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# Explanation to the stratigraphic map of Middle Finland

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# EXPLANATION TO THE STRATIGRAPHIC MAP OF MIDDLE FINLAND

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The stratigraphic map of Middle Finland covers the operational area of the Middle Finland regional office of the Geological Survey of Finland. The map was compiled on the basis of published material as well as on unpublished data received from exploration companies, the Department of Geology at the University of Oulu, and the Exploration and Petrological Departments of the Geological Survey. Excluding some checking done by the authors, no real field work was done.

Stratigraphically, the area of Middle Finland is divided into the eastern late Archaean subarea and the western early Proterozoic subarea. The lithostratigraphic hieararchy of the stratigraphic map is based on supergroups, groups and subgroups. The rocks are divided into thirteen lithological types, and two late Archaean and five early Proterozoic lithostratigraphic groups. Contrary to international practice, the lithostratigraphic and chronostratigraphic divisions have been combined in the stratigraphic division, and hence the map is a combination of these divisions.

Key words: stratigraphic maps, explanatory text, lithostratigraphy, metamorphic rocks, igneous rocks, chronostratigraphy, Proterozoic, Archaean, eastern Finland

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## PREFACE

In the winter of 1980, state geologist Kauko Meriläinen set up a working group within the mapping and research group of the Middle Finland office with the purpose of compiling a stratigraphic map of Middle Finland in the course of 1981 (Fig.1).

The working group consisted of two geologists, Erkki Luukkonen and Heikki Lukkarinen, and their supervisor, Kalevi Korsman, head of mapping and research at the Middle Finland office. After the transfer of Kalevi Korsman to another post, Luukkonen and Lukkarinen completed the assignment alone.

The duties of the working group were divided as follows:

Luukkonen was responsible for the Archaean migmatites, granitoids and greenstone belts, the early Proterozoic Sariola and Jatuli Group formations, and the Kainuu schist area. Lukkarinen was responsible for the Archaean formations west of the Kallavesi-Onkivesi line and the early, middle and late Proterozoic supracrustal formations.

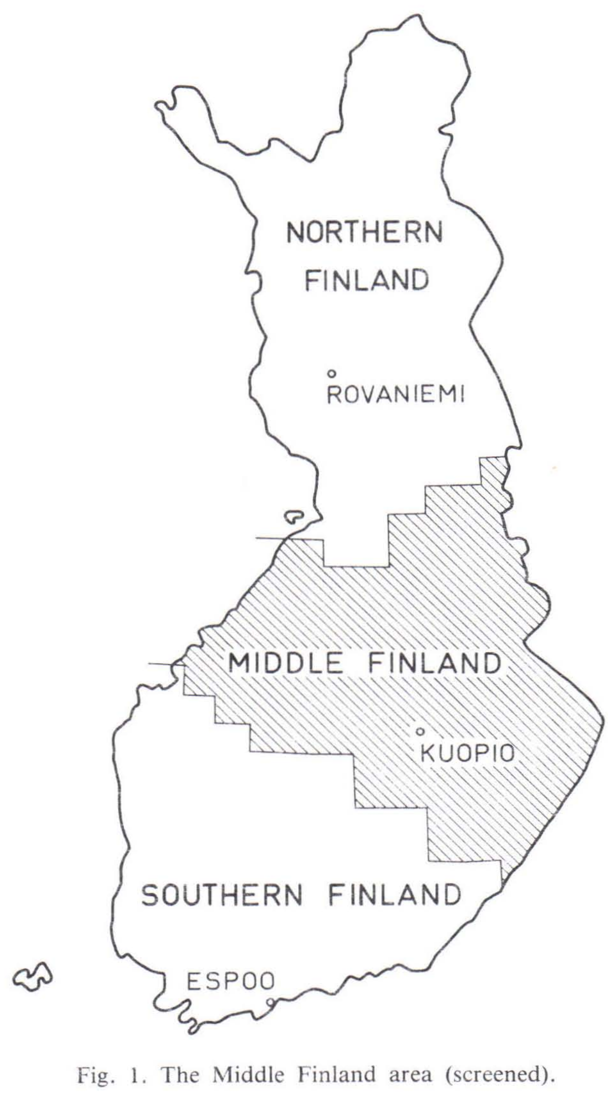


Fig. 1. The Middle Finland area (screened).

Geologist Antti Pääjärvi assisted in the classification of the Proterozoic granitoids. Research assistant Antti Mäkelä was involved in processing the mapping data, and Mrs. Anni Vuori drew the final map.

Our main sources of material for the map were the lithologic and bedrock maps at a scale of 1:400 000 and 1:100 000 published for the Middle Finland area. Other source material, some of it still unpublished, was received from the Exploration and Petrological Departments of the Geological Survey of Finland, Outokumpu Exploration, Rautaruukki Exploration, Kajaani Oy Exploration and the Department of Geology and Mineralogy of Oulu University. We also checked some of the data in the field.

We should like to express our gratitude to all those with whom we worked and particulary to Dr. Olavi Kouvo for the unstinting help he gave us throughout the assignment.

Dr. Olavi Kouvo, state geologist Kauko Meriläinen and head of department Atso Vorma revised the manuscript, and we thank them for their constructive criticism. The manuscript was translated into English by Mrs. Gillian Häkli and clean typed by Mrs. Irja Mykkänen and Mrs. Saara Kaijalainen.

Kuopio, 9th September, 1983.

*Erkki Luukkonen* *Heikki Lukkarinen*

## INTRODUCTION

The whole of Middle Finland has been mapped lithologically at a scale of 1:400 000 and part of it also at a scale of 1:100 000. The stratigraphy of the area has been discussed by Väyrynen (1933, 1938, 1954), Eskola (1963), Piirainen (1968), Simonen (1971, 1980), Meriläinen (1980), Gaál *et al.* (1974) and Gaál (1982, 1983). No purely stratigraphic map, however, has been compiled for the area before.

Our stratigraphic division is based mainly on the contact and crosscutting relations between the rocks in the area and on the ages determined for them. Correlations were made with the stratigraphy of the Karelia block in the USSR.

Lithostratigraphic and chronostratigraphic studies are still incomplete for many areas of Middle Finland, and for others they have not even been started. In the stratigraphic division we, therefore, had to deviate from established international practice and combine the lithostratigraphic and chronostratigraphic divisions (Hedberg 1976). For the same reason we used the names, e.g. Sariola, Jatuli and Kaleva, previously given and defined for the stratigraphic groups, but in a wider sense than originally intended. The chronostratigraphic and lithostratigraphic division is shown in Fig. 2.

The rocks of the stratigraphic groups are shown by the overprints as follows (Fig. 3.):

1. Supracrustal rocks
    - Metasediments
    - Metavolcanites
        - Acid and intermediate metavolcanites
        - Basic and ultrabasic metavolcanites
2. Migmatites
    - Weakly migmatized, such as veined gneisses, phlebitic migmatites and rocks that are clearly paragneisses
    - More intensely migmatized rocks, such as banded, schlieren and nebulite migmatites and orthogneisses
3. Plutonic rocks
    - Granitoids in general
    - Granites
    - Syenites (+alkaline rocks)
    - Granodiorites, quartz diorites, tonalites and quartz monzonites
    - Diorites, gabbros, pyroxenites, peridotites, dunites and serpentinites
4. Dyke rocks
    - Diabase and metadiabase dykes
    - Lamprophyre dykes
5. Meteorite crater

The distribution of the rocks in stratigraphic groups and subgroups is depicted in various colours (see also Fig. 2).

STRATIGRAPHY

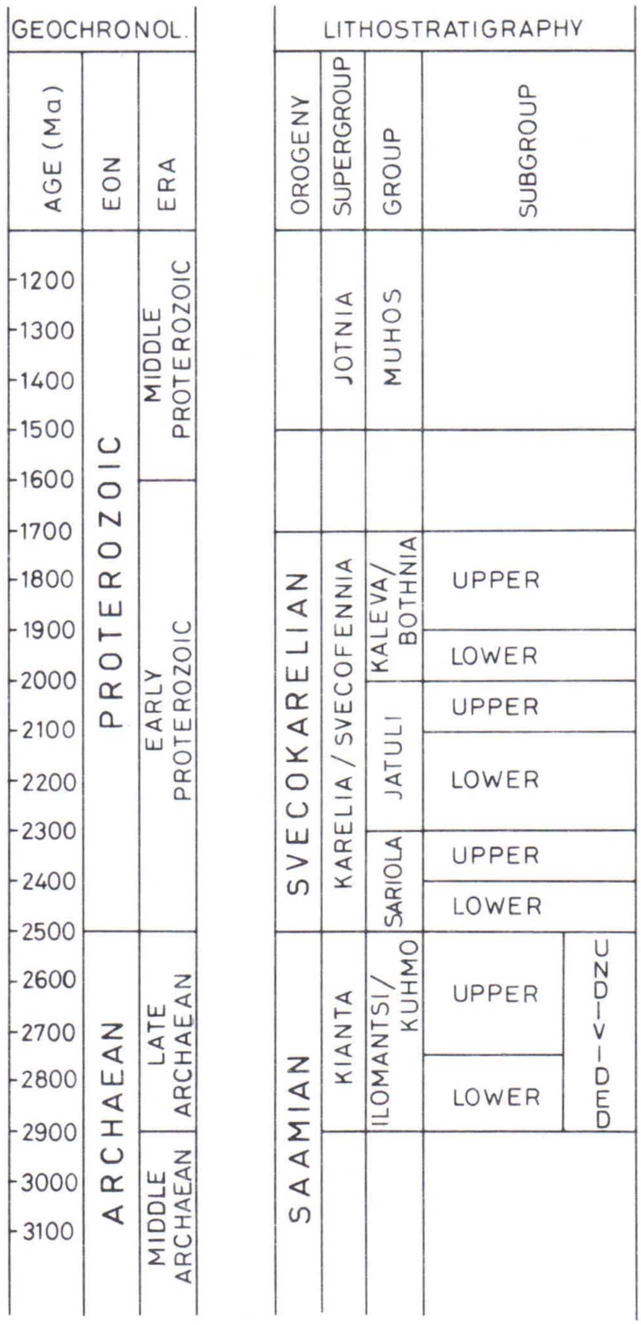


Fig. 2. The geochronological and lithostratigraphic division of the Middle Finland area.

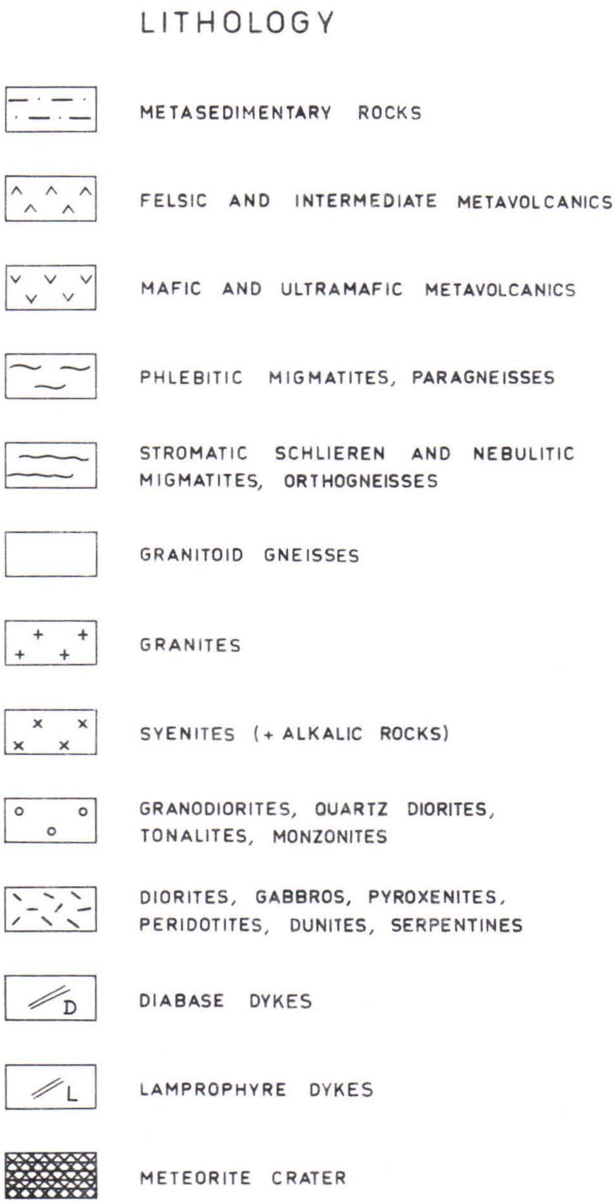


Fig. 3. The lithologic symbols used on the stratigraphic map of the Middle Finland.

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# LATE ARCHAEAN ERA

## Kianta Supergroup

The bedrock of the eastern and northeastern part of the Middle Finland area is composed almost exclusively of the formation of the Kianta Supergroup. On our map the Kianta Supergroup covers geochronologically formations c. 2900—2500 Ma in age. As recommended internationally, the lower age limit, c. 2900 Ma, of the Kianta Supergroup is that of the late Archaean (Sims 1980).

The Kianta Supergroup is divided into the Ilomantsi and Kuhmo Groups, and these further into the Lower Ilomantsi and Lower Kuhmo Subgroups (c. 2900—2750 Ma in age) and the Upper Ilomantsi and Upper Kuhmo Subgroups (c. 2750—2500 Ma in age).

The boundary between the Lower and Upper Ilomantsi Subgroups and the Lower and Upper Kuhmo Subgroups has been set at about 2750 Ma, because 1) the mafic sill at Moisiovaara, which is included in the greenstones of the Lower Kuhmo Subgroups in the Kuhmo greenstone belt, is c. 2760 Ma dated from zircon by U/Pb method (GSF, Ann. Rep. 1980; Patchett *et al.* 1981), 2) the corresponding U/Pb age of zircon from the acid porphyroid dykes of the Lower Ilomantsi Subgroup at Ingonvaara in the Ilomantsi greenstone belt is c. 2750 Ma (GSF, Ann. Rep. 1968), and 3) the quartz diorites and granodiorites that have not been noted to cut the Upper Kuhmo Subgroup have been dated at 2750 Ma Hyppönen 1983; (GSF, Ann. Rep. 1972, 1976, 1977; GSF, Petrol. Dep. Rep. act. 1980, 1981; from zircon by U/Pb method). The upper age limit, c. 2500 Ma, of the Upper Ilomantsi and Upper Kuhmo Subgroups, constitutes the internationally recommended boundary between the late Archaean and early Proterozoic Eras (Sims 1980, Meriläinen 1980).

### Migmatites and granitoids older than or contemporaneous with the late Archaean greenstone belts

Migmatites and granitoids of this group are encountered east of the Proterozoic schist areas of Kainuu and North Karelia (Fig. 4). The oldest Archaean migmatites, which occur in the northern part of the area, have undergone polyphase folding and metamorphism and are partly anatectic polymigmatites. Banded and schlieren structures are typical of the migmatites. The paleosome is usually hornblende ± biotite tonalite and biotite tonalite. The neosome is often trondhjemite and aplite granite.

The U/Pb age of zircon from the paleosome in Kuusamo and Kuhmo, c. 2858—2837 Ma, can be considered the minimum age of the paleosome in the old migmatites (GSF, Ann. Rep. 1975, 1980, 1981).

Migmatites like those described above are also encountered in the west of the Proterozoic Kainuu and North Karelia schist areas (within the Iisalmi microcontinent, or inter plate; cf. Väyrynen 1954), and strongly altered, in the southern parts of the western Archaean area (see p. 15—17 and Fig. 4).

The migmatites in Kuusamo, Suomussalmi, Hyrynsalmi and Kuhmo frequently contain amphibolite and microtonalite xenoliths.

Microtonalites with mica gneissic and phlebitic structures and stratigraphically below the Archaean greenstone belts of the Upper Kuhmo Subgroup occur extensively in the municipalities of Kuhmo and Valtimo and in the town of Nurmes.

There are many places in Suomussalmi, Hyrynsalmi, Kuhmo and Nurmes with migmatites that in structural features and mode of occurence resemble the gneisses and migmatites of the Keretti Group of the Belomoridian Supergroup descriped from Viena Karelia in the USSR (Stenar 1972; Kratz and Mitrofanov 1980; Sokolov and Stenar 1980).

The oldest granitoids, which occur in the Lieksa and Ilomantsi areas, exhibit plutonic, gneissose and cataclastic features. The oldest tonalites and granodiorites in the Ilomantsi area can be assigned minimum ages of 2855 and 2858 Ma from zircon by U/Pb method (GSF, Ann. Rep. 1972, 1975; GSF. Petrol. Dep. Rep. act. 1980, 1981).

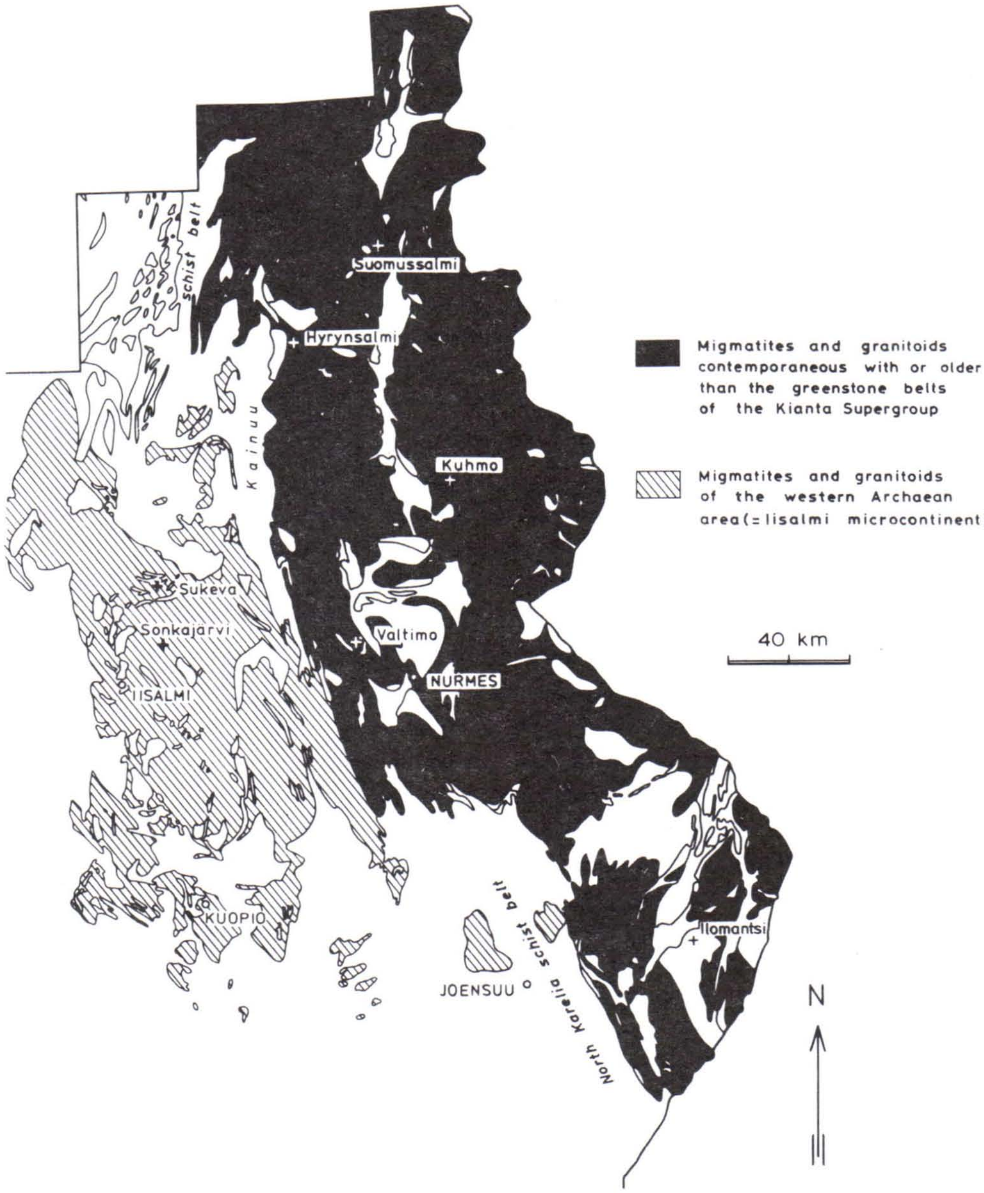


Fig. 4. Migmatites and granitoids older than or contemporaneous with the Kianta Supergroup greenstone belts.

According to Frosterus and Wilkman (1920), Wilkman (1921) and Matisto (1958), the above granitoids are oligoclase-bearing banded gneiss granites and granite gneisses younger than the Archaean greenstone belts. This misinterpretation is probably due to the lack of distinct contacts between the old migmatites and the greenstones, and to the foliation in the younger tonalites and quartz diorites crosscutting the greenstone belts.

## The area of the late Archaean greenstone belts

*Kuhmo and Ilomantsi Groups.*

In the area of the late Archaean greenstone belts, the Kianta Supergroup is divided into the Kuhmo Group and the Ilomantsi Group.

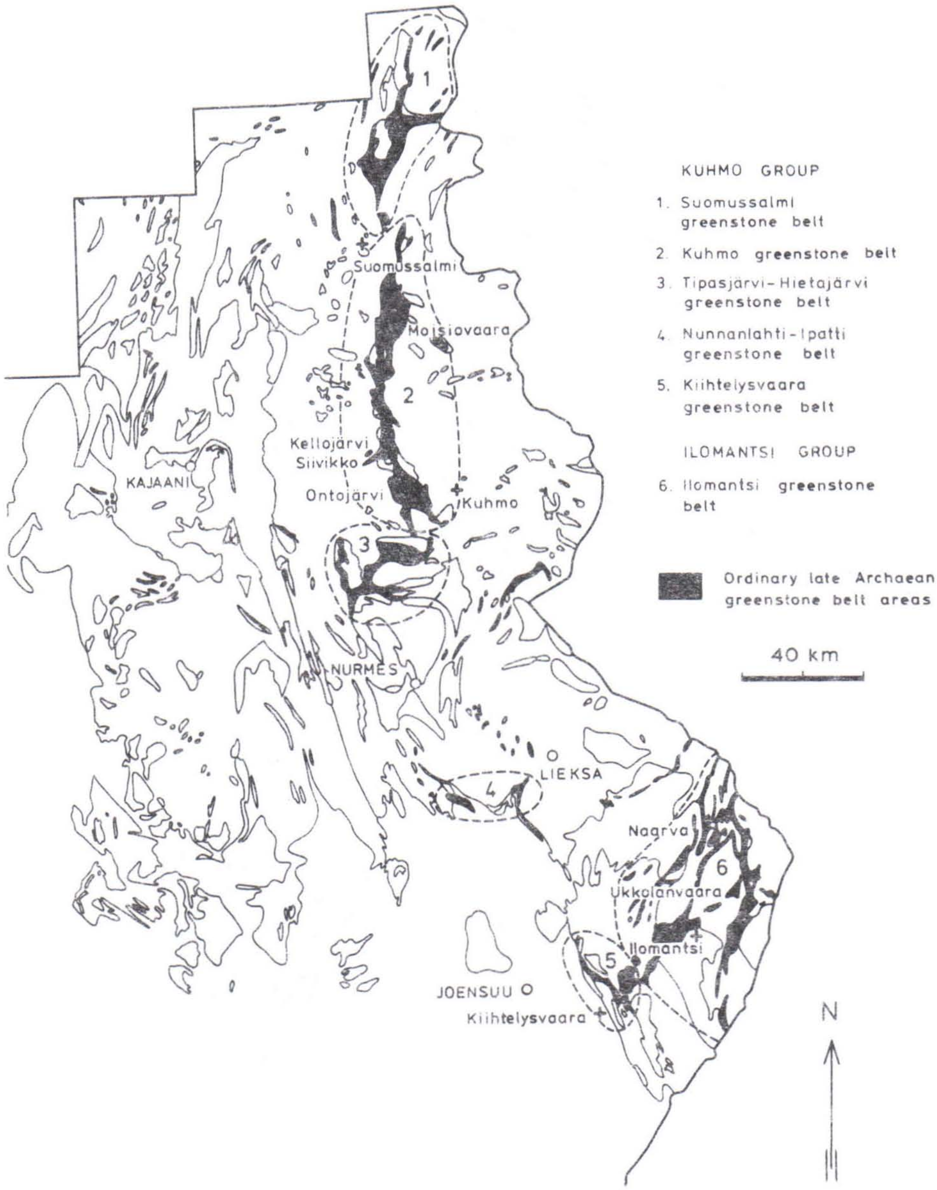


Fig. 5. The greenstone belts of the Kianta Supergroup.

The Kuhmo Group is characterized by the roughly NS trend of the formations, tectonic contacts with the old Archaean granitoids (Väyrynen 1954, Gaál *et al.* 1978), the predominance of volcanic rocks over sedimentary rocks, the abundance of mafic volcanites, small iron formations and sericite quartzites (Figs 5 and 6).

Typical of the Ilomantsi Group are the approximately NE-SW and WE trends of the formations, basal conglomerates, sizeable iron formations and the preponderance of sedimentary rocks over volcanic rocks (Figs 5 and 6).

No geochronological difference has been established between the Kuhmo and Ilomantsi Groups, both groups having started to evolve simultaneously. The Kuhmo Group may have continued to evolve longer or then only the lowermost parts of the Ilomantsi Group have survived erosion. Formations of the Kuhmo Group are encountered in the greenstone belts of Suomussalmi, Kuhmo, Tipasjärvi-Hietajärvi, Nunnanlahti-Ipatti and Kiihtelysvaara. There are also some small unnamed greenstone belts in Kuhmo, Nurmes, Valtimo and Lieksa whose stratigraphic position has not been established.

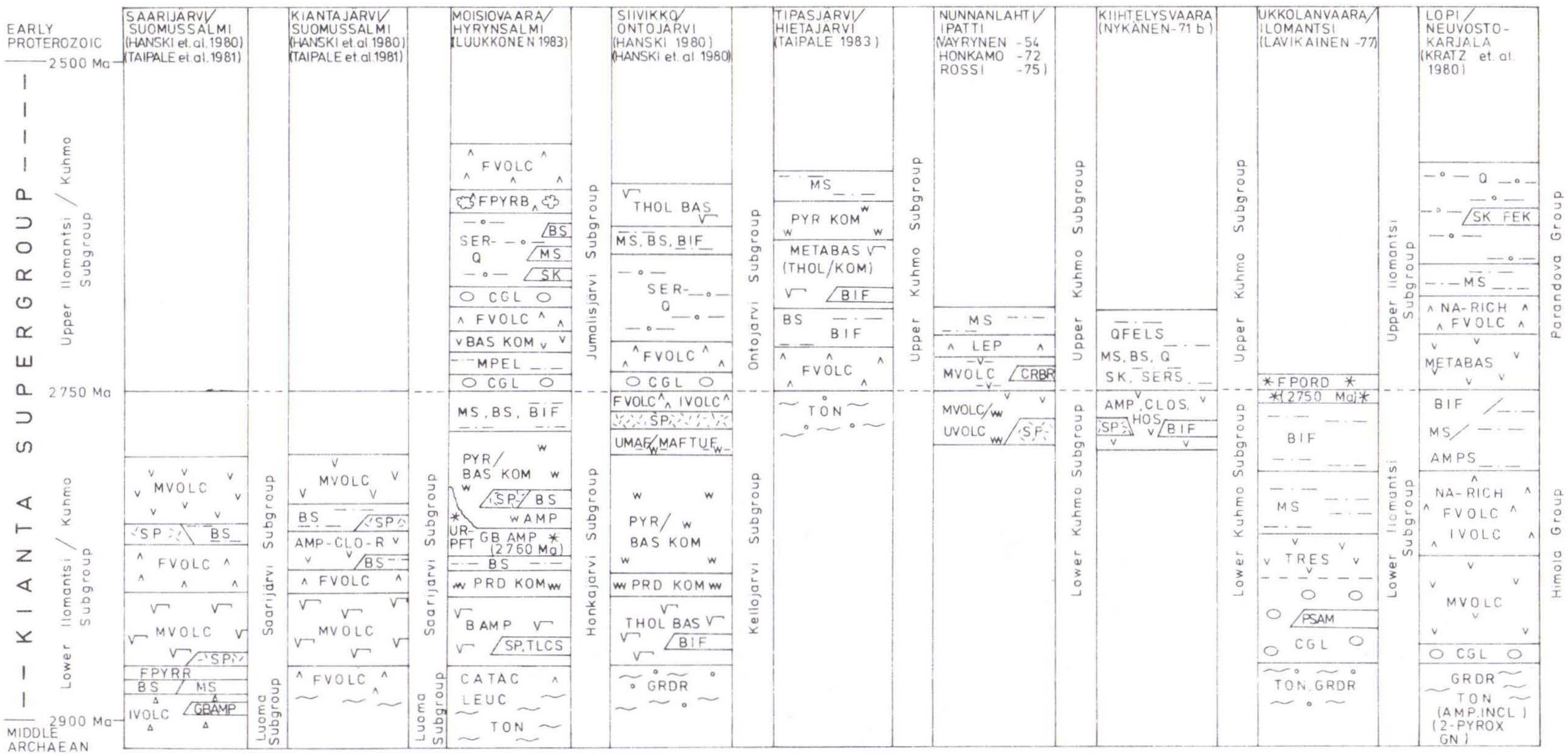


Fig. 6. The stratigraphy of the Kianta Supergroup.

- AMP = amphibolite
- AMP INCL = amphibolite inclusions
- AMP-CLO-R = amphibole-chlorite-rock
- AMPS = amphibolite schist
- BAS KOM = basaltic komatiite
- BAMP = banded amphibolite
- BIF = banded iron formation
- BS = black schist
- CATAC LEUC TON = cataclastic leucocratic tonalite
- CGL = conglomerate
- CLOS = chlorite schist
- CRBR = carbonate rock
- FEK = pyrrhotite
- FPORD = felsic porphyry dyke
- FPYRB = felsic pyroclastic breccia
- FPYRR = felsic pyroclastic rock
- FVOLC = felsic volcanite
- GBAMP = gabbroic amphibolite
- GRDR = granodiorite
- HOS = hornblende schist
- IVOLC = intermediate volcanite
- LEP = leptite
- MAF TUF = mafic tuff
- METABAS = metabasalt
- MPEL = metapelite
- MS = mica schist
- MVOLC = mafic volcanite
- Na-RICH FVOLC = Na-rich felsic volcanite
- PRD KOM = peridotitic komatiite
- PSAM = psammitic interlayers
- PYR KOM = pyroxenitic komatiite
- Q = quartzite
- QFELS = quartz-feldspar-schist
- SERS = sericite schist
- SERQ = sericite quartzite
- SK = pyrite
- SP = serpentinite
- THOLBAS = tholeiitic basalt
- THOL/KOM = tholeiite/komatiite
- TLCS = talc schist
- TRES = tremolite schist
- UMAF = ultramafite
- URPFT = uralite porphyrite
- UVOLC = ultramafic volcanite
- 2-PYROX GN = two-pyroxene gneisses

Hanski *et al.* (1980) divided the Kuhmo-Suomussalmi greenstone belt stratigraphically into the Luoma, Saarijärvi, Kellojärvi, and Ontojärvi Subgroups. In this paper the Kuhmo Group has been presented in the same manner. The Luoma Subgroup (Fig. 6) is in the lowermost stratigraphic position in the Lower Kuhmo Group in the *Suomussalmi greenstone belt.* It is composed of intermediate volcanites, gabbroic amphibolites, black schists, mica schist and acid pyroclastic rocks. The majority of the rocks in the Luoma Subgroup are intermediate volcanites metamorphosed into cordierite-anthophyllite rocks (Kopperoinen 1980, personal comm.). The Luoma Subgroup is best developed in the western part of the Suomussalmi greenstone belt. Indications of the cataclastic quartz-feldspar schists or leucotonalites, or both, of the Luoma Subgroup are also encountered at the eastern contact of the Suomussalmi greenstone belt in the northern part of the lake Kiantajärvi, at Moisionvaara in the western and eastern contact of the Kuhmo greenstone belt and at Kellojärvi in the western contact of the greenstone belt only.

In the above areas the cataclastic quartz-feldspar schists or the leucotonalites, or both, of the Luoma Subgroup seem to grade into Archaean granitoids, whereas the contact with the overlying and intercorrelated formations of the Saarijärvi, Honkajärvi and Kellojärvi Subgroups is sharp and conformable (Taipale and Tuokko 1981, Fig. 6).

In the Suomussalmi greenstone belt the Luoma Subgroup is overlain by the Saarijärvi Subgroup, named by Hanski *et al.* (1980), composed of serpentinites, mafic volcanites, acid volcanites, black schist, komatiitic amphibole-chlorite rocks, serpentinites, black schists and mafic volcanites (Fig. 6).

At Moisiovaara in the *Kuhmo greenstone belt* the Kuhmo Group begins with the cataclastic leucotonalites correlated with the above Luoma Subgroup. They are overlain in stratigraphy by tholeiite-basaltic banded amphibolites (with serpentinite and talc schist portions), peridotitic komatiites (serpentinized in places), black schists, uralite porphyry/mafic sills (c. 2760 Ma, dated from zircon by U/Pb method; GSF, Ann. Rep. 1980; Patchett *et al.* 1981), pyroxenitic/basaltic komatiites, metalavas (with occasional serpentinite and black schist interlayers), black schists, iron formations and mica schists of the Honkajärvi Subgroup (Fig. 6).

In the Moisiovaara area the Honkajärvi Subgroup is overlain by conglomerates, metapelites, basaltic komatiites, acid volcanites, conglomerates, sericite quartzites (with pyrite, black schist and mica schist interlayers), acid pyroclastic breccias and acid volcanites of the Jumalisjärvi Subgroup (Fig. 6).

In the Siivakko-Ontojärvi area the Kuhmo Group begins with the Kellojärvi Subgroup described by Hanski (1980), Hanski *et al.* (1980) and Taipale *et al.* (1981), which consists of tholeiitic basalts (with iron formations), peridotitic komatiites, pyroxenitic/basaltic komatiites, ultramafic to mafic tuffs, serpentinites and acid to intermediate volcanites. The Kellojärvi Subgroup is overlain by conglomerates, acid volcanites (partly pyroclastites), sericite quartzites, mica schists, black schists, iron formations and tholeiitic basalts of the Ontojärvi Subgroup described by Hanski (1980), Hanski *et al.* (1980) and Taipale *et al.* (1981) (Fig. 6).

The acid volcanites, black schists, iron formations, metabasalts (tholeiitic/komatiitic in composition), pyroxenitic komatiites and mica schists described by Taipale (1982, 1983) from the *Tipasjärvi—Hietajärvi greenstone belt* have been correlated with the Upper Kuhmo Subgroup (Fig. 6).

The ultramafites (some of them apparently extrusives) and a mafic volcanite with carbonate rock lenses described by Väyrynen (1954), Honkamo (1972) and Rossi (1975) form the *Nunnanlahti—Ipatti greenstone belt* have been classified in the Lower Kuhmo Subgroup. The leptites and mica schists have been correlated with the Upper Kuhmo Subgroup (Fig. 6).

The lower group of the *Kiihtelysvaara greenstone belt,* consisting of amphibolites, banded hornblende schists, chlorite schists, serpentine rocks and iron formations (Nykänen 1971b) has been correlated with the Lower Kuhmo Subgroup. The quartz-feldspar schists, mica schists, black schists, ore quartzites, sericite schists and pyrite formations of the upper group by Nykänen (1971b) have been correlated with the Upper Kuhmo Subgroup (Fig. 6).

The Ilomantsi Group is met with only in the *Ilomantsi greenstone belt,* where its basal part, the Lower Ilomantsi Subgroup, consists of the basal conglomerates with psammitic interlayers described by Lavikainen (1977) from the Ukkolanvaara area in Ilomantsi, tremolite schists, mica schists, iron formations and acid porphyroid dykes (2750 Ma from zircon by U/Pb method Fig. 6, GSF. Ann. Rep. 1968). In the Naarva area acid volcanites have also been encountered in the basal part of the Ilomantsi Group, and the polymictic conglomerates, greywacky schists, mafic volcanites and leptites that occur there might represent the upper part of the Ilomantsi Group (the Upper Ilomantsi Subgroup; ch. v/o Technoexport/Suhanova, Malyshev, Kuzmina 1978).

The Kianta Supergroup and the Lopi Supergroup in the Karelia block in the USSR are analogous supergroups. Lithostratigraphically the Ilomantsi Group of the Kianta Supergroup corresponds to the Himola group of the Lopi Supergroup (Fig. 6), and the Kuhmo Group of the Kianta Supergroup corresponds to the Parandova Group of the Lopi Supergroup (Kratz and Mitrofanov 1980; Sokolov and Stenar 1980. The contacts of the Archaean greenstone belts with the older Archaean migmatites and granitoids, and also the tectonic features of the greenstone belts are similar in both Middle Finland and Soviet Karelia (Sokolov and Stenar 1980; Rybakov and Lobach-Zhuchenko 1981).

## Migmatites and granitoids younger than the late Archaean greenstone belts

The granitoids younger than the Archaean greenstone belts east of the Kainuu and North Karelia schist areas (Fig. 7) are divisible lithologically and geochronologically into a number of types:

1. Porphyric and/or porphyroblastic quartz diorites and tonalites intruded in the margins of the late Archaean greenstone belts. They are c. 2740—2720 Ma from zircon and sphene by U/Pb method. (GSF, Ann. Rep. 1977; GSF, Petrol. Dep. act. 1981, 1982; Hyppönen 1983).
2. Granite, granodiorite, quartz diorite and tonalite massifs enveloped by old migmatites and granitoids. The large and extensive massifs include those of the Konivaara granite/granodiorite, the Hattuvaara granite/granodiorite, the Koitere granite/granodiorite, the Kutsu granite/granodiorite and some of the granodiorite, quartz diorite and tonalite provinces described by Lavikainen (1977) from the Ilomantsi area (Fig. 7). They are porphyric or porphyroblastic in structure, often sligthly foliated and c. 2750—2665 Ma from zircon and sphene by U/Pb method (GSF, Ann. Rep. 1971, 1972, 1973, 1976, 1977, 1980, 1981, 1982; Hyppönen 1983).
3. The youngest granitoids in the eastern Archaean area. They are potassium granites with a fairly high potassium feldspar abundance, marked fluorite content and a porphyric structure that is often well preserved. The potassium granites crosscut all the other Archaean rocks (some of the potassium granites may be even early Proterozoic; see Fig. 7).

## The undivided migmatites and granitoids west of the Kainuu and north Karelia schist areas within the Iisalmi microcontinent

On the basis of current knowledge, the Archaean migmatites and granitoids in the Iisalmi microcontinent (or inter plate, cf. Väyrynen 1954) west of the Kainuu and North Karelia schist areas cannot be divided into lithostratigraphic or chronostratigraphic groups. The area is depicted on the map in the colours of the Lower Ilomantsi and Lower Kuhmo and Upper Ilomantsi and Upper Kuhmo Subgroups (Fig. 7); only the distinctly younger and crosscutting granitoids are depicted in the colours of the Upper Ilomantsi and Upper Kuhmo Subgroups. Lithologically the rocks are grouped as follows:

1. The northern part of Archaean area west of the Kainuu schist area is composed mainly of various feldspar gneisses and mica gneisses (Archaean/Proterozoic?) crosscut

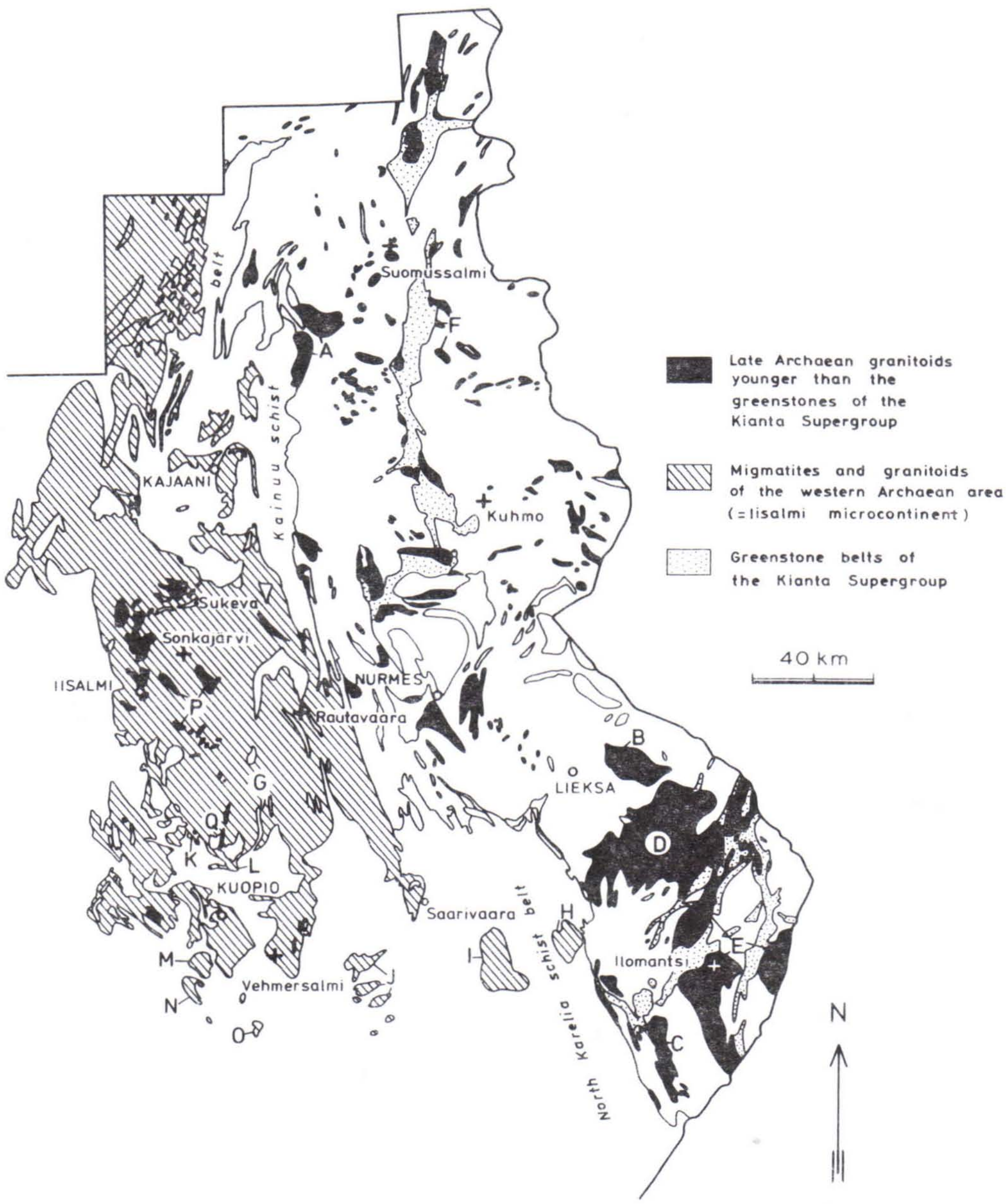


Fig. 7. Late Archaean granitoids younger than the Kianta Supergroup greenstone belts, and migmatites and granitoids of the western Archaean area.

A = Konivaara granite/granodiorite
B = Hattuvaara granite/granodiorite
C = Kutsu granite/granodiorite
D = Koitere granite/granodiorite
E = the youngest granodiorite, quartz diorite and tonalite provinces at Ilomantsi
F = Late Archaean potassium granites
G = Tahkomäki-Temo schist belt
H = Kontiolahti dome structure
I = Sotkuma dome structure
J = Juojärvi dome structures
K = Kuivasteenmäki dome structure
L = Kasurilanmäki dome structure
P = high-grade metamorphic blocks of Iisalmi, Varpaisjärvi and Lapinlahti
Q = Siilinjärvi alkaline rock area.

and migmatized by the Karelian granites and often containing amphibolite interlayers. The rocks probably also have late Archaean deformed trondhjemite as tectonic slices. The West Puolanka paragneiss described above grades into staurolite-mica schist and metapelite close to the Kainuu schist area. The age relation between the West Puolanka paragneiss and the late Archaean granitoids has not yet been established owing to the complex structure of the boundary zone (Laajoki 1980).

The analogous paragneisses NW of the lake Oulujärvi, the Koutaniemi and Paltaniemi gneisses and migmatites north and northwest of Kajaani and the paragneiss-like migmatites west of Rautavaara have been correlated with the above group.

2. East of the Tahkomäki-Temo schist zone there is an area extending from Rautavaara to Vehmersalmi and Saarivaara that is characterized by Archaean granitoids, augen gneisses and paragneiss-like migmatites, in places exhibiting intense cataclastic processes (Paavola 1983, personal comm.)

3. The Archaean migmatites and granitoids surrounded by the above paragneisses, cataclastic granitoids, migmatites and Proterozoic formations, and particulary those in the central part of the Iisalmi microcontinent at Sukeva and Sonkajärvi, resemble the old migmatites and granitoids with amphibolite and microtonalite xenoliths in the eastern Archaean area. According to Paavola (1983, personal comm.), there are blocks in the bedrock of the Iisalmi, Varpaisjärvi and Lapinlahti area that differ from the other Archaean migmatites and granitoids in the environment principally in their high grade of metamorphism. The blocks are characterized by enderbites and amphibolites with two pyroxenes. The enderbites have been assigned an age of 2680 Ma from zircon by U/Pb method, which has been interpreted as the age of high-grade metamorphism in the area Neuvonen *et al.* 1981.

The granitoids, gneisses and migmatites of the domes of Kontiolahti, Sotkuma, Oravisalo (a narrow tectonic slice; Peter Ward 1983, personal comm.), Juojärvi, Kuivasteenmäki, Kasurilanmäki, Kuopio, Puutossalmi, Sotkanniemi, Paukarlahti, Kotalahti and Konnuslahti have been correlated with this group (cf. Wilkman 1923b; Parkkinen 1974; Huhma 1975; Gaál 1981; Paavola and Vanne 1980, personal comm.; Niskanen 1980). Age determinations suggest that the granitoids of this group are c. 2700-2500 Ma from zircon by U/Pb method (GSF, Ann. Rep. 1966, 1970, 1972; GSF, Petrol. Dep. act. 1980, 1981).

The exact boundary between the 'reworked' Archaean migmatites and granitoids and the Karealian synorogenic quartz diorites and tonalites has still to be established in the marginal zone of the Archaean craton in the western part of the Iisalmi microcontinent.

4. At Siilinjärvi in the southern part of the western Archaean region there is an area of alkaline rocks that grade into Archaean migmatites and granitoids (Lukkarinen and Paavola 1980, personal comm.). The Siilinjärvi carbonatite formation is c. 2590 Ma from zircon by U/Pb method (GSF, Ann. Rep. 1977; Patchett *et al.* 1981).

## EARLY PROTEROZOIC ERA

### Karelia and Svecofennia Supergroups

The formations of the Karelia and Svecofennia Supergroups occur in the central and western parts of the Middle Finland area. Geochronologically the formations dated at c. 2500—1700 Ma belong to the former supergroup. The boundary between the Karelia and Svecofennia Supergroups, which still has to be checked, is marked with a dotted line on the map (Fig. 8). It runs approximately along the traditional boundary between the Karelides and Svecofennides (Simonen 1980, Fig. 3), coinciding in the south with the geosuture proposed by Koistinen (1981, Fig. 22).

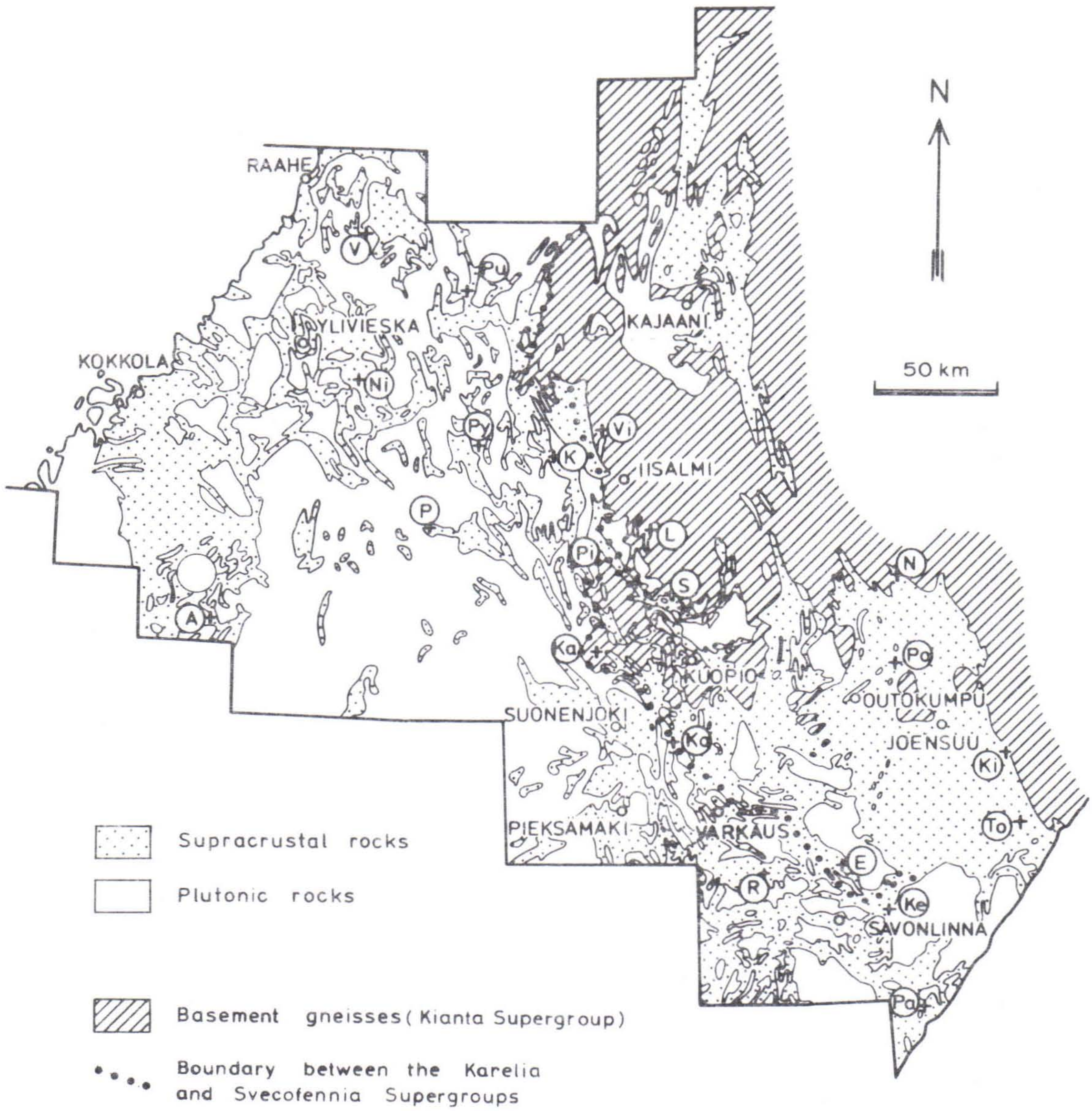


Fig. 8. Karelia and Svecofennia Supergroups in MiddleFinland.

| | |
|---|---|
| A = Alajärvi | Pa = Parikkala |
| E = Enonkoski | Pi = Pielavesi |
| K = Kiuruvesi | Po = Polvijärvi |
| Ka = Karttula | Pu = Pulkkila |
| Ke = Kerimäki | Py = Pyhäsalmi |
| Ki = Kiihtelysvaara | R = Rantasalmi |
| Ko = Kotalahti | S = Siilinjärvi |
| L = Lapinlahti | To = Tohmajärvi |
| N = Nunnanlahti | V = Vihanti |
| Ni = Nivala | Vi = Vieremä |
| P = Pihtipudas | |

The Karelia Supergroup is divided into three early Proterozoic groups: Sariola (c. 2500—2300 Ma), Jatuli (c. 2300—2000 Ma) and Kaleva (c. 2000—1700 Ma). The lower age limit for the Sariola, c. 2500 Ma, defines the internationally recommended boundary between the Archaean and Proterozoic mentioned above (Sims 1980; Meriläinen 1980). The boundary between the Sariola and Jatuli Groups has been set at about 2300 Ma because the Mustalampi quartz vein, fragments of which occur in the pre-Jatulian arkosite at Kiihtelysvaara, has been dated at c. 2340 Ma (Pekkarinen 1979; dated by Pb/Pb method; Meriläinen 1980) and because the oldest metadiabase dykes that can be correlated with the Jatuli Group are c. 2200 Ma from zircon by U/Pb method (Sakko 1971; Pekkarinen 1979; Laajoki 1980). The boundary between the Jatuli and Kaleva Groups has been established at c. 2000 Ma because the younger metadiabase dykes of that age, which intrude the Jatuli Group, have not been observed to cut the sedimentary rocks of the Kaleva Group (Simonen *et al.* 1978; Simonen 1980; Meriläinen 1980), and because the iron formations in the upper part of the Jatuli Group are c. 2080—2050 Ma by the whole-rock Pb/Pb dating (Sakko and Laajoki 1975). The upper age limit of the Kaleva Group, 1700 Ma, is based on the fact that the U/Pb age of zircon from the oldest rapakivi granites in southern Finland is 1700—1640 Ma (Vaasjoki 1977).

The Svecofennia Supergroup includes the early Proterozoic Bothnia Group, whose lower age limit has been set at 2000 Ma even though rocks of this age or older have not been encountered in the Middle Finland area. The upper age limit of this group, 1700 Ma, is based on the age of the rapakivi granites, as is the upper age limit of the Kaleva Group.

## Sariola Group

Formations of the Sariola Group, small compared with those of the Kianta Supergroup, are encounted in several places in the area of Middle Finland in association with fracture zones trending NW-SE (Fig. 9). The formations occur as relics in Archaean formations and between rocks of the Archaean and the Jatuli Group. Hence, the original meaning of the term Sariola (Eskola 1919, 1963; Väyrynen 1954; see also Meriläinen 1980) has been extended to include all the formations that lie lithostratigraphically and geochronologically between the Kianta Supergroup and the Jatuli Group (2500—2300 Ma).

Whenever possible the Sariola Group has been divided lithostratigraphically into two subgroups: the Lower Sariola (age limits c. 2500—2400 Ma) and the Upper Sariola (age limits c. 2400—2300 Ma). The boundary between the Lower Sariola and Upper Sariola Subgroups has been set at 2400 Ma because the Koillismaa layered intrusions that can be correlated geochronologically with the Lower Sariola are c. 2440 Ma from zircon by U/Pb method (Kouvo 1977).

The Lower Sariola Subgroup begins with a polymictic conglomerate with angular or subangular clasts of younger Archaean granite, microtonalite and sericite schist. The conglomerate matrix is quartz, plagioclase and sericite. Arkosites often occur on top of and as interlayers in the breccia conglomerate. The breccia conglomerate-arkosite formation is encountered in several places including the Saari-Kiekki greenstone belt, Kurkikylä greenstone belt (cf. Laajoki 1980), Sotkamo area (cf. K. Mäkelä 1976, Havola 1980) and the Kiihtelysvaara-Värtsilä area (cf. Nykänen 1968, 1971b; Pekkarinen 1979; Fig. 10). At Saari-Kiekki and Kurkikylä the Lower Sariola Subgroup breccia-conglomerate-arkosite formation is overlain by a mafic volcanite (andesitic basalt and andesite are also encountered at Saari-Kiekki; cf. Fig. 10). The Näränkävaara layered intrusion has been correlated in age with the above conglomerate-arkosite-volcanite subgroup (cf. Alapieti *et al.* 1979, Figs 9 and 10).

The Upper Sariola Subgroup consists of sublitharkosite, arkose and polymictic conglomerate (Fig. 10). The clasts in the polymictic conglomerate highest in stratigraphy are of younger Archaean granitoids (2750—2655 Ma), Lower Sariola Subgroup rocks and mafic volcanites of the Kianta Supergroup. As a rule the conglomerate matrix is

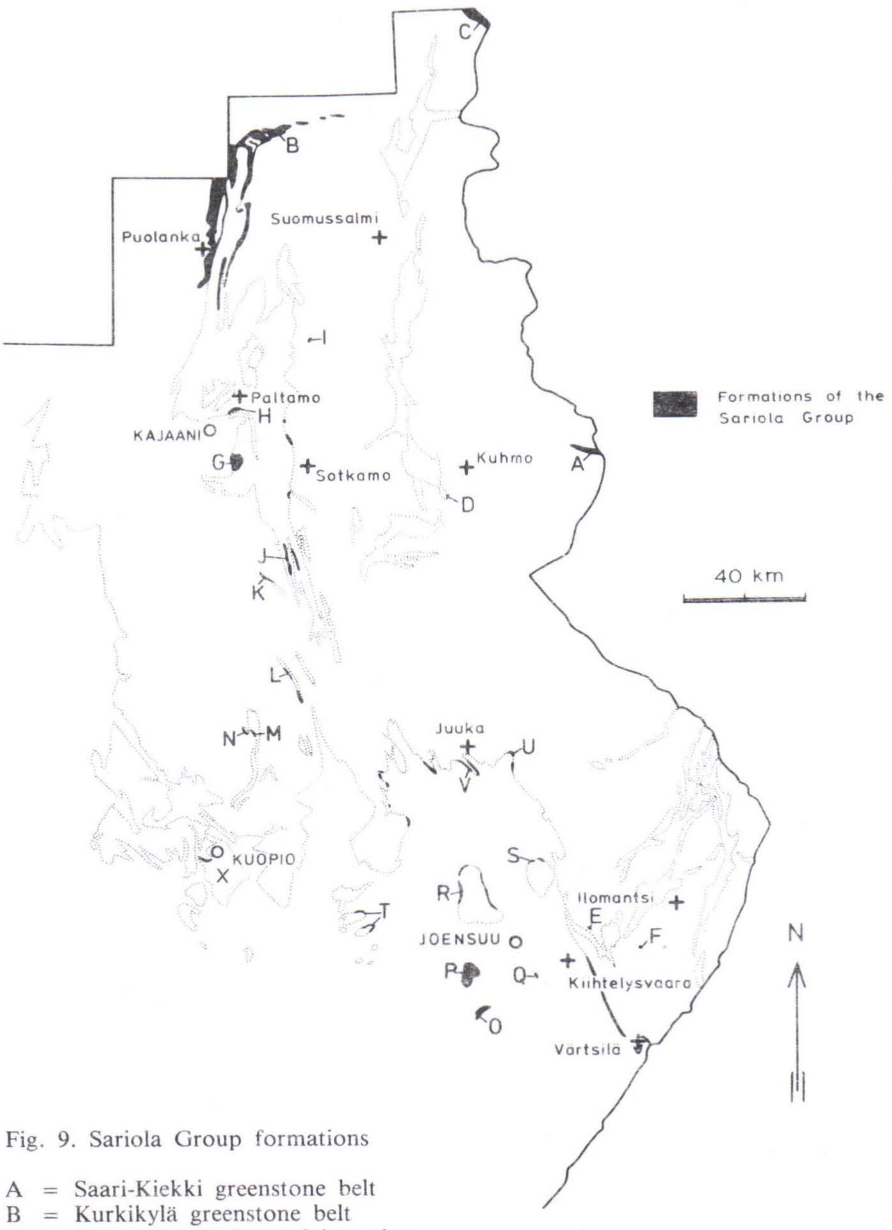


Fig. 9. Sariola Group formations

A = Saari-Kiekki greenstone belt
B = Kurkikylä greenstone belt
C = Näränkävaara layered intrusion
D = Kirkkosuo polymictic conglomerate
E = Löytöjärvi
F = Pamilonvaara
G = Soidinvaara
H = basal conglomerate at Hietalahti, Paltamo
I = Jokikylä conglomerate at Ristijärvi
J = Hiienvaara conglomerate in southern Sotkamo
K = Älänteenjärvi conglomerate
L = basal conglomerates of the Keyritty belt
M = basal conglomerates of the Tahkomäki-Temo belt
N = Reittiö basal conglomerates
O = Oravisalo dome structure
P = Liperinsalo dome structure
Q = Suhmura dome structure
R = Sariola formations in the margin of the Sotkuma dome structure
S = Sariola formations in the margin of the Kontiolahti dome structure
T = Sariola formations of the Juojärvi dome structure
U = Ipatti polymictic conglomerate
V = basal conglomerates at Mölöjärvi, Juuka
X = basal conglomerates at the western margin of the Kuopio dome structure

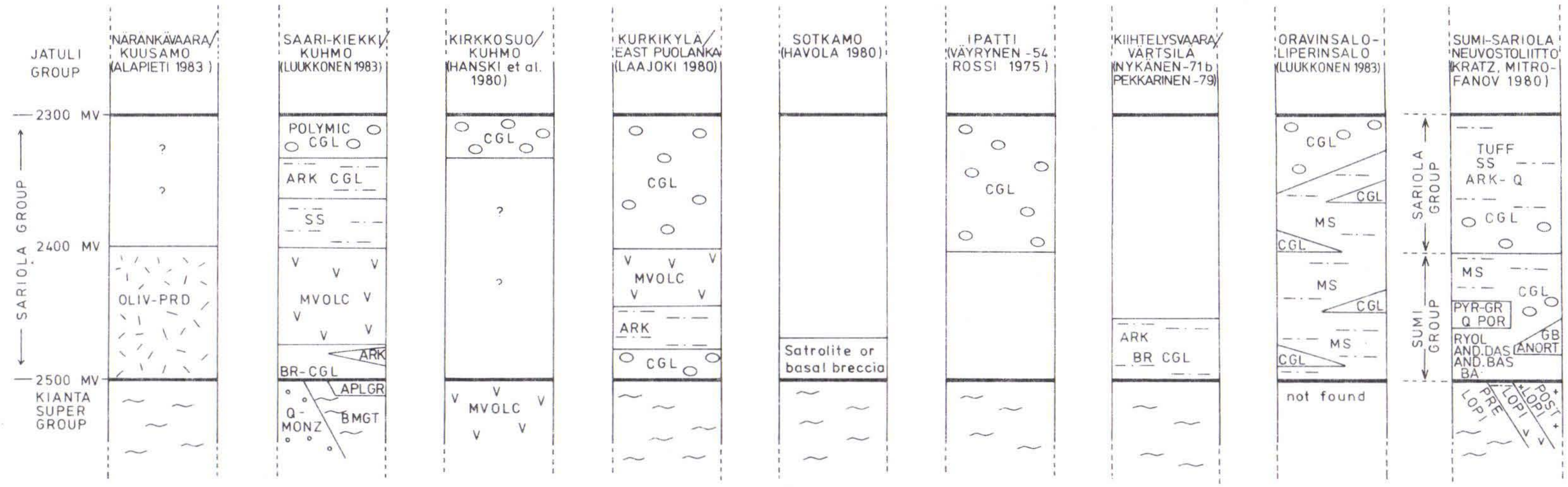


Fig. 10. Stratigraphy of the Sariola Group

| | | |
|---|---|---|
| AND BAS | = | andestic basalt |
| AND DAS | = | andesitic dacite |
| ANORT | = | anorthosite |
| APLGR | = | aplite granite |
| ARK | = | arkosite |
| ARK CGL | = | arkosic conglomerate |
| ARK Q | = | arkosic quarzite |
| BA | = | basalt |
| BMGT | = | banded migmatitic tonalite-trondhjemite |
| BR CGL | = | breccia conglomerate |
| CGL | = | conglomerate |
| GB | = | gabbro |
| MS | = | mica schist |
| MVOLC | = | mafic volcanite |
| OLIV PRD | = | olivine peridotite |
| POLYMIC CGL | = | polymictic conglomerate |
| PYR GR | = | pyroxene granite |
| Q MONZ | = | quartz monzonite |
| Q POR | = | quartz porphyry |
| RYOL | = | rhyolite |
| SS | = | sandstone |
| TUFF | = | tuff |

mafic weathered volcanite of the Lower Sariola Subgroup or the Kianta Supergroup, or both.

All the above Upper Sariola Subgroup formations are encountered in the Saari-Kiekki greenstone belt in the eastern Kuhmo. The Kirkkosuo polymictic conglomerate in the southern part of the Kuhmo schist area (cf. Taipale and Tuokko 1981; Hyppönen 1983; a granitoid clast in the conglomerate is c. 2536 Ma old; dated from zircon by U/Pb method).

The Kurkikylä volcanic conglomerate in Puolanka (cf. Laajoki 1980), the Ipatti polymictic conglomerate in Juuka (cf. Rossi 1975), the Löytöjärvi conglomerate in Tuupovaara (cf. Nykänen 1971b), the Pamilonvaara conglomerate in Tuupovaara (cf. Nykänen 1971b) and the Torohvinniemi polymictic conglomerate in the SE part of the Liperinsalo dome structure are probably analogous to the uppermost polymictic conglomerate.

There are several places in which it has not been possible to divide the Sariola Group into subgroups because of the lack of relevant information; the formations have therefore been discussed under the general term Sariola Group. In the following they are discussed by the names of their sites of occurence as marked in Fig. 9.

In the Kainuu schist area the Akanvaara Formation in Central Puolanka, Phyllite Formation I, the arkosites that occur in many places between the Archaean granitoids and the Jatuli Group (cf. Wilkman 1921, 1923; Laajoki 1973, 1976, 1980; Heino 1980, personal comm.), the Soidinvaara acid metatuffs (or hybrid granite) in western Sotkamo, the carbonate rocks, the amphibolites and the iron formations in Sotkamo (Kopperoinen 1982, personal comm.) have all been correlated with the Sariola Group. Whether or not the Jokikylä conglomerate at Ristijärvi (Wilkman 1921) and some of the conglomerates at Hiienvaara and Älänteenjärvi in southern Sotkamo (Wilkman 1921; Heino and Vanne 1980, personal comm.) are Sariola conglomerates is still a subject of debate.

In the area between the Kainuu and North Karelia schist zones the basal conglomerates in the Keyritty belt in Rautavaara, at the western margin of the Tahkomäki-Temo belt and at Reittiö in Nilsiä (Paavola 1980, personal comm.) are included in the polymictic conglomerates of the Sariola Group.

In the North Karelia schist area the Sariola Group is represented by greywackes and arkosites of the Oravisalo and Liperinsalo dome structures, which often contain interlayers of small-pebbled conglomerate (pebbles of Archaean granitoids and feldspar). Some of the arkosites and conglomerates in the inner parts of the Suhmura dome structure could possibly also be classified as Sariola Group (Heino 1980, personal comm.).

Sariola arkosites occur in many places between the Jatulian quartzites and the Archaean granitoids, e.g. at the margins of the Sotkuma dome (cf. Huhma, 1975; Äikäs 1980, personal comm.), at the margins of the Juojärvi dome (cf. Huhma 1975) and in the northern and eastern parts of the North Karelia schist areas (cf. Wilkman 1921, Huhma 1975). The basal conglomerates at Mölönjärvi in Juuka, some of the basal conglomerates in the northern part of the Kontionlahti dome previously interpreted as glaciogenic (Marmo and Ojakangas 1983) are also polymictic conglomerates of the Sariola Group, and the proposed Sariolan basal conglomerates at the western margin of the Kuopio dome (the conglomerates at Lippumäki; cf. Frosterus and Wilkman 1920, Aumo 1983 a, b) are under discussion.

The Sariola Group described from the area of Middle Finland can be correlated with the Sumi-Sariola Group in Soviet Karelia (cf. Kratz and Mitrofanov 1980; Sokolov and Stenar 1980). The Sumi Group in Soviet Karelia corresponds to the Lower Sariola Subgroup in the area of Middle Finland, and the Sariola Group in Soviet Karelia to the Upper Sariola Subgroup.

**Jatuli Group**

The majority of the formations in the Kainuu schist area and a considerable number of those in the northern and eastern parts of the North Karelia schist area belong to the early Proterozoic Jatuli Group. The schist belts of Rautavaara, Keyritty, Pisa and Tahkomäki-Temo are among the smallest of the formations of this group. Other small formations are the sericite schists, quartzites, amphibolites, black schists, dolomites, mica schists and cordierite-anthophyllite rocks at the margins of the dome structures of Suhmura, Kontiolahti, Sotkuma, Liperinsalo, Oravisalo, Juojärvi, Kuopio, Puutossalmi, Kasurilanmäki, Kuivasteenmäki, Sotkanniemi, Paukarlahti, Kotalahti and Konnuslahti (cf. Nykänen 1971a, b, c; Huhma 1975; Pekkarinen 1979; Aumo 1983a, b; Lukkarinen 1981, personal comm.; Niskanen 1980; Paavola and Äikäs 1981, personal comm.). The formation overlain by the Kaleva Group at Tohmajärvi described by Nykänen (cf. 1971a, b) has also been correlated with the Jatuli Group (Fig. 11).

The Jatuli Group is characterized by rocks trending NNW-SSE or N-S (Fig. 11). In the area of Middle Finland the Jatuli Group has been divided lithologically and geochronologically into two subgroups: the Lower Jatuli Subgroup (c. 2300—2100 Ma) and the Upper Jatuli Subgroup (c. 2100—2000 Ma). The boundary between the Lower Jatuli and Upper Jatuli has been set at c. 2100 Ma, because the metadiabase dykes, which intrude the quartzites of the Lower Jatuli Subgroup, are c. 2200—2100 Ma from zircon by U/Pb method and from whole rock by Pb/Pb method (Sakko 1971; Pekkarinen 1979). The upper age limit of the Upper Jatuli Subgroup has been set at 2000 Ma because the youngest metadiabase dykes, which do not crosscut the Kaleva Group formations, are c. 2000 Ma old (Kouvo 1976; Simonen *et al.* 1978; Simonen 1980).

Most of the rocks of the Lower Jatuli Subgroup are autochthonous and allochthonous Kainuan quartzites named and described by Väyrynen (1933, 1954). In the *Kainuu schist area* and in the northern and eastern parts of the *North Karelia schist area* the quartzites occur in piles often several hundred metres thick (Fig. 11). Wherever the stratigraphic sequence is well preserved the quartzites have a basal part rich in sericite with kaolin and quartz (vein quartz and quartzite) grading upwards into orthoquartzite. The whole sequence is intruded by metadiabase dykes (Väyrynen 1933, 1938, 1954; Eskola 1963; Piirainen 1968; Piirainen, Honkamo and Rossi 1974; Nykänen 1971b, c; Laajoki 1973, 1976, 1980; Pekkarinen 1979; Meriläinen 1980, see Fig. 12). In places the quartzites contain kyanite or sillimanite, or both, in addition to sericite. Sillimanite is common, particularly in the quartzites of the Lower Jatuli Subgroup at the margins of the Kuopio, Kotalahti and Juojärvi dome structures.

In contrast to the typical stratigraphy of the Lower Jatuli Subgroup, the upper part of the Lower Jatuli Subgroup at Tuomivaara in Sotkamo contains dolomite and phyllite (cf. Mäkelä 1976) or then merely dolomite (Havola 1980). According to Paavola (1980, personal comm.), blue-grey quartz is encountered in the upper part of the Lower Jatuli Subgroup in the Tahkomäki-Temo schist belt. Mafic volcanite also occurs in the upper part of the Lower Jatuli Subgroup in the Kiihtelysvaara-Värtsilä area, (Fig. 12; cf. Pekkarinen 1979).

On our map the Upper Jatuli Subgroup has a somewhat broader definition than that intended by Väyrynen (1933, 1954) with the term Marine Jatuli. The Upper Jatuli Subgroup is composed of dolomites, mica schists, quartzites, sericite schists, black schists, iron formations (silicate, oxide and sulphide facies), mafic volcanites and mafic abyssal and hybabyssal intrusions (cf. Pekkarinen 1979). In many places the uranium and apatite-bearing quartz-feldspar rocks and dolomites of the Upper Jatuli Subgroup probably deposited between 2080 and 1900 Ma ago (Vaasjoki *et al.* 1980). According to Ervamaa (1980), the black schists of the Upper Jatuli Subgroup in the Kainuu schist area have often undergone nickel-copper-zinc mineralization.

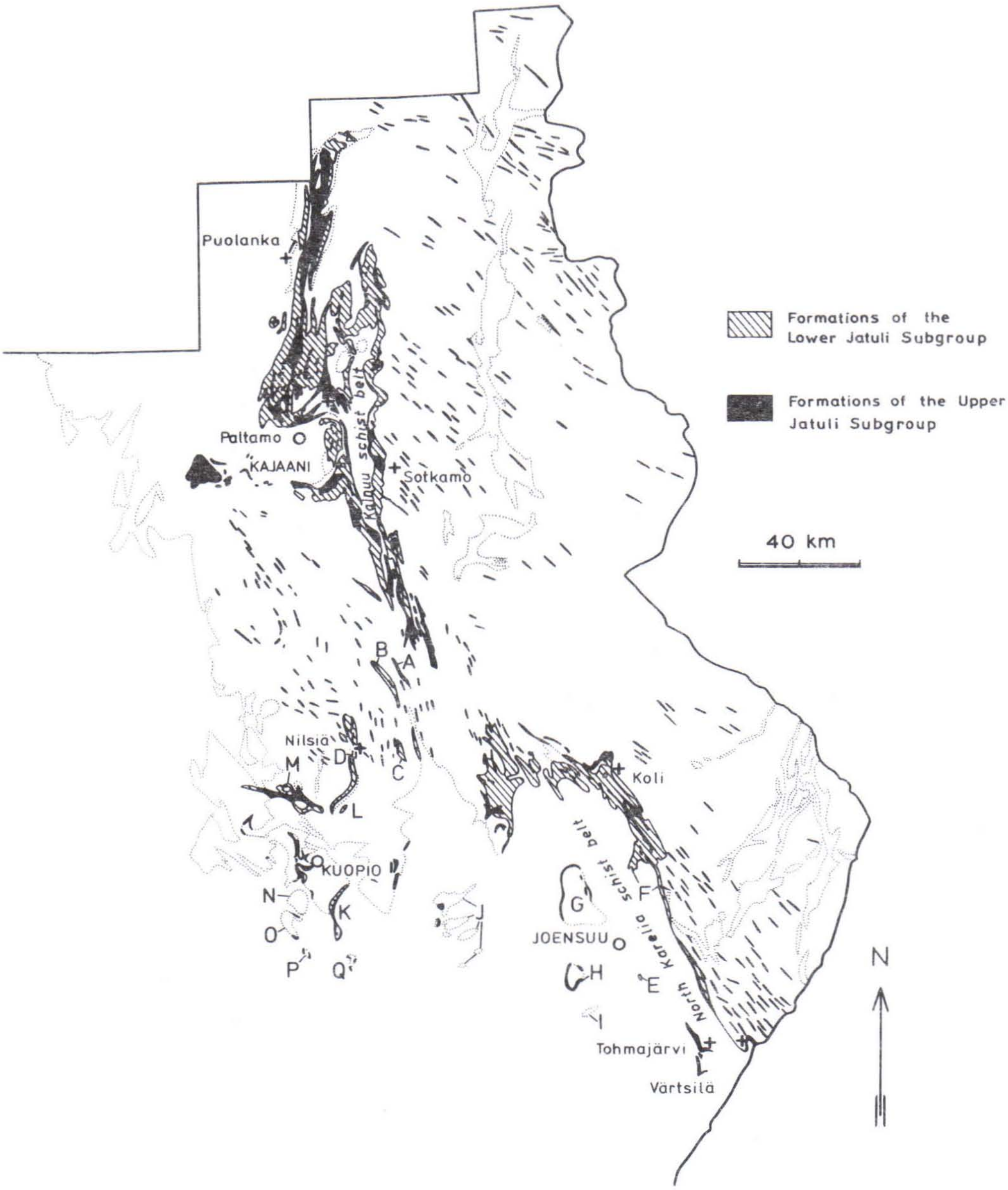


Fig. 11. Jatuli Group formations

A = Rautavaara schist belt
B = Keyritty schist belt
C = Pisa schist belt
D = Tahkomäki-Temo schist belt
E = Suhmura dome structure
F = Kontiolahti dome structure
G = Sotkuma dome structure
H = Liperinsalo dome structure
I = Oravisalo dome structure
J = Juojärvi dome structures
K = Puutossalmi dome structure
L = Kasurilanmäki dome structure
M = Kuivasteenmäki dome structure
N = Sotkanniemi dome structure
O = Paukarlahti dome structure
P = Kotalahti dome structure
Q = Konnuslahti dome structure

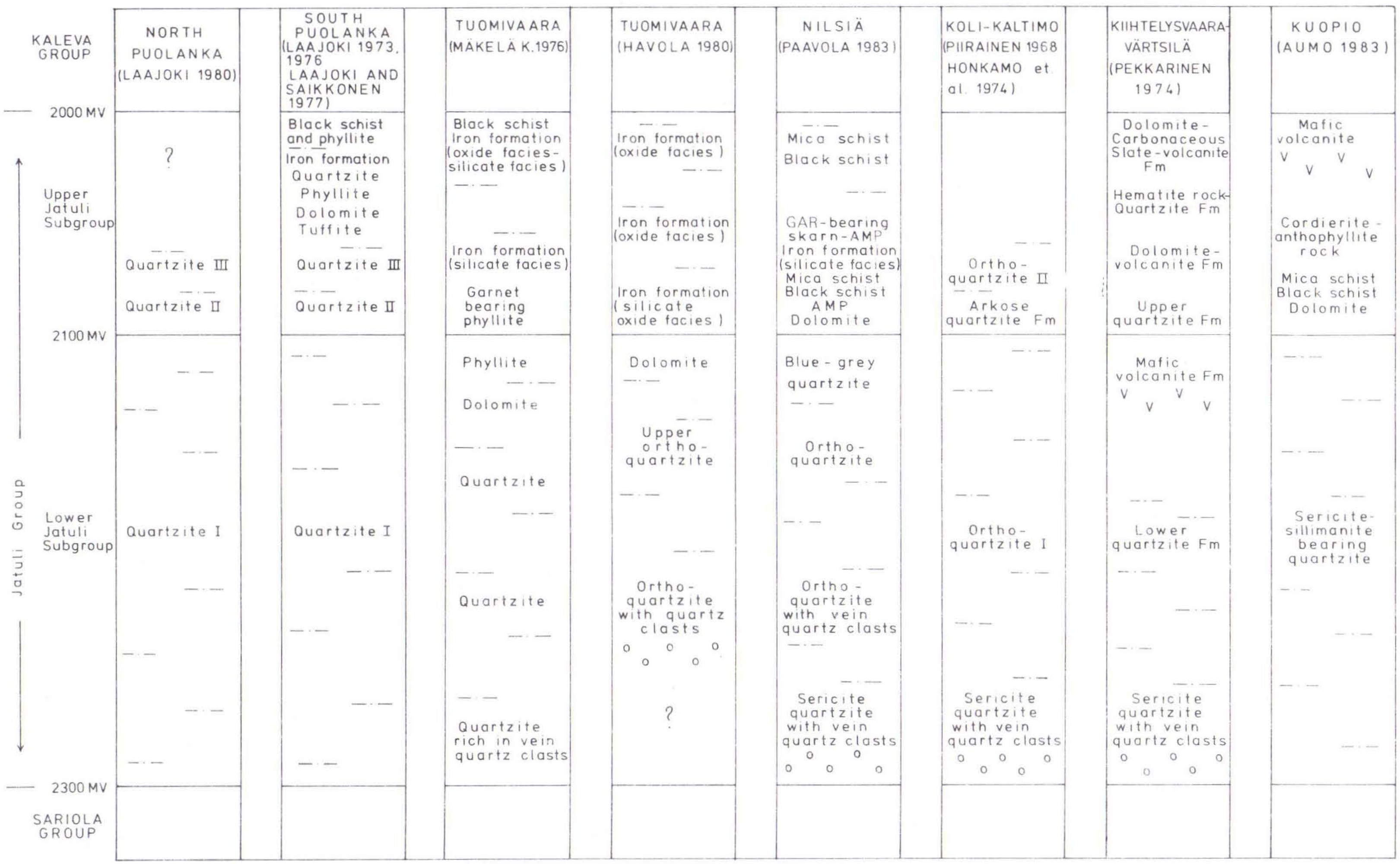


Fig. 12. Stratigraphy of the Jatuli Group

AMP = amphibolite
Fm = formation
GAR = garnet

**Kaleva Group**

The Kaleva Group has been divided into two subgroups: the Lower and Upper Kaleva. The boundary between the subgroups, 1900 Ma (Fig. 2), is based on the fact that the synorogenic and late-orogenic plutonic rocks that intrude the sedimentary rocks are 1900—1800 Ma old (Kouvo 1976; Simonen *et al.* 1978; Simonen 1980). Hence, despite insufficient lithostratigraphic information, it has been possible on geochronological grounds to distinguish the sedimentary rocks and volcanites preceding the major stage of orogenic movements from the intrusive rocks and volcanites of the major stage and also from contemporaneuous and later sedimentation.

The rocks of Kaleva Group have been described as incompletely weathered flysch sediments metamorphosed into phyllites, mica schists and mica gneisses (Wegman 1928, 1929a; Väyrynen 1954; Simonen 1960b). They contain interlayers of graphite and sulphide schists, arkosites and quartzites, particulary in their basal parts. Volcanites are not encountered in Kaleva Group in the area of Middle Finland except in the Outokumpu area and possibly also the Jormua area. The Kaleva sediments often exibit ovoidal bodies of variable composition, although in general they contain quartz, feldspar, micas and calc-silicates (Frosterus and Wilkman 1920; Hackman 1933; Nykänen 1971c; Gaál and Rauhamäki 1971; Mattila 1971; Huhma 1975; Havola 1980; Lavikainen 1983, personal comm.). They may be silica and lime precipitates — concretions (Hackman 1933) and also boudins of lime-bearing layers (Huhma 1975). Note that similar bodies also occur in the Bothnia Group sediments (Saksela 1933). The distribution and stratigraphy of the sediments classified as Lower Kaleva Subgroup are shown in Figs. 13 and 14.

In the *Nunnanlahti—Tohmajärvi area,* which corresponds roughly to the Höytiäinen basin described by Väyrynen (1954), there is a phyllite-mica schist formation with a N-S trend (Frosterus and Wilkman 1920; Hackman 1933; Väyrynen 1933, 1954; Pelkonen 1966; Nykänen 1968, 1971d, c; Mattila 1971; Huhma 1975; Pekkarinen 1979). Huhma (1975) calls the sediments in the northern part of the zone fine-grained mica gneisses and phyllites, but Piirainen *et al.* (1974) call them greywacky schists. The rocks of the phyllite-mica schist formation are fine-grained sediments showing layering and often distinct graded bedding, the average thickness of the varves being 1—2 cm (Nykänen 1968, 1971b). The mica schists frequently contain graphite and sulphides, and, depending on the grade of metamorphism, porphyroblasts of staurolite, andalusite, garnet and sillimanite (Nykänen 1968, 1971b, c; Huhma 1975; Campbell *et al.* 1979).

The phyllite-mica schist formation in the Kiihtelysvaara — Värtsilä area has a turbiditic conglomerate-quartzite formation in its basal part (Pekkarinen 1979). Similar conglomerates also occur in the Koli area (Piirainen *et al.* 1974; Piirainen 1976). The Kiihtelysvaara conglomerate-quartzite formation, which wedges out westwards, deposited on top of the Jatulian sediments with an unconformity in between (Pekkarinen 1979). The pebbles in the conglomerate are quartzite, volcanic rocks, carbonaceous phyllite and vein quartz. The conglomerate grades into a dark varved quartzite, in which the lower part of the varves is quartzitic and the upper part phyllitic. With the increase in phyllite and the decrease in quartzite it grades into phyllite and mica schist. The conglomerates, which in the Koli area grade into greywacky schists, lie directly on the basement gneiss in places, in which case their pebbles also include rocks from the basement gneiss complex (Piirainen *et al.* 1974). According to Nykänen (1968, 1971b, c), the intraformational conglomerate at Kirkkoniemi in Tohmajärvi, in which the pebbles derive from rocks of the basement gneiss area, quartzites, amphibolites, phyllites and mica schists, and the impure arkoses and intraformational conglomerates at Hammaslahti in Pyhäselkä are located stratigraphically on the lower parts of the phyllite-mica schist formation. The Kirkkoniemi conglomerate and its stratigraphic position have also been discussed by Wilkman (1923a), Wegman (1928, 1929c) and Pokki (1965). According to Huhma (1976) and Pekkarinen (1979), the zone in which the above phyllite-mica schist formation is located is a miogeosynclinal trough (the Höytiäinen basin). The miogeosynclinal ridge, which runs through the domes of Sotkuma, Liperinsalo and Oravisalo, separates it from the eugeosynclinal trough west of it.

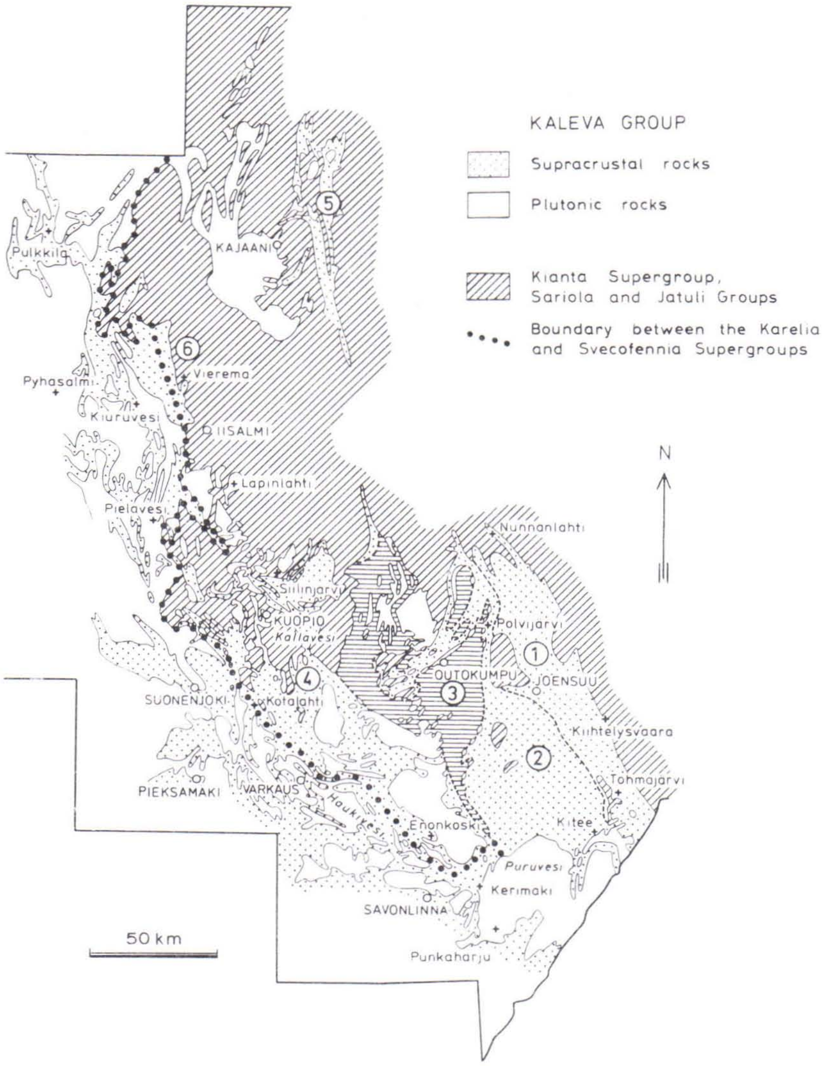


Fig. 13. Areas in which Kaleva Group rocks occur
1. Nunnanlahti-Tohmajärvi
2. Puruvesi-Polvijärvi
3. Outokumpu Ore District (Koistinen 1981)
4. Puruvesi-Kallavesi
5. Ristijärvi-Nuasjärvi
6. Vieremä

The zone named the *Puruvesi—Polvijärvi area* is bounded in the northwest and west by the Outokumpu Ore District (Koistinen 1981, Fig. 22) and in the southwest by a fracture zone trending NW-SE. The Pyhäselkä and Orivesi basins by Väyrynen (1954) are located in the southern and central parts of the zone. Medium-grained varved mica gneiss with abundant black schist interlayers (Huhma 1975) is the predominant rock type in the northern part of the zone. In the central parts of the zone, at Liperi and Rääkkylä, there are pale mica schists and mica gneisses that are layered and often also varved. The varves are conspicuously thicker (avarage 10 cm) than in the adjacent area of the phyllite-mica schist formation (Lavikainen and Laiti 1983, personal comm.). In the southern part of the zone there are also mica schists and mica gneisses that often contain black schist interlayers. The rocks are layered and frequently exhibit graded bedding, current bedding and slumping structures as primary features (Nykänen 1975; Lavikainen 1983, personal comm.). At Puhos in Kitee the mica schist has a three-metre-thick

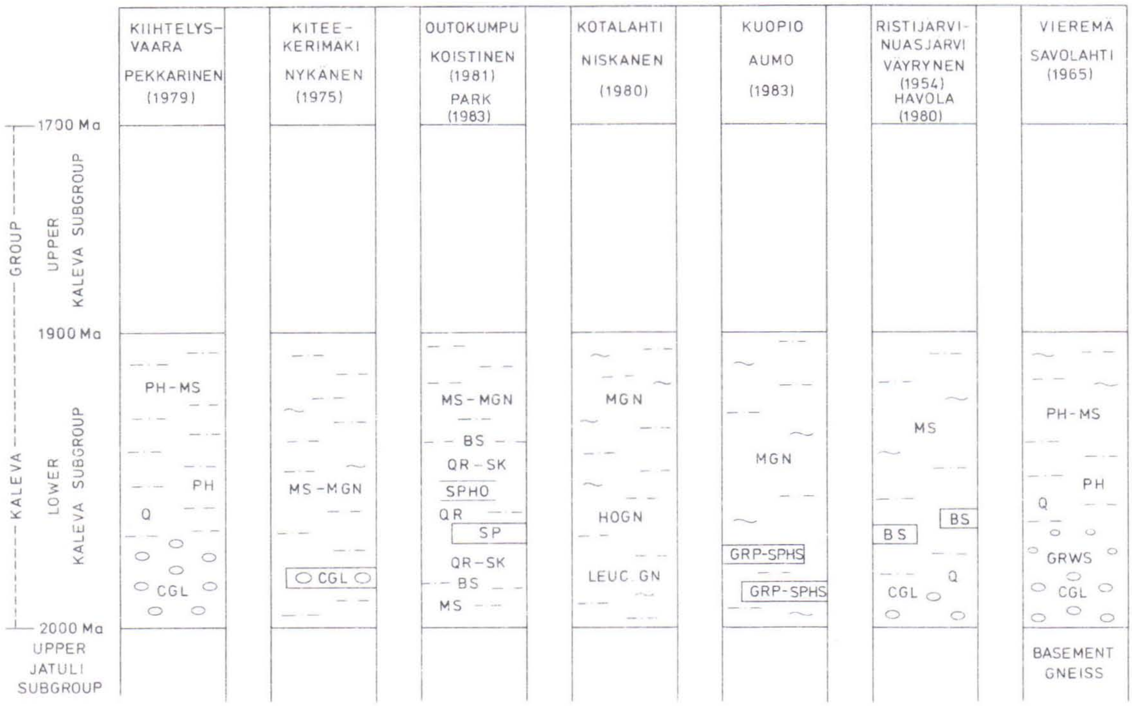


Fig. 14. Stratigraphy of the Kaleva Group.

| | | | |
|---|---|---|---|
| PH | = phyllite | SK | = skarn |
| MS | = mica schist | SPHO | = sulphide ore |
| Q | = quartzite | SP | = serpentinite |
| CGL | = conglomerate | HOGN | = hornblende gneiss |
| MGN | = mica gneiss | LEUC. GN | = leucocratic gneiss |
| BS | = black schist | GRP-SPHS | = graphite-sulphide schist |
| QR | = quartz rock | GRWS | = greywacky schist |

intraformational conglomerate with pebbles of granodiorite, amphibolite, quartzite and quartz-feldspar schist (Nykänen 1975).

The *Outokumpu Ore District* has been outlined as proposed by Koistinen (1981, Fig. 22). The area is characterized by flysch-type sediments, serpentinites of the Outokumpu Association (Gaál *et al.* 1975) and associated quartz rocks, carbonate and skarn rocks, Cu-Co-Zn ores and black schists (Huhma 1970; Huhma and Huhma 1970; Huhma 1975, 1976; Gaál *et al.* 1975). Hornblende gabbro, too, has been encountered in the serpentinite at Horsmanaho, and amphibolites at Miihkali, Kokka and Losomäki, of which the banded amphibolite at Losomäki has been interpreted as a deformed pillow lava (Koistinen 1981; Park and Bowes 1982). The serpentinites have been defined as ophiolites marking the position of an overthrust fault (Wegman 1928; Väyrynen 1954). According to Koistinen (1981), the above rocks constitute an ophiolite complex that, representing the remnant of an oceanic crust, was overthrust from the southwest into flysch-type sediments before the main phase of Svecokarelidic folding (Koistinen 1981; Koistinen *et al.* 1983; see also Gaál *et al.* 1975). Park (1983), however, maintains that the serpentinites derive from an ultramafic magma that formed sills in the sediments and volcanites of a back-arc type of basin c. 1970 Ma ago. They were covered by flysch sediments, and the whole lithologic association was displaced to its present site as a nappe (the Outokumpu nappe) c. 1900 Ma ago. M. Mäkelä (1983) has suggested that the serpentinites were formed when a lava, probably basaltic in composition, erupted on the sea floor and reacted with seawater.

The flysch sediments in the Outokumpu area are pale, fine-grained mica schists with layers from a few centimetres to over 0.5 m thick, but in which varved structure is rare (Koistinen 1981). In some places east of Juojärvi the mica schists contain granitic veins whose abundance gradually increases westwards, and the schists pass into veined gneisses (Huhma 1975).

The Outokumpu Association (Gaál *et al.* 1975) has been interpreted as Kalevian (Huhma 1975, 1976; Simonen *et al.* 1978; Simonen 1980; K. Mäkelä 1981; Koistinen 1981; Park 1983). The U/Pb age, 2285 Ma, of detrital zircon from mica schist from the Vuonos mine gives the minimum age of the source material; the model age of lead from the Outokumpu ore (2100 Ma) refers to the age of galena, not to the true age of the formation (Vaasjoki 1981).

The geology of the Outokumpu area has also been reported by Frosterus and Wilkman (1920) and Väyrynen (1933, 1939). Haapala (1936) and Marttila (1972) have described the serpentinites; Peltola (1960, 1968) has discussed the black schists; Vähätalo (1953), Saksela (1957), Mikkola and Väisänen (1972) and Peltola (1978, 1980) have described the ores; and Distler (1954), Park (1983) and Koistinen (1981) the tectonic structure. Borchert (1954) and M. Mäkelä (1974) have proposed a marine volcanic-exhalative origin, and K. Mäkelä (1981) a marginal trench environment, for the ores.

The *Puruvesi-Kallavesi area,* which extends from Kerimäki to north of Kuopio, includes the areas immediately west of Kuopio and the surroundings of Leppävirta and Kotalahti. The rocks interpreted as belonging to the Lower Kaleva Subgroup are biotite plagioclase gneisses migmatized in many places by granitic and trondhjemitic neosomes. They have interlayers of calc-silicate rocks (skarns) and sedimentary amphibolites and, in the Kuopio area, graphite-sulphide schists as well. The mica schists frequently contain porphyroblasts of garnet, staurolite, cordierite and sillimanite. The mica gneisses are pelitic and psammitic sediments in origin, although migmatization has often obliterated the primary structures (Frosterus and Wilkman 1920; Hackman 1933; Wilkman 1923b, 1938; Väyrynen 1954; Preston 1954; Gaál and Rauhamäki 1971; J. Parkkinen 1974; Huomo 1976; Väänänen 1977; Korsman and Pääjärvi 1980; Paavola 1980; M. Parkkinen 1980; Aumo 1983a, b). At Kuopio and Kotalahti the mica gneisses deposited on the formations of the Upper Jatuli Subgroup (Huomo 1976; Aumo 1983a, b; J. Parkkinen 1974; Gaál 1980; Niskanen 1980). The U/Pb age of detrital zircon from the leucocratic gneiss in the basal part of the mica gneiss in the Kotalahti area, which is similar in appearance to the gneisses in the Archaean basement gneiss complex, is 2800 Ma (Niskanen 1980).

The *Ristijärvi-Nuasjärvi area* in the Kainuu schist belt contains phyllites and mica schists (Wilkman 1921, 1931; Väyrynen 1928, 1933, 1954; K. Mäkelä 1976; Havola 1980; Heino and Havola 1980). Petrographically, the phyllites and mica schists classified as Lower Kaleva Subgroup resemble the schists in the Höytiäinen and Pyhäselkä basins (Väyrynen 1954). In places there are conglomerates and quartzites in the basal parts of the schists (Väyrynen 1954; K. Mäkelä 1976; Havola 1980). At Tuomivaara the clasts in the conglomerate are quartz, quartzite, phyllite and also garnetiferous phyllite of the iron formation stratigraphically below the conglomerate (K. Mäkelä 1976). According to Havola (1980), the basal parts of the phyllites and mica schists also contain graphite and sulphide-bearing phyllites, in which case the boundary between the Upper Jatuli and the Kaleva schists is not always clear (see also Rastas 1969).

The stratigraphic position of the Jormua mafic volcanite-gabbro-metadiabase-serpentinite formation (the Jormua mafic complex; Rastas 1969) is still somewhat ambiguous. According to Wilkman (1931) and Väyrynen (1954), these volcanic rocks extruded on the Kalevian sediments, whereas Rastas (1969) maintains that the volcanites invaded the Jatulian sediments during eugeosynclinal magmatic activity and that the serpentinites were emplaced at the peak of sediment folding. Heino (1983, personal comm.) prefers to classify the volcanites and serpentinites as Kaleva, but because of the tectonic contacts between them and the sediments it is difficult to establish the stratigraphic postition of the rocks. According to K. Mäkelä (1980, 1981), the Kainuu schist belt and the Outokumpu area are located in the same Kalevian marginal trench. In the present paper the Jormua mafic complex has been correlated with the Outokumpu formation on account of its mafic rocks and thus classified as Lower Kaleva Subgroup. Quartz rocks, limestones and skarns typical of the Outokumpu association have not been found in the Jormua area (Heino 1983, personal comm.) but Vanne (1982) has established that they occur at Rautavaara, south of the Jormua area.

The belt of sedimentary rocks, some 40 km long and 2—8 km wide, of the *Vieremä area* is located northwest of Iisalmi. The belt is bordered in the east by Archaean granitoids, but because of the poor outcrops, the western border is less clearly defined (Mäkinen 1919; Wilkman 1931; Väyrynen 1954; Savolahti 1965; Marttila 1976, 1981; Huhtala 1979). The lowermost unit in stratigraphy is a polymictic conglomerate with clasts of quarzite, quartz-feldspar schist, limestone, phyllite, mica schist, mica gneiss and aplite granite from the basement gneiss complex (Wilkman 1931; Savolahti 1965; Marttila 1976, 1981). At Haajainen at the southern end of the belt, augen gneisses and augen schists are associated with the conglomerate, having formed from it through tectonic movements (Marttila 1976, 1981). The conglomerate is overlain by alternate layers of feldspathic quartzite and mica schist 0.5—5 cm thick with a total thickness of 200 m. Upwards in stratigraphy the rock grades into mica schist with local staurolite and garnet porphyroblasts (Savolahti 1965; see also Marttila 1981).

Several concepts have been proposed for the stratigraphic position of the Vieremä schist zone. According to Mäkinen (1919), the Kalevian sediments in the eastern part of the sedimentary wedge between Vieremä and Kiuruvesi (the same as in the present paper) are younger than the Bothnian sediments in the west. Wilkman (1931) included the whole area in the Kaleva, but considered it younger than the Bothnian rocks. According to Savolahti (1965), there is no definite boundary between the Karelian and Svecofennian schists but the conglomerates in the eastern margin and the overlying phyllites and mica schists are stratigraphically below the mica schists and hornblende schists at Kiuruvesi in the west. Marttila (1976, 1981) is of the opinion that the rocks in the southern part of the belt (the Vieremä-Haajainen series) are probably a Kalevian formation not intruded by the diabases and ophitic gabbros 1885 Ma old (U/Pb age from zircon). This series is the uppermost stratigraphic sedimentary unit in the area. In the present paper the conglomerate-quartzite-phyllite-mica schist formation in the eastern part of the belt has been included in the Lower Kaleva Subgroup on the basis of its lithology (compare with the Kiihtelysvaara area, Pekkarinen 1979) and is thus distinct from the mica schists, hornblende schists and amphibolites in the west (Marttila 1976, 1981; Huhtala 1979).

### Bothnia Group

Sederholm (1883, 1897) was the first to use the name Bothnia for the mafic metavolcanites, well-preserved conglomerates, and pelitic and psammitic metasediments that did not include pure quartzites and limestones in the Tampere schist zone. Simonen (1955, see also Väyrynen 1954) placed the rocks of the Bothnia group — mafic metavolcanites, greywacky schists, conglomerates and meta-arkoses — in the upper section of the deposits of the Svecofennidic orogeny cycle. Bothnian formations are encountered not only in their type area (the Tampere schist zone) but also elsewhere in southern Finland and Ostrobothnia. Simonen (1960b, 1980) later included the Bothnian formations at Tampere in the Middle Svecofennides. Mäkinen (1916) correlated the plagioclase gneisses, mafic and intermediate porphyrites, leptites, conglomerates, mica schists and associated quartzites and limestones of central Ostrobothnia with the Bothnia formations of southern Finland. On account of the complexity of the tectonic structure of the rocks, however, Mäkinen (1916) was not sure whether the volcanic and sedimentary rocks represented different stratigraphic levels of different sedimentation facies. Wilkman (1931), Saksela (1933b) and Laitakari (1942) later came to the conclusion that the volcanic formations in central Ostrobothnia were below the sedimentary formations.

In the present paper the Bothnia Group is understood to consist of pelitic and psammitic metasediments metamorphosed to various degrees, mafic, intermediate and

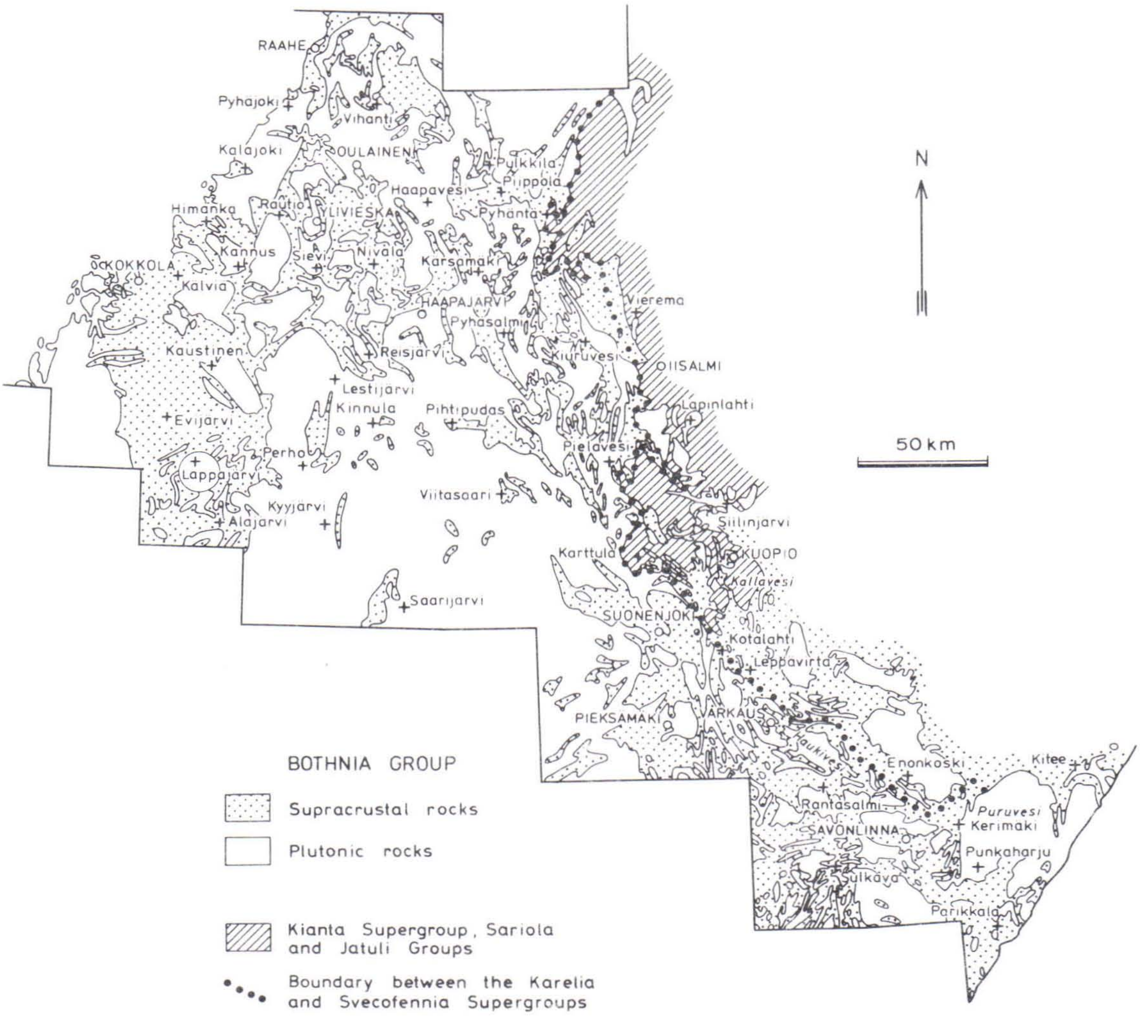


Fig. 15. Areas in which Bothnia Group rocks occur.

acid volcanites, limestones, skarns, quartzites, arkoses and black schists, which often occur in these rocks as interlayers. The Bothnia Group covers the southeastern and western parts of Middle Finland, i.e. the schist areas of Savo and Ostrobothnia (Fig. 15). Excluding some sedimentary rocks and volcanites interpreted as comagmatic with the mafic plutonites, the majority of the Bothnia Group rocks belong to the lower subgroup. The stratigraphy of the various areas is shown in Fig. 16a and b.

According to Nykänen (1980, 1982, 1983), the lowermost rocks in the *Punkaharju—Parikkala area* are sedimentogeneous diopside amphibolites and associated limestones and quartzite. These are overlain by a leptite-amphibolite formation consisting of metalavas and metatuffs in which the rocks vary from rhyodacite to picrite in chemical composition. Above the volcanite formation there is a volcanic conglomerate with clasts of leptite and amphibolite. The conglomerate is overlain by coarse-grained garnet-sillimanite-cordierite gneisses — kinzigites with alternating layers of fine-grained pelitic mica gneisses in many places migmatized by granite. The kinzigite-mica gneiss formation has interlayers of volcanic leptites, sedimentary quartz-feldspar schists, hornblende gneisses, black and graphite gneisses. The schists in the Parikkala and Punkaharju areas were initially eugeosynclinal sediments (Nykänen 1983).

The *Rantasalmi—Sulkava area* has pelitic and psammitic sediments and diopside amphibolites, some of which, e.g. at Rantasalmi, are pillow lavas (Korsman 1973). In the Sulkava area, the metaturbidites of Rantasalmi (Gaál and Rauhamäki 1971) have been altered by progressive metamorphism into garnet-cordierite-sillimanite gneisses, migmatized by a coarse-grained granite that has obliterated the primary sedimentary structures (Korsman 1977, Korsman and Lehijärvi 1973). Small limestone, skarn and quartzite occurrences are to be found here and there among the gneisses in the Sulkava area. Korsman (1981, personal comm.) maintains that the metasediments in the Rantasalmi area are above and below the amphibolites in stratigraphy.

Gaál and Rauhamäki (1971) have interpreted the garnet-cordierite-sillimanite gneisses in the *Savonlinna—Haukivesi area* as metamorphosed counterparts of the Rantasalmi miogeosynclinal metaturbidites. These gneisses occur east of Savonlinna and in the central parts of Haukivesi, e.g. at Voinsalmi and Torasalo (Gaál and Rauhamäki 1971; Väänänen 1977). Rocks similar to the Rantasalmi metaturbidites are also encountered at Makkola, northeast of Savonlinna (Grundström 1979). The basal parts of the metaturbidites often contain polymictic conglomerates with clasts of amphibolite, leptite, mica schist, mica gneiss and vein quartz, the Savonlinna conglomerate has granite clasts as well. The matrix is greywacke, arkose, hornblende gneiss or even amphibolite (Gaál and Rauhamäki 1977). In the southern part of Haukivesi there are banded diopside amphibolites with narrow interlayers of limestone, skarn and, in places, quartzite. Among the amphibolites there is a pillow lava zone that extends from Parkunmäki northwest of Savonlinna via Varparanta to Makkola (Saltikoff 1965; Gaál and Rauhamäki 1971). According to Gaál and Rauhamäki (1971), the diopside amphibolites with associated pillow lavas are below the metaturbidites in stratigraphy.

In the *Kerimäki area,* northwest and west of the village of Kerimäki, there are garnet-cordierite-sillimanite gneisses of the Savonlinna type veined with granite. Below them in stratigraphy are diopside amphibolites, limestones and black schists. These rocks have been included in the Lower Bothnia Subgroup, although Nykänen (1975) considers the garnet-cordierite-sillimanite gneisses and diopside amphibolites at Kerimäki to be more intensely metamorphosed counterparts of the Tohmajärvi Kalevian and Jatulian formations farther east. According to Nykänen (1975), the schists at Kerimäki represent a transition between the schists at Haukivesi-Savonlinna and the Ladogian formation at Sortavala (see Väyrynen 1954).

The lowest stratigraphic formation in the *Pieksämäki area* (Vorma 1971; Vorma 1981, personal comm.; Virtakainen 1966) contains mica gneisses, quartz-feldspar schists and sedimentary and volcanogeneous amphibolites and hornblende gneisses with limestone and skarn interlayers. They are overlain by pelitic and psammitic metasediments metamorphosed into mica schists and mica gneisses with interlayers of black schist.

The basal parts of the supracrustal rocks in the *Suonenjoki—Rautalampi area* often contain garnet-cordierite-sillimanite veined gneisses — kinzigites with graphite and sulphide-bearing interlayers (Äikäs 1977). The volcano-sedimentogeneous amphibolites with meta-arkose and pyroxene gneiss interlayers are younger than the veined gneisses. East of Suonenjoki there are greywacky mica gneisses, veined gneisses, cordierite gneisses, graphite gneisses and hornblende gneisses, of which the mica gneisses veined with granite predominate (Wilkman 1938; M. Parkkinen 1980). M. Parkkinen (1980) correlates the hornblende gneisses with the hornblende gneisses at Kotalahti. J. Parkkinen (1974) classifies the Kotalahti hornblende gneisses with the Jatulian schists immediately below the Kalevian sediments. According to Niskanen (1980), hornblende gneisses are encountered between the Kalevian leucocratic gneiss and the mica gneisses. Koistinen (1982, personal comm.) maintains that the hornblende gneisses at Suonenjoki and Pieksämäki are of similar type.

Intermediate volcanites with mafic and felsic interlayers predominate in the metasediment and volcanite formation in the *Säviä area* south of Pielavesi. Metasediments — biotite-plagioclase gneisses, with interlayers of quartz-feldspar gneisses, diopside gneisses and graphite-bearing gneisses — constitute narrow layers in the eastern margin of the formation (Makkonen 1981). In the central parts of the volcanites there are garnet-cordierite-anthophyllite rocks and gneisses that overlie the volcanites in stratigraphy owing to the synclinal structure of the formation. Makkonen (1981) considers these

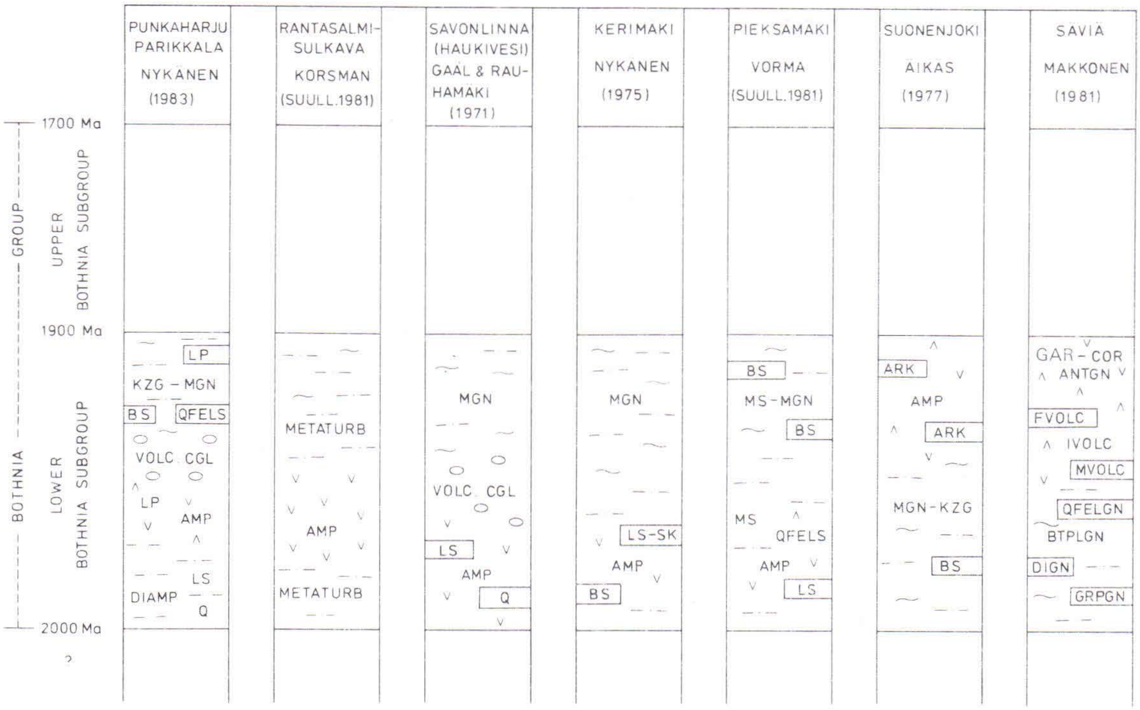


Fig. 16 a. Stratigraphy of the Bothnia Group.

| | | | |
|---|---|---|---|
| LEP | = leptite | METATURB | = metaturbidite |
| KZG | = kinzigite | SK | = skarn |
| MGN | = mica gneiss | ARK | = arkosite |
| BS | = black schist | GAR-COR-ANTGN | = garnet-cordierite-anthophyllite gneiss |
| QFELS | = quartz-feldspar schist | FVOLC | = felsic volcanite |
| VOLC. CGL | = volcanic conglomerate | IVOLC | = intermediate volcanite |
| AMP | = amphibolite | MVOLC | = mafic volcanite |
| LS | = limestone | BTPLGN | = biotite-plagioclase gneiss |
| DIAMP | = diopside amphibolite | DIGN | = diopside gneiss |
| Q | = quartzite | GRPGN | = graphite gneiss |

rocks to be volcanites that underwent metasomatic alterations through the action of seawater and obtained their current composition through metamorphism.

The supracrustal rocks in the *Viitasaari area* (Pipping 1972) are arkositic quartz-feldspar schists with narrow intraformational conglomerate layers. Besides arkosites there are greywacky mica gneisses with amphibolite and uralite porphyrite interlayers. The conglomerate clasts are mainly quartz-feldspar schist, although volcanite clasts also occur. The matrix is mica gneiss. The amphibolitic conglomerate, or agglomerate at Hännilänsalmi differs from the above conglomerates on the basis of the hornblende - plagioclase gneiss matrix resembling uralite porphyrite. The clasts are predominantly quartz-feldspar gneiss but some coarse-grained plagioclase porphyrite occur, too. The relative stratigraphic positions of the rocks have not yet been established (Pipping 1972), and the rocks have been classified as the Lower Bothnia Subgroup.

The geology of the *Pyhäsalmi—Pielavesi—Kiuruvesi area* has been discussed by a number of authors including Mäkinen (1916), Wilkman (1931, 1938), Väyrynen (1954), Savolahti (1965), Marttila (1976, 1981), Helovuori (1979), Huhtala *et al.* (1978), Huhtala (1979) and Salli (1983). The Lower Bothnia Subgroup has been interpreted to contain biotite-plagioclase gneisses, felsic and mafic volcanites. The biotite-plagioclase gneisses, which are lowermost in stratigraphy, are psammitic and pelitic sediments in origin (Huhtala *et al.* 1978; Huhtala 1979) with interlayers of acid and intermediate tuffites (quartz-feldspar gneisses and hornblende gneisses), meta-arkoses, in places, graphite

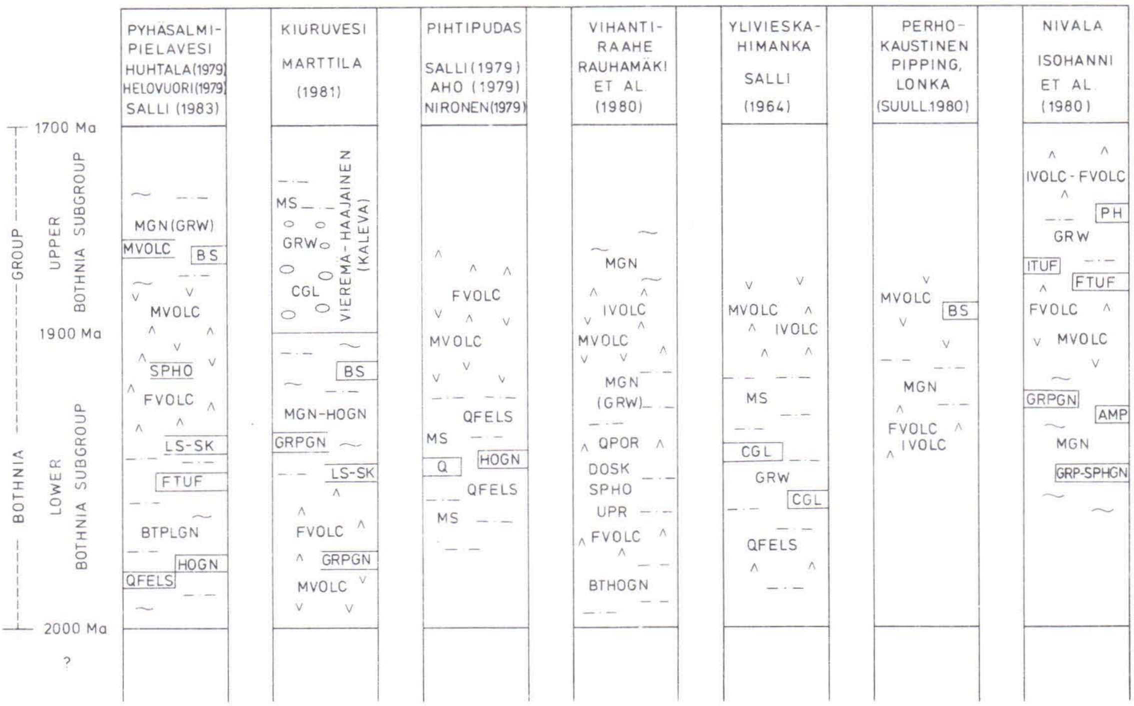


Fig. 16 b. Stratigraphy of the Bothnia Group

| | | | | | |
|---|---|---|---|---|---|
| MGN | = | mica gneiss | CGL | = | conglomerate |
| GRW | = | greywacke | BS | = | black schist |
| BS | = | black schist | HOGN | = | hornblende gneiss |
| MVOLC | = | mafic volcanite | GRPGN | = | graphite gneiss |
| FVOLC | = | felsic volcanite | IVOLC | = | intermediate volcanite |
| SPHO | = | sulphide ore | QPOR | = | quartz porphyry |
| LS | = | limestone | DOSK | = | dolomite skarn |
| SK | = | skarn | UPR | = | uranium-phosphorous rock |
| FTUF | = | felsic tuffite | BTHOGN | = | biotite-hornblende gneiss |
| BTPLGN | = | biotite-plagioclase gneiss | PH | = | phyllite |
| HOGN | = | hornblende gneiss | ITUF | = | intermediate tuffite |
| QFELS | = | quartz-feldspar schist | AMP | = | amphibolite |
| MS | = | mica schist | GRP-SPHGN | = | graphite-sulphide gneiss |

gneisses and diopside skarns. In the upper parts of the biotite-plagioclase gneisses the volcanic, and particularly the acid, component increases and the rocks grade into acid tuffs and tuffites, often with skarns and carbonate rocks in their basal parts (Huhtala 1979; Marttila 1981). Basic and intermediate lavas and pyroclasts have deposited on the acid volcanites (Huhtala 1979).

In contrast to the above stratigraphy, Marttila (1981) maintains that in the Kiuruvesi area the volcanites are the lowest rocks and that the sedimentary rocks deposited on them.

The Upper Bothnia Subgroup includes greywacky mica gneisses with interlayers of mafic volcanite and graphite gneiss. The mica gneisses contain garnet, cordierite and sillimanite (Huhtala 1979). Mica gneiss of this type may also occur in the Piippola and Pulkkila areas farther north (see Väyrynen 1954).

At Pyhäsalmi a massive zinc and copper-bearing pyrite ore is enveloped by sericite schist and cordierite-anthophyllite rocks in acid tuffite. The model age of lead from the ore is 1970 Ma and the isotope composition suggests that the lead derives from the mantle (Helovuori 1979). The U/Pb age of zircon from an acid volcanite inclusion (quartz porphyry) in the ore is 1892 ± 1.5 Ma, whereas the whole-rock Pb/Pb age of this inclusion and nine other metavolcanite samples from Pyhäsalmi is 1909 ± 27 Ma

(Helovuori 1979). The isotope compositions of the lead from galena and volcanites plot on the same isochrone, implying a genetic relationship between volcanism and the emplacement of the ores (Vaasjoki 1981; Helovuori 1979). The minimum 207Pb/206Pb age of zircon from plagioclase porphyry from the mine is 1875 Ma (Helovuori 1979). The U/Pb ages of sphenes from the Pyhäsalmi rocks are 1860 and 1830 Ma (Helovuori 1979; Vaasjoki 1981).

The Kinturijärvi fracture zone trending NW-SE in the eastern part of the *Pihtipudas area* separates two schist zones differing in lithology but nevertheless included in the Lower Bothnia Subgroup. The lower parts of the synform zone in the northeast consist of pelitic and psammitic schists, carbonaceous quartz-feldspar schists and quartzites. These are overlain by acid and mafic tuffites and, in the middle, by cordierite-anthophyllite rocks as their alteration products. According to Nironen (1979), the zone could possibly be correlated with the Ruotanen schists zone at Pyhäsalmi. Lowermost in the syncline zone southwest of the fracture zone are layers of mafic lavas and pyroclasts of variable thickness overlain by a thick layer of arkosic quartz-feldspar schists, which in the west pass sharply into the Pihtipudas acid volcanites (Salli 1971; Nironen 1979).

The volcanites in the western part of the Pihtipudas area, which are predominantly acid in composition (Salli 1971; Aho 1979) have been classified as Upper Bothnia Subgroup. The U/Pb age of zircons from the volcanites and the surrounding granitoids is 1883 ± 20 Ma, but the whole-rock Pb/Pb age of the volcanites is slightly older, 1893 ± 26 Ma. According to Aho (1979), the age difference suggests that volcanism preceded the emplacement of the cogenetic granitoids. The model age of lead from the galena at Ritovuori on Pihtipudas is 1800 Ma. Its isotope composition indicates an orogenic origin. The compositions of the leads from the galena and volcanites plot on the same isochrone, implying a genetic similarity (Aho 1979; Vaasjoki 1981).

The basal parts of the sediments in the *Kinnula area* (Nykänen 1963) contain greywacky, migmatitic biotite-plagioclase gneisses with interlayers of arkosic quartz-feldspar schists, and hornblende gneisses and amphibolites that are partly volcanic and partly sedimentary in origin. The uralite and plagioclase porphyrites, which occur as interbeds in mica gneisses, are lavas, subvolcanic intrusions and dykes. According to Nykänen (1963), they can be considered cogenetic with the mafic intrusive rocks. The sediments and volcanites in the Kinnula area have been included in the Lower Bothnia Subgroup.

According to Hautala (1968), at the *Venetpalo area* north of Pyhäsalmi there are oligoclase gneiss domes (Venetpalo and Kiimakallio) surrounded by amphibolites, mica gneisses, cordierite-sillimanite gneisses and ore potential cordierite-anthophyllite rocks. Quartz-feldspar schists, skarns, and cummingtonite and gedrite amphibolites occur as interlayers in the amphibolites. Hautala (1968) correlates the rocks with the Jatulian sediments. Since, however, typical Jatulian formations are absent from the area (cf. Pekkarinen 1979) the rocks have been interpreted as Lower Bothnia Subgroup.

The geology of the *Raahe—Vihanti area* has been discussed earlier by Nykänen (1959), Salli (1965) and Rouhunkoski (1968). The lowermost rocks in the Vihanti area are biotite-hornblende gneisses and quartz-feldspar schists derived from dacitic and andesitic volcanites and pelitic and psammitic sediments (Huhtala *et al.* 1978; Rauhamäki *et al.* 1980). They are overlain, with a sharp contact, by rocks of the 'Lampinsaari-type', which can be traced as a discontinuous formation for dozens of kilometres. The lowermost rocks in the formation are acid volcanites, uranium and phosphorus-bearing dolomites and skarns, and pyritic copper-zinc-lead ore overlain by graphite-bearing tuffs, quartz porphyry (crystal tuff) and cordierite gneisses (Rehtijärvi *et al.* 1979; Vaasjoki *et al.* 1980; Rauhamäki *et al.* 1980). The phyllites with quartzite, limestone and skarn interlayers at Pattijoki in Raahe (Nykänen 1959) belong to this formation (T. Mäkelä 1980, personal. comm.). The rocks grade into migmatitic and greywacky mica gneisses with occasional mafic volcanite interlayers via quartz-feldspar schists that are the weathering products of acid volcanites. The greywackes with intercalating conglomerates and overlying phyllites at Saloinen in Raahe (Nykänen 1959) could possibly be correlated with the above greywacky mica gneisses.

The model age of lead from the galena of the Lampinsaari ore is 1930—1960 Ma

(Rehtijärvi *et al.* 1979; Rauhamäki *et al.* 1980). In isotope composition the galena is of the Pyhäsalmi type (Vaasjoki 1982). The similarity in the $^{208}Pb/^{204}Pb$ ratio of the lead from the ore and the uranium-phosphorus rocks shows that they deposited at the same time (Rehtijärvi *et al.* 1979). The whole-rock Pb/Pb age of the quartz porphyry is 1920 Ma (Rauhamäki *et al.* 1980). The rocks of Vihanti and Raahe are in the Lower Bothnia Subgroup.

The concept of the stratigraphy of the *Pyhäjoki—Kalajoki—Ylivieska—Haapavesi—Sievi—Lestijärvi—Reisjärvi area* is based mainly on observations by Salli (1968, 1964, 1966, 1967), supplemented with subsequent studies on the Sievi and Rautio areas (Västi 1978; Isokoski 1982). The geology of these areas is dominated by the alternation of anticlinal ridges and synclinal basins (Salli 1964). Lowest in the stratigraphy are quartz-feldspar schists, which, according to Salli (1964), are mainly sedimentary, although some of them have later been interpreted as volcanic in origin (Gaál *et al.* 1974). The conclusion that volcanites are the lowest rocks in corroborated by Isokoski's (1982) concept regarding the central part of the Rautio schist zone, where the lowest unit is an intermediate volcanic conglomerate with abundant clasts of tuff and tuffite, and by Västi's (1978) observations on mafic tuffs, tuffites and uralite porphyrite, which are the lowest members at the margins of the synclinal Rautio-Sievi schist belt farther south. On account of the geosynclinal structure the volcanites in the schist areas of Lestijärvi and Reisjärvi (Salli 1967) may have the same stratigraphic position as the above volcanites.

The quartz-feldspar schists and volcanites are overlain by greywackes with intraformational conglomerate layers, feldspathic mica schists and porphyroblastic mica schists. According to Isokoski (1982) and Västi (1978), the sediments contain abundant volcanic material. The above volcanites and sediments have been included in the Lower Bothnia Subgroup. The mafic and intermediate volcanites that, according to Salli (1969), overlain the above sediments and which in places grade into mafic comagmatic plutonies belong to the Upper Bothnia Subgroup. The volcanites have not yet been dated.

In the *Nivala area* (Isohanni *et al.* 1980) the lowermost rocks — migmatitic mica gneisses with interlayers of graphite and sulphide gneisses and amphibolites — belong to the Lower Bothnia Subgroup. The Upper Bothnia Subgroup has andesitic and dacitic, and locally basaltic and rhyolitic, tuffs, tuffites and agglomerates and volcanic conglomerates on top of the mica gneisses. They are overlain by greywackes with intermediate and acid tuff interlayers and thin conglomerate and phyllite beds.

The predominant rock in the *Kannus area* is biotite-plagioclase gneiss with calc-silicate boudins (Neuvonen, 1971). In the east and northeast there are amphibolites that belong to the same zone in which Salli (1961) encountered pillow lavas at Himanka. The amphibolites are included in the Upper Bothnia Subgroup, whereas the biotite-plagioclase gneisses belong to the Lower Bothnia Subgroup. O. Äikäs (1982, personal comm.) considers that the quartz porphyries, limestones and diopside skarns at Ruotsalo are the lowest horizon in stratigraphy. The associated uranium and phosphorus-bearing rocks could possibly be correlated with similar rocks at Lampinsaari.

The mica gneisses and mica schists in the *Kokkola—Pietarsaari area* (Laitala 1980, 1981) are older than the intrusive rocks in the same areas, and have thus been placed in the Lower Bothnia Subgroup.

In the *Kaustinen—Alajärvi—Perho area* (Lonka 1971; Pipping 1976) the felcic and intermediate and, in places, mafic volcanites, which are leptites, plagioclase and uralite porphyrites (Laajoki 1966), are the lowest formations in stratigraphy (Pipping, Lonka 1980, personal comm.). They are overlain by the mica schists and mica gneisses that also occur in the Kokkola and Pietarsaari areas. The volcanites and sediments belong to the Lower Bothnia Subgroup even though the U/Pb age of zircon from the quartz porphyry at Kellokangas in Kaustinen, attributed to this group, is 1883 Ma old (GSF, Petrological Dep. Ann. Rep. 1982). The mafic volcanites (amphibolites) with occasional black schist interlayers (Lonka, Pipping 1980, personal comm.) overlying the mica schists and mica gneisses are Upper Bothnia Subgroup.

The intermediate and acid volcanites — quartz-feldspar porphyrites and hornblende porphyrites — in the *Kyyjärvi—Saarijärvi area* are lavas or subvolcanic dykes in origin and closely associated with the local plutonites (Wilkman 1938). The rocks are included in the Upper Bothnia Subgroup.

## Plutonic rocks of the Kaleva and Bothnia Groups

The Kaleva and Bothnia Groups contain similar plutonic rocks, although, according to Simonen (1980), granitic rocks prevail in the area of the Kaleva Group but granodiorites and quartz diorites in the area of the Bothnia Group. The plutonic rocks were classified as upper subgroup on the basis of the crosscutting relations between the plutonites and meta-sediments and metavolcanites but also on the basis of radiometric age determination. The plutonites in the Middle Finland area can be divided into two groups: synorogenic rocks with the U/Pb age of zircon 1900—1860 Ma and late-orogenic rocks with the U/Pb age of zircon 1860—1750 Ma (Kouvo 1976). On account of the insufficient number of age determinations and the irregular coverage of the ages, these groups are not distinguished on the map; the other data do not provide grounds for such a distinction either.

The synorogenic plutonites are mainly foliated granodiorites and quartz diorites associated with granites and trondhjemites but also small mafic differentiates, such as peridotites, gabbros and diorites (Simonen 1980). Hence the rocks constitute a magmatic differentiation from peridotite to granite. Among the synorogenic plutonites, pyroxene-bearing rocks form a distinct group with members ranging from pyroxene-bearing gabbro to pyroxene granite (Huhtala 1979). The pyroxene-bearing plutonites occur in a zone 100 km wide and 400 km long that extends from Lake Ladoga to the Gulf of Bothnia, and in which their occurrence is controlled by deep-seated fractures trending NW-SE (Wahl 1963). Likewise the peridotite, hornblende gabbro, norite and diorite intrusions in the Kotalahti Ni-Cu ore belt at Nivala, Kotalahti, Laukunkangas and Parikkala constitute a separate type (Kahma 1973, 1978; Isohanni *et al.* 1980; Gaál 1980; Grundström 1979; Patchett *et al.* 1981; Nykänen 1983).

Contact relations and age determinations show that the mafic plutonites are slightly older than the intermediate and acid rocks. Table 1 gives examples of the U/Pb ages of some synorogenic plutonites. Note that the ages of sphene and monazite, which are younger than those of zircon, refer to a late-metamorphic event (Aho 1979; Helovuori 1979; Nykänen 1983). The age of the granite pegmatite that intrudes the ultramafic

Table 1. Ages of synorogenic plutonic rocks.

| Rock type | Area | U/Pb age Ma | Mineral | Reference |
|---|---|---|---|---|
| Gabbro | Vihanti, mine | 1895 | zircon | Rauhamäki et al., 1980 |
| Granodiorite | ,, | 1875 | ,, | ,, |
| Granite | ,, | 1875 | ,, | ,, |
| Gabbro | Ylivieska | 1884 | ,, | Pesonen & Stigzelius, 1972 |
| Pegmatite granite | Nivala, Hitura | 1877 ± 2 | ,, | Isohanni et al., 1980 |
| Granitoid | Pihtipudas | 1883 ± 20 | ,, | Aho, 1979 |
| ,, | ,, | 1800 | sphene | ,, |
| Gabbro pegmatoid | Pielavesi, Saarisenjärvi | 1873 | zircon | GSF Petrol. Dept. Ann. Rep. 1982 |
| Hypersthene granite | Pielavesi, Vaaraslahti | 1884 ± 5 | ,, | Salli, 1983 |
| ,, | ,, | 1874 | monazite | ,, |
| Pyroxene diorite | Pielavesi, Kotajärvi | 1882 ± 2 | zircon | ,, |
| Gabbro pegmatoid | Kiuruvesi, Tuli-Toiviainen | 1886 ± 5 | ,, | Marttila, 1981 |
| Quartz diorite | Pyhäsalmi, Jusko | 1892 ± 1.5 | ,, | Helovuori, 1979 |
| ,, | ,, | 1867 | sphene | ,, |
| Diorite | Kotalahti, Vehka | 1883 ± 6 | zircon | Gaál, 1980 |
| Quartz diorite | Rantasalmi, Tuutmäki | 1888 ± 15 | ,, | GSF Petrol. Dept. Ann. Rep. 1982 |
| Gabbro | Parikkala | 1884 | ,, | Nykänen, 1983 |
| Quartz diorite | Kitee, Närsäkkälä | 1884 ± 19 | ,, | ,, |
| ,, | Kitee, Misola | 1904 ± 32 | ,, | ,, |
| ,, | ,, | 1811 | sphene | ,, |

rocks at Hitura (1877 Ma) is interpreted as the minimum age of the complex (Isohanni *et al.* 1980).

The late-orogenic stage, the ages of whose rocks are listed in Table 2, was characterized by granitic magmatism, and the predominant rock — microcline granite — either occurs as extensive massifs or forms migmatites with the schists and synorogenic plutonites (Simonen 1980). Of these large granite bodies, mention should be made of the Puruvesi granite (Nykänen 1975, 1983), the Kajaani granite (Wilkman 1931), part of which is pegmatite granite (Alviola 1977), the Kitee pegmatite granite (Nykänen 1975) and the Maarianvaara granite-granodiorite, in which the mafic variants and granite form a differentiation series from diorite to pegmatite granite (Huhma 1976). The late-orogenic rocks also include small nonfoliated granitoid massifs, such as the Petravaara trondhjemite at Tohmajärvi (Nykänen 1968) and the Luontarivesi (Hirvensalo) granodiorite at Anttola (Korsman and Lehijärvi 1973). The molybdenum-bearing plutonites in the Rautio batholith in Ostrobothnia have also been associated with late-orogenic (Gaál and Isohanni 1979). This group of late-orogenic rocks includes the microtonalite dykes in the Outokumpu area (Huhma 1975, 1981), the lamprophyre dykes at Niinivaara in Kaavi (Huhma 1975, 1981) and the lamprophyre dykes at Haukivesi (Hackman 1933; Neuvonen *et al.* 1981; Laukkanen 1983).

The intensely foliated quartz dioritic trondhjemitic rocks in the zone between the Pyhäsalmi mine and the Archaean craton from Rautalampi to north of Kiuruvesi (Huhtala 1979) constitute a group that differs from the synorogenic and late-orogenic plutonites. Similar rocks may also occur at Varkaus (Pääjärvi 1981, personal comm.). Whether they represent Archaean gneiss or blocks mobilized by metamorphism remains to be seen (Marttila 1976). Scarce though they may be, the U/Pb age determinations on zircon do not indicate Archaean age. The rocks of this zone include the granite gneiss at Kettuperä in Pyhäsalmi (1932 ± 15 Ma, Helovuori 1979), the Kirkkosaari quartz diorite gneiss at Pielavesi (1937 Ma, GSF, Petrol. Dep. Ann. Rep. 1982) and the Rastinpää quartz diorite gneiss Rautalampi (1922 Ma, GSF, Petrol. Dep. Ann. Rep. 1982). The zircon age, 1870 Ma, of the Lammasaho granodiorite at Kiuruvesi, a rock assigned to the same zone, might refer to the mobilization of the basement gneiss complex in the Svecokarelian orogeny (Marttila 1976, 1981).

West of the above zone there are plagioclase-predominant foliated granitoids — gneiss granites, very similar in composition to the above rocks (Wilkman 1931; see also Huhtala 1979) in the Pyhäsalmi, Kärsämäki, Haapavesi, Nivala and Reisjärvi areas (Wilkman 1931) and at Kalajoki and Kannus (Saksela 1933b). Wilkman (1931) considers them transitional types between the granite gneisses of the basement gneiss complex and the orogenic plutonites. On account of their mineralogical and chemical compositions and foliation they have not been included in the differentiation series of orogenic plutonites (Wilkman 1931; Saksela 1933b). Simonen (1980) does not regard the rocks as a separate group; nor have we done so on our map. The U/Pb age of zircon from the granodioritic orthogneiss at Vasankari in Kalajoki is 1882 Ma (GSF, Petrol. Dep. Ann.

Table 2. Ages of late-orogenic plutonic rocks.

| Rock type | Area | U/Pb age Ma | Mineral | Reference |
|---|---|---|---|---|
| Granite | Kesälahti, Puruvesi | 1797 ± 19 | zircon | Nykänen, 1983 |
| ,, | ,, | 1809 | monazite | ,, |
| Microtonalite dyke | Kaavi, Mäntyjärvi | 1850 | sphene | Huhma, 1981 |
| Lamprophyry dyke | Kaavi, Niinivaara | 1830 | zircon | ,, |
| ,, | Haukivesi, Iso-Uski | 1836 ± 20 | 1) | Neuvonen et al., 1981 |
| Granodiorite | Anttola, Hirvensalo | 1820 | zircon | Korsman & Lehijärvi, 1973 |
| Granite | Kajaani, Murtomäki | 1810 | 2) | Kouvo & Tilton, 1966 |

1) Pb-Pb age of whole rock and apatite
2) Rb-Sr age of muscovite (new constant)

Rep. 1982). According to Neuvonen (1971), the Kannus granodiorite may represent the depositional floor of the supracrustal rocks in the area.

The serpentinites in the Outokumpu area (Huhma 1975; Koistinen 1981; Park 1983; see also p. 28 in the present paper) and in the Kainuu schist zone (Wilkman 1931; Väyrynen 1954; Rastas 1969) form a separate igneous rock type. In the Outokumpu area the U/Pb age of zircon from the metamorphosed Horsmanaho gabbro, which intrudes the serpentinites embedded in the Kaleva group sediments, is 1972 ± 18 Ma (Koistinen 1981). According to Väyrynen (1954), the mode of occurrence of the Kainuu serpentinites, associated with metagabbros and amphibolites, is similar to that of the serpentinites in North Karelia. Rastas (1969) maintains that the serpentinites at Jormua were emplaced at the peak of folding in the Jatulian sediments. The serpentinites have been included in the Lower Kaleva Subgroup.

## MIDDLE PROTEROZOIC ERA

### Jotnia Supergroup

#### Muhos group

The Muhos Group of the Jotnia Supergroup has been assigned a lower age limit of 1500 Ma because Jotnia sedimentation is considered to have preceded the emplacement of the rapakivi granites whose youngest zircon U/Pb ages are 1540 Ma (Vaasjoki 1977). The $K^{40}/Ar^{40}$ method has given c. 1300 Ma for the age of diagenesis of the sediments (Simonen 1960a), and Rb-Sr determinations date the rocks at 1300—1400 Ma (Kouvo 1976). A conglomerate-sandstone layer constitutes the basal horizon of the Muhos claystone complex overlain (c. 80—90 % of the total thickness) by a pink and grey-green claystone with gypsum interlayers (Nykänen 1959). The pebbles in the conglomerate are mainly granite. In the MiddleFinland area (in the NE corner of the Paavola map sheet) all that has survived of the Muhos Group formations is a layer of claystone-sandstone only a few metres thick on the granite (Nykänen 1959). According to Simonen and Kouvo (1955), the Muhos sandstone horizon resembles the Satakunta Jotnian sandstone in petrography.

On the basis of the microfossils in the claystone, Tynni (1978) maintains that the Muhos sediments are comparable with the middle Riphean Terin Series in the Kola Peninsula with radiometric ages of 1260 Ma and 1080 Ma (Tynni 1978). The microfossils suggest that the corresponding sedimentary rock on the island of Hailuoto is c. 600 Ma old. Hence the sediments on Hailuoto and the mainland may represent two different Jotnian sedimentation levels (Tynni and Donner 1980).

## MESOZOIC ERA

#### Lappajärvi meteorite crater

The Lappajärvi meteorite crater has been defined as proposed by Pipping (1979). The rock type on the island of Kärnäsaari in Lappajärvi was initially interpreted to be the dacitic lava known as kärnäite (Laitakari 1942). Saksela (1949) considered it a pyroclastic rock composed of matter from the old bedrock. Lehtinen (1970, 1976) defined the kärnäite as impact lava produced by meteorite impact. Impact breccia and suevite are encountered as floats around the lake Lappajärvi (Lehtinen 1976). Rb-Sr isotope analysis shows that kärnäite is a mixture of rocks that originally contained c. 76 % mica schist, c. 11 % granite pegmatite and c. 13 % amphibolite (Reimold and Stöffler 1979). According to the $Ar^{40}/Ar^{39}$ method, the kärnäite is 77.3 ± 0.4 Ma old (Reimold and Stöffler 1979).

## SUMMARY

The stratigraphic map of Middle Finland and its explanation are based largely on outdated reports and on regrettably little checking in key areas. The map is therefore a hybrid of lithostratigraphic and chronostratigraphic divisions; it is also schematic for many areas and in need of further research.

1. The Archaean granitoid area in Middle Finland is poorly known as a whole. The classification and age grouping of the granitoids applied in the present work are based on a division made within rather small subareas. Moreover the data on Nurmes, Lieksa, the northern part of Ilomantsi and the central part of the Iisalmi microcontinent are based on lithologic maps compiled in the early years of the present century and on high-altitude aeromagnetic maps produced in the 1970s.

The present stratigraphy will be elaborated by studies on structural geology to be undertaken in the area of the Kianta Supergroup greenstones.

2. The early Proterozoic Sariola Group formations are likely to be substantailly more abundant in the area of the Archaean formations than is indicated by the map.

Migmatized formations composed mainly of sedimentogeneous rocks and possibly contemporaneous with the Sariola Group, although wholly distinct from them in lithology, are encountered west of the Kainuu schist area (cf. Laajoki 1983) and in the marginal zone of the Archaean craton west and northwest of Kuopio. For lack of a detailed study, they have been included in the Late Archaean in the present work.

3. The division of the early Proterozoic Jatuli Group into two subgroups is based on the somewhat outdated Jatuli — Marine Jatuli division supplemented with more recent data. This division may be further modified by new palaeosedimentogeneous and structural geological studies on the Jatuli Group.

The formations of the Jatuli Group in the southern part of Puolanka, Paltamo, Ristijärvi, southern Sotkamo and Rautavaara are based on information from high-speed mapping done by the Exploration Department of the GSF and high-altitude aeromagnetic maps compiled by the Geophysics Department of the GSF.

Studies on the mutual stratigraphic positions of the Jatuli Group formations at the margins of the dome structures in and around Kuopio and in the North Karelia schist area are still incomplete.

4. The early Proterozoic Kaleva and Bothnia Groups were distinguished as separate groups on the basis of differences in lithology. The Kaleva Groups is composed mainly of metamorphic equivalents of the clays and sands — phyllites, mica schists and mica gneisses — subjected to rather moderate chemical weathering. Excluding possibly the Jormua and Outokumpu formations, no volcanites have been encountered within the Kalevian sediments, whereas the Bothnia Group contains not only mica schists and mica gneisses but also abundant mafic and acid volcanites and their weathering products, and also arkosites, limestones and skarns. The paucity of lithologic information prevented us from dividing the Kaleva and Bothnia Groups into lower and upper subgroups on a lithologic basis; instead we based the division on the geochronology of the supracrustal and plutonic rocks.

The boundary between the Karelia and Svecofennia Supergroups and between the Kaleva and Bothnia Groups is schematic and based partly on previous concepts. The sediments of the Karelides (Sariola, Jatuli and Kaleva) have long been assigned to an epicontinental or miogeosynclinal association, whereas the Svecofennides have represented an eugeosynclinal area (Väyrynen 1954; Metzger 1959; Mikkola 1961; Simonen 1960b, 1980). Recently the differences between the areas have been interpreted in the light of plate tectonic models (Piirainen, Hugg et al. 1974; Hietanen 1975; Bowes 1980; K. Mäkelä 1980, 1981; Gaál 1980), in which the Svecofennides represent mainly an island arc environment and the Karelides a marginal trench between the arc and the continent. Studies are continuing with the aim of establishing the most likely geotectonic model and the boundaries between the above supergroups.

The regional boundaries of the stratigraphic maps of northern Finland, Middle Finland and southern Finland are not based on discontinuities in lithology, and hence the chronostratigraphic divisions in these areas are analogous. The differences in the

nomenclature of the supergroups and groups in the stratigraphic maps of northern Finland and Middle Finland are due to differences in the interpretation of the lithostratigraphy (cf. Silvennoinen *et al.* 1980).

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