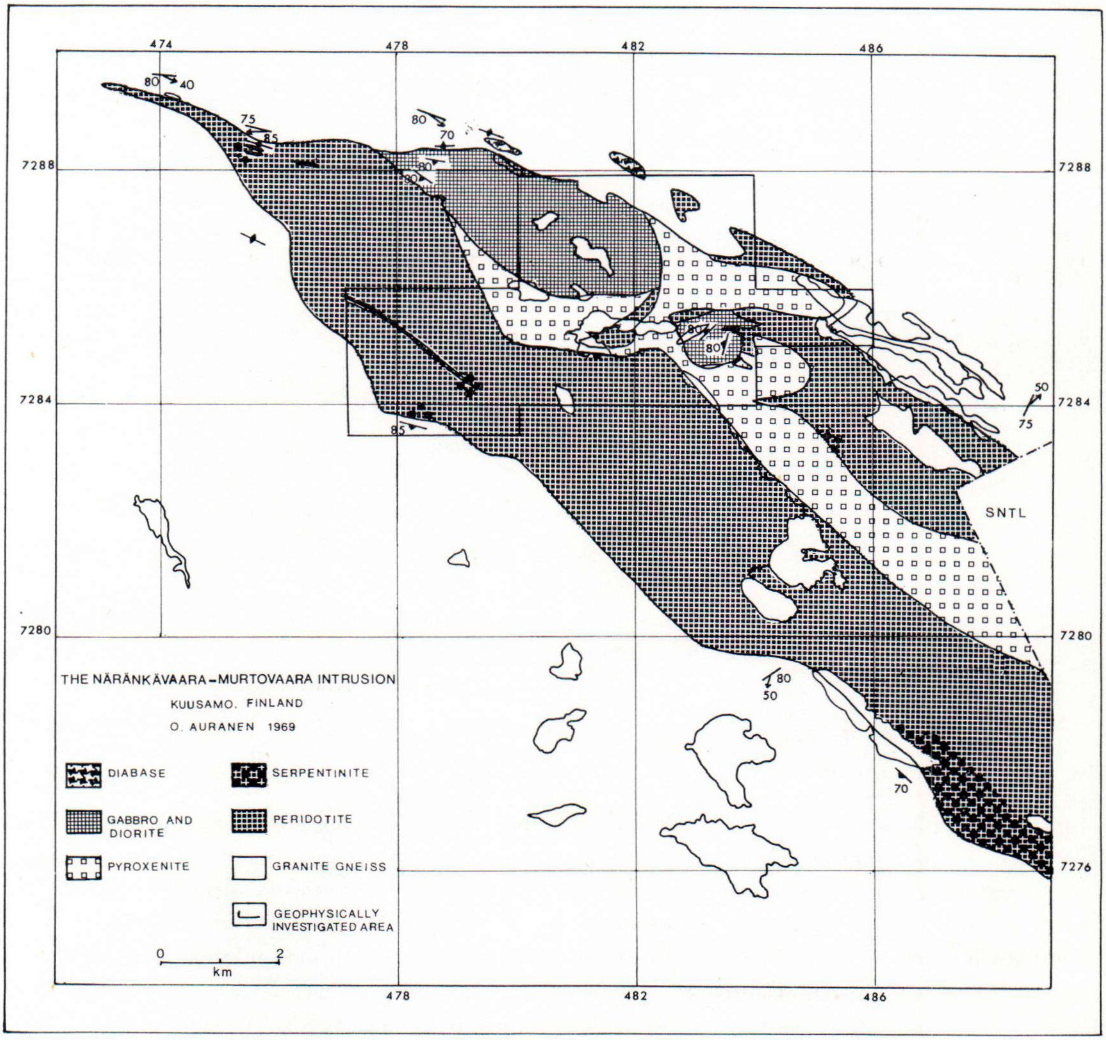

Fig. 7. Geological map of the Näränkävaara intrusion.

vaara intrusion is composed mainly of ultrabasic rocks (Fig. 7). The primary rock types are peridotite and pyroxenite, but gabbros and diorites are also encountered. The diorites are found at the northern border of the intrusion which is composed of brecciating schists of volcanic origin. In the Näränkävaara intrusion the cumulus crystals are olivine and pyroxenes. In this respect the Näränkävaara intrusion differs from those of the western parts of the Syöte—Näränkävaara belt, and resembles the Kemi—Suhanko intrusions.

Geotectonics and ore forming processes in the basic intrusive belts

The basic intrusions described above and the associated volcanics are products of a 2.1—2.2 billion year old magmatism. The question is whether the initial magmatism of the Svecokarelian orogenic cycle corresponds to Stille's (1940) »initialer Vulkanismus». According to Stille, the initial volcanism is a dominating feature in eugeosynclines but is missing from miogeosynclines.

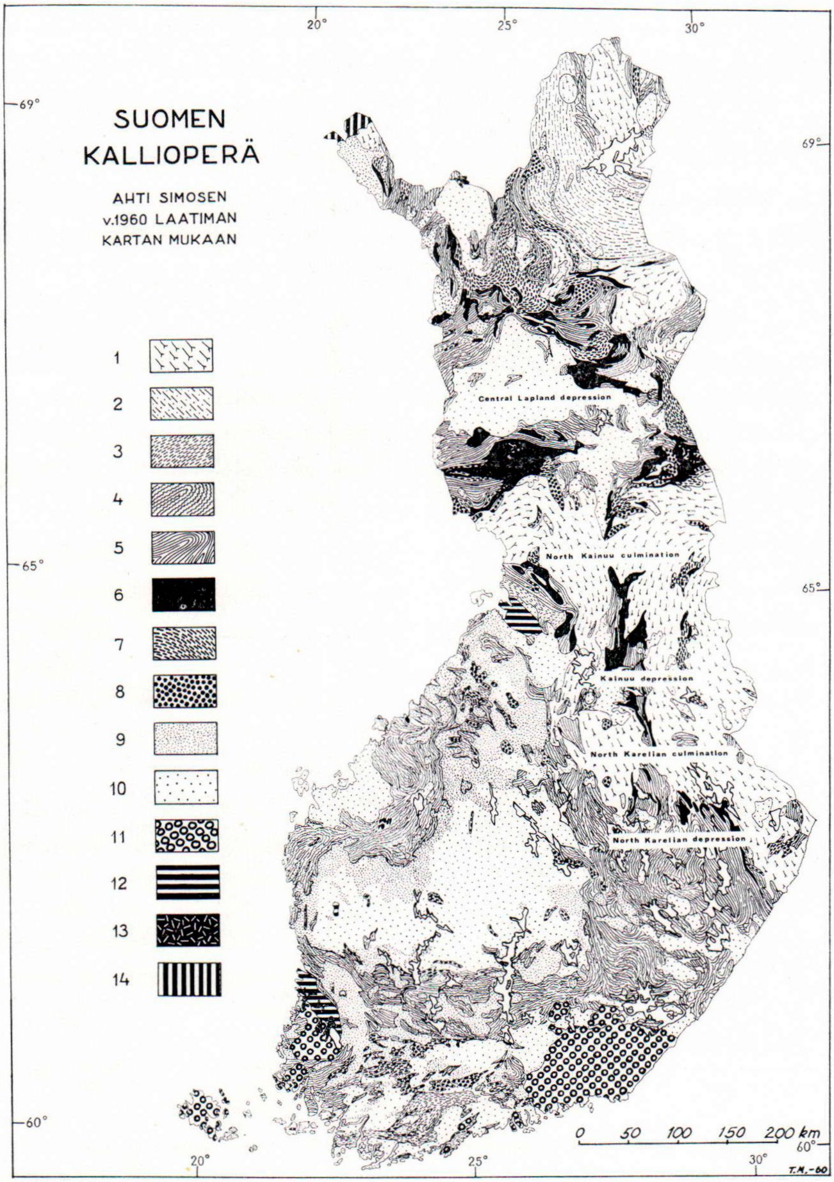

Fig. 8. Geological map of Finland after Simonen 1960.

1. granite gneiss
2. granulite
3. leptite
4. mica gneiss and migmatite
5. phyllite and mica schist
6. quartzite
7. metabasalt and amphibolite
8. gabbro, anorthosite and peridotite
9. granodiorite and quartz diorite
10. granite and acid plutonic rocks in general
11. rapakivi and other anorogenic granites
12. unmetamorphosed sedimentary rocks
13. diabase (Jotnian)
14. Paleozoic schists (Caledonian)

Since Stille's time information about the structure of the earth, and about the factors leading to the development of geosynclines has increased considerably and recent oceanographic research has also added to this data. According to the present state of knowledge, the ocean floor is being formed in some places and in others is being destroyed by being pushed underneath the earth's crust. On the basis of these facts, the concept of geosynclines takes on a new meaning.

In any case, the occurrence of two separate geosynclines bordering on each other but developing in different ways, is still generally accepted. Such a system can also be observed in the Finnish Svecokarelides where the Svecofennides and the Karelides have developed in two completely different ways (Fig. 8). The Svecofennides display several features which indicate that they correspond to that zone of the plate tectonic model along which the earth's crust subsides with regard to the foreland (Fig. 9). On the other hand, the Karelides display features which indicate that they represent a basin developed on the foreland. These two separate basins can be regarded as depressions in the Svecokarelian geosyncline (Fig. 10). Even though Stille's (1940) criteria for the eugeosyncline-miogeosyncline system do not quite fit the Finnish bedrock, a geotectonic system of similiar character is involved. Therefore, Stille's terms may well be applied to the Finnish bedrock

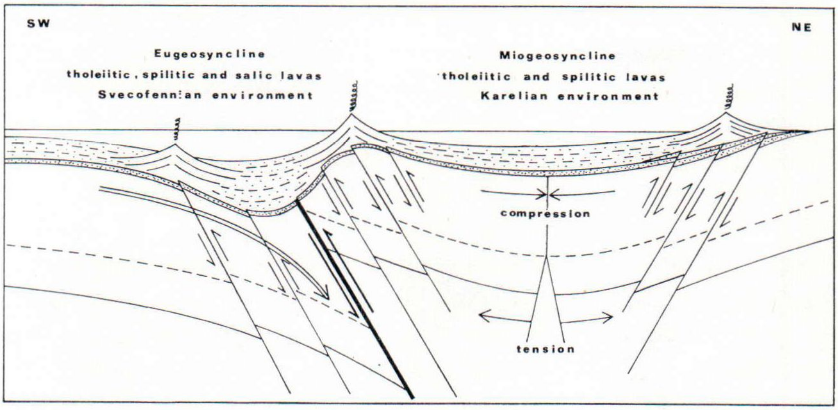

Fig. 9. Schematic section across the miogeosynclinal-eugeosynclinal basins during the initial igneous activity of the Svecokarelian orogeny, about 2.1—2.2 billion years ago.

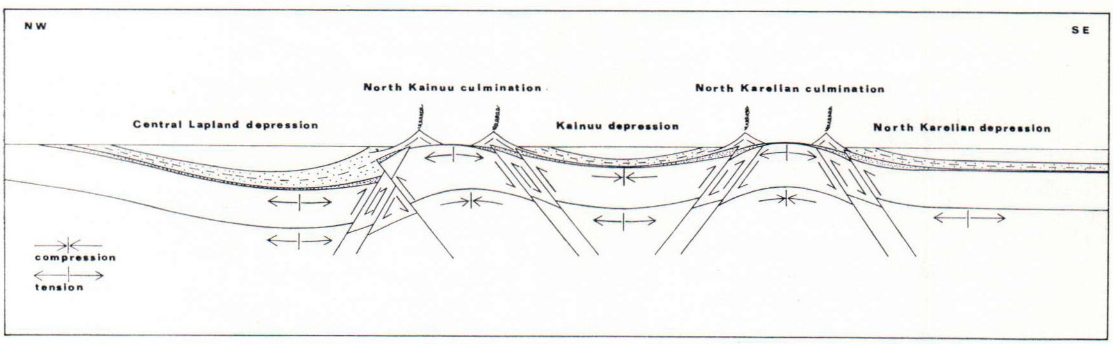

Fig. 10. Longitudinal profile of the Karelian geosyncline during the initial igneous activity about 2.1—2.2 billion years ago.

so that the Svecofennides represent formations deposited in the eugeosynclinal milieu and the Karelides represent those of the miogeosynclinal milieu.

At the time when the geosynclinal conditions described above prevailed a strong tension was generated in the upper parts of the mantle in the depression areas, thus creating circumstances favourable for the development of basic magmatic activity (Fig. 9 and 10). The sudden releases of the strain field triggered off movements in a direction diagonal to the direcrion of principal pressure thus opening fractures which served as channels for the rising basic magmas which poured out at the edges of the depression basins. That is why these basins contain various quartzite formations which are separated from each other by hiatuses and lava flows (Piirainen 1968, Piispanen 1972, Silvennoinen 1972, Laajoki 1973).

The Kemi—Suhanko and Syöte—Näränkävaara intrusive belts described above are situated between the Central Lapland depression and the North Kainuu culmination area. In the Central Lapland depression area the main tension was perpendicular to the Svecokarelian tectonic b-axis. The basic magmas rose up from these deep-seated E—W oriented tensional zones to the diagonal movement zones and spread to the slopes between the culmination and depression areas. These magmas formed layered intrusions between the granite gneiss complex and the Svecokarelian sedimentary formations. Depending on local circumstances the water content of the basic magma was different at different locations, hence also the fugacity of oxygen was different in different places. Consequently, the changes in the fugacity of oxygen effected both the manner of crystallization of the magma, and the ore forming processes.

In the Kemi area the water content of the magma was high because there were water saturated clastic sediments below clayey layers immediately above the layered intrusion. In the high temperature the water was dissociated into hydrogen and oxygen. The small hydrogen atoms were diffused out of the system which led to the increased fugacity of oxygen. Under these circumstances the crystallization in the magma commenced with Mg—Fe silicate and spinel, as experimental studies (Muan and Osborn 1956) also indicate. As the chromium content of the magma was still high in the early stage of crystallization the crystallizing spinel was a chromian one, which led to the formation of chromium ore deposits. Because of the high fugacity of oxygen no compounds were formed of metals and sulphur, hence there are no sulphide ores in the area.

In the culmination areas the water content of the basic magma was lower, resulting in the low fugacity of oxygen, so that the crystallization of magma started with plagioclase. Under these conditions the bonds between metals and sulphur became stable, and the sulphide phase, separated from the silicate magma as a sulphide melt, formed mineralizations at the bottoms of the intrusions. This happened for example in the Suhanko area (Isohanni 1971), and in the western parts of the Syöte—Näränkävaara belt. Here also, as the crystallization proceeded, the fugacity of oxygen increased and close to the final stage of crystallization reached the level required for the crystallization of spinel. The spinel formed under these circumstances was vanadium bearing titanomagnetite.

The geological evolution which led to the appearance of the basic magmatic activity, and to the emplacement of the layered intrusion described above continued as the succeeding stages of the Svecokarelian orogenic cycle. In the Central Lapland depression area the basic initial magmatism, which developed under the tectonic b-axis, was so strongly represented that it changed the direction of geological evolution in the area. A new geosyncline was generated whose axis almost perpendicular to the b-axis of the previous geosyncline. The new geosyncline displays eugeosynclinal features. The subsidence of the bottom of the new geosyncline to great depths resulted in the regional remobilization of the material, and the later rising of these remobilized parts as the Central Lapland granite area. With regard to this syncline the North Kainuu culmination area formed a foreland and when this foreland began to rise, the basic layered intrusions which had spread over ist edge were split into pieces and, later on, were mostly eroded. Only the edges of the layered intrusions and their channel systems are visible on the earth's surface at the present time.

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