of the Kemi, Karunki, Simo and Runkaus map-sheet areas. Geological Map of Finland 1 : 100 000, Explanation to the maps of pre-Quaternary rocks, Sheets 2541, 2542 + 2524, 2543 and 2544. Geological Survey of Finland. 80 p.

Piirainen, T. 1988. The geology of the Archaean greenstone - granitoid terrain in Kuhmo, eastern Finland. Geological Survey of Finland, Special Paper 4, 39–51.

Piirainen, T., Honkamo, M. & Rossi, S. 1974. A preliminary report on the geology of the Koli area. Bulletin of the Geological Society of Finland 46 (2), 161–166.

Piirainen, T. & Vuollo, J. 1991. Arkeeinen ja proterotsooinen geologinen evoluutio ja malminmuodostus: Pohjois-Karjalan loppuraportti. Pohjois-Karjalan malmiprojekti. Oulun yliopisto. Raportti 31. 145 p. (In Finnish)

Puustinen, K. 1971. Geology of the Siilinjärvi carbonatite complex, eastern Finland. Bulletin de la Commission géologique de Finlande 249. 43 p.

Sorjonen-Ward, P. 1993. An overview of structural evolution and lithic units within and intruding the late Archean Hattu schist belt, Ilomantsi, eastern Finland. In: Nurmi, P.A. & Sorjonen-Ward, P. (eds.) Geological development, gold mineralization and exploration methods in the Archaean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17, 9–102.

Sorjonen-Ward, P. & Claoué-Long, J. 1993. A preliminary note on ion microprobe results for zircons from the Silvevaara Granodiorite, Ilomantsi, eastern Finland. In: Autio, S. (ed.) Geological Survey of Finland, Current Research 1991-1992. Geological Survey of Finland, Special Paper 18, 25–29.

Taipale, K. 1988. Volcanism in the Archaean Kuhmo greenstone belt, eastern Finland. Geological Survey of Finland, Special Paper 4, 151–160.

Taipale, K. & Tuokko, I. 1981. Kuhmon arkeeisen vihreäkivivyöhykkeen geologiasta ja malmimineralisaatioista [On the geology and ore mineralisations of the Kuhmo greenstone belt]. Oulun Yliopisto, Kuhmon ja Kittilän malmiprojektit. Raportti 47. 65 p. (In Finnish)

Taipale, K., Tuokko, I. & Piirainen, T. 1980. A brief introduction to the geology and geochemistry of the Kuhmo greenstone belt, eastern Finland. In: Papunen, H. (ed.) Nickel sulfide field conference. Excursion guide. Finland. IGCP Project no. 161 Sulfide deposits in mafic and ultramafic rocks, 37–73.

Tuisku, P. & Sivonen, S. 1984. Paine- ja lämpötilaolosuhteet Kuhmon vihreäkivivyöhykkeen metamorfoosissa (with an English summary). Arkeeisten alueiden malmiprojekti, Oulun yliopisto. Raportti 19. 59 p.

Tuukki, P.A., Männikkö, K.H, Ojala, V.J. & Pitkäjärvi, J.T. 1987. Koveron liuskejakson geologia [Geology of the Kovero schist belt]. Oulun yliopisto, Pohjois-Karjalan malmiprojekti. Raportti 9. 123 p. (In Finnish)

Vaasjoki, M., Sorjonen-Ward, P. & Lavikainen, S. 1993. U-Pb age determinations and sulfide Pb-Pb characteristics from the late Archean Hattu schist belt, Ilomantsi, eastern Finland. In: Nurmi, P.A. & Sorjonen-Ward, P. (eds.) Geological development, gold mineralization and exploration methods in the Archaean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17, 103–131.

Vaasjoki, M., Taipale, K. & Tuokko, I. 1999. Radiometric ages and other isotopic data bearing on the evolution of Archaean crust and ores Kuhmo-Suomussalmi Area, Eastern Finland. In: Kähkönen, Y. & Lindqvist, K. (eds.) Studies on the evolution of the Precambrian in Finland contributed by the Global Geoscience Transect / SVEKA - Project. Bulletin of the Geological Society of Finland 71 (1), 155–176.

Väyrynen, H. 1933. Über die Stratigraphie der karelischen Formation. Comptes Rendus de la Société géologique de Finlande 6. Bulletin de la Commission géologique de Finlande 101, 54–78.

Väyrynen, H. 1939. On the geology and tectonics of the Outokumpu ore field and region. Bulletin de la Commission géologique de Finlande 124. 91 p.

Wetherill, G.W., Kouvo, O., Tilton, G.R. & Gast, P.W. 1962. Age measurements on rocks from the Finnish Precambrian. Journal of Geology 70 (1), 74–88.

Wilkman, W.W.W. 1938. Kuopio. Kivilajikartan selitys (with an English summary). Explanation to the map of rocks. General Geological Map of Finland 1 : 400 000, Pre-Quarternary rocks, Sheet C3. Geological Survey of Finland.171 p.

3.2. Proterozoic crystalline rocks

Jukka Kousa, Heikki Lukkarinen and Thomas Lundqvist

3.2.1 General features

The Proterozoic crystalline rocks of the Finnish and Swedish Mid-Norden area range between c. 2500 and 1100 Ma in age. Until the middle of the century, it was commonly believed that the Proterozoic rocks in Finland are products of two orogenic cycles, during which two mountain chains, the Karelides and the Svecofennides, were formed (e.g. Eskola 1941). The Karelian schists in eastern and northern Finland, known also as the Karelian Formations (Eskola 1925), were considered younger than the Svecofennian schists in the western part of Finland. In the 1960's, radiometric age determinations of particularly the plutonic rocks, have shown that both orogenic belts contain coeval plutonic rocks. An increase in our knowledge of Precambrian sedimentation and tectonics led to the interpretation that the Svecofennian lithologies (Svecofennides) form a geosynclinal facies and the Karelian formations (Karelides) the foreland facies of a single orogenic belt (or an orogen), referred to as the Svecokarelides. This belt was formed during the Svecokarelidic (or Svecokarelian) orogeny c. 1900–1800 Ma ago (Simonen 1986, and references therein). Gaál and Gorbatschev (1987) have suggested that the term *Svecokarelian orogeny* is misleading and should be replaced by *Svecofennian orogeny*, because the development of the Karelian formations was a process of anorogenic craton-cover deposition more than 2000 Ma ago, whereas the Svecofennian lithologies were developed as a result of orogenic processes during a short time interval between c. 1930 and 1870 Ma. On the recently published Bedrock map of Finland to the scale of 1 : 1 000 000 (Korsman et al. 1997), the Svecofennian area (the Svecofennian Domain) is interpreted to consist of three island-arc complexes developed during the afore mentioned time. Nironen (1997) has used a name Svecofennian Orogen for these complexes. Since orogenic processes have affected the lithologies of both the Svecofennian and Karelian Domains as well as the Archaean basement complexes, there is good reason to retain the traditional term Svecokarelian for this orogenic event.

On the Mid-Norden Bedrock Map, the area containing Proterozoic rocks is subdivided into two major units, viz. the Karelian and Svecofennian Domains. Both are made up of various metamorphic supracrustal lithologies intruded by plutonic and dyke rocks of several generations. The metamorphic grade varies from a low to high, in places even to granulite high grade. Rocks have also undergone polyphase deformation. Deformation and regional metamorphism mainly occurred in Finland during the interval c. 1900–1860 Ma and in Sweden c. 1840–1800 Ma.

Supracrustal rocks of the Karelian Domain in Finland form four assemblages: the Sumian-Sariolan, Kainuan-Lapponian, Jatulian and Kalevian. They consist of lithologies formed in an epi- to pericontinental or continental margin setting, in part related to rifting. They are older than c. 1900 Ma. Supracrustal sequences of the Karelian Domain in Sweden, which predate the Svecofennian, are made up of mafic metavolcanites and metasedimentary rocks of the Kalix-Sockberget area, referred to the Jatulian assemblages, and of the Kalevian schists and migmatites of the Råneå area. The latter, which grade into the similar, generally somewhat younger Svecofennian lithologies, can in fact be regarded as having formed during the initial phases of Svecofennian deposition (Gaál & Gorbatschev1987).

Rocks of the Svecofennian Domain were formed in a plate-convergent setting. In Finland they are dominantly composed of acidic, intermediate and basic volcanic rocks of island arc affinity, 1930–1920 Ma in age, and c. 1910–1890 Ma old metamorphosed greywackes and argillites with conglomerate interbeds and minor carbonate rocks. The Svecofennian Domain of Sweden is dominated by c. 1950–1870 Ma supracrustal rocks, mainly comprising felsic volcanites and greywackes/argillites. The major part of the latter were deposited in the Bothnian Basin of Central Fennoscandia, whereas an important part of the former were formed in an ancient volcanic arc system in the present Skellefte-Arvidsjaur Fields.

The various generations of plutonic rocks, mostly granitoids, which have intruded into the supracrustals of the Karelian and Svecofennian Domains, essentially belong to three major groups. The oldest, termed early-orogenic (or synkinematic, synorogenic), predate and are therefore affected by the main Svecokarelian deformation and regional metamorphism and have ages between c. 1950 and 1840 Ma. The second group, mostly comprising granites and pegmatites, was formed by plutonic rocks termed late-orogenic to postorogenic (late- to postkinematic), with ages usually between c. 1820 and 1780 Ma. The third group is anorogenic with regard to the Svecokarelian (Svecokarelidic) orogeny, and comprises plutonic rocks of rapakivi associations, c. 1580–1500 Ma old, and younger, post-Jotnian dolerites (diabases) of c. 1270–1200 Ma age.

Only minor remnants of anorogenic sedimentary rocks are found in the Finnish and Swedish Mid-Norden area. In Finland, the anorogenic sedimentary rocks - the siltstones and shales of the Muhos Formation (MuF) near Oulu and the Pokela Formation (PoF) in the Lappajärvi meteorite crater - are Meso- to Neoproterozoic. The age of the locally conglomeratic sandstones and related siltstones and shales of the Hailuoto Formation (HaF) near Oulu is Vendian to Cambrian. In Sweden, the only known example is the Jotnian Nordingrå Formation (NoF) of the coastal region south of Örnsköldsvik, consisting of sandstone with minor shale and conglomerate. The formation was deposited during the time interval between the rapakivi intrusions and the post-Jotnian dolerites. Large areas with similar sandstones and related sedimentary rocks etc. exist on the floor of the Gulf of Bothnia (p. 76).

3.2.2 Karelian Domain, *Heikki Lukkarinen and Thomas Lundqvist*

3.2.2.1 Sumian-Sariolan assemblages

The name Sariola (Sariolan or Sariolian) was originally defined by Eskola (1919) for metamorphosed arkosites and tillite-like polymictic conglomerates with pebbles derived from the Archaean basement complex in Russian Karelia. These basal deposits overlie the Archaean basement complex non-conformably, but underlie the Jatulian sedimentary rocks conformably. Eskola's (op. cit.) original definition did not include volcanites as Sariola rocks. Later, mafic and felsic volcanic rocks closely associated with the Sariola-type metasediments proper outside the original occurrences were referred to as Sumian (Sumi) in Russian Karelia (Kratz & Mitrofanov 1980). On the Bedrock Map, the combined term Sumian-Sariolan assemblages is used to denote formations which resemble lithologically and in their strati-graphical position the lithologies defined as typical Sumian and Sariolan rocks in Finland and Russian Karelia. Laajoki (1990) has proposed the name Sumi-Sariola tectofacies for those rocks. The time of sedimentation and volcanism of the Sumian-Sariolan rocks ranges from 2500 to 2300 Ma (Meriläinen 1980). Pb-Pb dating assigns an age of 2455±45 Ma to a Sumian felsic metalava in Russian Karelia (Negrutza & Negrutza1981).

In Finland, the occurrences of the Sumian-Sariolan formations occupy only small areas. On the Bedrock Map, the 40–100 m thick subaerial tholeiitic lava flows of the Runkaus Formation (RuF) in the Kemi area belong to the Sumian-Sariolan assemblages. Locally, between the lavas of the RuF and the Archaean basement, or between the lavas and layered mafic intrusions (Kem, Pen), there occur 20–40 m-thick formations consisting of arkosites and polymictic metaconglomerates with well-rounded granite, migmatite and quartz clasts (Perttunen 1985). A Sm-Nd isotopic age for the lavas of the Runkaus Formation is 2330±180 Ma (Huhma et al. 1990).

In the Kainuu Schist Belt (KSB), to the north of Kajaani, metamorphosed breccias, conglomerates and arkosites, originally deposited as immature fluvial and alluvial gravel and sand of the 300–400 m-thick Laanhongikko Formation (LaF) and the 100–200 m-thick Iso Tolpanjärvi Formation (ITF), rest on the Archaean basement (Strand 1988, Laajoki 1991). They are overlain by the 300–400 m-thick subaerial massive or amygdaloidal basaltic to andesitic lavas of the Matinvaara Formation (MvF), and the mafic lavas with minor pyroclastics of the c. 1 200 m-thick Vihantaselkä Formation (VsF; Strand 1988, Laajoki 1991). Whole-rock Pb-Pb dating gives an age of 2271±93 Ma for the Matinvaara lavas (Laajoki 1991). These Sumian-Sariolan formations, named the Kurkikylä Group (see Laajoki 1991, and references therein), were deposited and extruded in narrow, fault-controlled, intracratonic rift basins.

In the Koli area, on the western side of Lake Pielinen, three supracrustal formations form the Kyykkä Group (KyG) with a maximum thickness of 400 m. They consist of metamorphosed arkosites, conglomerates and minor argillites (Marmo et al. 1988, Kohonen & Marmo 1992, Marmo 1993), and were deposited nonconformably upon the Archaean basement complex during a period of glaciation. This interpretation is based on the presence of a diamictite member (Fig. 10) and dropstone-bearing siltstone-argillite members of the 300 m-thick Urkkavaara Formation (see Marmo & Ojakangas 1984) within the Kyykkä Group. A quartz-sericite schist (the Hokkalampi Paleosol of Marmo 1992) overlies the Kyykkä Group, reflecting a period of weathering between Sumian-Sariolan and Jatulian sedimentation.

Fig. 10. Glaciogenic diamictite of the Urkkavaara Formation. Kyykkä, Kontiolahti. Photo, H. Lukkarinen.

Besides these Sumian-Sariolan assemblages there are also some thin (usually less than 100 m) arkosite-conglomerate formations lying between the Archaean basement gneisses and Jatulian quartzites, but they are too small to be shown on the Bedrock Map. Examples are occurrences in the Nilsiä area northeast of Kuopio (Paavola 1984), the Lippumäki Formation in Kuopio (Aumo 1983), and the Viesimo Group in the Kiihtelysvaara area, south of Joensuu (Pekkarinen 1979, Pekkarinen & Lukkarinen 1991). Some volcanites occurring just south of Lake Oulujärvi (i. e. the Lautakangas formation; Laajoki & Luukas 1988) have also been interpreted to belong to the Sumian-Sariolan assemblages.

3.2.2.2 Kainuan-Lapponian assemblages

In the Mid-Norden area, the type localities of the Kainuan-Lapponian assemblages are within the Kainuu Schist Belt east and north of Lake Oulujärvi. The name Kainuu (Kainuan) was originally defined by Väyrynen (1928) for quartz conglomerates and quartzites which belong to the Jatulian formations in the eastern part of the Kainuu Schist Belt. Recent detailed studies in the belt, however, show that the definition of the original Kainuan quartzites is so incomplete that to continue using it will cause confusion. The concept of Kainuu is therefore redefined, and its use is restricted to the name of the Kainuu tectofacies, i.e. the tectofacies in the eastern part of the Kainuu Schist Belt that consists of formations deposited unconformably on the Sumian-Sariolan lithologies or, where these are lacking, directly on the Archaean basement (KuC). These formations are also overlain unconformably by the Jatulian formations (Laajoki 1991). The name Lapponian (Lapponi) is used for lithologies within the western part of the Kainuu Schist Belt that have the same stratigraphic position as the Kainuan formations and, on the basis of lithological similarities and structural evidence, have been tentatively correlated with the Lapponian of Central Lapland (Laajoki 1991; Geological Map, Northern Fennoscandia, 1 : 1 million). On the Mid-Norden Bedrock Map, the combined term Kainuan-Lapponian assemblages [equal to the Kainuu-Lapponi tectofacies of Laajoki (1990, 1991)] is used for these rocks.

In the eastern part of the Kainuu Schist Belt the Korvuanjoki Group (KoG) belongs to the Kainuan-Lapponian assemblages. This group is composed of formations containing quartz arenites with quartz-pebble conglomerates and with varying amounts of sericite and feldspar. In places, the lowest stratigraphic level consists of aluminous conglomerates and sandstone with porphyroblasts of kyanite, andalusite and chloritoid, indicating chemical weathering in the source area (Laajoki 1991). These lithologies represent alluvial fan, braided river and fluvial deposits, and were deposited in shallow-water parts of a narrow sea or inland basin system (Laajoki 1991). The thickness of the formations belonging to the Korvuanjoki Group varies from 600 to 1 400 m (Laajoki, op. cit.). The central and western parts of the Kainuu Schist Belt consist of turbiditic arenites, hummocky cross-stratified micaceous arenites, cross-bedded quartzites and shallow-water muddy sedimentary rocks with some volcanites forming the Central Puolanka Group (CPG) of Laajoki (1991). The thickness of the formations within this group varies from 500 to 2 000 m (Laajoki, op. cit.). Tonalitic gneisses, quartz-feldspar gneisses, micagneisses, gneissic quartzites and amphibolites of the Kalpio (KpC) and Kalhamajärvi (KjC) Complexes represent higher-grade metamorphic derivatives of the Central Puolanka Group lithologies (Laajoki 1991). These Lapponian assemblages form the deeper-water counterparts to the Kainuan assemblages in the same narrow sea or inland basin system.

The age of the rocks of the Central Puolanka Group, and of the Kalpio and Kalhamajärvi Complexes, is assumed to be Proterozoic (Laajoki 1991), but recent Sm-Nd isotopic data indicate that source material for the lithologies belonging to the former is dominantly Archaean in age. Whether the Central Puolanka Group lithologies were deposited in Archaean or Proterozoic time is under discussion, and additional isotopic work is needed before this problem can be satisfactorily resolved (Kontinen et al.1996). On the 1 : 1 000 000 Bedrock Map of Finland (Korsman et al. 1997), the Central Puolanka Group and its higher-grade metamorphic derivatives are interpreted to be of Archaean age.

3.2.2.3 Jatulian assemblages

The name Jatulian (Jatuli) was initially proposed by Sederholm (1897) for metasedimentary deposits (quartzites, slates and dolomites) in eastern and northern Finland. In eastern Finland, these lithologies form chains of hills extending from Kiihtelysvaara to Koli and Juuka, north of Outokumpu, and from Kainuu to Kuusamo, outside the Mid-Norden area. Jatulian formations also occur in the Kemi area and in the Kalix-Sockberget area in Sweden. The original type localities of Jatulian rocks are the Suojärvi (Metzger 1924) and Soanlahti (Hausen 1930) areas in Russian Karelia, where epicontinental Jatulian (Eo-Jatulian of Metzger, op. cit.) sedimentary rocks (conglomerates and quartzites) underlie marine Jatulian (Meso- and Neo-Jatulian

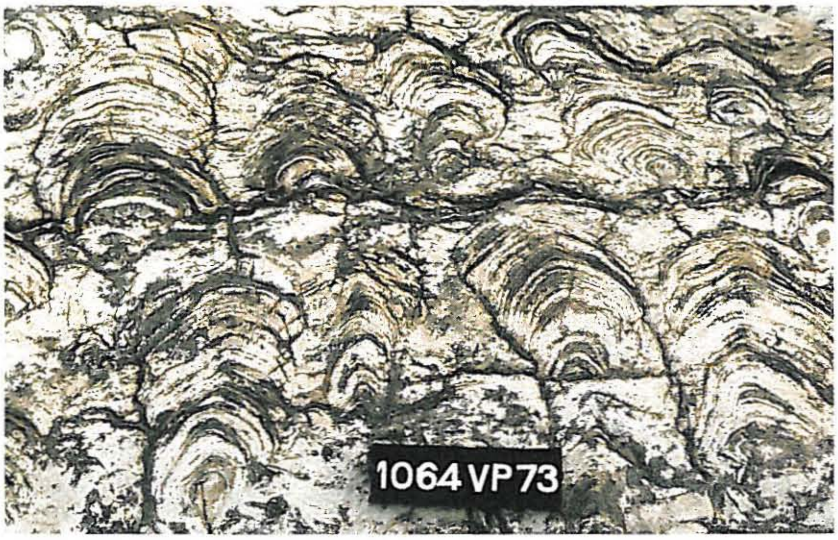

Fig. 11a. Stromatolite structures (Cryptozoon) in dolomite of the Rantamaa Formation. Rantamaa, Tornio. Photo, V. Perttunen.

of Metzger, op. cit.) dolomites and pelitic schists. Väyrynen (1933) divided the Jatulian sedimentary rocks into three different facies: Sariolan (arkosites with conglomerates), Kainuan (quartzites with conglomerates) and marine Jatulian (dolomites and pelitic schists). According to present-day definition, the Jatulian lithologies were deposited unconformably on the Sumian-Sariolan assemblages or on the Kainuan-Lapponian assemblages of the Kainuan Schist Belt, or, where these are lacking, directly on the Archaean basement. The lower part of the Jatulian stratigraphic sequence consists of epi/pericontinental arkosites, sericite quartzites and orthoquartzites with conglomerate interbeds; in places, volcanic rocks overlie the orthoquartzites. The upper part of the Jatulian lithologies, for which the name marine Jatulian is also used, consists of dolomites, quartzites, volcanites, black schists and mica schists. On the Mid-Norden Bedrock Map, these Jatulian rocks are named Jatulian assemblages, corresponding to the Jatuli tectofacies as defined by Laajoki (1990).

According to Perttunen (1985, 1991), 1 000 to 1 500 m-thick quartzite deposits form the Kivalo Formation (KiF) of the Kemi area. They are overlain by subaerial mafic lava flows of the 300–1 000 m-thick Jouttiaapa Formation (JuF), and have been intruded by Jatulian diabase dykes. A Sm-Nd isotope mineral isochron has yielded an age of 2090±70 Ma for the lavas of this formation (Huhma et al. 1990). The 250–800 m-thick upper part of the Jatulian lithologies of the Kemi area consists of quartzites of the Kvartsimaa Formation (not shown on the Bedrock Map), stromatolite-structured dolomites (Figs. 11a and 11b) of the Rantamaa Formation (RaF) (Härme & Perttunen 1964), and mafic tuffitic layers (Fig. 12) of the Tikanmaa Formation (TiF).

Fig. 11b. Stromatolite structures (Gymnosolen) in dolomite of the Rantamaa Formation. Rantamaa, Tornio. Photo, V. Perttunen.

The Jatulian supracrustal rocks of the Kemi area continue westward into Sweden. There, the Jatulian Sockberget Group (SoG) north of Kalix consists mainly of quartzites, in part strongly recrystallised or even migmatised. In a minor area near Pålänge, west of Kalix, a fuchsite-bearing Jatulian-type quartzite is found (Wikström 1993).

The major part of the Jatulian assemblages found in Sweden belong to the Kalix Group, which comprises the older Karlsborg Formation (KaF) and the younger Vitgrundet Formation (ViF; Åhman & Wikström 1990). The former consists of metamorphosed mafic tuffs and tuffites, in part intercalated with limestone, and lavas. Among the lavas, feldspar-porphyritic, hornblende-rich and amygdaloidal varieties are found. Pillow lavas also occur, but do not appear to be common. Mafic volcanites, in part pillow lavas, are also found on the island of Hindersön, east of Luleå (Ödman 1957). They contain intercalations of dolomite and phyllite, and should probably be correlated with the Karlsborg Formation.

Dolomite is the major constituent of the Vitgrundet Formation in the Kalix archipelago. It contains quartzite intercalations. The dolomite is well known for its excellently exposed stromatolites, which are mainly found on Vitgrundet and Lutskäret c. 10 km south of Karlsborg, and on V. Gräddmanhällan 15 km SSW of Karlsborg. A Pb–Pb age of 2.1±0.2 Ga has been reported for the dolomite (Öhlander et al. 1992).

Arkosites and quartz arenites with quartz-pebble conglomerates and, in places, with polymictic conglomerates belong to the East Puolanka (EPG) and Vihajärvi (ViG) Groups (Laajoki 1991), and the Vuokatti Group (VkG; Gehör & Havola 1988). They form most of the Jatulian rocks within the Kainuu Schist Belt. The upper parts of the East Puolanka Group have commonly been displaced by tectonic movements (Laajoki 1991). In the upper part of the Vuokatti Group, quartzites are interstratified with minor volcanites and mica schists (Gehör & Havola 1988). The quartz arenites, arkosites and arkosic quartzites of the Vihajärvi Group were deposited on the Central Puolanka Group (CPG). They underlie the quartzites, dolomites containing black schist and mica schist interbeds, and mafic tuffites of the Somerjärvi Group (not shown on the Bedrock Map). The rocks of the latter group show a transition to a more basinal facies (Laajoki 1991).

Quartzites and arkosites of the Juuanvaarat quartzite (Juv) and the Herajärvi Group (HeG) are situated in the Juuka and Koli areas, north of Outokumpu and Joensuu, respectively. The Juuanvaarat quartzite is an informal collective name for quartzites and arkosites with some carbonate rocks and black schists in the arcuate region north of Outokumpu. Updated lithostratigraphic and sedimentological information is not available on these rocks. The Herajärvi Group (maximum thickness 2 500 m) contains three quartzitic and one arkositic formation with westward-dipping beds (Kohonen & Marmo 1992, and references therein). They form a c. 60 km-long chain of quartzitic hills on the western side of the Lake Pielinen named the Nunnanlahti-Koli-Kaltimo area. No carbonate rocks, black schists or volcanites have been encountered within these Jatulian lithologies, which however have been cut by 2200–1970 Ma Jatulian metadiabase dykes and karjalite sills.

Arkosites and quartz arenites with some quartz-pebble conglomerate interbeds of the 150–550 m-thick Haukilampi Formation (HaF) in the Kiihte-

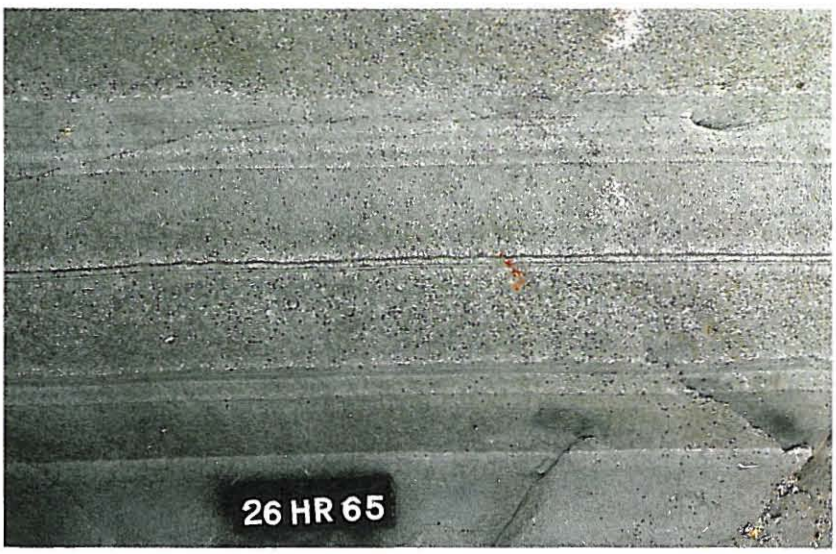

Fig. 12. Mafic tuffitic volcanite of the Tikanmaa Formation. Narkauskumpu, Tervola. Photo, V. Perttunen.

lysvaara area are overlain by mafic lavas of the 30–80 m-thick Koljola Formation (KjF; Pekkarinen 1979, Pekkarinen & Lukkarinen 1991). These lavas were erupted 2120–2100 Ma ago, based on U-Pb zircon ages of closely associated metadiabase dykes (Pekkarinen & Lukkarinen 1991). Quartzites, dolomites, black schists and mafic volcanites of the Hyypiä Group (HyG) form the up to 350 m-thick upper part of the Jatulian assemblages in the Kiihtelysvaara area.

In addition to the mentioned Jatulian lithologies, there are also Palaeoproterozoic arkosites, sericite quartzites and orthoquartzites in the Archaean Rautavaara Complex, i.e. the Keyritty (Key), Pisa (Pis) and Kinahmi (Kin) quartzites (Paavola 1984), and within the Palaeoproterozoic formations surrounding the Archaean basement gneiss domes between Kuopio and Joensuu (see Wilkman 1938, Gaál et al. 1975, Gaál 1980, Aumo 1983, Koistinen 1993). Dolomites with skarn rocks, black schists and volcanites representing marine Jatulian lithologies are present within the Pisa quartzites and within the Palaeoproterozoic rocks surrounding the Archaean basement gneiss domes. In the Kuopio region, quartzites and dolomites are covered by mafic lavas of the Vaivanen Formation (VaF) and mafic lavas with felsic tuffs of the Koivusaari Formation (KoF). The age of this volcanism is 2060 Ma, based on U-Pb zircon age data from the felsic tuff of the Koivusaari Formation (Geological Survey of Finland, unpublished data). It is noteworthy that these Jatulian sequences, which are associated with basement gneiss domes, are much thinner compared with those in the Koli, Kainuu and Kemi areas in eastern and northern Finland. For example, the total thickness of the quartzites, dolomites and volcanites in Kuopio is c. 1 000 m (Aumo 1983).

3.2.2.4 Kalevian assemblages

The name Kaleva (Kalevian) was originally proposed by Frosterus (1902) for mica schists and phyllites in the region between Lake Pielinen in the north and Lake Ladoga in the south, and by Ramsay (1902) for mica schists and phyllites in the Lake Onega area in Russian Karelia. According to the view prevailing at that time, Kalevian rocks were underlying the Jatulian formations, but were younger than the Ladogian schists defined earlier by Sederholm (1897) on the northern shore of Lake Ladoga (Fig. 13). According to Eskola (1925), Kalevian schists were higher-grade metamorphic derivatives of the Jatulian lithologies. Later, based on the studies of Väyrynen (1928, 1933), Kalevian schists were stratigraphically considered to rest on the Jatulian deposits. Originally, Väyrynen (op. cit.) included black schists, iron formations and some dolomites in the Kainuu Schist Belt in the Kalevian schists, but later he (Väyrynen 1954) defined these rocks as marine-Jatulian. The view that black schists and associated lithologies were classified as Jatulian was favoured up to the mid-80's, when Kontinen (1986) reported unconformities between the Jatulian dolomites and the Kalevian black schists and iron formations of the Kainuu Schist Belt.

In this description, Kalevian assemblages represent lithologies commonly classified as Kalevian in Finland (e.g. Simonen 1980, Perttunen 1985, Korkiakoski & Laajoki 1988, Ward 1988, Laajoki 1991). On the Bedrock Map, the Kalevian assemblages are shown by two colours: grey (colour no. 121) and grey with green dots (colour no.119), following an informal division into 'Lower Kalevian' and 'Upper Kalevian', respectively (e.g. Kontinen 1986, Kontinen & Sorjonen-Ward 1991, see also Gaál 1990). Because the depositional age and stratigraphical relationships between the Kalevian lithologies in different areas are not firmly established, a division into 'the Eastern Kaleva' and 'the Western Kaleva' (Laajoki & Luukas 1988, Kohonen 1995), or a division into geographical provinces (Ward 1987), has also been suggested. Stratigraphically, the Kalevian assemblages overlie the Jatulian lithologies, or, in places, rest directly on the Archaean basement. $^{207}Pb/^{206}Pb$ age data on detrital zircons from the Upper Kalevian greywackes in the Kainuu Schist Belt and in Outokumpu range from 2820 to 1920 Ma. Only about one third of the analysed crystals were Archaean, showing that the source material of these greywackes is mainly Proterozoic (Claesson et al. 1993). Detrital zircons from the Lower Kalevian Höytiäinen schists (Hös), from the Ylikiiminki Formation (YkF) east of Oulu and from the Martimo Formation (MaF) in the Kemi area yield Archaean average ages, demonstrating a difference in provenance between the Lower Kalevian schists and the Upper Kalevian and Svecofennian lithologies (Huhma 1990). $\varepsilon_{Nd\ (1900)}$ values for Lower Kalevian schists (e.g. MSIA Map 112, 113, 139, 145), however, range from -5.5 to -1 (Huhma 1987, 1990 and unpublished data), indicating that, besides the Archaean material, Lower Kalevian schists also contain Palaeoproterozoic crustal material.

On the Mid-Norden Bedrock Map, the schists named Höytiäinen schists (Hös) within the North Karelian Schist Belt (Fig. 13) are classified as Lower Kalevian. Metamorphosed to phyllites and mica schists, they are thin-bedded, commonly distinctly graded-bedded pelites and greywackes (Piirainen et al. 1974, Huhma 1975, Nykänen 1971, Pekkarinen 1979) with some coarse-clastic deposits (Ward 1987, 1988). Within

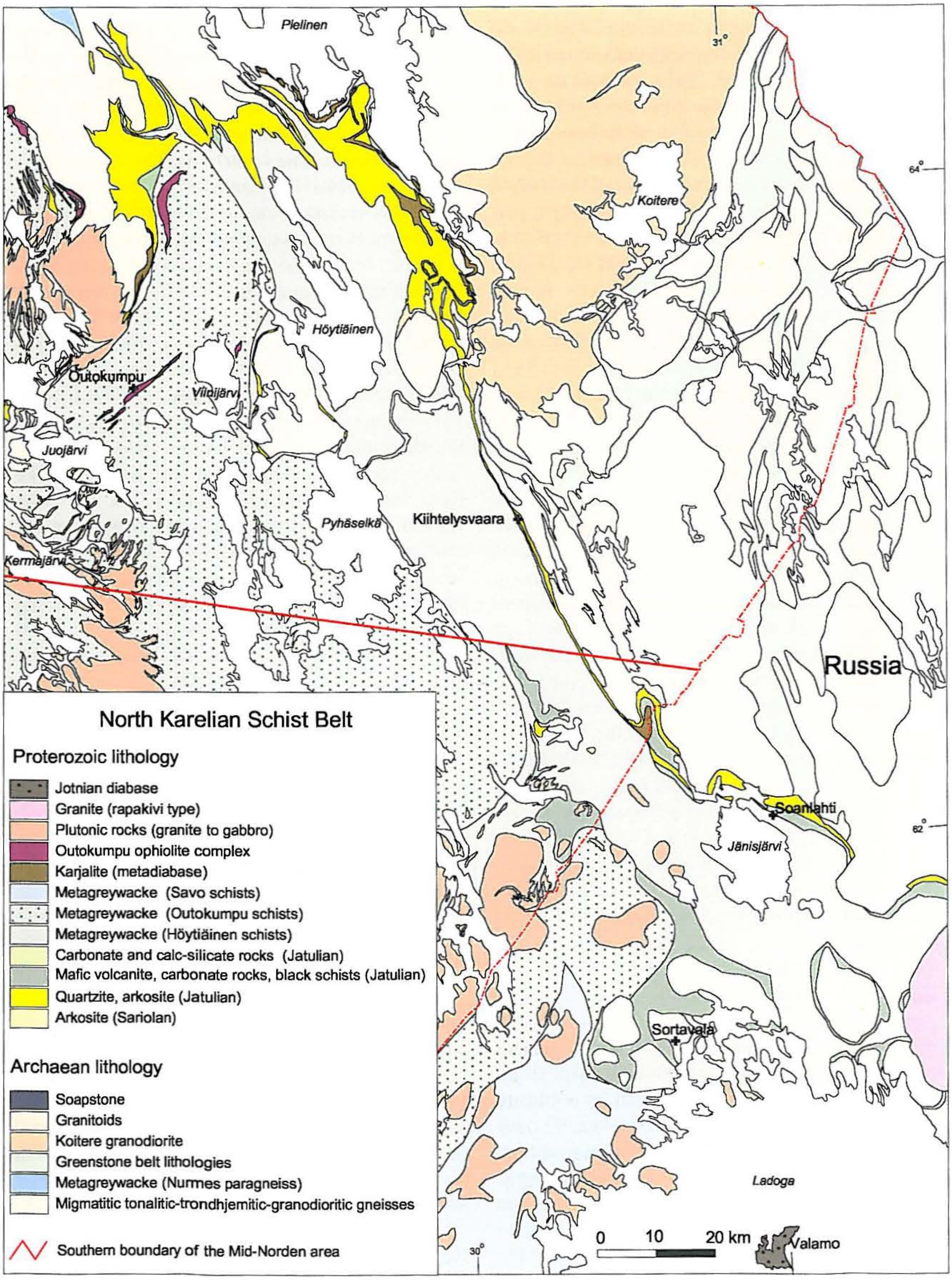

Fig. 13. North Karelian Schist Belt. The map is modified after the Mid-Norden Bedrock Map. The lithology in Russian Karelia is modified after Koistinen and Saltykova (1999).

the phyllites and mica schists there are arkositic and quartzitic, sharp-bounded interbeds of varying thickness (Kohonen 1995), or quartzitic beds which grade upwards into the phyllites and mica schists with an increase in pelitic material and decrease in quartzitic material (Pekkarinen 1979). Depending on the grade of metamorphism, phyllites and mica schists contain andalusite, sillimanite, cordierite or staurolite porphyroblasts (Nykänen 1971, Campbell et al. 1978).

Along the contacts between Kalevian and Jatulian and, in places, also Kalevian and Archaean basement lithologies, there are polymictic conglomerate beds containing clasts mainly of quartzite, volcanic rocks, carbonaceous phyllite, granitoids and vein quartz. In the Kiihtelysvaara area (Fig. 13), Pekkarinen (1979) interpreted these as turbiditic conglomerates, which occur as a basal unit of the schists, deposited unconformably upon the Jatulian sediments. Similar conglomerates east of Lake Höytiäinen, described as basal conglomerates by Piirainen et al. (1974), have recently been interpreted to occur at several different stratigraphic levels, and are not regarded as basal units (sensu stricto) to the Kalevian schists (Kohonen 1995). As a whole, the Höytiäinen schists represent sediments deposited either in a shelf or in a rift basin environment (Kohonen, op. cit.).

West of the Höytiäinen schists there are monotonous, thick-bedded, sandy metaturbidites with black schist interbeds, referred to as the Outokumpu schists (Ous) on the Bedrock Map. Within these schists there also occur fault-bounded bodies of serpentinites (originally mantle peridotites), including minor pyroxenites and gabbros, closely associated dolomite rocks, calc-silicate rocks (skarns), quartz rocks and infolded or sheared black schist lenses. Massive sulphide ore deposits (Cu, Co, Zn) of the Outokumpu mining district are associated with these lithologies, referred to as the Outokumpu association by Gaál et al. (1975). Koistinen (1981) was the first who interpreted rocks of the Outokumpu association as fragments of ancient ophiolites. On the Bedrock Map they are labelled Out (the Outokumpu ophiolite complex). It is very likely that these serpentinites represent upper mantle fragments formed in a crustal thinning zone without extensive volcanic activity, because sheeted dykes are not known to occur within the serpentinites, and mafic lavas are only minor components of the Outokumpu ophiolite complex (Koistinen 1981, Peltonen & Kontinen 1997). The origin of the dolomite and quartz rocks is assumed to be as pervasively carbonatised and silicified peridotites or serpentinites (Haapala 1936), volcanic-exhalative sediments (Borchert 1954, Mäkelä 1974), or chemogenic sedimentary rocks (Vähätalo 1953, Huhma & Huhma 1970). Recent studies concerning, for example, the habit and composition of chromite in serpentinites and dolomite and quartz rocks, imply that the last mentioned rocks represent residual rocks after pervasive leaching of a peridotite or serpentinite precursor (Peltonen & Kontinen 1997). That is why it is also very likely that the sedimentary and volcanic-exhalative models for the rocks and the Cu-Co-Zn ore of the Outokumpu association are no longer credible (Peltonen & Kontinen, op. cit.). Magmatism of the Outokumpu ophiolite complex was active about 1970 Ma ago, based on the U-Pb-zircon age of 1972±18 Ma (MSIA Map 121) from gabbro associated with serpentinite (Huhma 1986). The $\varepsilon_{Nd(1970)}$ value of the same gabbro is +3.1 (MSIA Map 122), suggesting a depleted mantle origin. The youngest $^{207}Pb/^{206}Pb$ age of 1920 Ma for detrital zircons from the metagreywacke of the Outokumpu schists suggests that these metaturbidites were deposited on the ocean floor after the 1970 Ma old ophiolites (Claesson et al. 1993). As a whole, the Outokumpu schists together with the Outokumpu ophiolite complex represent allochthonous sequences emplaced onto the craton margin (Koistinen 1981).

The coarse-clastic sedimentary rocks referred to as the Liperi arkosite (Lip) southeast of Outokumpu are interpreted to belong to the Lower Kalevian lithologies within the Outokumpu schists. These rocks are impure arkosites containing thick conglomerate interbeds with clasts of quartzite and granite. In the east and north the Liperi arkosite is bounded by black schists.

The schist area to the west of the Outokumpu schists is informally named (by the author HL) the Soisalo schists (Sos), and classified as Lower Kalevian assemblages. It consists of mica schists and mica gneisses, originally pelites and greywackes, with thin black schist interlayers. They are variably migmatitic but, in places, they also display primary sedimentary structures such as graded bedding. The boundary between the Soisalo and Outokumpu schists on the Bedrock Map is based on the distribution of the serpentinites within the latter, and it coincides with the tectonic lines drawn along the NW–SE-trending lakes southeast of Kuopio. The boundary is different from that presented on the 1 : 1 million Bedrock map of Finland (see Korsman et al. 1997). The western boundary against the Svecofennian schists is tectonic and somewhat obscure because of migmatisation and deformation of the rocks.

Defined as the Salahmi Schist Belt by Korkiakoski and Laajoki (1988), a narrow schist zone northwest of Iisalmi (Fig. 14) consists of the Haajainen and Rotimojoki Formations (the last mentioned formation is not labelled on the Mid-Norden Bedrock Map). The Haajainen Formation, containing turbiditic conglomerates and conglomeratic arkosites, is situated between the Archaean basement and the Rotimojoki Formation. Its contacts with the basement are strongly tectonised. The contact with the overlying Rotimojoki Formation is not exposed, but seems to be gradual. The majority of the Rotimojoki Formation consists of massive arkosites, originally turbidites, and turbiditic, laminated to thinly bedded and graded mica schists. Some conglomerate members (e.g. the Ilkonahonkallio Member; Korkiakoski & Laajoki 1988) occur in the middle part of the formation. The basal stratigraphic member of the Rotimojoki Formation contains turbiditic, massive arkosites alternating with mica schists. The Rotimojoki and Haajainen Formations belong to the Lower Kalevian assemblages, although the Haajainen Formation (the easternmost formation) is incorrectly coloured as a Jatulian assemblage on the Bedrock Map.

Three schist groups are represented in the Kalevian assemblages of the Kainuu Schist Belt. On the Bedrock Map the Väyrylänkylä Group (VäG) (Laajoki 1991) and the Sotkamo Group (StG; Gehör & Havola 1988; see also Kontinen 1986, 1987) represent Lower Kalevian assemblages. They are composed of presumably rift-related quartzose turbidites (phyllites and mica schists), quartzites, black schists, iron formations (Laajoki & Saikkonen 1977), tuffaceous schists, carbonaceous schists and some sedimentary breccias and conglomerates. Turbiditic, deep-water greywackes with intercalated black schists of the Nuasjärvi Group (NuG; Gehör & Havola 1988, Kontinen 1987) are interpreted as Upper Kalevian assemblages.

Three fault-bounded blocks (total area of 50 km^2), referred to as the Jormua ophiolite complex (Jor), or the Jormua Ophiolite (Kontinen 1987, Peltonen et al. 1996, 1998) occur within the metaturbidites of the Nuasjärvi Group. They are composed of serpentinites (extensively serpentinised mantle peridotites), sheeted dykes (Fig. 15a), cumulate metagabbros, plagiogranites, mafic lavas and some hyaloclastic tuffites. The lavas are either massive or pillowed (Fig. 15b) but free of sedimentary intercalations. The U-Pb zircon age of the metagabbro (MSIA Map 29) and the plagiogranite (MSIA Map 28) associated with this complex is 1960±12 Ma (Kontinen 1987). However,

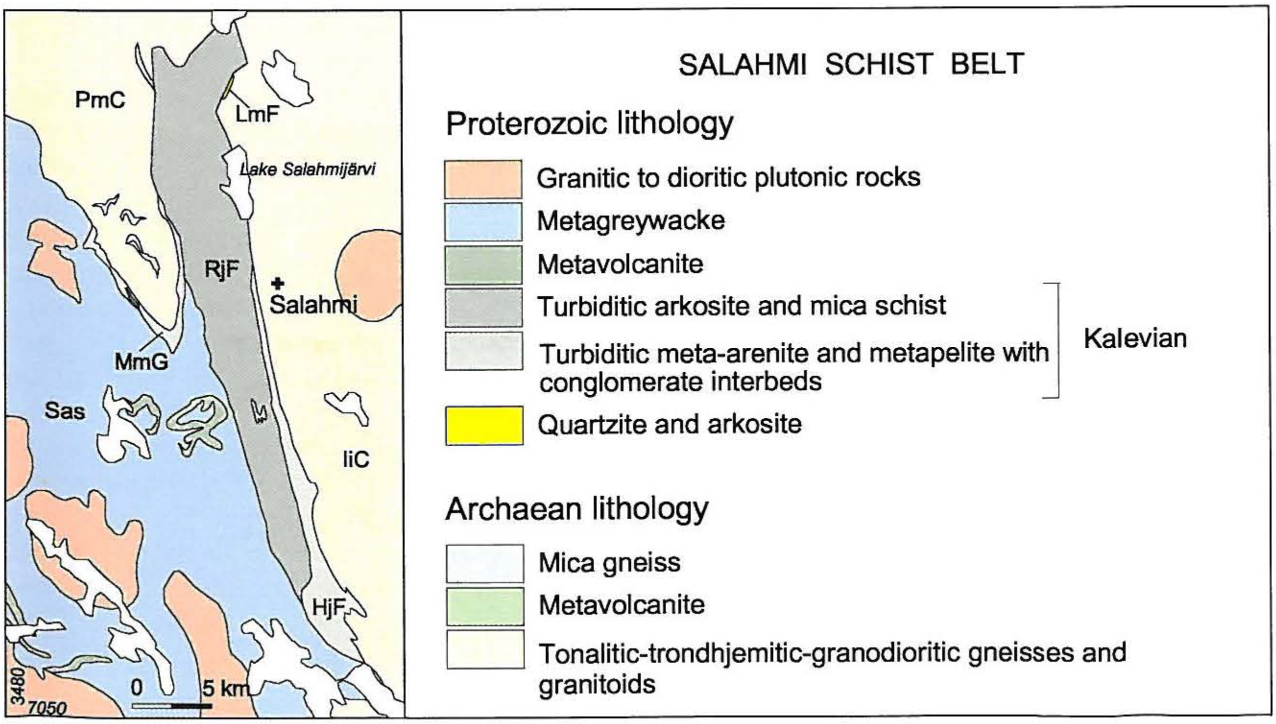

Fig. 14. Salahmi Schist Belt. The map is modified after the Mid-Norden Bedrock Map. Names of the lithological units are according to Laajoki and Luukas (1988): PmC - Pirttimäki Complex; LmF - Lähdemäki Formation (Kainuan-Lapponian assemblages); RjF - Rotimojoki Formation; HjF - Haajainen Formation; MmG - Mataramäki Gneiss (more distal extension of the HjF). Sas (Savo schists / Svecofennian Domain) and IiC (Iisalmi Complex), are according to the Mid-Norden Bedrock Map.

a new concordant age of 1953±2 Ma obtained from a gabbroic dyke cross-cutting the serpentinite yields a better age estimate for the magmatism of this ophiolite complex (Peltonen et al. 1996). Some dykes ('earlier dykes') are chemically akin to ocean island basalts and the 'main dyke and lava suite' displays an E-MORB affinity, but there is no evidence to suggest that the Jormua Ophiolite was formed in an arc-related setting (Peltonen et al. 1996, 1998). The Jormua ophiolite complex represents an allochthonous assemblage emplaced onto the craton margin from the present west (Peltonen et al. 1996).

The Northern Ostrobothnia (Pohjanmaa) schist area east of Oulu (see Fig. 14) represents a sedimentary-

Fig. 15a. Sheeted dykes of the Jormua ophiolite complex. Sammakkolampi, Kajaani. Photo, A. Kontinen.

Fig. 15b. Mafic pillowed lava of the Jormua ophiolite complex. Kylmä, Paltamo. Photo, A. Kontinen.

volcanic basin developed in a cratonic or epicratonic rift environment (Honkamo 1985, 1988, 1989). It consists of metamorphosed sedimentary and volcanic rocks classified as Lower Kalevian assemblages. The sedimentary rocks are mainly greywackes and mica schists named the Vuotto (VuF), Ylikiiminki (YkF) and Haukipudas (HaF) Formations. The greywackes show well preserved primary sedimentary structures characteristic of turbidites. The mica schists are more deformed derivatives of the greywackes, probably containing more pelitic material than the typical greywackes. The greywackes of the Vuotto Formation grade into arkosites and conglomerates of the Utajärvi Formation (not shown on the Mid-Norden Bedrock Map), in the southeastern part of the Vuotto Formation. The minor Koiteli Formation (KtF) consists dominantly of a coarse-grained, pebbly arkosic quartzite. It also contains interbeds of polymictic, unsorted conglomerate.

The volcanic rocks [the Martimojoki (MjF), Pyyräselkä (PyF), and Kiiminki (KmF) Formations] are mainly subaqueous, fine- to medium-grained, massive lavas. Pillowed, brecciated and amygdaloidal lavas occur in places. Chemically, they are MORB-like tholeiitic basalts. In addition to mafic volcanic rocks, the minor Vepsä Formation (not shown on the Bedrock Map; see Honkamo 1989) contains interbeds of chemical sedimentary rocks such as iron formations, black schists, dolomites, skarn rocks and cherts.

The thickness of the greywackes varies from 2 000 to 3 000 m. The thickness of the volcanites may attain c. 1 500 m, but is generally only a few hundred metres. The total thickness of the sedimentary and volcanic sequences at Kiiminki, in the middle part of the basin, is c. 5–8 km. The greywackes of the Vuotto Formation (including the Utajärvi Formation) are the lowermost lithostratigraphic units. The lithologies of the Vepsä Formation were deposited above the Vuotto Formation. The lavas of the Martimojoki, Pyyräselkä and Kiiminki Formations erupted roughly at the same stratigraphic level, on top of the Vepsä Formation, or, where this formation does not exist, directly on the greywackes of the Vuotto Formation. Stratigraphically, the Koiteli Formation is situated on top of the Kiiminki Formation, or partly within it. The metagreywackes of the Ylikiiminki Formation were deposited above the volcanic formations or, where these are lacking, on top of the greywackes of the Vuotto Formation. The stratigraphic relationship between the Haukipudas Formation and the surrounding Ylikiiminki Formation is uncertain.

The time of sedimentation and volcanism of this basin is uncertain. A U-Pb zircon age for a K-feldspar porphyry clast from a conglomerate bed of the Koiteli Formation is 2093±35 Ma (MSIA Map 5), indicating a maximum age for the sedimentation of this conglomerate. The arkosic quartzite of the Koiteli Formation is cut by a 1873±4 Ma old gabbro dyke (MSIA Map 6, Honkamo 1988).

In the Kemi area, the Lower Kalevian lithologies referred to as the Martimo Formation (MaF) consist of thin-bedded phyllites and mica schists, which are more strongly metamorphosed counterparts of the phyllites (Perttunen 1985, 1991). In places they are graphite-bearing, and some conglomerate interbeds are also present (Perttunen, op. cit.).

In the Haparanda-Luleå area of Sweden, the Jatulian Kalix Group is overlain by Kalevian-type phyllites,

Fig. 16. Kalevian mica schist with large porphyroblasts of andalusite (chiastolite) and smaller, reddish brown porphyroblasts of staurolite. Sören, W of Kalix. Photo, Th. Lundqvist.

schists and greywackes of the Råneå Group (RnG). The metamorphic grade of this group varies from upper greenschist to upper amphibolite facies (migmatites). West of Kalix, staurolite and andalusite (chiastolite) are present in medium-grade metapelites (Fig. 16; Wikström 1995). Intercalations of graphite schist and mafic lava occur. Near Prästholm, 9 km northwest of Råneå, there is a minor intercalation of crystalline limestone (calcite with minor dolomite) in veined greywacke gneisses.

The Råneå Group sedimentary rocks are transitional to the greywackes of the Svecofennian Härnö group (Häg) in the west and southwest. Therefore, the border between the two groups on the Bedrock Map is somewhat arbitrarily drawn.

3.2.2.5 Plutonic rocks of the Karelian Domain

The composition of the plutonic rocks of the Karelian Domain in the Finnish Mid-Norden area varies from pyroxenite to granite. The ages of the plutonic rocks range between 2500 and 1800 Ma, but most of them are 1890–1850 Ma. Although the majority of the Palaeoproterozoic plutonic rocks in the Karelian and Svecofennian Domains are almost coeval (1890–1860 Ma), traditionally classified as syn- or late-orogenic products of the same orogeny, they are in this description interpreted to belong to the different domains for the following reasons: 1) Sm-Nd data and $\varepsilon_{Nd(t)}$ values (varying from -9 to -5; Huhma 1986) of the granitoids investigated from the Karelian Domain show that these rocks either were derived from the Archaean continental crust or were contaminated by Archaean material when they intruded through the crust. Granitoids from the Svecofennian Domain have $\varepsilon_{Nd(t)}$ values from -1 to +3, suggesting a minor (10–30 %) admixture of Archaean continental crust (Huhma 1986, Lahtinen & Huhma1997); 2) geophysical studies confirm that the Karelian Domain is underlain by Archaean continental crust (Korja 1991), but there is no evidence for predominantly reworked Archaean continental crust in the Svecofennian Domain (Huhma 1986); and 3) recent interpretations prefer an island-arc origin for the lithologies of the Svecofennian Domain, and the1890–1880 Ma old plutonic rocks of this Domain are arc-related (e.g. Lahtinen & Huhma 1997, Nironen 1997, Korsman et al. 1997).

The oldest plutonic rocks in the Karelian Domain are rift-related, layered mafic and ultramafic intrusions in northern Finland. They occur as sheets or lopolith-like bodies within the Archaean basement gneisses or along the contact zone between basement gneisses and the Proterozoic supracrustal lithologies of the Karelian Domain. The Kemi (Kem), Penikat (Pen) and Syöte (Syö) intrusions (Alapieti 1982, Alapieti & Lahtinen 1986, Alapieti et al. 1989) and the unlabelled Kukkola/Tornio intrusion continuing into Sweden (Alapieti & Lahtinen 1989, Perttunen 1991) are shown on the Bedrock Map. These intrusions display cryptic and rhythmic layering (Fig. 17) and igneous lamination, features typical of layered intrusions. Petrographically, the rocks of the lower parts of these intrusions are generally pyroxenites and peridotites with chromite cumulates. In addition to chromite, these layered intrusions also contain mineralisations of the platinum group elements (PGE mineralisations; Lahtinen et al. 1989). The middle and upper parts of the intrusions consist of gabbro and anorthosite. Granophyres corresponding in their composition to alkali-feldspar granites cap the Syöte and

Fig. 17. Layered ultramafic rock of the Penikat intrusion. Keski-Penikka, Keminmaa. Photo, V. Perttunen.

Penikat intrusions (Alapieti 1982, Alapieti & Lahtinen 1986). Age determinations for these layered intrusions, based on the U-Pb zircon, Pb-Pb whole-rock and Sm-Nd methods, yield a fairly coherent set of ages, ranging from 2435 to 2450 Ma (Alapieti & Lahtinen 1989). The U-Pb zircon age of the Syöte intrusion is 2436±5 Ma (MSIA Map 1, Alapieti 1982).

Porphyritic potassium granite bodies and associated granite porphyry dykes (apophyses) occur east of the Kuhmo Greenstone Belt, i.e. the Tuliniemet (Tul), Iso-Kikonvaara (Iki) and Kettuvaara (Ket) intrusions (Luukkonen 1988), and the Rasinmäki (Ras) intrusion southwest of the Tipasjärvi Greenstone Belt (Hyvärinen 1989). On the Bedrock Map, the unlabelled granite intrusion at Hoikanvaara, southeast of Puolanka (Kontinen 1989), also belongs to these granites, which have a modal composition and texture typical of rapakivi granite: potassium feldspar ovoids, up to 5 cm in size, with or without a plagioclase mantle (wiborgite- or pyterlite-type, respectively). Fluorite is a characteristic accessory mineral. The granites are massive and almost non-foliated. Bluish quartz crystals up to 3 mm in size and pinkish potassium feldspar and oligoclase crystals up to 5 mm in size are typical phenocrysts. The width of the granite porphyry dykes varies from 20 to 30 m. Radiometric ages of the rapakivi-type granites and the associated dykes show a Palaeoproterozoic magmatic event, which is partly coeval with the magmatism of the mafic layered intrusions, e.g. zircons from the granite porphyry dyke in Kokonniemi, just west of the Kettuvaara intrusion, have yielded an age of 2435±12 Ma (MSIA Map 12, Luukkonen 1988), and the Rasinmäki intrusion is 2352±25 Ma old (MSIA Map 52, Vaasjoki et al. 1999). The emplacement of these granites has been interpreted to be postorogenic in relation to the late Archaean orogeny (e.g. Luukkonen 1988).

The Otanmäki gneissic granite (Oag) is a quartz-, plagioclase- and hornblende-bearing gneissic peralkaline to alkaline granite south of Oulujärvi. It is interpreted to be spatially associated with the Jormua ophiolite complex (Peltonen et al. 1996). Its age on the Legend of the Bedrock Map is set as c. 1970 Ma, but new determinations yield a more precise age of 1958–1965 Ma (Geological Survey of Finland, unpublished data; Peltonen et al. 1996).

There are many gabbro and diorite bodies of variable size within the Karelian Domain, but only the most prominent intrusions are shown on the Bedrock Map. An Fe-Ti-bearing layered gabbro-anorthosite intrusion, the Otanmäki gabbro (Ota), south of Lake Oulujärvi, is 2060±4 Ma old (MSIA Map 49, Talvitie & Paarma 1980, Lindholm & Anttonen 1980). The Lapinlahti gabbro (Lap), south of Iisalmi, is composed of gabbroic and anorthositic lithologies. Its age is 1895±15 Ma (MSIA Map 71, Paavola 1988). An unpublished $\varepsilon_{Nd(1900)}$ value for the gabbro is -5.2, indicating an influence from Archaean crust on the composition of the gabbro magma (H. Huhma, oral communication 1998). The composition of the Kaarakkala (Kaa) intrusion (on the Bedrock Map named Kaarakka) is mainly dioritic, but also gabbroic, particularly in the central parts of the intrusion.

The age group 1900–1860 Ma on the Bedrock Map consists of rocks of quartz dioritic, tonalitic, granodioritic, granitic and quartz monzodioritic composition. They are more or less foliated, even-grained and, in places, porphyritic intrusive rocks. Some of them have been classified as collision-related (1.89–1.88 Ga old) or post-collisional intrusions (1.86 Ga and 1.88 Ga old) on the Bedrock Map of Finland (Korsman et al. 1997). The Kermajärvi (Ker) and Suvasvesi (Suv) intrusions, southeast of Kuopio, are mainly granodioritic. In many places the composition of the Kermajärvi rocks is also dioritic or quartz dioritic, and the Suvasvesi intrusion also displays a granitic composition. Both intrusions have porphyritic plagioclase or K-feldspar crystals 1–2 cm in size. These intrusions postdate the essential part of the migmatitic structures of the surrounding mica gneisses, based on cross-cutting contact relations (Koistinen 1993). The Kermajärvi intrusion is 1871±5 Ma (MSIA Map 144) and the Suvasvesi intrusion 1870±4 Ma (Huhma 1986). $\varepsilon_{Nd(1900)}$ values are -2.7 and -3.6 to -3.4, respectively (MSIA Map 146, Huhma, op. cit.).

The Maarianvaara intrusion (Maa), north of Outokumpu, is mainly granodioritic in composition with more mafic derivatives forming a continuous differentiation series from diorite and quartz diorite to granite (Huhma 1975). The contacts with the country rocks are sharp, and contact effects, like granitisation or migmatisation, are weak and purely local (Huhma, op. cit.). Two samples of the granodiorite, some kilometres to the northwest of the main body, have provided an upper intercept age of 1900 Ma, but more precise data yield an age of 1857±8 Ma (MSIA Map 108), showing that the Maarianvaara intrusion is somewhat younger than the Kermajärvi and Suvasvesi bodies. The $\varepsilon_{Nd(1900)}$ value of the Maarianvaara intrusion is -6 (MSIA Map 107, Huhma 1986).

The Juurusvesi tonalite (Juu), north and northeast of Kuopio, forms an extensive intrusion containing both even-grained and porphyritic types (Figs. 18a, b) with variable amounts of mica schist and amphibolite inclusions. The composition of the intrusion varies from tonalite and minor quartz diorite to granodiorite. The zircon U-Pb dating yields an uncertain age of 1880 Ma for the Juurusvesi tonalite (unpublished data, Geological Survey of Finland).

The medium-grained and rather homogeneous Onkivesi granodiorite (Onk), north of Kuopio, has intruded with sharply cutting contacts into the country rocks (Paavola 1988). The zircons from three samples of this granodiorite are very heterogeneous, and yield an age of 1908±16 Ma (Paavola, op. cit.). An $\varepsilon_{Nd(t)}$ value of -3.6 for a sample from the Onkivesi intrusion suggests an influence of Archaean crust (MSIA Map 89, Huhma 1986). A homogeneous quartz diorite near the Onkivesi granodiorite, but not in genetic relation to the latter, contains zircons which have provided an age of 1902 Ma (MSIA Map 88, Paavola 1988).

The Ristijärvi granodiorite (Ris), intruded with sharply cutting contacts into the metagreywackes of the Kainuu Schist Belt north of Kajaani, contains 1859±8 Ma old zircons (MSIA Map 23, Kontinen 1993) and is therefore contemporaneous with the Maarianvaara intrusion. The composition of the Ristijärvi intrusion varies from granodiorite to granite, but is mainly granodioritic.

Lithologies belonging to the Haparanda suite (Hap) in the Kemi area (Perttunen 1991) continue into the

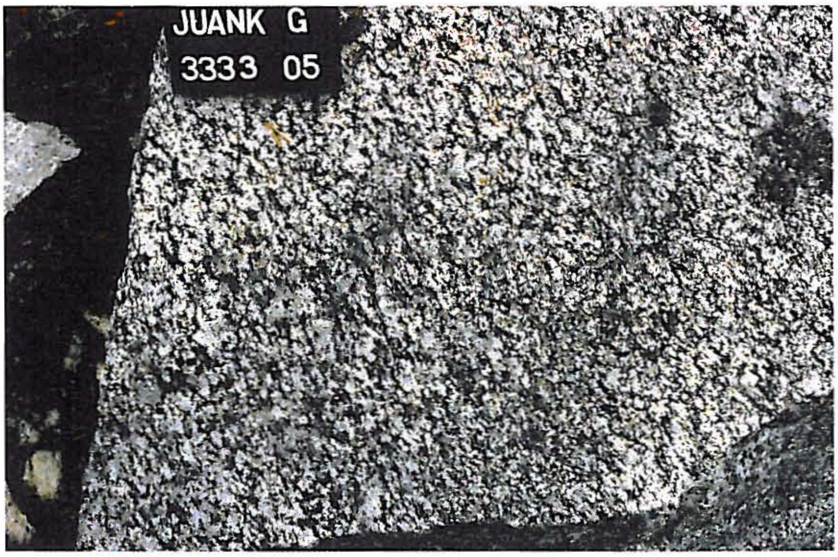

Fig. 18a. Porphyritic Juurusvesi tonalite. Ylä-Pieksä, Juankoski. Photo, O. Äikäs.

Fig. 18b. Juurusvesi tonalite (the commercial name Juankoski Grey) is used as dimensional stone. Ylä-Pieksä, Juankoski. Photo, O. Äikäs.

Swedish part of the Mid-Norden area. Petrographically, the rocks of this suite range from gabbro to granite, being mainly quartz dioritic, quartz monzodioritic, tonalitic and granodioritic in composition. A typical mineral for rocks of this suite is a subhedral and oscillatory zoned plagioclase. Two age determinations have yielded c. 1890 Ma (Perttunen 1991) and 1883±6Ma (MSIA Map 204, Wikström & Persson 1997a). On the Swedish side there have been reported abundant magma-mixing and mingling structures, as well as composite, in part hybridised and synplutonic dykes in rocks of the Haparanda suite (Fig. 19; Wikström 1992). It should also be noted that the term 'Haparanda granite' has been frequently used for granitoids in northern Sweden regardless of the environment (Karelian or Svecofennian assemblages). In the Mid-Norden Bedrock map the term 'Haparanda suite' has, however, been restricted to areas with Jatulian or Kalevian supracrustal assemblages, although, admittedly, the border to the Svecofennian is poorly defined.

Several gabbro massifs belonging to the Haparanda suite occur in Sweden. An example is the Sangis gabbro east of Kalix.

ε_{Nd} determinations on members of the Haparanda suite have yielded distinctly negative values, indicating Archaean rocks in the protolith. This Archaean influence continues westward up to the Archaean palaeoboundary, the Luleå-Jokkmokk Zone (e.g. MSIA Map 201–203, 206, 236, 237, 239, Öhlander et al. 1993; see also p. 70).

The age group c. 1890–1880 Ma, colour no. 115 on the Bedrock Map, consists in the Finnish Mid-Norden area of plutonic rocks which are mainly granitic or pegmatite granitic in composition. Most prominent of these are the Kajaani pegmatite granite (Kaj), and the Iisalmi (Iis), Kauppilanmäki (Kau) Honkamäki (Hon) and Vehmersalmi (Veh) granites. They are medium- or coarse-grained and more or less foliated. Because no age determinations are available, the emplacement time of these intrusions is uncertain. It is also very probable that the Kajaani pegmatite granite is much younger than the lower age limit mentioned in the legend of the Bedrock Map, based on the age1796±19 Ma of a coarse-grained granite within this pegmatite granite (Kärki et al. 1995). A new, unpublished age of 1868±3 Ma for zircons from the Honkamäki granite (north of Kuopio) indicates that this rock is coeval with the Suvasjärvi and Kermajärvi intrusions.

In Sweden, the dominantly microcline-porphyritic, in part foliated1880±7 Ma (MSIA Map 216, Wikström et al. 1996) Degerberget granite (Deg) has also been marked with colour115 on the Bedrock Map. In its northern parts this granite shows mingling structures with a nearby gabbro (Fig. 20). (This gabbro, the Skogsträsk gabbro, is incorrectly marked with colour symbol 95 on the Bedrock Map. The correct symbol should be 117.)

Fig. 19. Mafic, synplutonic dyke in Haparanda tonalite. The dyke shows mingling and mixing phenomena. Vånafjärden, E of Kalix. Photo, Th. Lundqvist.

The Degerberget granite, which resembles the c. 1.80 Ga late- to post-tectonic granites found in the Svecofennian Domain in Sweden, is particularly interesting since it separates two phases of deformation and migmatisation. The granite [and the similarly c. 1.88 Ga cross-cutting mafic-felsic Bläsberget dykes (Bdg), see below] cuts an older foliation and migmatite structures. It is, however, locally involved in migmatisation (Romer & Öhlander 1991, Wikström & Persson 1997). A younger phase of migmatisation is probably associated with the 1783±3 Ma Lina granite of the same area (Wikström & Persson 1997b). This granite forms small massifs in the Kalix area, but is a widespread rock further north (see Geological Map, Northern Fennoscandia, 1 : 1 million 1987).

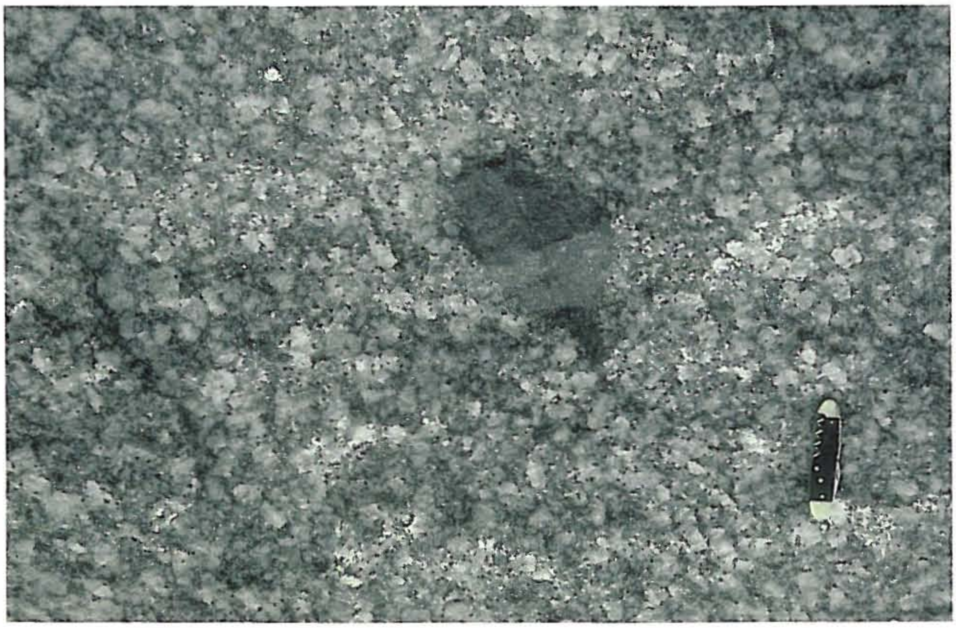

Fig. 20. Grey Degerberget granite with a mafic enclave. Degerberget, SW of Kalix. Photo, Th. Lundqvist.

3.2.2.6 Dyke rocks of the Karelian Domain

Mafic dyke rocks, shown on the Bedrock Map in the Finnish Mid-Norden area of the Karelian Domain, are mainly Fe-tholeiitic and tholeiitic Jatulian metadiabase dykes, differentiated metadiabase sills and dykes referred to as Karjalites (Kar) and the Kapustakangas Suite (Kas), and the Niinivaara lamprophyre dyke (Nii). Besides these particular dykes there are gabbroic (noritic) dykes closely associated with the mafic layered intrusion (not shown on the Bedrock Map). The age of these mafic dykes and sills ranges from c. 2440 to 1970 Ma, showing a prolonged Palaeoproterozoic magmatic evolution. The lamprophyre dykes are younger, c. 1830 Ma.

The Jatulian metadiabase dykes, which are Fe-tholeiitic in composition (Nykänen 1968, Paavola 1987, Kontinen 1987b, Perttunen 1989, Vuollo et al. 1992, Nykänen et al. 1994), have the most extensive areal distribution in the Finnish Mid-Norden area. These dykes were intruded vertically or subvertically through the stabilised Archaean craton (Figs. 21a,b), and they also cross-cut the Karelian metasedimentary rocks, excluding the Kalevian greywackes. Some of them have been interpreted to represent feeding channels for the Jatulian lavas (e.g. Pekkarinen & Lukkarinen 1991). The width of these dykes varies from some tens of centimetres up to 200 m, though they are usually 10–100 m (Nykänen 1968, 1971b, Paavola 1987, Kontinen 1987b, Perttunen 1991). Their lengths range from hundreds of metres to several kilometres. On the Bedrock Map lots of dykes have been drawn which are more extensive than those shown in the original maps. This has been done by using low-altitude aeromagnetic data. The Jatulian diabases are c. 2100 Ma in age (MSIA Map 3, 135, Perttunen 1987, Pekkarinen & Lukkarinen 1991), but recent age determinations have also demonstrated the existence of metadiabase dykes as old as 2300 Ma (Paavola 1988, and unpublished data of the Geological Survey of Finland).

Tholeiitic metadiabase dykes occur along with Fe-tholeiitic dykes, cutting the Archaean basement gneisses (Vuollo et al. 1992) and the lithologies of the Kuhmo Greenstone Belt (Halkoaho, oral communication, June 1998). They are c. 1965±10 Ma in age and are interpreted to be associated with the 1.97 Ga ophiolite magmatism of the Outokumpu area (MSIA Map 100, Vuollo et al. 1992). Because the areal distribution of these dykes is poorly known, they are not separated from the Jatulian metadiabase dykes on the Bedrock Map.

Gabbroic (noritic) dykes close to the layered mafic intrusions are boninite-like in composition (Perttunen 1991, Vuollo 1994). These dykes are interpreted to be feeder channels for the mafic layered intrusions (Piispanen 1972), and are possibly c. 2440 Ma (Perttunen 1991, Vuollo 1994). Similar dykes occur also in the Kuhmo Greenstone Belt (Halkoaho, oral communication, June 1998). These gabbroic dykes are also combined with the Jatulian diabase dykes on the Bedrock Map.

Karjalite sills, dykes and intrusions (Vuollo 1988), referred to as the gabbro-wehrlite association by Hanski (1984), occur in the Koli area north of Joensuu (Hanski 1986, Vuollo & Piirainen 1992, Vuollo et al.

Fig. 21a. Proterozoic metadiabase dyke with Archaean basement gneiss inclusions. In the dyke there is a 10–20 cm-thick alteration rim (dark green) at the contact with the basement gneiss. Kulvemäki, Sonkajärvi. Photo, J. Paavola.

Fig. 21b. Sharp contact between metadiabase dyke (dark) and Archaean tonalitic basement gneiss. Toivakkojärvi, Sonkajärvi. Photo, J. Paavola.

1992), in the Kainuu Schist Belt (Kontinen 1987b, Laajoki 1991) and in the Kemi area (Perttunen 1987, 1991). Dykes similar in composition and age to the gabbro-wehrlite association occur also in the Kuhmo Greenstone Belt (Hanski 1986, Halkoaho, oral communication, June 1998). Stratigraphically, the karjalite dykes are restricted to the vicinity of the unconformity between Palaeoproterozoic Karelian metasedimentary rocks (i.e. the Jatulian quartzites and the formations stratigraphically below these) and the underlying Archaean lithologies (Hanski 1986, Vuollo & Piirainen 1992, Kontinen 1987b, Laajoki 1991, Perttunen 1991). Their lengths range from a few kilometres up to 150 kilometres (in the Kemi area). The thickness is usually 200–400 m. The karjalite sills and dykes are strongly differentiated, varying in primary composition from wehrlite or pyroxenite at the base through gabbro to quartz-plagioclase-rich granophyre at the top. They are interpreted to originate from a low-Al tholeiitic (Vuollo & Piirainen 1992) or a picritic (Hanski 1986) parental magma. These differentiated sills and dykes have provided ages of c. 2200 Ma (Hyppönen 1983, Perttunen 1991, Laajoki 1991, Vuollo 1994).

The rocks of the Kapustakangas Suite were intruded into the metasediments at lower stratigraphic levels of the Central Puolanka Group, and into the corresponding level of the Kalpio Complex. They consist mainly of differentiated metagabbro intrusions with basal ultrabasic differentiates (Laajoki 1991).

The Niinivaara lamprophyre dykes (Nii) were intruded with very sharp and rectilinear contacts into country rocks north of Outokumpu (Huhma 1975, 1981, Laukkanen 1987). They dip at a high angle or vertically, and their predominating strike is NW–SE to E–W. Widths of the dykes vary from a few cm to 70 cm, most commonly being 25–50 cm. In places, it is possible to trace them for more than 100 m. They usually occur alone, but sporadically two or three parallel dykes form a closely spaced swarm. The dykes are fine-grained with many hexagonal biotite flakes up to 2 cm in diameter. Other typical phenocrysts are apatite and xenocrystic clinopyroxene (augite). The rocks are mainly shoshonitic in composition (Laukkanen & Mäkipää 1983) and were classified as kersantites, only one of the analysed samples being camptonitic (Laukkanen 1987). The age of the Niinivaara dykes is 1830 Ma (Huhma 1981). Lamprophyre dykes classified as minettes (not shown on the Bedrock Map) occur just east of the Kinahmi quartzite in the Nilsiä area north of Kuopio (Paavola 1984, Laukkanen1987).

In the Kalix area in Sweden there are some dykes of importance for the interpretation of the tectonic-metamorphic evolution (Wikström 1993). The c. 2 km-broad Siknäs diabase dyke (Sid) west of Kalix strikes N–S. It was earlier interpreted as mafic lavas but has now been shown to be intrusive. The dyke contains numerous fragments of rocks which are probably closely related to the matrix (autobreccia). Skeletal plagioclase crystals indicate rapid cooling.

Some kilometres west of the Siknäs dyke occurs the NNE–SSW trending, c. 20 km-long Bläsberget diabase and granite porphyry dyke swarm (Bdg), mainly in the Degerberget granite but also in rocks of the Haparanda suite (cf. above). These dykes, of which the mafic generally postdate the felsic, are of a chemical within-plate character. A more or less pronounced foliation is visible in the diabase dykes. The felsic dykes have yielded a U-Pb zircon age of 1881±8.5 Ma (MSIA Map 217, Wikström et al. 1996), similar to the 1880±7 Ma age of the Degerberget granite (MSIA Map 216). The emplacement of the Bläsberget dykes, the Siknäs dyke and possibly also the Degerberget granite, has been interpreted to be related to movements along the N–S trending Bothnian shear zone of Wikström (1995) or the Baltic-Bothnian megashear of Berthelsen and Marker (1986). The contact relations of the Bläsberget dykes and the Degerberget granite with their wall-rocks demonstrate the presence of a generation of migmatite in the area which is older than the c. 1.8 Ga, Lina granite-related migmatisation (Wikström & Persson 1997b).

In the Kalix area there are also numerous dykes of ultramafic lamprophyres (Fig. 22), striking roughly N–S with a vertical or steep westward dip (Larsson 1943, Åhman 1950, Kresten et al. 1981, Åhman & Wikström 1990). These dykes, indicated as Klx on the Bedrock Map, have an age of c. 1140 Ma (1150–1120 Ma; MSIA Map 220, 224, 229, 230, Kresten et al. 1997 and references therein). Although they are not associated with an exposed plutonic complex, a positive gravimetric anomaly in the area (Ruotoistenmäki et al. 1996) possibly reflects the existence of such a complex at depth.

Fig. 22. Ultramafic lamprophyre dykes (Kalix dykes) in Degerberg granite. L. Båtöklippan, SSW of Kalix. Photo, A. Wikström.

3.2.2.7 References

Åhman, E. 1950. Ett fynd av frisk olivin i kimberlit från Kalix skärgård i Norrbotten. Geologiska Föreningens i Stockholm Förhandlingar 72, 207–211.

Åhman, E. & Wikström, A. 1990. Berggrundskartan Kalix SO. 1 : 50 000. Sveriges geologiska undersökning Ai 45.

Alapieti, T. 1982. The Koillismaa layered igneous complex, Finland - its structure, mineralogy and geochemistry, with emphasis on the distribution of chromium. Geological Survey of Finland, Bulletin 319. 116 p.

Alapieti, T.T. & Lahtinen, J.J. 1986. Stratigraphy, petrology, and platinum element mineralization of the early Proterozoic Penikat layered intrusions, Northern Finland. Economic Geology 81, 1126–1136.

Alapieti, T.T. & Lahtinen, J.J. 1989. Early Proterozoic layered intrusions in the northeastern part of the Fennoscandian Shield. In: Alapieti, T. (ed.) 5th international platinum symposium. Guide to the post-symposium field trip, August 4-11, 1989. Geological Survey of Finland, Guide 29, 3–41.

Alapieti, T.T., Kujanpää, J., Lahtinen, J.J. & Papunen, H. 1989. The Kemi stratiform chromite deposit, Northern Finland. Economic Geology 84, 1057–1077.

Aumo, R. 1983. The Proterozoic metasedimentary and metavolcanic mantle of the Kuopio domes. In: Laajoki, K. and Paakkola, J. (eds.) Exogenic processes and related metallogeny in the Svecokarelian geosynclinal complex. Guidebook of the field trip for the IGCP projects 91 and 160 to eastern, central and southern Finland, August17-26, 1983. Geological Survey of Finland, Guide 11, 86–99.

Berthelsen, A. & Marker, M., 1986. 1.9-1.8 Ga old strike-slip megashears in the Baltic Shield, and their plate tectonic implications. Tectonophysics 128, 163–181.

Borchert, H. 1954. Kritische Anmerkunge zu zwei neuen Arbeiten über Outokumpu, Finnland. Chemie der Erde 17, 1–5.

Campbell, D.S., Treloar, P.J. & Bowes, D.R. 1979. Metamorphic history of staurolite-bearing schist from the Svecokarelides, near Heinävaara, eastern Finland. Geologiska Föreningens i Stockholm Förhandlingar 101, 105–118.

Claesson, S., Huhma, H., Kinny, P.D. & Williams, I. S. 1993. Svecofennian detrital zircon ages - implications for the Precambrian evolution of the Baltic Shield. Precambrian Research 64, 109–130.

Eskola, P. 1919. Huvuddragen av Onega-Kareliens geologi. Meddelanden från Geologiska Föreningen i Helsingfors, 1917-1918, 13–18.

Eskola, P. 1925. On the petrology of the Eastern Fennoscandia. Fennia 45 (19), 1–19.

Eskola, P. 1941. Erkki Mikkola und der heutige Stand der präkambrischen Geologie in Finnland. Geologische Rundschau 32, 452–483.

Frosterus, B. 1902. Bergbyggnaden i sydöstra Finland. Bulletin de la Commission géologique de Finlande 13. 168 p.

Gaál, G. 1980. Geological setting and intrusion tectonics of the Kotalahti nickel-copper deposit, Finland. Bulletin of the Geological Society of Finland 52 (1), 101–128.

Gaál, G. 1990. Tectonic styles of Early Proterozoic ore deposition in the Fennoscandian Shield. Precambrian Research 46, 84–114.

Gaál, G., Koistinen, T. & Mattila, E. 1975. Tectonics and stratigraphy of the vicinity of Outokumpu North Karelia, Finland, including a structural analysis of Outokumpu ore deposits. Geological Survey of Finland, Bulletin 271. 67 p.

Gaál, G. & Gorbatschev, R. 1987. An outline of the Precambrian evolution of the Baltic Shield. Precambrian Research 35, 15–52.

Gehör, S. & Havola, M. 1988. The depositional environment of the early Proterozoic Tuomivaara Iron-Formation and associated metasediments, eastern Finland. Geological Survey of Finland, Special Paper 5, 109–133.

Geological Map, Northern Fennoscandia, 1 : 1 million 1987. Geological Surveys of Finland, Norway and Sweden. Helsinki.

Haapala, P. 1936. On serpentine rocks in Northern Karelia. Bulletin de la Commission géologique de Finlande 114, 80 p.

Hanski, E. 1986. The gabbro-wehrlite association in the eastern part of the Baltic Shield. In: Friedrich, G.H., Naldrett, A.J., Ridge, J.D., Sillitoe, R.H. & Vokes, F.M. (eds.) Geology and metallogeny of copper deposits. Berlin: Springer-Verlag, 151–170.

Härme, M. & Perttunen, V. 1964. Stromatolite structures in Precambrian dolomite in Tervola, North Finland. Bulletin de la Commission géologique de Finlande 212, 79–83.

Hausen, H. 1930. Geologie des Soanlahti-Gebietes im südlichen Karelian. Bulletin de la Commission géologique de Finlande 90. 105 p.

Honkamo, M. 1985. On the Proterozoic metasedimentary rocks of the Northern Pohjanmaa schist area, Finland. In: Laajoki, K. & Paakkola, J. (eds.) Proterozoic exogenic processes and related metallogeny. Proceedings of the symposium held in Oulu, Finland, August 15-16, 1983. Geological Survey of Finland, Bulletin 331, 117–129.

Honkamo, M. 1988. Haukiputaan ja Kiimingin kartta-alueiden kallioperä. Summary: Pre-Quaternary rocks of the Haukipudas and Kiiminki map-sheet areas. Geological Map of Finland 1 : 100 000, Explanation to the maps of pre-Quaternary rocks, Sheets 2433 and 3511. Geological Survey of Finland. 46 p.

Honkamo, M. 1989. Pohjois-Pohjanmaan vulkaniitit - Volcanic rocks in northern Ostrobothnia. Lapin vulkaniittiprojektin raportti - A report of the Lapland Volcanite Project. Geological Survey of Finland, Report of Investigation 89. 46 p.

Huhma, A. 1975. Outokummun, Polvijärven ja Sivakkavaaran kartta-alueiden kallioperä. Summary: Pre-cambrian rocks of the Outokumpu, Polvijärvi and Sivakkavaara map-sheet areas. Geological Map of Finland 1 : 100 000, Sheets 4222, 4224, 4311. Geological Survey of Finland. 151 p.

Huhma, A. 1981. Youngest Precambrian dyke rocks in North Karelia, East Finland. Bulletin of the Geological Society of Finland 53 (2), 67–82.

Huhma, H. 1986. Sm-Nd, U-Pb and Pb-Pb isotopic evidence for the origin of the Early Proterozoic Svecokarelian crust in Finland. Geological Survey of Finland, Bulletin 337. 48 p.

Huhma, H. 1987. Provenance of early Proterozoic and Archaean metasediments in Finland: a Sm-Nd isotopic study. Precambrian Research 35, 127–143.

Huhma, H. 1990. Isotopic studies on early Proterozoic metasediments in Finland. In: Kähkönen, Y. (ed.) Proterozoic geochemistry, Helsinki '90: symposium December 13-14, 1990 Helsinki, Finland: abstracts. IGCP Project 217 Proterozoic Geochemistry. University of Helsinki, Department of geology, 19–20.

Huhma, H., Cliff, R.A., Perttunen, V. & Sakko, M. 1990. Sm-Nd and Pb isotopic study of mafic rocks associated with early Proterozoic continental rifting: the Peräpohja schist belt in northern Finland. Contributions to Mineralogy and Petrology 104, 369–379.

Huhma, A. & Huhma, M. 1970. Contribution to the geology and geochemistry of the Outokumpu region. Bulletin of the Geological Society of Finland 42, 57–88.

Hyppönen, V. 1983. Ontojoen, Hiisijärven ja Kuhmon kartta-alueiden kallioperä. Summary: Pre-Quaternary rocks of the Ontojoki, Hiisijärvi, and Kuhmo map-sheet areas. Geological Map of Finland 1 : 100 000, Explanation to the maps of pre-Quaternary rocks, Sheets 4411, 4412 and 4413. Geological Survey of Finland. 60 p.

Hyvärinen, T. 1989. Granitoids on the Puukari map-sheet. In: Gaál, G. (ed.) Archaean granitoids and associated Mo, W and Au mineralization in eastern Finland. Symposium: Precambrian granitoids. Petrogenesis, geochemistry and metallogeny. August 14-17, 1989, University of Helsinki, Finland. IGCP Projects 217, 247. Geological Survey of Finland, Guide 25, 29–32.

Kärki, A., Laajoki, K. & Vaasjoki, M. 1995. Tectonic settings and isotopic datings of late Archaean and Palaeoproterozoic granitoids in the Central Fennoscandian Shield, Finland. In: Kärki, A. Palaeoproterozoic shear tectonics in the Central Fennoscandian Shield, Finland. Publications of the Department of Geology University of Oulu, Res Terrae, Ser. A (10), Paper III, 1–24.

Kohonen, J. 1995. From continental rifting to collisional crustal shortening - Paleoproterozoic Kaleva metasediments of the Höytiäinen area in North Karelia, Finland. Geological Survey of Finland, Bulletin 380. 79 p.

Kohonen, J. & Marmo, J. 1992. Proterozoic lithostratigraphy and sedimentation of Sariola and Jatuli-type rocks in the Nunnanlahti-Koli-Kaltimo area, eastern Finland; implications for regional basin evolution models. Geological Survey of Finland, Bulletin 364. 67 p.

Koistinen, T.J. 1981. Structural evolution of an early Proterozoic strata-bound Cu-Co-Zn deposit, Outokumpu, Finland. Transactions of the Royal Society of Edinburgh: Earth Sciences 72, 115–158.

Koistinen, T. 1993. Heinäveden kartta-alueen kallioperä. Summary: Pre-Quaternary rocks of the Heinävesi map-sheet area. Geological Map of Finland 1 : 100 000, Explanation to the maps of pre-Quaternary rocks, Sheet 4221. Geological Survey of Finland. 64 p.

Koistinen, T. & Saltykova, T. (eds.) 1999. Structure-lithology, metamorphism and metallogeny of the Raahe-Ladoga Zone, Map 1: Structure-lithology 1 : 1 000 000. Geological Survey of Finland, Espoo, Finland.

Kontinen, A. 1986. Early Proterozoic stratigraphy and sedimentation in the Hyrynsalmi area, eastern Finland. In: Sokolov, V.A. & Heiskanen, K.I. (eds.) Early Proterozoic of the Baltic Shield. Proceedings of Finnish-Soviet Symposium held in Petrozavodsk 19th-27th August, 1985. The Committee for scientific and technical co-operation between Finland and the Soviet Union. Petrozavodsk 1986, 75–103.

Kontinen, A. 1987a. An early Proterozoic ophiolite - The Jormua mafic-ultramafic complex, northeastern Finland. Precambrian Research 35, 313–341.

Kontinen, A. 1987b. Early Proterozoic mafic dyke rocks in the Hyrynsalmi area, northeastern Finland (in Finnish with an English abstract). In: Aro, K.& Laitakari, I. (eds.) Suomen diabaasit ja muut mafiset juonikivilajit - Diabases and other mafic dyke rocks in Finland. Geological Survey of Finland, Report of Investigation 76, 13–20.

Kontinen, A. 1989. Hyrynsalmi. Geological map of Finland 1 : 100 000, Pre-Quaternary rocks, Sheet 3443. Geological Survey of Finland.

Kontinen, A. & Meriläinen, K. 1993. Paltamo. Geological map of Finland 1 : 100 000, Pre-Quaternary rocks, Sheet 3434. Geological Survey of Finland.

Kontinen, A. & Sorjonen-Ward, P. 1991. Geochemistry of metagraywackes and metapelites from the Palaeoproterozoic Nuasjärvi Group, Kainuu schist belt and the Savo Province, North Karelia: implications for provenance, lithostratigraphic correlation and depositional setting. In: Autio, S. (ed.) Geological Survey of Finland, Current Research 1989-1990. Geological Survey of Finland, Special Paper 12, 21–22.

Kontinen, A., Huhma, H. & Laajoki, K. 1996. Sm/Nd isotope data on the Central Puolanka Group, Kainuu Schist Belt, Finland, constraints for provenance and age of deposition. In: Kohonen, T. & Lindberg, B. (eds.) Abstracts. The 22nd Nordic Geological Winter Meeting, 8-11 January 1996 in Turku-Åbo, Finland. 95 p.

Korja, A. 1991. Geological interpretation of DDS profile Baltic, SE Finland. In: Tuisku, P. & Laajoki, K. (eds.) Metamorphism, deformation and structure of the crust, Abstracts. University of Oulu, Res Terrae, Ser A 5. 33 p.

Korkiakoski, E. & Laajoki, K. 1988. The palaeosedimentology of the early Proterozoic Salahmi Schist belt, central Finland. In: Laajoki, K. & Paakkola, J. (eds.) Sedimentology of the Precambrian formations in eastern and northern Finland. Proceedings of IGCP 160 Symposium at Oulu, January 21-22, 1986. Geological Survey of Finland, Special Paper 5, 49–73.

Korsman, K., Koistinen, T., Kohonen, J., Wennerström, M., Ekdahl, E., Honkamo, M., Idman, H. & Pekkala, Y. (eds.) 1997. Suomen kallioperäkartta - Berggrundskarta över Finland - Bedrock map of Finland 1 : 1 000 000. Espoo: Geological Survey of Finland.

Kratz, K. & Mitrofanov, 1980. Main type reference sequences of the early Precambrian in the U.S.S.R. Earth Science Review 16, 295–301.

Kresten, P., Åhman, E. & Brunfelt, A.O. 1981. Alkaline ultramafic lamprophyres and associated carbonatite dykes from the Kalix area, northern Sweden. Geologische Rundschau 70, 1215–1231.

Kresten, P., Rex, D.C. & Guise, P.D. 1997. ^{40}Ar-^{39}Ar ages of ultramafic lamprophyres from the Kalix area, northern Sweden. In: Lundqvist, Th. (ed.) Radiometric dating results 3, Division of Bedrock Geology, Geological Survey of Sweden. Sveriges geologiska undersökning C 830, 14–19.

Laajoki, K. 1990. Early Proterozoic tectofacies in eastern and northern Finland. In: Naqvi, M. (ed.) Precambrian continental crust and its Economic Resources. Developments in Precambrian Geology 6. Amsterdam: Elsevier, 437–452.

Laajoki, K. 1991. Stratigraphy of the northern end of the early Proterozoic (Karelian) Kainuu Schist Belt and associated gneiss complexes, Finland. Geological Survey of Finland, Bulletin 358. 105 p.

Laajoki, K. 1991. Stratigraphy of the northern end of the Kainuu schist belt and associated gneiss complexes, 1 : 100 000. In: Stratigraphy of the northern end of the early Proterozoic (Karelian) Kainuu Schist Belt and associated gneiss complexes, Finland. Geological Survey of Finland, Bulletin 358 (Appendix 1, Map 1). 105 p.

Laajoki, K. & Saikkonen, R. 1977. On the geology and geochemistry of the Precambrian iron formation in Väyrylänkylä, South Puolanka area, Finland. Geological Survey of Finland, Bulletin 292. 137 p.

Laajoki, K. & Luukas, J. 1988. Early Proterozoic stratigraphy of the Salahmi-Pyhäntä area, central Finland, with an emphasis on applying the principles of lithodemic stratigraphy to a complexly deformed and metamorphosed bedrock. Bul-letin of the Geological Society of Finland 60 (2), 79–106.

Lahtinen, J.J., Alapieti, T.T., Halkoaho, T.A.A., Huhtelin, T.A. & Iljina, M.J. 1989. PGE mineralization in the Tornio - Näränkävaara layered intrusion belt. In: Alapieti, T. (ed.) 5th international platinum symposium. Guide to the post-symposium field trip, August 4-11,1989. Geological Survey of Finland, Guide 29, 43–58.

Lahtinen, R & Huhma, H. 1997. Isotopic and geochemical constraints on the evolution of the 1.93-1.79 Ga Svecofennian crust and mantle in Finland. Precambrian Research 82, 13–34.

Larsson, W. 1943. Zur Kenntnis der alkalinen ultrabasischen Ganggesteine des Kalixgebiets, Nordschweden. Sveriges geologiska undersökning C 456. 41 p.

Laukkanen, J. 1987. The lamprophyres of Middle Finland (in Finnish with an English abstract). In: Aro, K. & Laitakari, I. (eds.) Suomen diabaasit ja muut mafiset juonikivilajit - Diabases and other mafic dyke rocks in Finland. Geological Survey of Finland, Report of Investigation 76, 91–98.

Laukkanen, J. & Mäkipää, H. 1983. On the chemical classification of lamprophyric rocks. Geologi 35 (3), 54–55.

Lindholm, O. & Anttonen, R. 1980. Geology of the Otanmäki mine. In: Häkli, T. (ed.) Precambrian ores of Finland. 26th International Geological Congress Paris 1980. Geological Survey of Finland, Guide to excursions 078 A+C, Part 2 (Finland), 43–58.

Luukkonen, E.J. 1988. The structure and stratigraphy of the northern part of the late Archean Kuhmo greenstone belt, eastern Finland. In: Marttila, E. (ed.) Archaean geology of the Fennoscandian Shield. Proceedings of a Finnish - Soviet Symposium in Finland, July 28 - August 7, 1986. Geological Survey of Finland, Special Paper 4, 71–96.

Mäkelä, M. 1974. A study of sulfur isotopes in the Outokumpu ore deposit, Finland. Geological Survey of Finland, Bulletin 267. 45 p.

Marmo, J. 1992. The lower Proterozoic Hokkalampi Paleosol in North Karelia, eastern Finland. In: Schidlowsky, M., Golubic, S., Kimberley, M.M. & Trudinger, P.A. (eds.) Early organic evolution: Implications for mineral and energy resources. Berlin: Springer Verlag, 41–66.

Marmo, J. 1993. The early Proterozoic glaciogenic and deep weathering geologic record in northern Karelia, eastern Finland. University of Helsinki, Department of Geology. 11 p. (dissertation)

Marmo, J.S & Ojakangas, R.W. 1984. Lower Proterozoic glaciogenic deposits, eastern Finland. Geological Society of America Bulletin 95, 1055–1062.

Marmo, J, Kohonen, J., Sarapää, O. & Äikäs, O. 1988. Sedimentology and stratigraphy of the lower Proterozoic Sariola and Jatuli Groups in the Koli-Kaltimo Area, eastern Finland. In: Laajoki, K. & Paakkola, J. (eds.) Sedimentology of the Precambrian formations in eastern and northern Finland. Proceedings of IGCP 160 Symposium at Oulu, January 21-22, 1986. Geological Survey of Finland, Special Paper 5, 11–28.

Meriläinen, K. 1980. Stratigraphy of the Precambrian in Finland. Geologiska Föreningens i Stockholm Förhandlingar 102, 177–180.

Metzger, A.Th. 1924. Die jatulischen Bildungen von Suojärvi im Ostfinnland. Bulletin de la Commision géologique de Finlande 64. 86 p.

Negrutza, T.F. & Negrutza, V.Z. 1981. Early Proterozoic Sarioli tilloids in the eastern part of the Baltic Shield, U.S.S.R. In: Hambray, M.J. & Harland, W-B. (eds.) Earth's Pre-Pleistocene glacial record. Cambridge: Cambridge University Press, 683–686.

Nironen, M. 1997. The Svecofennian Orogen: a tectonic model. Precambrian Research 86, 21–44.

Nykänen, O. 1968. Tohmajärvi. Geological Map of Finland 1 : 100 000, Explanation to the map of rocks, Sheet 4232-4234. Geological Survey of Finland. 66 p.

Nykänen, O. 1971a. On the Karelides in the Tohmajärvi area, Eastern Finland. Bulletin of the Geological Society of Finland 43, 93–108.

Nykänen, O. 1971b. Kiihtelysvaara. Geological map of Finland 1 : 100 000, Explanation to the map of rocks, Sheet 4241. Geological Survey of Finland. 68 p.

Nykänen, V.M., Vuollo, J.I., Liipo, J.P. & Piirainen, T.A. 1994. Transitional (2.1 Ga) Fe-tholeiitic - tholeiitic magmatism in the Fennoscandian Shield signifying lithospheric thinning during Palaeoproterozoic extensional tectonics. Precambrian Research 70, 45–65.

Ödman, O., 1957. Beskrivning till berggrundskarta över urberget i Norrbottens län. English summary: Description to Map of the Pre-Cambrian Rocks of the Norrbotten County, N. Sweden (excl. the Caledonian Mountain Range). With map to the scale of 1 : 400 000. Sveriges geologiska undersökning Ca 41. 151 p.

Öhlander, B., Skiöld, T., Elming, S.-Å., BABEL Working Group, Claesson, S. & Nisca, D.H. 1993. Delineation and character of the Archaean–Proterozoic boundary in northern Sweden. Precambrian Research 64, 67–84.

Paavola, J. 1984. Nilsiän kartta-alueen kallioperä. Summary: Pre-Quaternary rocks of the Nilsiä map-sheet area. Geological Map of Finland 1 : 100 000, Explanation to the maps of pre-Quaternary rocks, Sheet 3334. Geological Survey of Finland. 57 p.

Paavola, J. 1987. The dyke rocks of the Nilsiä and Lapinlahti areas (in Finnish with English abstract). In: Aro, K. & Laitakari, I. (eds.) Suomen diabaasit ja muut mafiset juonikivilajit - Diabases and other mafic dyke rocks in Finland. Geological Survey of Finland, Report of Investigation 76, 45–51.

Paavola, J. 1988. Lapinlahden kartta-alueen kallioperä. Summary: Pre-Quaternary rocks of the Lapinlahti map-sheet area. Geological Map of Finland 1 : 100 000, Explanation to the maps of pre-Quaternary rocks, Sheet 3332. Geological Survey of Finland. 60 p.

Pekkarinen, L.J. 1979. The Karelian formations and their depositional basement in the Kiihtelysvaara - Värtsilä area, East Finland. Geological Survey of Finland, Bulletin 301. 141 p.

Pekkarinen, L.J. & Lukkarinen, H. 1991. Paleoproterozoic volcanism in the Kiihtelysvaara-Tohmajärvi district, eastern Finland. Geological Survey of Finland, Bulletin 357. 30 p.

Peltonen, P. & Kontinen, A. 1997. The Outokumpu Association. In: Rutland, R.W.R. & Drummond, B.J. (eds.) Palaeoproterozoic tectonics and metallogenesis: Comparative analysis of parts of the Australian & Fennoscandian Shields. Australian Geological Survey Organisation (AGSO) Record 1997/44, 99–101.

Peltonen, P., Kontinen, A. & Huhma, H. 1996. Petrology and geochemistry of metabasalts from the 1.95 Ga Jormua Ophiolite, Northeast Finland. Journal of Petrology 37 (6), 1359–1383.

Peltonen, P., Kontinen, A. & Huhma, H. 1998. Petrogenesis of the mantle sequence of the Jormua Ophiolite (Finland): Melt migration in the upper mantle during Palaeoproterozoic continental break-up. Journal of Petrology 39 (2), 297–329.

Perttunen, V. 1985. On the Proterozoic stratigraphy and exogenic evolution of the Peräpohja area, Finland. In: Laajoki, K. & Paakkola, J. (eds.) Proterozoic exogenic processes and related metallogeny. Proceedings of the symposium held in Oulu, Finland, August 15-16, 1983. Geological Survey of Finland, Bulletin 331, 131–141.

Perttunen, V. 1987. Mafic dykes in the northwestern part of the Pudasjärvi Granite Gneiss Complex (in Finnish with English abstract). In: Aro, K.& Laitakari, I. (eds.) Suomen diabaasit ja muut mafiset juonikivilajit - Diabases and other mafic dyke rocks in Finland. Geological Survey of Finland, Report of Investigation 76, 29–34.

Perttunen, V. 1991. Kemin, Karungin, Simon ja Runkauksen kartta-alueiden kallioperä. Summary: Pre-Quaternary rocks of the Kemi, Karunki, Simo and Runkaus map-sheet areas.

Geological Map of Finland 1 : 100 000, Explanation to the maps of pre-Quaternary rocks, Sheets 2541, 2542 + 2524, 2543 and 2544. Geological Survey of Finland. 80 p.

Piirainen, T., Honkamo, M. & Rossi, S. 1974. A preliminary report on the geology of the Koli area. Bulletin of the Geological Society of Finland 46 (2), 161–166.

Ramsay, W. 1902. Om de prekambriska formationerna och bergveckningarna i den sydöstra delen af Fennoskandia. Geologiska Föreningens i Stockholm Förhandlingar 24, 28–36.

Romer, R.L. & Öhlander, B. 1991. The occurrence of the Degerberg migmatite granite and its constraints on the geological development of the Luleå area, northern Sweden. Geologiska Föreningens i Stockholm Förhandlingar 112, 121–129.

Ruotoistenmäki, T., Aaro, S., Elo, S. et al. 1990. Gravity anomaly map of central Fennoscandia. Scale 1 : 1 000 000. Geological Surveys of Finland (Espoo), Norway (Trondheim) and Sweden (Uppsala).

Sederholm, J.J. 1897. Über eine archäische Sedimentformation in südwestlichen Finland. Bulletin de la Commission géologique de Finlande 6. 254 p.

Simonen, A. 1980. The Precambrian in Finland. Geological Survey of Finland, Bulletin 304. 56 p.

Simonen, A. 1986. Stratigraphic studies on the Precambrian in Finland. Geological Survey of Finland, Bulletin 336, 21–37.

Strand, K. 1988. Alluvial sedimentation and tectonic setting of the early Proterozoic Kurkikylä and Kainuu Groups in northern Finland. Geological Survey of Finland, Special Paper 5, 75–90.

Talvitie, J. & Paarma, H. 1980. Precambrian basic magmatism and the Ti-Fe ore formation in central and northern Finland. In: Siivola, J. (ed.) Metallogeny of the Baltic Shield. Proceedings of the symposium held in Helsinki, Finland, June 12-21, 1978. Geological Survey of Finland, Bulletin 307, 98–107.

Vaasjoki, M., Taipale, K. & Tuokko, I. 1999. Radiometric ages and other isotopic data bearing on the evolution of Archaean crust and ores, Kuhmo-Suomussalmi Area, Eastern Finland. In: Kähkönen, Y. & Lindqvist, K. (eds.) Studies related to the Global Geoscience Transects / Sveka Project in Finland. Bulletin of the Geological Society of Finland 71 (1), 155–176.

Vähätalo, V. 1953. On the geology of the Outokumpu ore deposit in Finland. Bulletin de la Commission géologique de Finlande 164. 98 p.

Ward, P. 1987. Early Proterozoic deposition and deformation at the Karelian craton margin in southeastern Finland. Precambrian Research 35, 71–93.

Ward, P. 1988. Early Proterozoic Kalevian lithofacies and their interpretation in the Hammaslahti-Rääkkylä area, eastern Finland. Geological Survey of Finland, Special Paper 5, 29–48.

Väyrynen, H. 1928. Geologische und petrografische Untersuchungen im Kainuu gebiete. Bulletin de la Commission géologique de Finlande 78. 127 p.

Väyrynen, H. 1933. Über die Stratigraphie der karelischen Formation. Comptes Rendus de la Socété géologique de Finlande 6. Bulletin de la Commission géologique de Finlande 101, 54–78.

Väyrynen, H. 1939. On the geology and tectonics of the Outokumpu ore field and region. Bulletin de la Commission géologique de Finlande 124. 91 p.

Väyrynen, H. 1954. Suomen kallioperä, sen synty ja geologinen kehitys. Tiedekirjasto 27. Helsinki: Otava. 260 p. (In Finnish)

Wetherill, G.W., Kouvo, O., Tilton, G.R. & Gast, P.W. 1962. Age measurements on rocks from the Finnish Precambrian. Journal of Geology 70 (1), 74–88.

Wikström, A. 1993. Berggrundskartan Kalix SV. 1 : 50 000. Sveriges geologiska undersökning Ai 81.

Wikström, A. 1995. Berggrundskartan Kalix NV. 1 : 50 000. Sveriges geologiska undersökning Ai 79.

Wikström, A. & Persson, P.-O. 1997a. Two Haparanda type granodiorites with contrasting ages in the southeastern part of Norrbotten County, northern Sweden. In: Lundqvist, Th. (ed.) Radiometric dating results 3, Division of Bedrock Geology, Geological Survey of Sweden, Sveriges geologiska undersökning C 830, 73–80.

Wikström, A. & Persson, P.-O. 1997b. U-Pb zircon and monazite dating of a Linatype leucogranite in northern Sweden and its relationship to the Bothnian shear zone. In: Lundqvist, Th. (ed.) Radiometric dating results 3, Division of Bedrock Geology, Geological Survey of Sweden. Sveriges geologiska undersökning C 830, 81–87.

Wikström, A., Skiöld, T. & Öhlander, B. 1996. The relationship between 1.88 Ga old magmatism and the Baltic-Bothnian shear zone in northern Sweden. In: Brewer, T.S. (ed.) Precambrian Crustal Evolution in the North Atlantic Region. Geological Society Special Publication 112, 249–259.

Wilkman, W.W. 1938. Kuopio. Kivilajikartan selitys (with an English summary). Explanation to the map of rocks. General Geological Map of Finland 1 : 400 000, Pre-Quaternary rocks, Sheet C3. Geological Survey of Finland. 171 p.

Vuollo, J. 1988. Kolin kerrosjuonen petrologia - Kaunisniemen profiili (Petrology of the Koli layered sill - section from Kaunisniemi). University of Oulu. Pohjois-Karjalan malmiprojekti, Report 16. 122 p. (In Finnish)

Vuollo, J. 1994. Palaeoproterozoic basic igneous events in eastern Fennoscandian Shield between 2.45 Ga and 1.97 Ga, studied by means of mafic dyke swarms and ophiolites in Finland. Acta Universitatis Ouluensis, Series A 250. 47 p.

Vuollo, J. & Piirainen, T. 1992. The 2.2 Ga old Koli layered sill: The low-Al tholeiitic (karjalitic) magma type and its differentiation in northern Karelia, eastern Finland. Geologiska Föreningens i Stockholm Förhandlingar 114, 131–142.

Vuollo, J., Piirainen, T. & Huhma, H. 1992. Two Early Proterozoic tholeiitic metadiabase dykes swarms in the Koli-Kaltimo area, eastern Finland - their geological significance. Geological Survey of Finland, Bulletin 363. 32 p.

3.2.3 Svecofennian Domain, *Jukka Kousa and Thomas Lundqvist*

3.2.3.1 General overview

The bedrock of the Svecofennian Domain is bordered in the east by the Archaean Basement Complex with its Karelian sedimentary-volcanic cover (cf. Fig. 23). The predominating supracrustal rocks of the Svecofennian Domain are turbidites, deposited in what Hietanen (1975) called the Bothnian Basin (cf. Fig. 24). Graphite- and pyrrhotite-bearing schists, black schists, in Finland also carbonate rocks closely related to synsedimentary mafic volcanites, e.g. in Ostrobothnia (Pohjanmaa), are common intercalations in the turbidites. Major sedimentary units of the

Svecofennian Domain, shown on the Mid-Norden Bedrock Map, are in Finland the Pohjanmaa schists (Pos), also called the Bothnian schists, and the Savo schists (Sas), and in Sweden the Härnö group greywackes (Häg). The detrital zircons in these metaturbidites show a bimodal age distribution. The majority are Palaeoproterozoic and have ages between 2.1 and 1.9 Ga, but a significant contribution of Archaean zircons has also been recorded (Huhma et al. 1991, Claesson et al. 1993).

The easternmost parts of the Svecofennian Domain in Finland belong lithologically to the Savo schists (Sas) and structurally to the locally highly sheared Raahe-Ladoga Zone (RLZ), well known for its volcanogenic massive sulphide (VMS) deposits, e.g. in the Pyhäsalmi Formation (PyF).

Svecofennian volcanic rocks form major belts but also occur as narrow discontinuous belts or limited occurrences within both metasedimentary and intrusive complexes. Extensive, mainly felsic, volcanic rocks are found in the Arvidsjaur Group (ArG) and the economically important Skellefte Group (SkG) of the Skellefte District in Sweden. In Finland the volcanic rocks represent two different age groups (c. 1.92 and 1.88 Ga), which also have distinct chemical characteristics. Metavolcanic rocks that are significantly older (age c. 1.95 Ga) than the c. 1.88 Ga, predominating volcanic rocks of the Skellefte and Arvidsjaur Groups, exist to an unknown extent also in Sweden.

The idea first put forward by Hietanen (1975) that the c. 1.9–1.8 Ga volcanic rocks of the Palaeoproterozoic Svecofennian Domain were formed in an environment similar to that of Phanerozoic volcanic arcs, is now widely accepted, although opinions differ on a more precise definition of the environment (Rickard 1979, Gaál 1985, Vivallo & Claesson 1987, Kähkönen 1989, Park 1991, Weihed et al. 1992, Ekdahl 1993, Lahtinen 1994, Kousa et al. 1994). In agreement with this, magnetotelluric and seismic reflection measurements indicate structures in the crust and mantle that have been interpreted to be related to an ancient subduction zone dipping northeast, below the Skellefte District (Rasmussen et al. 1987, BABEL Working Group 1990).

Major plutonic complexes of the Svecofennian Domain are the c. 1.88 Ga Central Finland Granitoid Complex (CFi) and the c. 1.80 Ga Revsund granite (Rev) and associated granitoids of Sweden. Among the plutonic rocks, quartz-dioritic to granodioritic as well as granitic intrusions predominate over mafic and ultramafic rocks (e.g. Simonen 1980). Intrusions of granites of S-type and related pegmatites are common in the Härnö group, and similar, probably S-type pegmatite granites and pegmatites also occur in the Bothnian schists of western Finland. Intrusive rocks of the Central Finland Granitoid Complex and the major part of the Svecofennian Domain in Sweden (except for the region northeast of the Luleå-Jokkmokk Zone; cf. p. 40 and Öhlander et al. 1993) do not contain any significant contribution from Archaean protoliths (Wilson et al. 1985, Huhma 1986, Öhlander et al. 1993, Lahtinen 1994, Andersson 1997).

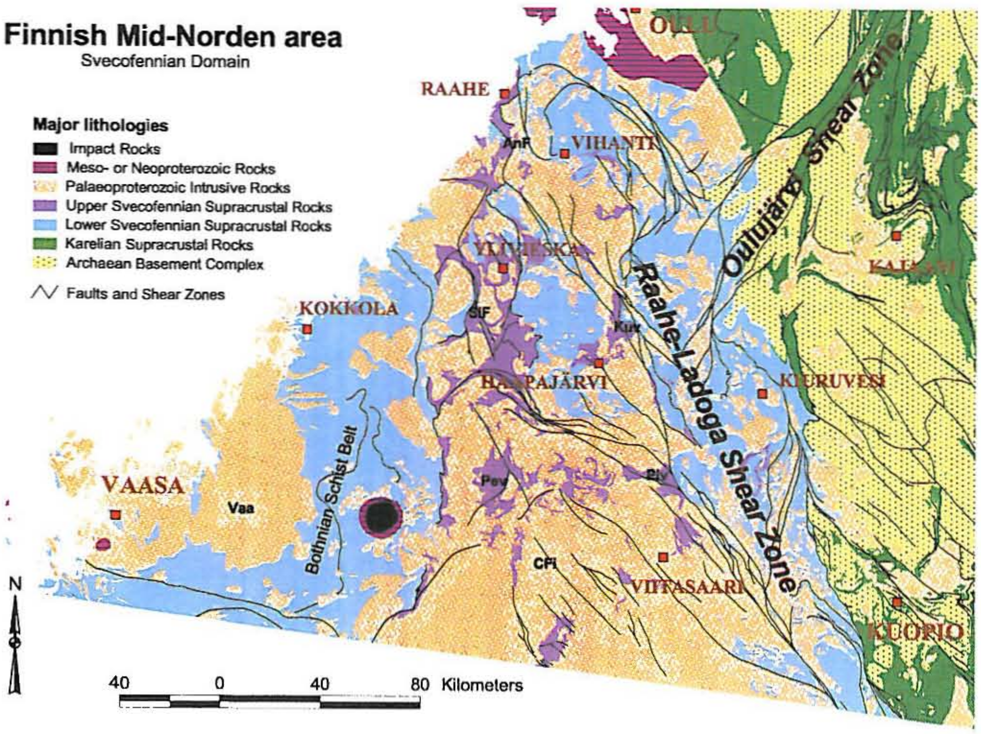

Fig. 23. Major stratigraphic units of the Svecofennian Domain in Finland.

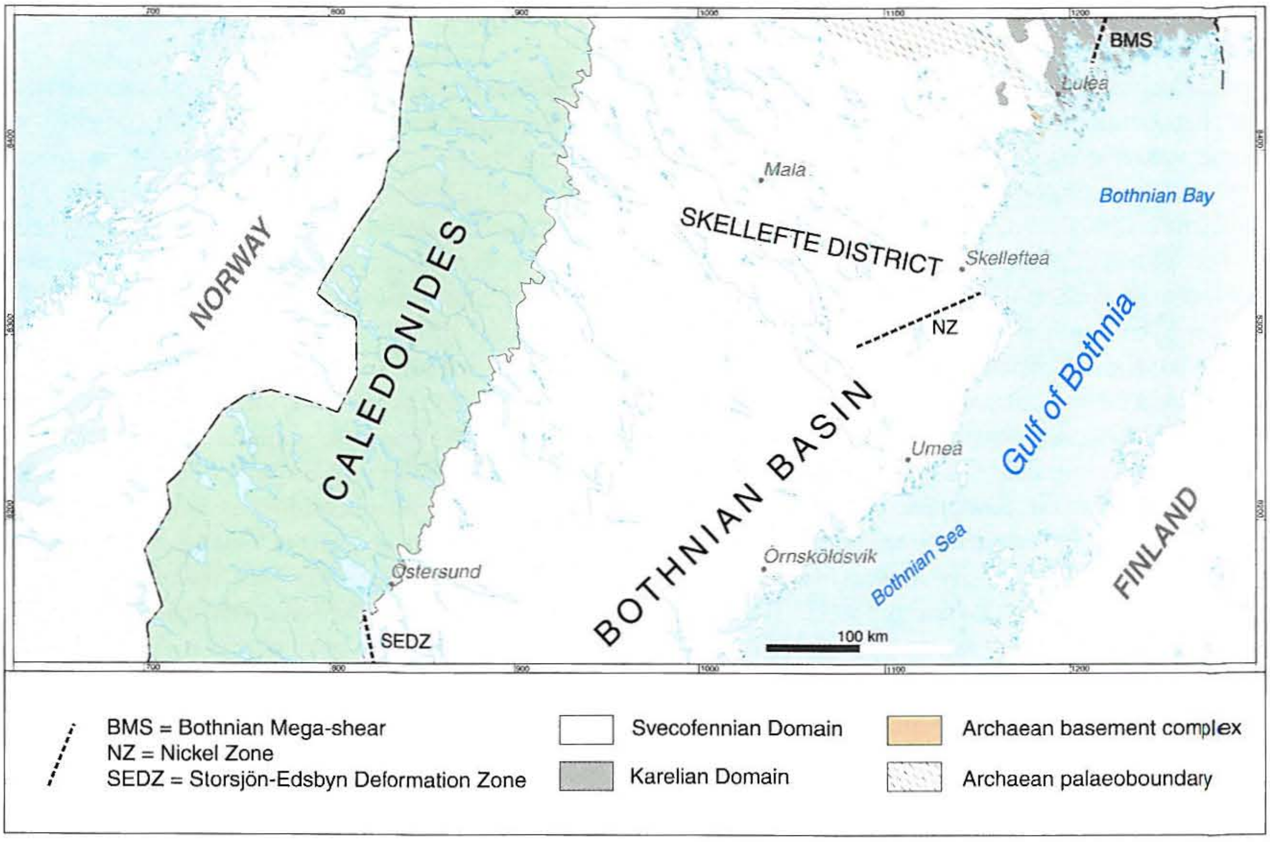

Fig. 24. Some important geological units and zones of the Swedish Mid-Norden area, mentioned in the text.

Younger (1.6–1.2 Ga), anorogenic intrusions also occur in the Svecofennian Domain. The most important of these are 1.6–1.5 Ga rapakivi complexes of Sweden and post-Jotnian dolerites (diabases) of Sweden and Finland.

3.2.3.2 Oldest supracrustal rocks of the Svecofennian Domain

In the central part of the Swedish Mid-Norden area, a particularly interesting supracrustal sequence, readily seen on aeromagnetic maps (see Mid-Norden Magnetic Anomaly Map), occurs in the Knaften area south of Lycksele. In the lower part of this Knaften group (Kng), mafic volcanic rocks are intercalated with greywackes of Härnö group type. These mafic volcanic rocks, which are massive flows and pillow lavas (Fig. 25) as well as debris flows, chemically reflect an evolution from MORB-type to island-arc type. They are overlain by calc-alkaline, felsic volcanic rocks (Wasström 1990). The whole sequence was subsequently intruded by c.1.95–1.94 Ga calc-alkaline, tonalitic to granodioritic granitoids and associated dykes (see below). Evidently the Svecofennian volcanic and sedimentary assemblages of the Swedish Mid-Norden area therefore contain successions which can be stratigraphically and chronologically correlated with the Kalevian assemblages closer to the Archaean basement in the east (see above). That such old sequences also occur in the Härnö group south of Knaften is supported by U-Pb zircon ages of c. 1930 Ma recorded for the Husum and Seltjärn granodiorites, intrusive into the greywackes of this group in the Örnsköldsvik area (see below).

A further indication of the occurrence of pre-1950 Ma metavolcanic rocks in the Mid-Norden area has been found after the printing of the Bedrock Map. The region c. 20 km ESE of Storuman (Barsele), in the western part of the Svecofennian Domain, is a target area for gold prospecting. In the metagreywackes at Barsele a quartz-plagioclase-porphyritic metadacite has been dated at 1959±14 Ma (Eliasson & Sträng 1998).

3.2.3.3 Earliest plutonic and dyke intrusions of the Svecofennian Domain

Along the Savo schist belt (Sas) in Finland, a group of gneissic plutonic rocks including the Kirkkosaari (Kir) and Kettuperä (Ket) granodiorites and the Venetpalo tonalite (Vet) has been documented. Their age range is 1930–1910 Ma (Helovuori 1979, Korsman 1984, Ekdahl 1993, Lahtinen 1994). Based on field observations in the Pielavesi area, Ekdahl (1993) proposed that these gneisses represent the depositional basement of the Savo schist belt supracrustal rocks and that they were probably generated from a reworked Archaean crust. On the other hand, whole-rock geochemical and isotope evidence indicate that the Kirkkosaari granodiorites may be coeval with some volcanic rocks stratigraphically above them, and that their protolith cannot have been Archaean (Lahtinen 1994).

The plutonic rocks discussed above are closely related to the volcanic activity producing the earliest Lower Svecofennian assemblages of the region, like the Pyhäsalmi Formation (PyF). Recently there has been speculation on a close relationship between these gneissic plutonic rocks and the oldest known Svecofennian volcanites. It seems that, at least in the Pyhäsalmi area, the Kettuperä granodioritic gneiss itself is of volcanic origin and may actually constitute one of the stratigraphically lowest members of the felsic volcanic rocks (Lahtinen 1994). This is also indicated by similar ε_{Nd} values of c. +3 for these two rock types (Lahtinen & Huhma 1996).

In Sweden, the oldest presently known plutonic and dyke rocks of the Svecofennian Domain are found in the Knaften area (cf. above). They are 1954±6 Ma and 1940±14 Ma calc-alkaline, tonalitic to granodioritic granitoids (Kna) and related dyke rocks, respectively, intrusive into the Knaften group (MSIA Map 323 and 324). Further south in Sweden, in northern Ångermanland, two microcline-porphyritic, gneissic granodiorites at Husum and Seltjärn (Hus and Sel, respectively, on the Bedrock Map), which are intrusive into the Härnö group greywacke migmatites, have yielded ages of 1931±11 Ma and c. 1930 Ma (Lundqvist et al. 1999, MSIA Map 353 and 363).

3.2.3.4 Lower Svecofennian assemblages

The Savo schist belt (Sas) in Finland, situated near the Archaean craton in the northeast, consists of moderately to strongly metamorphosed, in places also intensively sheared Palaeoproterozoic rocks. This part of the Svecofennian Domain in Finland has been proposed to represent the earliest stage of a complex collisional, arc-forming process (Korsman et al. 1997). Major parts of the supracrustal rocks in the Savo schist belt are more or less strongly migmatised mica gneisses (Fig. 26). They are intercalated with minor quartz-feldspar gneisses, graphite schists, and some amphibolites of volcanic origin. Locally, a few dolomite and skarn intercalations, as well as uranium-bearing phosphate beds in the Vihanti, Kiuruvesi and Pielavesi areas, have also been documented. Volcanic formations of the Savo schist belt have only limited extension, but have played a very important economic role as hosts for numerous massive sulphide deposits.

The migmatitic mica gneisses of the Savo schist belt can be traced from Rautalampi to the poorly exposed northwestern parts of the belt, where they have been observed in a few outcrops and also in diamond drill cores near the coast of the Bothnian Bay north of Raahe. An economically interesting sequence of felsic, intermediate and mafic volcanites with dolomites, skarn rocks and black schists, hosting the Lampinsaari zinc ore with few known satellites, occurs at Vihanti, between the migmatites and a large intrusive complex,

The Vihanti-Pyhäsalmi ore belts constitute the north-

Fig. 25. Pillow lava of the Knaften group, Hästliden, Knaften area. Photo, Th. Lundqvist.

western part of the Savo schist belt, bordered by the Ruhaperä Fault Zone and the Haapavesi igneous complex in the southwest, and by the Revonneva Shear Zone and the Archaean Basement Complex in the north and east. They can be subdivided into two major blocks by the NE–SW-trending Oulujärvi shear zone, described by Kärki et al. (1993). This indicates that the two belts at Vihanti and Pyhäsalmi are at least tectonically separated. Massive sulphide deposits of the Savo schist belt are closely related to these volcanic environments, and the most important deposits occur here. The lithologically similar Pielavesi and Kiuruvesi fields southeast and east of Pyhäsalmi have been correlated with the Vihanti-Pyhäsalmi belts (Ekdahl 1993).

The Pyhäsalmi Formation (PyF), in the middle part of the Savo schist belt, is composed mainly of felsic and mafic volcanic rocks with rare graphite- and sulphide-bearing, calcareous/skarn and tuffaceous rocks. These rocks have been intruded by numerous syntectonic intrusions. The lowest part of the Pyhäsalmi Formation consists of felsic mass flows or tuffaceous and pyroclastic rocks with minor mafic intercalations. Towards the proposed stratigraphic top, mafic massive lavas and pyroclastic rocks, pillow lavas and pillow breccias become more abundant. The metavolcanic rocks in the Pyhäsalmi area are locally well preserved, but most of the rocks have been strongly altered by hydrothermal processes and deformed during later tectonic events.

The volcanic rocks of the Pyhäsalmi Formation have a clear bimodal signature (Mäki 1986, Kousa et al. 1994). Most of the felsic rocks can be classified as calc-alkaline, low-K rhyolites, and probably originated by melting of an unknown Palaeoproterozoic sialic crust (Lahtinen & Huhma 1996). A quartz-porphyritic variety of these rhyolites from Riitavuori, near the Mullikkoräme massive sulphide ore, has yielded a U-Pb zircon age of 1921±2 Ma (Kousa et al. 1994). The felsic volcanic rocks have been proposed to be cogenetic with the oldest known rock in the Pyhäsalmi area (Kousa 1990, Lahtinen 1994), the Kettuperä granodioritic gneiss dated at 1930±15 Ma (Helovuori 1979). The mafic metavolcanic rocks are sub-alkalic, and resemble recent low-K tholeiitic basalts to basaltic andesites, with a primitive island-arc tholeiitic (IAT) affinity (Kousa et al. 1994). Metavolcanic sequences, which are lithologically and geochemically almost identical with the Pyhäsalmi Formation, have been described in the Pielavesi (Ekdahl 1993) and Rautalampi (Kousa & Lahtinen 1988) areas southeast of Pyhäsalmi, along the eastern boundary zone of the Svecofennian Domain.

The bedrock of south and central Ostrobothnia (Pohjanmaa) is dominated by metamorphosed greywackes and pelites of turbiditic origin, belonging to the Pohjanmaa schists (Pos), also called the Bothnian schists. Although these rocks have been metamor-

Fig. 26. Migmatitic mica gneiss, Ruukki. Photo. J. Kousa.

phosed to biotite-plagioclase schists and gneisses and locally also migmatised, they still demonstrate primary turbiditic structures in numerous places (Fig. 27).

The Pohjanmaa greywackes contain thin elongated intercalations of mafic to intermediate metavolcanic rocks, which are exposed only in a few outcrops in the south, for example at Vittinki in the vicinity of the town of Seinäjoki, and at Evijärvi, and continue towards the north via Kaustinen to Kannus and Himanka (Hiv) in central Ostrobothnia. The Vittinki volcanic rocks (Viv) are mostly deformed and metamorphosed to diopside-banded amphibolites with pillow structures preserved only in a few places. Chemically, they resemble tholeiitic basalts of MORB affinity. Closely associated with these volcanic rocks are glassy or banded quartz-rock layers which have been documented to represent chert precip-itates (Tuukki 1984). Together with mafic volcanic rocks, these layers can be traced tens of kilometres from Laihia to Lapua as a discontinuous formation. Metacherts at the village of Vittinki are known for their manganese mineral occurrences.

The Evijärvi area volcanites (Evv) can mostly be classified as tholeiitic basalts and basaltic andesites having N-type MORB to WPB characteristics (Vaarma & Kähkönen 1994). Well-preserved pillow lavas can be found in almost all units of the Evijärvi volcanic rocks, although pyroclastic and primary sedimentary structures predominate in places. Black schist, skarn and carbonate rocks are very common intercalations in these volcanic formations. The best known are probably the carbonate rocks at Vimpeli (Vim). Northward from Evijärvi, identical metavolcanic formations can be traced to Kaustinen, Kannus and Himanka (Hiv; Fig. 28), where also an ultramafic member was found in the course of the Mid-Norden mapping (J. Kousa, unpublished data). This unit can probably be correlated with mafic-ultramafic volcanic layers described from numerous places within the Härnö group metagreywackes in the Swedish part of the Mid-Norden area.

Felsic volcanites are rare among the rocks of the Bothnian schist belt, and have been observed only at Ruotsalo near the town of Kokkola, where they have been described as quartz-feldspar schists or quartzites. Structurally, these felsic volcanites occur in the central parts of an antiformal dome stratigraphically beneath skarn and carbonate rocks, black schists and metagreywackes. These rocks are also the host of uranium-bearing phosphorite layers (Äikäs 1988, 1989).

The metamorphic grade in this part of the Bothnian schist belt increases towards the Vaasa granite and the Bothnian Bay. In the Evijärvi area, the metapelites close to the Central Finnish granitoid complex, be-

Fig. 27. Gently northwest dipping open fold in metagreywacke with quartz and pegmatite veins, Himanka. Photo, J. Kousa.

longing to the eastern part of the schist belt, contain staurolite and garnet porphyroblasts, while muscovite pseudomorphs after andalusite occur in the central part (Vaarma & Pipping 1997). Near the contact with the Vaasa granite (Vaa), west of the Evijärvi area, sillimanite and K-feldspar occur as porphyroblasts. Further west, migmatisation and partial melting of these metasediments is a dominating feature.

The Nivala area, which is dominated by migmatitic mica gneisses, is situated north of the Central Finland granitoid complex, between a N–S-trending belt of granitoid batholiths (Toholampi-Rautio-Kalajoki) in the west and the Savo schist belt. These gneisses have locally amphibolitic, or graphite- and sulphide-bearing intercalations (Isohanni et al. 1985), and thus resemble the lithological association of the Savo schists. These migmatites are host rocks to Ni-bearing ultramafic intrusions in the Nivala area.

In the Swedish part of the Mid-Norden area, the major part of the metamorphic Svecofennian supracrustals consists of extensive turbiditic greywackes and argillites of the Härnö group (Häg), which forms a continuation of the Pohjanmaa or Bothnian schist belt in Finland. The Härnö group has a maximum thickness of the order of 10 000 m and has been metamorphosed at upper greenschist to upper amphibolite facies conditions (Lundqvist et al. 1990). In areas of low metamorphic grade the greywackes display well preserved primary structures such as Bouma sequences, graded bedding (Fig. 29), cross-bedding, load casts, etc. High grade rocks, however, predominate, and are characterised by the formation of veined gneisses and raft migmatites (Fig. 30). Intercalations of graphite- and pyrrhotite-bearing schists, chert, basalts (in part pillow lavas), and, in rare cases, rhyolites and dacites are found in the greywackes. The U-Pb zircon ages of felsic volcanic intercalations at Rocksjö in the Junsele area and near Sollefteå are as young as 1874±6 Ma (MSIA Map 338) and 1870±2 Ma (MSIA Map 386 and Lundqvist et al. 1998), respectively, and date the younger parts of the greywacke sequence. As already mentioned, the oldest parts of the Härnö group are intercalated with the pre-1.95 Ga Knaften group, and therefore the total time of deposition of the Härnö group is at least 80 Ma (Lundqvist et al. 1998).

In the northern part of the Swedish Mid-Norden area, low-grade (greenschist-facies), felsic volcanic rocks with subordinate mafic volcanic rocks predominate in the Skellefte District. The older volcanites here belong to the submarine Skellefte Group (SkG), deposited in a volcanic arc setting and having a total thickness of at least 3 000 m (Allen et al. 1996). The volcanic rocks display a compositional range from rhyolite to basalt, with a great predominance for the former (Allen et al., op. cit.). Chemically, they are calc-alkaline or subalkaline, and the basalts tholeiitic to calc-alkaline (Claesson 1985, Vivallo & Claesson

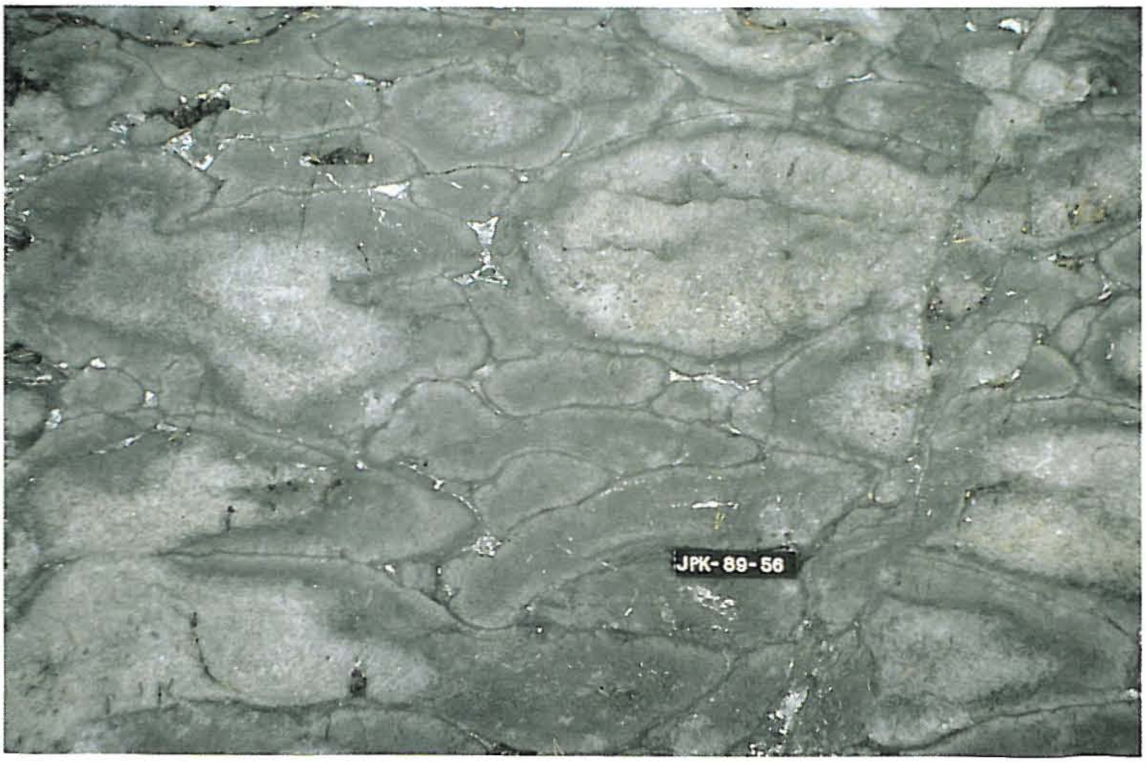

Fig. 28. Basaltic pillow lava, Himanka. Photo, J. Kousa.

Fig. 29. Low-grade greywacke of the Härnö group, showing graded bedding by upward decreasing frequency and size of clasts of plagioclase, quartz and phyllite. Road-cut near Bjästa, SW of Örnsköldsvik. Photo, Th. Lundqvist.

Fig. 30. Migmatised greywacke of the Härnö group (Schollen or raft migmatite). Härnön, near the town of Härnösand. Photo, Th. Lundqvist.

1987). Deposition of the felsic volcanic rocks occurred as breccias, flows, domes etc., mainly at c. 1890–1880 Ma (MSIA Map 296, 301, 308). A recent age determination of a possibly intrusive tonalite in the Kristineberg area, however, may indicate that the volcanicity started already at or before 1907±12 Ma (Bergström & Sträng 1999). The numerous massive sulphide ores of the Skellefte District (p. 116) are closely related to the felsic volcanic activity (e.g. Rickard 1979, Weihed et al. 1992, Bergman Weihed et al. 1996, Billström & Weihed 1996). They usually occur at a stratigraphic level near the overlying metasedimentary rocks of the Härnö group, in a proximal position to volcanic centres and near subvolcanic domes (Fig. 31; Allen et al. 1996). In the vicinity of the ores the volcanic rocks have been altered to sericite and chlorite schists.

The Skellefte Group volcanic rocks are overlain by (and intercalated with) the Härnö group greywackes in the Skellefte District (Gavelin 1955, Lundberg 1980). In the Malå-Kristineberg area the greywackes have been intruded by mafic, Mg-rich sills, and have

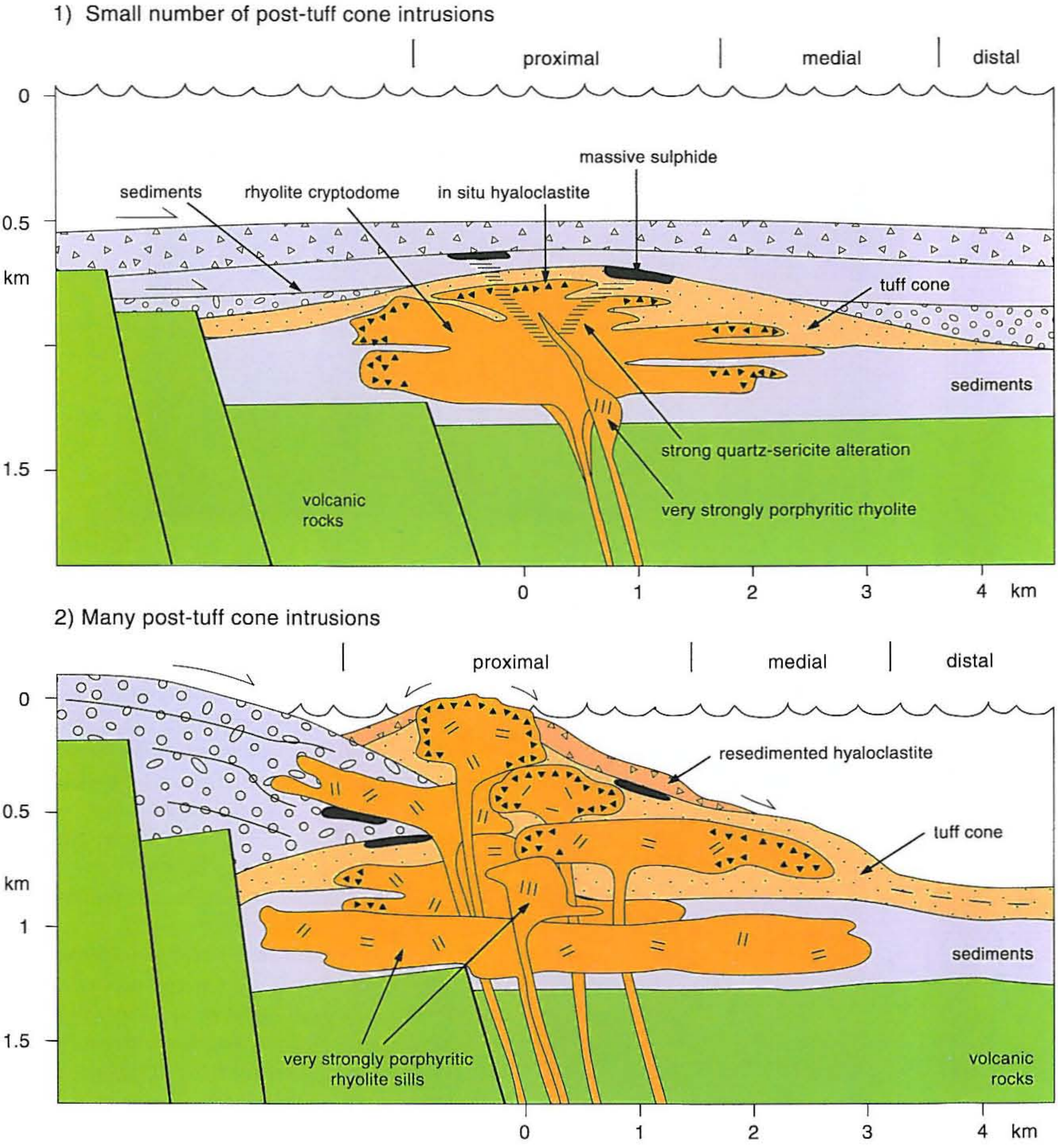

Fig. 31. Facies models for subaqueous rhyolite cryptodome–tuff volcanoes and massive sulphide ores: 1) with a small number of post-tuff intrusions, and 2) many post-tuff intrusions. From Allen et al. (1996).

here been separated as the Malå group by Bergström and Sträng (1996). Major accumulations of mafic volcanic deposits overlying the Skellefte Group felsic volcanites near Malå have been distinguished by Bergström and Sträng (1999) as the Tjamstan formation. (The Malå group and the Tjamstan formation are not shown on the Mid-Norden Bedrock Map.)

3.2.3.5 Supracrustal rocks transitional between the Lower and Upper Svecofennian assemblages

In the legend to the Mid-Norden Bedrock Map, the following supracrustal assemblages have been included with a broken bracket in the Lower Svecofennian assemblages, indicating that they occupy a rather high level in the Svecofennian stratigraphy. They can be regarded as transitional to the Upper Svecofennian assemblages described in the next chapter.

The younger, 1878±2 Ma (MSIA Map 272), more extensive complex of volcanic rocks of the Skellefte District belongs to the terrestrial Arvidsjaur Group and consists of felsic (rhyolitic to dacitic) flows and ignimbrites as well as mafic or intermediate (basaltic to andesitic) flows and tuffs. Their metamorphic

Fig. 32. Volcaniclastic, clast-supported conglomerate, Antinneva formation, Pyhäjoki. Photo, J. Kousa.

grade is usually low. Volcanic textures and structures are extremely well preserved, especially in the felsic rocks, where ignimbrite flames, porphyritic and glass-shard textures, flow banding (cf. excursion guide, p. 134), accretionary lapilli, perlitic cracks, lithophysae and spherulites are common (Grip 1935, Lilljequist & Svenson 1974). The volcanites of the Arvidsjaur Group overlie those of the Skellefte Group (Gavelin 1955, Lundberg 1980). Conglomerates with granitoid pebbles which indicate that at least the stratigraphically higher parts of this group belong to the Upper Svecofennian assemblages (see below) are intercalated in the Arvidsjaur Group.

Fig. 33. Cross-bedded tuffaceous metasediment with matrix-supported conglomerate intercalation. Antinneva formation, Pyhäjoki. Photo, J. Kousa.

According to Perdahl and Frietsch (1993) and Perdahl (1995), the Arvidsjaur Group volcanic rocks near Arvidsjaur are calc-alkaline to alkali-calcic and were formed in a mature volcanic arc environment. In the Arjeplog region northwest of Arvidsjaur, in the northernmost part of the Mid-Norden map area, the volcanic rocks of this group are bimodal, mildly alkaline, and extruded in an extensional arc or back-arc environment. Similar volcanic rocks near Luleå are, according to the same authors, calc-alkaline, with a rather high proportion of andesites, and were formed in the earlier stages of an arc development.

South of the Mid-Norden map area, the Härnö group greywackes are overlain by arkoses (the Naggen arkose and high-grade equivalents, cf. Lundqvist 1987 and Lundqvist et al. 1990), and mafic and felsic volcanites belonging to the Haverö group (Hag). Only minor parts of the volcanic rocks are exposed within the Mid-Norden map area (cf. Gorbatschev et al. 1997), whereas the arkose is found farther south (cf. Lundqvist et al. 1990). Tentatively, the volcanic rocks of the Haverö group have been correlated with those of the Arvidsjaur Group on the Bedrock Map.

The volcanic rocks of Pihtipudas and Perho (Piv and Pev, respectively) have been included in the rocks transitional between the Lower and Upper Svecofennian assemblages of Finland. They are situated in the area of the Central Finland granitoid Complex (CFi), and are mainly composed of intermediate to felsic plagioclase- and quartz-porphyritic rocks with minor mafic uralite-porphyritic members. At Pih-tipudas, the volcanic rocks and synorogenic plutonic rocks are considered to be cogenetic and have a U-Pb zircon age of 1883 Ma (Aho 1979). Several formations of volcanic rocks [the Kuusaa (Kuv) and Yli-vieska (Ylv) volcanites], probably situated strati-graphically above the migmatised Bothnian mica gneisses, occur further north, outside the Central Finland granitoid complex in the Lestijärvi, Ylivieska, Raahe and Kuusaa areas. These volcanic rocks display well preserved primary structures which indicate a shallow-water or even subaerial depositional environment (Figs. 32 and 33). They vary from basalts to K-rhyolites in composition, and have a mature, island-arc calc-alkaline affinity. This volcanism in the northern part of the Svecofennian Domain is closely related to the syntectonic magmatism of the Central Finland granitoids, which is c. 1890–1875 Ma in age, and is also broadly synchronous with the peak of regional metamorphism in this area. Structurally, the bedrock of the Nivala area is interpreted as a gently dipping dome surrounded by younger, locally flat-lying volcanic and sedimentary formations at Kuusaa, Ylivieska, Sievi and Lestijärvi.

3.2.3.6 Upper Svecofennian assemblages

Sedimentary-volcanic sequences which contain conglomerates with clasts of c. 1.88 Ga (early orogenic, synkinematic) granitoids occur in the northern and north-central parts of the Swedish Mid-Norden Svecofennian Domain, and in the central parts of the Finnish Mid-Norden Svecofennian Domain. Such granitoids normally display intrusive relationships with Svecofennian supracrustal rocks (cf. Kautsky 1957 and below). The term 'Upper Svecofennian', which was coined in the Nordkalott Map (Geological Map, Northern Fennoscandia, 1 : 1 million 1987) for similar formations, has also been adopted in the Mid-Norden Bedrock Map. This term, however, must be regarded as provisional, since a number of recent radiometric age determinations have demonstrated a wide range of ages for granitoids mapped as early orogenic or synkinematic. Therefore, formations containing pebbles of such granitoids cannot, without confirmation by radiometric age determination of the pebble granitoids, be termed 'Upper Svecofennian'. However, since granitoid pebble-bearing conglomerates give important information on the exhumation of granitoids and the geological evolution of a region, the term 'Upper Svecofennian assemblages' has been maintained as an informal concept on the Mid-Norden Bedrock Map.

The most important of the Swedish Upper Svecofennian assemblages in the Mid-Norden area are the Vargfors (VfG) and Ledfat (LeG) Groups [conglomerate (Figs. 34 and 35), sandstone, andesite], the

Fig. 34. Upper Svecofennian Vargfors conglomerate (Abborrtjärn conglomerate) with clasts of volcanites and Jörn-type granitoids. N of Vargforsdammen, on the northern side of the river Skellefteälven, W of Jörn. Photo, Th. Lundqvist.

Fig. 35. Upper Svecofennian Ledfat conglomerate with clasts of mainly volcanites of the Arvidsjaur Group and sandstone. N of Bockträsket, Ledfat area, NW of Malå. Photo, Th. Lundqvist.

Dobblon Group (conglomerate, felsic volcanites), the Svartlå Group (SvG; arkose, quartzite, conglomerate and phyllite), the Piteå Group (PiG; conglomerate, arkose, phyllite, mafic volcanites), at least the upper parts of the Arvidsjaur Group (ArG) at Hej north of Jörn, and greywackes and mafic volcanic rocks at Blåviksjön between Lycksele and Storuman. The Bälinge Group (BäG) west of Luleå is dominated by a conglomerate-like rock (Fig. 36) with rounded tonalite clasts, earlier interpreted as an epiclastic formation but recently reinterpreted as a magmatic, hydraulic breccia (Wikström et al. 1996). A similar reinterpretation has also been suggested for at least parts of the conglomerates with granitoid clasts occurring in the Vallen-Alhamn area south of Luleå (Åhman 1953, Wikström & Mellqvist 1995). On the Mid-Norden Bedrock map, these and related occurrences (cf. Wikström et al. 1996) are shown by the same colour symbol as (epiclastic) Upper Svecofennian supracrustal rocks.

The above-mentioned Upper Svecofennian supracrustal rocks have been deformed and regionally metamorphosed to greenschist or lower amphibolite facies during the Svecokarelian orogeny. Their ages

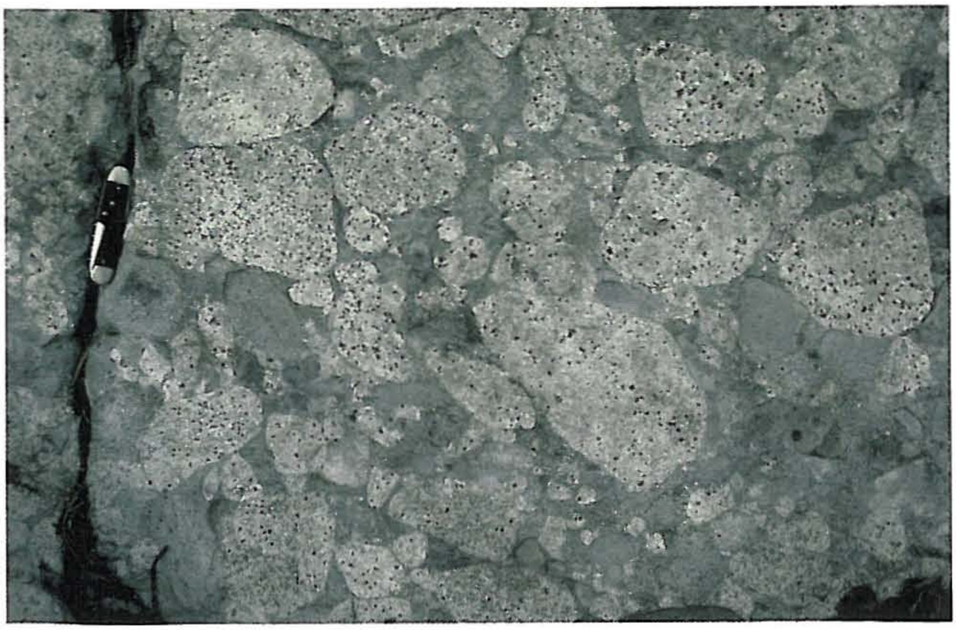

Fig. 36. Magmatic, hydraulic breccia (Bälinge 'conglomerate'). Bälingsberget, WNW of Luleå. Photo, Th. Lundqvist.

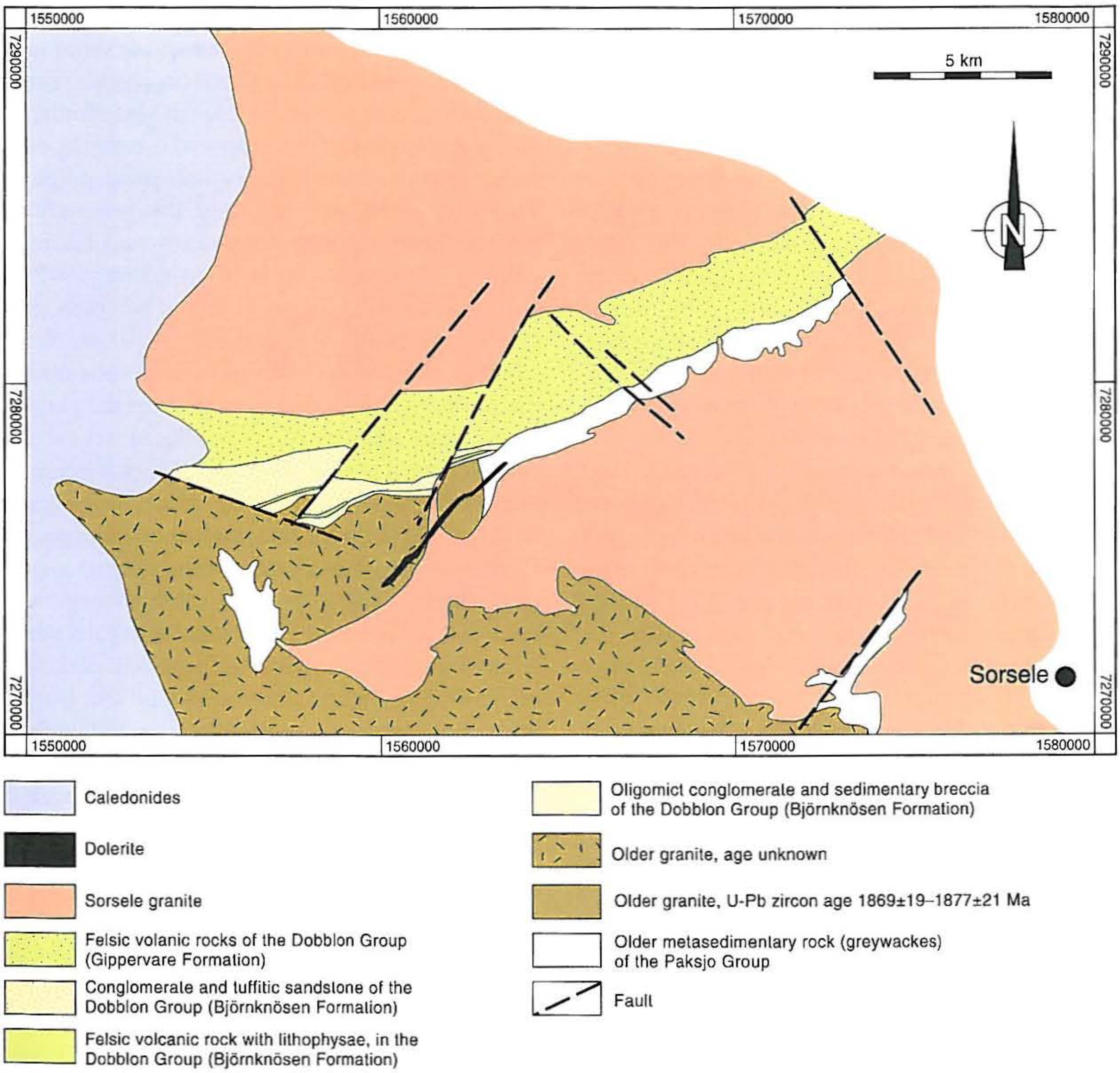

Fig. 37. Bedrock map of the Dobblon area west of Sorsele. Modified from Einarsson (1979).

are not always well known, but an ignimbrite in the Vargfors Group has yielded a U-Pb zircon age of 1874.9±3.7 Ma (Billström &Weihed 1996). Granitoid clasts in the Ledfat Group (see Offerberg 1959) have been dated at c. 1.87 Ga (Skiöld 1988), which gives a maximum age for this group. A granodiorite pebble in the Pite conglomerate on the coast near the town of Piteå has yielded a U-Pb zircon age of 1868±13 Ma (Persson & Lundqvist 1997), whereas a dyke of tonalite porphyry cutting the conglomerate has been dated at 1865+24/-10 Ma (Persson & Lundqvist, op. cit., MSIA Map 273). A granitoid clast in the conglomerate at Blåviksjön has yielded an age of 1890±7 Ma (MSIA Map 318).

Granitoid fragments in a breccia at Måttsundsberget, similar to that at Bälinge, has an age of 1879±4 Ma (MSIA Map 246). Fragments or pebbles in the conglomerate-like rocks at Vallen-Alhamn have yielded both Archaean (c. 2.7 Ga) and Palaeoproterozoic (1.9 Ga) ages (Lundqvist et al. 1996, Lundqvist et al. 2000). A megaxenolith of augen-gneiss in the Bälinge magmatic breccia (see Fig. 6, p. 19) is also of Archaean age (2638±19 Ma; MSIA Map 240).

Conglomerates intercalated with Arvidsjaur Group volcanic rocks dated at1878 Ma (MSIA Map 272) in the Hej area contain pebbles of the c. 1.89 Ga Jörn GI granitoid (see below). They demonstrate that at least the upper parts of the Arvidsjaur Group belong to the Upper Svecofennian.

It should be noted that the upper parts of the Härnö group greywackes probably belong to the Upper Svecofennian assemblages, although they can only rarely be positively identified as such. This conforms with the ideas put forward by Kautsky (1957) that what he called the Elvaberg series greywackes should correlate stratigraphically with the Vargfors Group. Fairly young ages of c. 1.87 Ga for felsic volcanic rocks intercalated with the greywackes in Ångermanland point in the same direction (see above, p. 53).

The Dobblon Group (DoG) of Einarsson (1979), including conglomerates with clasts of the underlying 1.87 Ga granitoid (MSIA Map 256, 257), as well as felsic, 1803±15 Ma volcanites (MSIA Map 250), is situated west of Sorsele (Fig. 37). This group appears to have been deposited on top of a folded greywacke sequence and therefore, in contrast to the above assemblages postdates the major Svecokarelian deformation. The Dobblon Group, along with the surrounding intrusive, 1791±22 Ma Sorsele granite (MSIA Map 238), has been included in the Transscandinavian Igneous (or Granite-Porphyry) Belt (see Gaál & Gorbatschev 1987 and below).

In the Bure area northeast of Sorsele, red, polymictic conglomerates with thick intercalations of reddish arkosic and tuffitic sandstones overlie volcanic rocks of the Arvidsjaur Group. The clasts of the conglomerates are dominated by sandstone and red rhyolite, but other rock types, e.g. grey granite, are also present. The conglomerates have been termed the Loito Formation and correlated with the Vargfors Group (Perdahl & Einarsson 1994). (The term Loito Formation has erroneously been omitted on the Bedrock Map, and should be added on the three small fields NE of Sorsele.)

In Finland, the Kuusaa (Kuv) and Ylivieska (Ylv) volcanic formations are separated from each other by more or less continuous belts of volcaniclastic rocks composed of polymictic conglomerates and finer-grained, immature, commonly cross-bedded volcaniclastic metasediments, named the Ylivieska (YlF) and Settijärvi (SeF) Formations. These are included among the Upper Svecofennian assemblages on the Mid-Norden Bedrock Map. Most of the pebbles of these conglomerates are of volcanic origin. Granitoid pebbles have been observed in some conglomerate layers in the Haapajärvi,Ylivieska and Raahe areas. The U-Pb zircon age of one granitoid pebble from the Settijärvi conglomerate (Haapajärvi area) is c. 1888 Ma (Vaasjoki & Sakko 1988).

3.2.3.7 Early (c. 1.90–1.85 Ga) plutonic and dyke rocks of the Svecofennian Domain

These intrusions occur throughout the Svecofennian Domain. Most predate the Svecokarelian regional deformation and metamorphism, the main exceptions being the pyroxene granitoids of Finland and the Perthite monzonite suite (Pms) of Sweden. They are, thus, generally more or less intensely foliated (gneissose). Migmatisation has also affected some of these intrusions, a process which has evidently been promoted by the presence of xenoliths and sheet-like inclusions of greywackes. The intrusions have been termed early orogenic, synkinematic or synorogenic.

The Vaasa granodiorite (Vaa) occupies a region in the southwestern part of the Finnish Mid-Norden map area. Lithologically, this granitoid is rather complex. In part, it can be classified as a synorogenic, porphyritic granitoid, mainly grey in colour. It is generally quite heterogeneous in both composition and fabric. According to the description of Laitakari (1942), the composition of the Vaasa granitoid is mostly granodioritic or tonalitic. Garnet- and hypersthene-bearing varieties have been observed in numerous places in the southern and southeastern parts of the pluton. In many areas, especially in the northern, southern and southeastern parts, migmatitic varieties are common, indicating a high metamorphic grade. Major parts of what has been called Vaasa granite, for example in the Pietarsaari area, can actually be interpreted as pervasively melted, raft-migmatitic mica gneisses with a granodioritic neosome. These contain a paleosome of mica gneiss and calc-silicate-rich rocks (Laitala 1981), originating from the greywackes of the Bothnian schist belt. Excellent outcrops to demonstrate this are found on the coast of the Gulf of Bothnia near Fäboda village, southwest of the town of Pietarsaari (see photo in excursion guide, p. 128).

The Central Finland Granitoid complex (CFi) is situated in the southern part of the Mid-Norden map area and consists mainly of plutonic rocks which have been variously classified as early, syn- and late-orogenic, and were formed in the age range 1890–1870 Ma. Systematic bedrock mapping of this granitoid complex was done during the early decades of the 20th century, and thus the overall geological outline and the lithological boundaries of this area are not very accurately known. However, the old, detailed descriptions of the various rock types are still very useful (Saksela 1934, Wilkman 1938, Laitakari 1942). Intrusions of the Central Finland granitoid complex consist of rocks ranging from gabbros to granites in composition. Major parts are composed of porphyritic granodiorites, but porphyritic granitic varieties are common as well. In some cases, these two rock types grade into each other with no detectable intrusive contact between them, indicating their close relationship. Less important by volume are diorites and gabbros. In the Viitasaari area, these mafic rocks have been quarried for building stone. Small peridotitic and anorthositic intrusions in a few places in the Kinnula and Viitasaari areas have also been documented (Nykänen 1962, Pipping 1966). During recent years, some of the mafic intrusions of the complex have been important targets for ilmenite exploration (Kärkkäinen et al. 1997).

The occurrence of pyroxene-bearing granitic to gabbroic intrusive rocks is a special feature of the Savo schist belt. This rock association occurs all along the belt from Rautalampi (Rau) in the southeast to Pielavesi and Kiuruvesi (Kiu), and again farther northwest to the Lamu (Lam), Rantsila (Ran; Fig. 38) and Kopsa (Kos) areas near Raahe. The intrusions closely follow the boundary zone between the Archaean and Svecofennian Domains. Major rock types of these intrusive complexes are coarse K-feldspar porphyritic granites, granodiorites and quartz syenites or monzonites. Even-grained dioritic and gabbroic differentiates are typically associated with these intrusions. Both the granitoid–syenitoid and the gabbroic rocks contain orthopyroxene as well as hornblende as main mafic components. In some varieties clinopyroxene is also present (Marttila 1981, Salli 1983, Lahti 1995).

Geochemically, the pyroxene-bearing intrusive complexes show I-type characteristics with slightly negative ε_{Nd} values. Some syenitic varieties have anomalously high Fe, K and Ba contents compared with other Svecokarelian granitoids (Lahti 1995). A U-Pb age of 1884 Ma has been obtained from the Vaaraslahti intrusion in the Pielavesi area (Salli 1983), and this is also considered to be the age of the other intrusions mentioned above.

The pyroxene granitoid intrusions have given rise to high-temperature and low-pressure granulitic contact aureoles in their wall-rocks (Hölttä 1988). On the Mid-Norden map they can be seen as cores of fault-bounded blocks, which have been metamorphosed at high amphibolite to granulite-facies conditions (see also Korsman et al. 1984).

A few rather large mafic intrusions, named the Ylivieska (Yli), Kumiseva (Kum) and Vihanti (Vih) gabbros, are situated north of the Central Finland granitoid complex. In fact, they are compositionally complex layered intrusions, also containing peridotitic differentiates. U-Pb zircon ages of the Ylivieska and Kumiseva intrusions are c. 1880 Ma. The Nivala area is well known for its numerous but quite small ultramafic bodies (Niv) in a migmatitic mica gneiss environment (the Nivala gneiss complex, Ngc, not shown in the Mid-Norden Bedrock Map). Ultramafic intrusions in the Nivala area have been deformed and metamorphosed, and altered to serpentinites and metaperidotites. The Hitura ultramafic body is intersected by felsic pegmatite dykes which have been dated at 1877 Ma (U-Pb zircon age, Isohanni et al. 1985). It has been proposed that the ultramafic rocks in the Nivala area are older than the Ylivieska gabbro (Isohanni et al. 1985). The Hitura and Makola ultramafic rocks at Nivala are important hosts for nickel, which has been mined during several periods from the 1940's until recently.

The plutonic Jörn suite (Jrn) is intrusive into the older Svecofennian supracrustal rocks of the Skellefte District, notably the volcanic arc rocks of the Skellefte Group and the Härnö group. The type massif at Jörn comprises four different granitoid (tonalitic to granitic) generations, termed GI–GIV, and minor gabbro (Wilson et al. 1987). The granitoid phases become younger and more evolved towards the centre of the massif. U-Pb zircon ages of various granitoid phases of the Jörn massif fall between 1.89 and 1.87 Ga

Fig. 38. Coarse K-feldspar porphyritic orthopyroxene granite (Rantsila granite), Rantsila. Photo, J. Mäkinen.

(Wilson et al. 1987, MSIA Map nos. 282, 285, 286, 295, 296).

Porphyritic intrusions of tonalite in the GI phase at Tallberg in the southern part of the Jörn massif are associated with mineralisations of porphyry copper type (Weihed 1992). In this same region a dyke of metadolerite, the Älgliden mafic dyke (Ämd), with parallel dykes of intermediate composition, is associated with Cu-Ni mineralisations (Weihed, op. cit.).

In the Kristineberg area of the western Skellefte District, recent U-Pb dating of a tonalite thought to belong to the Jörn suite has yielded a fairly old age of 1907±13 Ma. It is not clear whether this tonalite is intrusive into the Skellefte Group volcanites of this area, or whether it forms the local basement of the latter (Bergström & Sträng 1999).

A less common composition for plutonic rocks of the Svecofennian Domain is noted in the 1873±10 Ma (MSIA Map 281) Gallejaur monzonite of the Skellefte District. This intrusion has been interpreted as genetically related to the andesites of the Vargfors Group (see Weihed et al. 1992).

Northwest of Skellefteå, at Björkdal, a c. 1905 Ma tonalite contains quartz veins which are presently mined for gold (Billström & Weihed 1996).

In the region of the Arvidsjaur Group, more granitic compositions of intrusions prevail, e.g. in the Arvidsjaur, Antak and Avaviken granites, of which the last-mentioned is associated with U mineralisations. U-Pb ages for these granites are: Arvidsjaur 1877+8/-7 Ma (MSIA Map 261), Antak 1879+15/-12 Ma (MSIA Map 274) and Avaviken as young as c. 1840 Ma (Wilson et al. 1985). A somewhat older, grey granite, dated at 1892±62 Ma (MSIA Map 231), occurs c. 60 km ENE of Arvidsjaur. This granite body contains Mo mineralisations related to aplitic dykes.

In the Härnö group greywackes there are numerous, though usually not very voluminous intrusions of grey, foliated, in some cases augen-bearing tonalites and granodiorites–granites (Fig. 39). They are found throughout the Mid-Norden part of the Bothnian Basin from Piteå in the north to the vicinity of Östersund in the south. Their ages usually fall between 1.89 and 1.87 Ga, but the total age range is 1.90–1.85 Ga (see MSIA Map). However, the younger ages of this range (1.86–1.85 Ga; MSIA Map 311 and 315), recorded for the granodiorites and granites of the Sikträsk dome in the southern border zone of the Skellefte District, have turned out to be due to the presence of complex zircons. Ion probe dating of rocks from this dome has yielded 'normal' ages of c. 1.88 Ga (P. Weihed, personal communication 1999).

Gabbros and diorites of similar age as the granitoids are subordinate in volume. Examples are the Hoting-Rörström gabbro (Hot) near Dorotea (Lundqvist et al. 1990), the Näsberget gabbro (Näb) in the northern part of the Jörn massif and the Kallax gabbro near Luleå. Minor occurrences of related ultramafic rocks intruded into the Härnö group metagreywackes at Lappvattnet and Mjövattnet southwest of Skellefteå contain nickel mineralisations. A gabbro at Lainijaur in the western part of the Skellefte District was mined for nickel during World War II. The layered Hoting-Rörström and nearby Kläppsjö gabbros have attracted attention because some parts contain elevated platinum-group element contents (Lundqvist et al. 1990).

Fig. 39. Weakly foliated early-orogenic granodiorite with K-feldspar megacrysts. Skagsudde area, E of Örnsköldsvik. Photo, Th. Lundqvist.

Fig. 40. Gold-bearing quartz veins in gabbro. Åkerberg mine, NW of Skellefteå. Photo, Th. Lundqvist.

A gabbro at Åkerberg, 35 km NNW of Skellefteå contains a system of thin parallel quartz veins, which are mined for gold (Fig. 40). This gabbro probably belongs to the Jörn suite.

Interesting conglomerate-like breccias caused by bulb-like intrusions of dioritic–granodioritic magma into the greywackes of the Härnö group have been observed at Jan-Sakrisaberget, 35 km WSW of Skellefteå. The breccias generally contain rounded fragments of ultramafite, gabbro, diorite, tonalite–granodiorite and metagreywacke in a matrix which in part looks like an intrusive rock (granodiorite) but, in part, also resembles a metasediment (Kumpulainen 1995, Nilsson & Kero 1998).

The Perthite monzonite suite (Pms) has been correlated with the Finnish pyroxene-bearing granitoids at Rautalampi, etc. (see above). It is only sparsely represented in the northernmost parts of the Swedish Mid-Norden map area, but occupies large areas further north (Geological Map, Northern Fennoscandia, 1 : 1 million 1987), where it is spatially related to the felsic volcanic rocks of Kiruna-Arvidsjaur type. It is characterised by strongly perthitic feldspars, and in many cases also by the presence of pyroxene [mainly clinopyroxene but rarely also orthopyroxene; see Ödman (1957) and Witschard (1984)]. The relationship between rocks of this suite and other Svecokarelian plutonic rocks is problematic. In tectonic respects, the intrusion of the suite seems to postdate the major Svecokarelian orogenic deformation of its wall-rocks. However, U-Pb ages are old, 1.88–1.86 Ga (Skiöld & Öhlander 1989, Martinsson 1999). The results may perhaps be taken to indicate an earlier termination of this deformation in northernmost Sweden than in more southerly areas (cf. p. 40).

The Notträsk gabbro c. 6 km northeast of Boden was included in the Haparanda suite by Ödman (1957), but on the Mid-Norden Bedrock Map has provisionally been denoted as an early member of the Perthite monzonite suite. It has the shape of a downward pointing funnel (Widenfalk et al. 1985). Some other gabbro occurrences in the northern parts of the Swedish Mid-Norden area have also been given this colour symbol, but their age and relationship with the Perthite monzonite suite are not clear.

3.2.3.8 *1.8–1.7 Ga plutonic and dyke rocks of the Svecofennian Domain*

Large volumes of granitoid magma intruded into the Svecofennian Domain of the Swedish part of the Mid-Norden map area at c. 1.8 Ga, shortly after the Svecokarelian orogeny. In contrast, the Finnish part of the Domain is characterised by only few granitic intrusions of this age, mainly in the area southeast of Oulu.

The 1.8 Ga granitoid magmas were only to a minor extent accompanied by mafic magma. They were, in part, volatile rich, leading to the formation of abundant pegmatites, and, in part, volatile poor. To the former group belong the Lina granite of Norrbotten County (see Geological Map, Northern Fennoscandia, 1 : 1 million 1987 and p. 40), and the Skellefte and Härnö granites.

The mostly even-grained and reddish Lina granite (Lin) mainly occurs in the Swedish Nordkalott area

(Geological Map, Northern Fennoscandia, 1 : 1 million 1987), but also in some smaller massifs in the Mid-Norden area. These are not well known and are separated from other red granites, notably those of the Arvidsjaur granite type (see above). The Lina granite is found in both the Karelian and the Svecofennian Domains (cf. p. 40). Studies of this granite in the Nordkalott area show that it was formed by mobilisation of older crust (mainly 1.9 Ga granitoids, see Öhlander & Skiöld 1994). Pegmatites related to the Lina granite are abundant. A related, also pegmatite-rich granite occurs at Storliden north of Arvidsjaur, where it forms a distinct, rounded massif. The Storliden granite, with an age of 1792±5 Ma (MSIA Map 235), is U-anomalous.

The Härnö (Här) and Skellefte (Ske) granites are of S-type and commonly contain muscovite. They occur in the Härnö group greywackes, from which they were formed by partial melting (Claesson & Lundqvist 1995). Both even-grained, mostly fine-grained, and microcline-porphyritic varieties occur (Fig. 41). Their age is 1.82–1.80 Ga (Claesson & Lundqvist 1995, Billström & Weihed 1996). Associated pegmatites are usually simple, one- or two-mica rocks, and generally carry tourmaline. In some cases they display almost monomineralic concentrations of quartz or feldspar (Fig. 42). Complex pegmatites with Li, Nb and Sn have been noted in the Långsele, Järkvissle and Sidensjö areas of Västernorrland County (e.g. Romer & Smeds 1994), and at Varuträsk near Skellefteå (Quensel 1952). U-Pb columbite ages are 1.80–1.78 Ga (MSIA Map 313, 369–371). In the Varuträsk pegmatite, well known for its content of rare minerals, high rubidium contents are also noted. Li-bearing pegmatites also occur on Kluntarna near Piteå, and a complex pegmatite with e.g. beryl has been found near Kramfors (Ödman 1957 with references, Lundqvist et al. 1990).

Pegmatite granites are very common in the Bothnian schist area of Finland, where they mainly exist as dykes and veins within the mica gneisses, but also as larger intrusions. A group of dykes of complex pegmatites, for example in the Seinäjoki and Kuortane areas, occurs along the southern and eastern margin of the schist belt, close to the contact zone of the Central Finland Granitoid complex. These pegmatites have attracted special interest because of their rare mineral contents (e.g. beryl, cassiterite, columbite, topaz, lepidolite, spodumene and different varieties of tourmaline). Many of these are of gemstone quality (Haapala 1966, Lahti & Saikkonen 1986 and Vilpas 1996).

The largest volumes of 1.8 Ga granitoids were formed by high-temperature, volatile-poor (pegmatite-poor) magmas. The most important of these granitoids is the coarsely microcline-porphyritic, c. 1.81–1.78 Ga Revsund granite (Rev), which covers large parts of the Svecofennian Domain in Sweden (Fig. 43; MSIA Map 279, 305, 320, 331 and 355). Hornfels alteration is common in the wall-rocks of this granite (Lundqvist et al. 1990). It postdates the S-type Härnö granite and shows a differentiation from (rare) gabbro to quartz-monzodiorite, quartz monzonite, granodiorite and granite (Persson 1978). Porphyritic and non-porphyritic, in places dark-coloured, in part pyroxene- and olivine-bearing granites of the so-called Sörvik

Fig. 41. Härnö granite with lath-shaped K-feldspar megacrysts. Ödingen, SW of Sollefteå. Photo, Th. Lundqvist.

Fig. 42. Quartz-feldspar quarry in pegmatite associated with the Härnö granite. Quartz occupies the main part of the quarry, and is capped by K-feldspar. Långsjökullen, Edsele, NW of Sollefteå. Photo, Th. Lundqvist.

and similar granite types (Gorbatschev et al. 1997, Weihed & Antal 1998), are probably closely related to the Revsund granite. Similarly, the F-rich Grötingen (or 'Red Revsund') granite (Grö) in the southern part of the Swedish Mid-Norden area probably belongs to the Revsund suite, although no precise age data exist up to now (Gorbatschev et al. 1997).

C. 25 km southeast of Storuman the so-called Joran dome is seen as a rounded structure on the Bedrock Map. It is formed by a granite (the Joran granite, Jor), which is a highly evolved variety of Revsund granite. This granite has attracted interest because of its W mineralisations (e.g. Eliasson 1995).

Only very subordinate volumes of mafic rocks (diorite or gabbro) occur in the Revsund granite. By mingling and mixing phenomena they can be closely related to this granite. Such mafic rocks (colour 95 on the Bedrock Map) have been found for example in the Kalvträsk area, in the southern part of the Skellefte District (Weihed & Antal 1998).

An even-grained, reddish granite, the Adak granite (Adk), occurs in the western part of the Skellefte Dis-

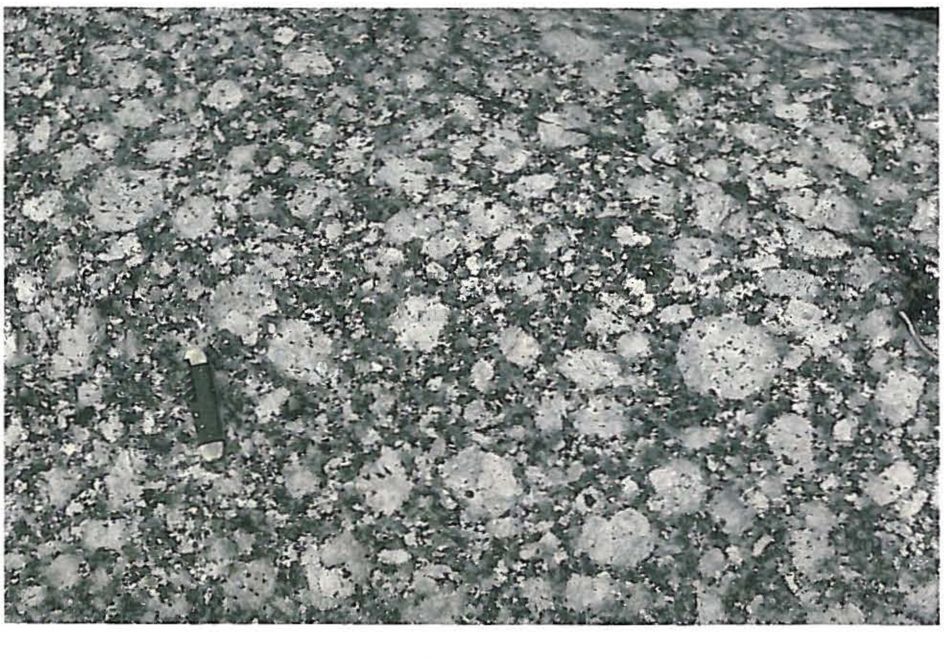

Fig. 43. Typical, reddish-grey Revsund granite with megacrysts of microcline. Stordalsberget, N of Örnsköldsvik. Photo, Th. Lundqvist.

trict. It has traditionally been correlated with the Revsund granite, and this has now been confirmed by radiometric dating (1802±3 Ma; Bergström & Sträng 1999).

The Sorsele granite (Sor), situated in the western part of the Skellefte District, resembles the Revsund granite in age (1791±22 Ma, MSIA Map 238) and in chemical-modal variation. This granite is usually included in the Transscandinavian Igneous Belt. Recent interpretations also include the Revsund granite in this concept (e.g. Gorbatschev & Bogdanova 1993).

Some granites and syenites with 1.8 Ga ages occur in the northern parts of the Mid-Norden area. The Edefors granite and syenite (Edf) near Älvsbyn, and the Boden syenite (Bod) northwest of Luleå (Öhlander & Skiöld 1994), as well as the porphyritic Ale granite (Ale) west of Luleå (MSIA Map 241; Öhlander & Schöberg 1991) belong to these intrusions, which were formed from dry magmas. The Edefors and Boden rocks contain clinopyroxene, in part also olivine. The Edefors syenite and granite were formed from mantle melts with less than 35% of crustal material (Öhlander & Skiöld 1994).

In the southwest, near the Caledonides, the microcline-porphyritic, 1.70–1.68 Ga Rätan granite (Rät) covers a total area of c. 5 000 km^2, but occupies only a small area on the Mid-Norden map. Like the Sorsele granite, it has been included in the Transscandinavian Igneous Belt (see Gorbatschev et al. 1997).

Around the Muhos Formation (MuF), south of the town of Oulu in Finland, the Mid-Norden Bedrock Map shows a large granitoid intrusion named the Tyrnävä granite (Tyr). This granitoid is very poorly exposed and seen only in a few scattered outcrops, and is therefore not well defined. The Tyrnävä granitoid area has been reported to contain a heterogeneous association of coarse pegmatite granites, even-grained microcline and aplite granites, and also K-feldspar porphyritic varieties (Kesola 1985). The Tyrnävä granite, on the boundary zone between the Sveco-fennian and Karelian Domains, is distinguished from other intrusions in the area because of its late-orogenic (cross-cutting) nature. A U-Pb zircon age of c. 1825 Ma has been reported for a homogeneous, slightly K-feldspar porphyritic variety (Honkamo 1989). The Tyrnävä granite has been observed to intrude both Karelian and Svecofennian schists, and also the Archaean basement complex.

3.2.3.9 Mesoproterozoic intrusive rocks of the Svecofennian Domain

3.2.3.9.1 Rapakivi complexes and dykes

A number of plutonic rapakivi complexes and related dyke rocks occur in the Mid-Norden area, mainly in Sweden. U-Pb ages for these fall in the interval 1.6–1.5 Ga. They have traditionally been termed sub-Jotnian, as some of them form the basement of Jotnian (see below) sandstone formations. Recent overviews on the Swedish rapakivi complexes are found in Ahl et al. (1997) and Andersson (1997).

The rapakivi complex of Ragunda (Rag; Kornfält 1976, Persson 1997, Gorbatschev et al. 1997) consists of leucogabbro, gabbro, quartz syenite and syenite, biotite granite and hornblende granite. It is composed of a number of rounded intrusions which become successively younger towards the east. Two U-Pb age

Fig. 44. Nordingrå gabbro with inclusions of leucogabbro/anorthosite. Bönhamn, Nordingrå area, E of Kramfors. Photo, Th. Lundqvist.

determinations of the granites have yielded 1506±13 and 1513±9 Ma (MSIA Map 382 and 391). Chemically, the granites are metaluminous to peraluminous (Persson 1997). They are porphyritic, with cm-large phenocrysts of alkali feldspar, and are usually mixed and mingled with the Ragunda gabbro (cf. photo on p. 138). Dykes of felsic as well as mafic composition occur in the Ragunda massif and its surroundings, and are closely related to the rapakivi magmatism.

In the rocks surrounding the Ragunda rapakivi complex, a transformation of microcline to orthoclase has been observed, caused by the heat of the rapakivi intrusions (Kornfält 1969).

The Nordingrå rapakivi complex (Nor) of 1578±9 Ma age (MSIA Map 390) consists of granite, gabbro and leucogabbro with anorthosite (Fig. 44). (The term anorthosite in the legend of the Bedrock Map denotes leucogabbro as well as anorthosite proper. This also concerns the Ragunda rocks.) The granite, which is porphyritic with cm-large alkali feldspar phenocrysts, forms a c. 1 km-thick sheet on top of gabbro/anorthosite (Lundqvist et al. 1990). It intrudes and brecciates the mafic rocks of the complex (Fig. 45). Mingling and mixing phenomena are not as conspicuous as at Ragunda. The gabbro was formed by multiple intrusion, and is layered. The Nordingrå complex is well known because of von Eckermann's (1938) theory of anorthosite formation through upward accumulation of floating plagioclase crystals in a gabbroic magma. This theory may still be valid for Nordingrå, although the structure is not as simple as envisaged by von Eckermann (Lundqvist et al. 1990).

Limited hornfels alteration has been observed in wall-rocks and xenoliths of metagreywacke, etc. (Lundqvist et al. 1990).

Other rapakivi massifs in the Mid-Norden area are smaller than those at Ragunda and Nordingrå. They occur at Mårdsjö (Mår; gabbro, leucogabbro or anorthositic gabbro, quartz syenite, granite; 1524±3 Ma, see MSIA Map 366), Nordsjö (Nom; monzonite or syenite, depending on method of classification, with dykes of dolerite, granite porphyry, syenite and monzonite porphyry; 1519±7 Ma, see MSIA Map 351), Mullnäset (gabbro, syenite and granite, 1526±3 Ma, see MSIA Map 339) and Strömsund (granite with minor quartz syenite); see also Andersson (1997), Gorbatschev et al. (1997) and Lundqvist et al. (1990). Rapakivi granite is also found on the Bonden skerry southeast of Nordmaling. This granite is probably connected with the Nordingrå granite at depth.

E-W-trending dykes of granite porphyry of rapakivi type as well as various hybrid rocks are found near Bollstabruk, between Ragunda and Nordingrå. The most important is the c. 10–20 m-wide Bollstabruk granite porphyry dyke (Bgp; see Lundqvist et al. 1990).

The undeformed Petolahti diabase dyke (Pdd), c. 35 km south of the town of Vaasa, on the western coast of Finland, is zoned and exhibits a differentiation from sulphide-bearing olivine diabase through pyroxene diabase to quartz diabase (Ervamaa 1962). The composition of the dyke is geochemically different from that of the Jotnian Vaasa diabase dykes (see below) exposed on a few islands in the Gulf of Bothnia. The Petolahti diabase dyke cuts sharply through the Svecofennian mica gneiss and has been

Fig. 45. Nordingrå granite brecciating Nordingrå gabbro. Salsåker, Nordingrå area, E of Kramfors. Photo, Th. Lundqvist.

proposed to be related to the c. 1.65 Ga, sub-Jotnian Häme diabase dyke swarm of southern Finland (Sipilä et al. 1985). Thus, it may be closely related to rapakivi intrusions, although radiometric age data are lacking. The ultramafic portion of the diabase dyke is the host rock for a small Ni-Cu ore that was mined in 1972–1973 (Sipilä et al. 1985).

3.2.3.9.2 Post-Jotnian mafic intrusions

The Jotnian (see 3.3), sub-Jotnian and older, Palaeoproterozoic bedrock has been intruded by numerous, up to some hundred metres wide sheets, sills and dykes of dolerite or diabase. (Cf. Saksela 1933, Laitakari 1942, Lundqvist et al. 1990, Gorbatschev et al. 1997.) It should be noted that these rocks, which are unmetamorphosed, have traditionally been called diabases in Finland and dolerites in Sweden. These terms have also been adopted on the Mid-Norden Bedrock Map.

In Sweden, the dolerites belong to the c. 1250–1220 Ma post-Jotnian Central Scandinavian Dolerite Group (CSD) and, in the Ångermanland coast region, to the Ulvö Dolerite Complex (UDC; Larson 1980; see also Welin & Lundqvist 1975). The latter is well exposed in the coast region and displays beautiful igneous layering, in part graded, and lamination (cf. photos in the excursion guide, p. 136). The dolerites are of alkali-olivine basalt type and consist of labradorite, olivine, titaniferous augite, titanomagnetite and minor K-feldspar, quartz and apatite. In titanomagnetite-rich layers the mineral ulvöspinel was first discovered (Mogensen 1946). In the upper parts of the flat-lying sheets, monzonitic and even granitic compositions are found (Lundqvist et al. 1990).

The Swedish post-Jotnian dolerites have generally intruded in the form of gently dipping sheets or lopoliths (cf. Larson 1980 and Gorbatschev et al. 1997). The most conspicuous lopolith occurs in the coast region of Ångermanland and Medelpad, and has a semi-circle shape with a diameter of 90 km (Lundqvist et al. 1990).

Numerous dolerite dykes, mostly striking E–W±30° and dipping steeply, are found in the Swedish Mid-Norden area. Their mineralogy (where known) is generally similar to that of the sheets and sills, and the dolerites are therefore usually considered to be of the same age (see Lundqvist et al. 1990). The dykes appear as distinct linear positive anomalies on aeromagnetic maps, from which their extensions have been drawn on the Bedrock Map. They have been denoted by the same colour as the post-Jotnian dolerites, but palaeomagnetic investigations completed after the Mid-Norden Bedrock Map has been published (Moakhar 1998) suggest that at least some of these dykes are associated with the rapakivi complexes and are thus older (1.6–1.5 Ga).

On a few islands in the Gulf of Bothnia, c. 30–40 km west of Vaasa in Finland, there are exposures of well preserved medium- to coarse-grained, olivine-pyroxene diabase (Vdd) intruding migmatised mica gneiss as roughly N–S to NE–SW-striking dyke swarms (Saksela 1933, Laitakari 1942). The Vaasa dykes are medium- to coarse-grained and composed mainly of labradoritic plagioclase, monoclinic and rhombic pyroxene, olivine and titanomagnetite (Nykänen 1960). Some of the dykes have a very coarse-grained diabase-pegmatitic core, which has been dated. The U-Pb zircon age of three samples taken from the dykes of Svall and Norrgrynnan islands is c. 1268 Ma (Suominen 1991), confirming that these dykes can be correlated with the post-Jotnian Satakunta diabase 200 km south of Vaasa, and also with the Ulvö dolerite and the Central Scandinavian Dolerite Group in Sweden.

3.2.3.10 Metamorphism and tectonic evolution of the Svecofennian Domain

3.2.3.10.1 General overview

Svecokarelian deformation and regional metamorphism affected the Svecofennian supracrustal rocks as well as the oldest (early orogenic, synorogenic or synkinematic) plutonic rocks. Available data indicate that the main phases of deformation and metamorphism occurred earlier in Finland (c. 1.88 Ga) than in Sweden (between c. 1.86 and 1.82 Ga). Early phases have, however, also been detected or suggested in Sweden (cf. p. 70). A noteworthy feature of the Svecofennian Domain in Sweden and Finland (except for the easternmost parts, near the Archaean craton) is the lack of structural trends persisting over large areas (cf. MSIA Map).

Regional Svecokarelian metamorphism of the Svecofennian Domain of the Mid-Norden area mainly occurred at amphibolite-facies conditions. In Finland, granulite facies has been attained in some regions, while in Sweden, particularly in the Skellefte District, vast areas are characterised by greenschist-facies metamorphism.

The regional metamorphism was of low-pressure type, as shown by the occurrence of andalusite and cordierite and the absence of kyanite. At higher grades andalusite is replaced by sillimanite. Available data point to Svecokarelian geothermal gradients of the order of 50°C/km.

Contact metamorphism (hornfels alteration), related to relatively late igneous intrusions, is superimposed on the regional metamorphism. In Finland, such metamorphism is found in the contact zone of the pyroxene granitoids, while in Sweden hornfelses are found particularly around the Revsund granite, but also near rapakivi complexes.

3.2.3.10.2 Tectonometamorphic features of the Svecofennian Domain in Finland

The Svecokarelian deformational history of the Svecofennian Domain in Finland has been documented to include four more or less well separated stages. These events have been studied mainly in the boundary zone between the Svecofennian and Karelian Domains (Korsman et al. 1984, Korsman 1988, Luukas 1991), but the stages can also be identified in the west, in the Bothnian schist belt (Vaarma & Pipping 1997). Especially along the Savo Schist Belt, fault-bounded blocks with internally different structural and metamorphic histories are a very prominent feature (Korsman et al.1984, Hölttä 1988).

Deformation in the Svecofennian Domain of Finland involved an early phase of thrusting towards the Archaean craton in the northeast, when D1 and D2 folds developed, and younger phases (D3 and D4) of shearing and fragmentation which produced the major shear zones of the central Fennoscandian Shield (Kärki et al. 1993). On the Mid-Norden Bedrock Map, the main two folding events of the polyphase Svecokarelian deformation (D2 and D3) are schematically presented by the same symbol lines, according to J. Luukas. The unclassified lines marking fault and shear zones have been constructed mainly from low-altitude airborne magnetic maps of the Geological Survey of Finland, but in many cases have also been confirmed from outcrops.

The metamorphic imprint on the Svecofennian supracrustal rocks varies between low-pressure medium grade and granulite high grade. The eastern margin of the Svecofennian Domain (i.e., the Savo schist belt), consisting mainly of migmatised mica gneisses with abundant metavolcanic rocks, has usually reached upper amphibolite facies. In many cases, even low-pressure high-temperature granulite-facies conditions have prevailed, as indicated by the occurrence of hypersthene, cordierite, garnet and in places also sillimanite. In the Pielavesi area, c. 100 km northwest of Kuopio, regional metamorphism culminated at a temperature of 800–880°C and a pressure of c. 5.5 kb (Hölttä 1988). Contemporaneous magmatism produced granitoids and tonalitic migmatites (Korja et al. 1994). The pyroxene granitoids, dated at c. 1884 Ma, intruded slightly after this peak of metamorphism. Some of these have caused clear contact-metamorphic aureoles in the surrounding rocks (Hölttä 1995).

High-grade conditions also prevailed in the area west of the Savo schist belt, as indicated by migmatised mica gneisses, for example around the Nivala ultramafic bodies. This feature may indicate the presence of a dome-like window structure in the area, where former deeper levels of the crust have been exposed, surrounded by the stratigraphically higher supracrustal rocks of the Upper Svecofennian, like the Kuusaa Formation and the Ylivieska volcanites and related sedimentary rocks.

Conditions in the Bothnian schist belt reflect a progressive increase in metamorphic grade from the contact with the Central Finland granitoid Complex towards the Vaasa granite. Near the contact zone of the Central Finland granitoids, metagreywackes are characterised by a paragenesis with staurolite and garnet, indicating medium-grade metamorphism. Through andalusite pseudomorphs (replaced by muscovite), the sillimanite - K-feldspar paragenesis is reached near the contact zone of the Vaasa granite (Vaarma & Pipping 1997). The Vaasa granite itself contains hypersthene-bearing varieties, also indicating a westward increasing metamorphic grade (Laitakari 1942).

The large area between the Savo schist belt and the high-grade area of the Bothnian schist belt reached medium-grade conditions west and north of the Central Finland granitoid Complex. This area consists of the greywackes of the eastern part of the Bothnian schist belt, stratigraphically overlain by the Upper Svecofennian supracrustal formations (rock numbers 99, 103 and 104 in the Mid-Norden Bedrock Map). No systematic study of metamorphism has been carried out here, but during bedrock mapping and exploration, andalusite and garnet have been observed in numerous places, sometimes also cordierite and staurolite, indicating low amphibolite facies metamorphism. Andalusite is typically replaced by muscovite and quartz (Västi 1989).

3.2.3.10.3 Tectonometamorphic features of the Svecofennian Domain in Sweden

During the last ten years, new ideas on the plate tectonic evolution of the Svecofennian Domain in the Swedish Mid-Norden area have been put forward, based on geophysical as well as isotope investigations. In agreement with the early ideas of Hietanen (1975), magnetotelluric and deep seismic reflection measurements indicate structures in the deep crust and mantle that have been interpreted to be related to an ancient subduction zone dipping NE, below the Skellefte District and its extension into the Gulf of Bothnia (Rasmussen et al. 1987, BABEL Working Group 1990). A model has also been suggested for the plate tectonic evolution in the border zone between the Svecofennian and Karelian Domains (the Luleå-Jokkmokk Zone). Measurements of ε_{Nd} values in c. 1.88 and 1.80 Ga granitoids indicate that a 1.9 Ga volcanic arc has collided here with the Archaean continent in the northeast in the time interval between the intrusion of these two granite groups (Öhlander et al. 1999, cf. also Öhlander et al. 1993).

In the Svecofennian Domain south of the Mid-Norden area (in Gävleborg County and south of Stockholm), the main Svecokarelian deformation has been interpreted as an early E–W compression producing N–S folds with east-dipping axial planes, followed by N–S compression, giving rise to fold interference (cf. Lundqvist et al. 1990). In the Mid-Norden area, however, such a relatively simple model is hard to confirm. The structures here seem to be strongly influenced by early orogenic (c. 1.89–1.85 Ga) granitoid massifs, which have formed relatively rigid blocks during deformation, and by a kind of diapiric upwelling during and after raft migmatite formation (e.g. Lundqvist et al. 1990).

In the Skellefte District, the first regional deformation resulted in upright isoclinal folds with E–W to NE–SW-striking axial planes and fold axes plunging c. 60°/E in the eastern part of the District (Bergman Weihed et al. 1996). A second deformation produced gentle to open folds with steep NE–SW-striking axial planes, and was largely coaxial with the first-generation folds in the eastern parts of the District. In more westerly parts the structural evolution is in principle similar, but the orientation of the structural elements differs.

In the so-called Nickel Zone southwest of Skellefteå (Fig. 24), a pronounced ENE–WSW structural trend is formed by subparallel foliations, lithological boundaries and shear zones.

As to the timing of the regional Svecokarelian deformation and metamorphism in the Swedish Mid-Norden area, these events are bracketed between c. 1865 and 1820 Ma (the age of the youngest supracrustal rocks and the oldest, essentially undeformed granites, respectively). However, older phases of deformation have been suggested to have occurred in the eastern part of the Skellefte District before 1875–1860 Ga, or in the time interval between the Jörn GI and GIII granitoids (at c. 1.88 Ga; see Lundström et al. 1999). South of Skellefteå, recent structural investigations combined with ion-probe dating have been interpreted to indicate the existence of deformation structures and migmatisation features as old as 1900–1890 Ma, followed by a younger phase of deformation and veining at 1860 Ma (Rutland et al. 1997). Further work, however, is needed to elucidate the tectono-metamorphic evolution of this part of the Bothnian Basin.

In Sweden, the regional Svecokarelian metamorphism involved mobilisation of large parts of the Härnö group greywackes to migmatites (Lundqvist et al. 1990, Gorbatschev et al.1997). These migmatites generally contain sillimanite and cordierite, in some cases also almandine. The transformation from andalusite in medium-grade rocks to sillimanite with rising temperature, according to field observations, seems to have taken place at a somewhat lower temperature than that necessary for migmatisation (Lundqvist et al. 1990).

Migmatisation of the Härnö group greywackes has taken place in three steps, the first of which involved formation of granitic veins, mainly in the pelitic layers of the metasediments. The second step produced raft migmatites (Schollen-migmatites) with more than 50 % of a granodioritic mobilisate that commonly contains scattered megacrysts of microcline. The third step was linked with the intrusion of the c. 1.8 Ga Härnö and Skellefte granites (cf. above), and involved injection of granitic–pegmatitic material into the greywacke gneisses (Lundqvist et al. 1990).

The largest area in the Svecofennian Domain with low-grade metamorphism is the Skellefte District, where volcanic rocks of the Skellefte and Arvidsjaur Groups as well as the Härnö group greywackes contain parageneses with chlorite, sericite and epidote. Only minor low-grade areas occur in the Bothnian Basin south of the Skellefte District.

After the Svecokarelian orogeny, important ductile deformation occurred along shear zones. Important N–S-striking shear zones crosscut the Revsund granite in the Kalvträsk area southwest of Skellefteå (Weihed & Antal 1998), and are therefore younger than 1.8 Ga. Post-1.8 Ga shear zones have similarly been recorded in the Revsund granite in northern Ångermanland (Lundqvist et al. 1990). In the south, the northernmost part of the important Storsjön-Edsbyn Deformation Zone (see Fig. 24) has a N–S trend near the Caledonian border south of Östersund. The latest deformations in this zone are bracketed between 1.7 and 1.2 Ga (Bergman & Sjöström 1994). According to U-Pb dating of titanite, earlier movements in the zone occurred at 1.80 Ga (Högdal et al. 1996).

Contact metamorphism related to the 1.8 Ga and later (post- and anorogenic) intrusions in Sweden is superimposed on the regional metamorphism. Around the Revsund granite, hornfelses with hypersthene, almandine, cordierite, sillimanite, andalusite, green spinel and microcline have formed in greywackes (Lundqvist et al. 1990). The regional schistosity has concomitantly been more or less wiped out. Similar hornfelses have been noted locally at the contacts of the Ragunda massif and in xenoliths of the Nordingrå granite, leucogabbro and gabbro. A transformation of microcline to orthoclase has been observed in the wall-rocks of the Ragunda massif, and locally also around major post-Jotnian dolerite sheets (Kornfält 1969, Lundqvist et al. 1990).

Numerous brittle deformation zones crosscut the bedrock of the Swedish Svecofennian Domain. They generally follow (earlier) ductile zones. Because of extensive rock units of uniform lithological composition (granitoids, raft migmatites) fault displacements are generally difficult or impossible to estimate. In the Nordingrå area, however, an E–W fault with a c. 1 km sinistral displacement is situated in Ullångerfjärden (Lundqvist et al. 1990). In the sub-Jotnian and Jotnian complexes of Nordingrå, numerous faults have been detected, in part by geophysical methods. Especially N–S faults have been noted, in which the eastern blocks have become uplifted c. 80–90 m relative to the western. In general, however, the entire Gulf of Bothnia block should have been depressed in relation to the land areas in the west and east, as on average 1 000 m of Jotnian sandstone occur below sea level (Axberg 1980, Ahlberg 1986). Faults have also been reported predating the intrusion of the post-Jotnian dolerites but affecting the c. 1.58–1.25 Ga Jotnian sandstone of Nordingrå (Lundqvist et al. 1990).

3.2.3.11 References

Ahl, M., Andersson, U.B., Lundqvist, T. & Sundblad, K. (eds.) 1997. Rapakivi granites and related rocks in central Sweden. Sveriges geologiska undersökning Ca 87. 99 p.

Ahlberg, P. 1986. Den svenska kontinentalsockelns berggrund. Sammanfattning av tillgängliga undersökningar. Sveriges geologiska undersökning, Rapporter och meddelanden 47. 101 p.

Åhman, E. 1953. Vallen-Alhamnområdet i Nederluleå s:n. Summary: The Vallen-Alhamn area, parish of Nederluleå, North-Eastern Sweden. Sveriges geologiska undersökning C 529. 21 p.

Åhman, E. & Wikström, A. 1990. Berggrundskartan 25M Kalix SO. 1: 50 000. With a short description in Swedish and an English summary. Sveriges geologiska undersökning Ai 45.

Aho, L. 1979. Petrogenetic and geochronological studies of metavolcanic rocks and associated granitoids in the Pihtipudas area, Central Finland. Geological Survey of Finland, Bulletin 300. 21 p.

Äikäs, O. 1989. Phosphate resources in early Proterozoic supracrustal rocks, Finland, with reference to the Baltic Shield. In: Notholt, A.J.G., Sheldon, R.P. & Davidson, D.F. (eds.) Phosphate deposits of the world. Vol. 2 : Phosphate rock resources. Cambridge: Cambridge University Press, 429–436.

Allen, R.L., Weihed, P. & Svenson, S.-Å. 1996. Setting of Zn-Cu-Au-Ag Massive Sulfide Deposits in the Evolution and Facies Architecture of a 1.9 Ga Marine Volcanic Arc, Skellefte District, Sweden. Economic Geology 91, 1022–1053.

Andersson, U.B. 1997. Petrogenesis of some Proterozoic granitoid suites and associated basic rocks in Sweden (geochemistry and isotope geology). Sveriges geologiska undersökning, Rapporter och meddelanden 91. 216 p.

Axberg, S. 1980. Seismic stratigraphy and bedrock geology of the Bothnian Sea, northern Baltic. Acta Universitatis Stockholmiensis, Stockholm Contributions in Geology, Vol. XXXVI:3, 153–213.

BABEL Working Group 1990. Evidence for early Proterozoic plate tectonics from seismic reflection profiles in the Baltic Shield. Nature 348, 34–38.

Bergman, S. & Sjöström, H. 1994. The Storsjön-Edsbyn Deformation Zone, central Sweden. Research report of a project entitled: "The thermometamorphic history of a major shear zone in central Sweden - integrated geological-geophysical study". Sveriges geologiska undersökning dnr 03-500/92:78. 46 p.

Bergman Weihed, J., Bergström, U., Billström, K. & Weihed, P. 1996. Geology, tectonic setting, and origin of the Paleoproterozoic Boliden Au-Cu-As deposit, Skellefte District, northern Sweden. Economic Geology 91, 1073–1097.

Bergström, U. & Sträng, T. 1996. Kartbladen 23I Malå. In: Wahlgren, C.-H. (ed.) Regional berggrundsgeologisk undersökning. Sammanfattning av pågående undersökningar 1995. Sveriges geologiska undersökning, Rapporter och meddelanden 84, 85–92.

Bergström, U. & Sträng, T. 1999. Kartbladen 23I Malå. In:Wahlgren, C.-H. (ed.) Regional berggrundsgeologisk undersökning. Sammanfattning av pågående undersökningar 1998. Sveriges geologiska undersökning, Rapporter och meddelanden 98, 48–54.

Berthelsen, A. & Marker, M. 1986. 1.9-1.8 Ga old strike-slip megashears in the Baltic Shield, and their plate tectonic implications. Tectonophysics 128, 163–181.

Billström, K. & Weihed, P. 1996. Age and provenance of host rocks and ores in the Paleoproterozoic Skellefte District, northern Sweden. Economic Geology 91, 1054–1072.

Claesson, L.-Å. 1985. The geochemistry of early Proterozoic metavolcanic rocks hosting massive sulphide deposits in the Skellefte district, northern Sweden. Journal of the Geological Society 142, 899–909.

Eckermann, H. von 1938. The anorthosite and kenningite of the Nordingrå-Rödö region. Geologiska Föreningens i Stockholm Förhandlingar 60, 243–284.

Einarsson, Ö. 1979. Den prekambriska berggrunden i Dobblonområdet,Västerbottens län. Sveriges geologiska undersökning C 748. 123 p.

Ekdahl, E. 1993. Early Proterozoic Karelian and Svecofennian formations and the evolution of the Raahe-Ladoga Ore Zone, based on the Pielavesi area, central Finland. Geological Survey of Finland, Bulletin 373. 137 p.

Eliasson, T. 1995. Berggrunden på kartbladen 23H Stensele. In: Wahlgren, C.-H. (ed.) Regional berggrundsgeologisk undersökning. Sammanfattning av pågående undersökningar 1994, 77–83.

Eliasson, T. & Sträng, T. 1998. Kartbladen 23H Stensele. In: Wahlgren, C.-H. (ed.) Regional berggrundsgeologisk undersökning. Sammanfattning av pågående undersökningar 1997. Sveriges geologiska undersökning, Rapporter och meddelanden 97, 55–59.

Ervamaa, P. 1962. The Petolahti diabase and associated nickel-copper-pyrrhotite ore. Finland. Bulletin de la Commission géologique de Finlande 199, 1–80.

Gaál, G. 1985. Nickel metallogeny related to tectonics. In: Papunen, H. & Gorbunov, G.I. (eds.) Nickel-copper deposits of the Baltic Shield and Scandinavian Caledonides. Geological Survey of Finland, Bulletin 333, 143–155.

Gaál, G. & Gorbatschev, R. 1987. An outline of the Precambrian evolution of the Baltic Shield. Precambrian Research 35,15–52.

Gavelin, S. 1955. Beskrivning till berggrundskarta över Västerbottens län. 1. Urbergsområdet inom Västerbottenslän. With map to the scale of 1 : 400 000. Sveriges geologiska undersökning Ca 37, 4–99.

Geological Map, Northern Fennoscandia, 1 : 1 million 1987. Geological Surveys of Finland, Norway and Sweden. Helsinki.

Gorbatschev, R. & Bogdanova, S. 1993. Frontiers in the Baltic Shield. Precambrian Research 64, 3–21.

Gorbatschev, R., Kornfält, K.-A., & Lundegårdh, P.H. 1997. Beskrivning till berggrundskartan över Jämtlands län. Del 1: Urberget. With map to the scale of 1 : 200 000. Sveriges geologiska undersökning Ca 53:1. 250 p.

Grip, E. 1935. Die Arvidsjaurporphyre. Eine archäische Effusivgesteinsreihe im nördlichen Schweden. Bulletin of the Geological Institutions of the University of Uppsala XXV, 135–220.

Haapala, I. 1966. On the granitic pegmatites in the Peräseinäjoki-Alavus area, South Pohjanmaa, Finland. Bulletin de la Commission géologique de Finlande 224. 98 p.

Helovuori, O. 1979. Geology of the Pyhäsalmi ore deposit, Finland. Economic Geology 74 (5), 1084–1101.

Hietanen, A. 1975. Generation of potassium-poor magmas in the northern Sierra Nevada and the Svecofennian of Finland. Journal of Research of the U.S. Geological Survey 3 (6), 631–645.

Högdal, K., Gromet, L.P. & Claesson, S. 1996. The geochronology of a ductile shear zone in Jämtland, central Sweden. GFF 118, Jubilee Issue, A14–A15.

Hölttä, P. 1988. Metamorphic zones and the evolution of granulite grade metamorphism in the early Proterozoic Pielavesi area, central Finland. Geological Survey of Finland, Bulletin 344. 50 p.

Hölttä, P. 1995. Contact metamorphism of the Vaaraslahti pyroxene granitoid intrusion in Pielavesi, Central Finland. In: Hölttä, P. (ed.) Relationship of granitoids, structures and metamorphism at the eastern margin of the Central Finland Granitoid Complex. Geological Survey of Finland, Bulletin 382, 27–79.

Honkamo, M. 1989. Pohjois-Pohjanmaan vulkaniitit : Lapin vulkaniittiprojektin raportti. Summary: Volcanic rocks in northern Ostrobothnia : a report of the Lapland Volcanite Project. Geologian tutkimuskeskus, Tutkimusraportti 89. 46 p.

Huhma, H. 1986. Sm-Nd, U-Pb and Pb-Pb isotopic evidence for the origin of the Early Proterozoic Svecokarelian crust in Finland. Geological Survey of Finland, Bulletin 337. 48 p.

Huhma, H., Claesson, S., Kinny, P.D. & Williams, I.S. 1991. The growth of Early Proterozoic crust: new evidence from Svecofennian detrital zircons. Terra Nova 3 (2), 175–178.

Isohanni, M., Ohenoja, V. & Papunen, H. 1985. Geology and nickel-copper ores of the Nivala area. In: Papunen, H. & Gorbunov, G. I. (eds.) Nickel-copper deposits of the Baltic Shield and Scandinavian Caledonides. Geological Survey of Finland, Bulletin 333, 211–228.

Kähkönen, Y. 1989. Geochemistry and petrology of the metavolcanic rocks of the early Proterozoic Tampere Schist Belt, southern Finland. Geological Survey of Finland, Bulletin 345. 107 p.

Kärki, A., Laajoki, K. & Luukas, J. 1993. Major Palaeoproterozoic shear zones of the central Fennoscandian Shield. In: Gorbatschev, R. (ed.) The Baltic Shield. Precambrian Research 64 (1-4), 207–223.

Kärkkäinen, N., Sarapää, O., Huuskonen, M., Koistinen, E. & Lehtimäki, J. 1997. Ilmenite exploration in western Finland, and the mineral resources of the Kälviä deposit. In: Autio, S. (ed.) Geological Survey of Finland, Current Research 1995-1996. Geological Survey of Finland, Special Paper 23, 15–24.

Kautsky, G. 1957. Ein Beitrag zur Stratigraphie und dem Bau des Skelleftefeldes, Nordschweden. Sveriges geologiska undersökning C 543. 65 p.

Kesola, R. 1985. Oulujoen kartta-alueen kallioperä. Summary: Pre-Quaternary rocks of the Oulujoki map-sheet area. Geological Map of Finland 1 : 100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheet 3422. Geological Survey of Finland. 29 p.

Korja, T., Luosto, U., Korsman, K. & Pajunen, M. 1994. Geophysical and metamorphic features of Palaeoproterozoic Svecofennian orogeny and Palaeoproterozoic overprinting on Archaean crust. In: Pajunen, M. (ed.) High temperature-low pressure metamorphism and deep crustal structures : meeting of IGCP project 304 'Deep Crustal Processes' in Finland, September 16-20, 1994. Geological Survey of Finland, Guide 37, 11–20.

Kornfält, K.-A. 1969. X-ray and optical observations on the K-feldspars from the Ragunda area, central Sweden. Sveriges geologiska undersökning C 636. 33 p.

Kornfält, K.-A. 1976. Petrology of the Ragunda rapakivi massif, central Sweden. Sveriges geologiska undersökning C 725. 111 p.

Korsman, K., Hölttä, P., Hautala, T. & Wasenius, P. 1984. Metamorphism as an indicator of evolution and structure of the crust in Eastern Finland. Geological Survey of Finland, Bulletin 328. 40 p.

Korsman, K. (ed.) 1988. Tectono-metamorphic evolution of the Raahe-Ladoga zone. Geological Survey of Finland, Bulletin 343. 96 p.

Korsman, K., Koistinen, T., Kohonen, J., Wennerström, M., Ekdahl, E., Honkamo, M., Idman, H. & Pekkala, Y. (eds.) 1997. Suomen kallioperäkartta - Berggrundskarta över Finland - Bedrock map of Finland 1 : 1 000 000. Espoo: Geological Survey of Finland.

Kousa, J. & Lahtinen, R. 1988. The geochemistry of basic metavolcanic rocks in Pyhäjärvi, Rautalampi and Rantasalmi. In: Pajunen, M. (ed.) Project No. 235 "Metamorphism and geodynamics" excursion in Finland 15.6.-19.6.1988. Geological Survey of Finland, Guide 21, 22–23.

Kousa, J., Marttila, E. & Vaasjoki, M. 1994. Petrology, geochemistry and dating of Paleoproterozoic metavolcanic rocks in the Pyhäjärvi area, central Finland. In: Nironen, M. & Kähkönen, Y. (eds.) Geochemistry of Proterozoic supracrustal rocks in Finland. IGCP Project 179 Stratigraphic methods as applied to the Proterozoic record and IGCP Project 217 Proterozoic Geochemistry. Geological Survey of Finland, Special Paper 19, 7–27.

Kumpulainen, R. 1995. Jan-Sakrisaberget. An intrusion breccia in the Palaeoproterozoic of northern Sweden. Sveriges geologiska undersökning, Research Report 03-500/92:18. 59 p.

Lahti, S. I. 1995. Mineralogy and geochemistry of the Vaaraslahti pyroxene granitoid in Pielavesi, Finland. In: Hölttä, P. (ed.) Relationship of granitoids, structures and metamorphism at the eastern margin of the Central Finland Granitoid Complex. Geological Survey of Finland, Bulletin

382, 5–25.

Lahtinen, R. 1994. Crustal evolution of the Svecofennian and Karelian domains during 2.1 - 1.79 Ga, with special emphasis on the geochemistry and origin of 1.93 - 1.91 Ga gneissic tonalites and associated supracrustal rocks in the Rautalampi area, central Finland. Geological Survey of Finland, Bulletin 378. 128 p.

Lahtinen, R. & Huhma, H. 1997. Isotopic and geochemical constraints on the evolution of the 1.93-1.79 Ga Svecofennian crust and mantle in Finland. Precambrian Research 82 (1-2), 13–34.

Laitakari, A. 1942. Vaasa. General Geological Map of Finland 1 : 400 000, Explanation to the Map of Rocks, Sheet B 3. Geological Survey of Finland. 66 p.

Laitala, M. 1981. Pietarsaari. Geological map of Finland 1 : 100 000, Pre-Quaternary Rocks, Sheet 2321. Geological Survey of Finland.

Larson, S.Å. 1980. Layered intrusions of the Ulvö Dolerite Complex, Ångermanland, Sweden. Department of Geology, University of Gothenburg, Publ. A36. 213 p.

Lilljequist, R. & Svenson, S.-Å. 1974. Exceptionally well preserved Precambrian ignimbrites and basic lavas in N. Sweden. Geologiska Föreningens i Stockholm Förhandlingar 96, 221–229.

Lundberg, B. 1980. Aspects of the geology of the Skellefte District, northern Sweden. Geologiska Föreningens i Stockholm Förhandlingar 102, 156–166.

Lundqvist, Th. 1987. Early Svecofennian stratigraphy of southern and central Norrland, Sweden, and the possible existence of an Archaean basement west of the Svecokarelides. Precambrian Research 35, 343–352.

Lundqvist, Th., Gee, D.G., Kumpulainen, R., Karis, L. & Kresten, P. 1990. Beskrivning till berggrundskartan över Västernorrlands län. With English Summary. Maps to the scale of 1 : 200 000. Sveriges geologiska undersökning Ba 31. 429 p.

Lundqvist, Th., Vaasjoki, M. & Persson, P.-O. 1998. U-Pb ages of plutonic and volcanic rocks in the Svecofennian Bothnian Basin, central Sweden, and their implications for the Palaeoproterozoic evolution of the Basin. GFF 120, 357–363.

Lundqvist, Th., Vaasjoki, M. & Skiöld, T. 1996. Preliminary note on the occurrence of Archaean rocks in the Vallen-Alhamn area, northern Sweden. In: Lundqvist, Th. (ed.) Radiometric dating results 2, Division of Bedrock Geology, Geological Survey of Sweden. Sveriges geologiska undersökning C 828, 32–33.

Lundqvist, Th., Skiöld, T. & Vaasjoki, M. 2000. Archaean-Proterozoic geochronology of the Vallen-Alhamn area, northern Sweden. GFF 122, 273–280.

Lundström, I., Persson, P.-O. & Bergström, U. 1999. Indications of early deformational events in the northeastern part of the Skellefte field. Indirect evidence from geologic and radiometric data from the Stavaträsk–Klintån area, Boliden map-sheet. In: Bergman, S. (ed.) Radiometric dating results 4. Division of Bedrock Geology, Geological Survey of Sweden. Sveriges geologiska undersökning C 831, 52–69.

Luukas, J. 1991. Salahmin-Pyhännän alueen stratigrafia ja rakennegeologia. Abstract: Stratigraphy and structure of the Early Proterozoic Salahmi-Pyhäntä area, central Finland. Res Terrae. Ser. B 16. 131 p.

Mäki, T. 1986. Lithogeochemistry of the Pyhäsalmi zinc-copper-pyrite deposit, Finland. In: Prospecting in areas of glaciated terrain 1986: papers presented at the seventh international symposium organized by The Institution of Mining and Metallurgy and The Geological Survey of Finland, Kuopio, 1-2 September, 1986. London: The Institution of Mining and Metallurgy, 69–82.

Martinsson, O., Vaasjoki, M. & Persson, P.-O. 1999. U-Pb zircon ages of Archaean to Palaeoproterozoic granitoids in the Torneträsk–Råstojaure area, northern Sweden. In: Bergman, S. (ed.) Radiometric dating results 4, Division of Bedrock Geology, Geological Survey of Sweden. Sveriges geologiska undersökning C 831, 70–90.

Marttila, E. 1981. Kiuruveden kartta-alueen kallioperä. Summary: Pre-Quaternary rocks of the Kiuruvesi map-sheet area. Geological Map of Finland 1 : 100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheet 3323. Geological Survey of Finland.

Moakhar, M.O. 1998. Rapakivi granite and basic dykes in the Fennoscandian Shield: A palaeomagnetic analysis. Department of Environmental Engineering, Division of Applied Geophysics, Luleå University of Technology, 1998:40, unpaginated. (dissertation)

Mogensen, F. 1946. A ferro-ortho-titanate ore from Södra Ulvön. Geologiska Föreningens i Stockholm Förhandlingar 68, 578–588.

Nilsson, G. & Kero, L. 1998. Bedrock map 22K Skellefteå NV, scale 1 : 50 000. Sveriges geologiska undersökning Ai 67.

Nykänen, O. 1960. Korsnäs. Geological map of Finland 1 : 100 000, Pre-Quaternary Rocks, Sheet 1242. Geological Survey of Finland.

Nykänen, O. 1962. Kinnula. Geological map of Finland 1 : 100 000, Pre-Quaternary Rocks, Sheet 2334. Geological Survey of Finland.

Offerberg, J. 1959. Rocks and stratigraphy of the Ledfat area, Västerbotten County, northern Sweden. Sveriges geologiska undersökning C 564. 45 p.

Ödman, O. 1957. Beskrivning till berggrundskarta över urberget i Norrbottens län. With map to the scale of 1 : 400 000. English summary: Description to map of the Pre-Cambrian rocks of the Norrbotten County, N. Sweden (excl. the Caledonian mountain range). Sveriges geologiska undersökning Ca 41. 151 p.

Öhlander, B. & Schöberg, H. 1991. Character and U-Pb zircon age of the Proterozoic Ale granite, northern Sweden. Geologiska Föreningens i Stockholm Förhandlingar 112, 105–112.

Öhlander, B. & Skiöld, T. 1994. Diversity of 1.8 Ga potassic granitoids along the edge of the Archaean craton in northern Scandinavia: a result of melt formation at various depths and from various sources. Lithos 33, 265–283.

Öhlander, B., Skiöld, T., Elming, S.-Å., BABEL Working Group, Claesson, S. & Nisca, D.H. 1993. Delineation and character of the Archaean–Proterozoic boundary in northern Sweden. Precambrian Research 64, 67–84.

Park, A.F. 1991. Continental growth by accretion: A tectonostratigraphic terrane analysis of the evolution of the western and central Baltic Shield, 2.50 to 1.75 Ga. Geological Society of America Bulletin 103, 522–537.

Perdahl, J.-A. 1995. Svecofennian volcanism in northernmost Sweden. Division of Applied Geology, Luleå University of Technology 1995:169D, unpaginated. (dissertation)

Perdahl, J.-A. & Einarsson, Ö. 1994. The marine–continental transition of the Early Proterozoic Skellefte-Arvidsjaur volcanic arc in the Bure area, northern Sweden. GFF 116, 133–138.

Persson, A.I. 1997. The Ragunda rapakivi complex. In: Ahl, M., Andersson, U.B., Lundqvist, T. & Sundblad, K. (eds.) Rapakivi granites and related rocks in central Sweden. Sveriges geologiska undersökning Ca 87, 49–58.

Persson, L. 1978. The Revsund-Sörvik granites in the western parts of the province of Ångermanland, central Sweden. Sveriges geologiska undersökning C 741. 59 p.

Persson, P.-O. & Lundqvist, Th. 1997. Radiometric dating of the Palaeoproterozoic Pite conglomerate in northern Sweden. In: Lundqvist, Th. (ed.) Radiometric dating results 3, Division of Bedrock Geology, Geological Survey of Sweden. Sveriges geologiska undersökning C 830, 41–49.

Pipping, F. 1966. Viitasaari. Geological map of Finland 1 : 100 000, Pre-Quaternary Rocks, Sheet 3311. Geological Survey of Finland.

Quensel, P. 1952. The paragenesis of the Varuträsk pegmatite. Geological Magazine LXXXIX, 49–60.

Rasmussen, T.M., Roberts, R.G. & Pedersen, L.B. 1987. Magnetotellurics along the Fennoscandian Long Range profile. Geophysical Journal of the Royal Astronomical Society 89, 799–820.

Rickard, D.T. 1979. Scandinavian metallogenesis. GeoJournal 3.3, 235–252.

Romer, R. & Smeds, S.-A. 1994. Implications of U-Pb ages of columbite-tantalites from granitic pegmatites for the Palaeoproterozoic accretion of 1.90-1.85 Ga magmatic arcs to the Baltic Shield. Precambrian Reserarch 67, 141–158.

Rutland, R.W.R., Skiöld, T. & Page, R.W. 1997. Age and regional significance of deformation episodes in the Svecofennian Province South of Skellefte. In: Rutland, R.W.R. & Drummond, B.J. (eds.) Palaeoproterozoic Tectonics and Metallogenesis: Comparative analysis of parts of the Australian & Fennoscandian Shields. Australian Geodynamics Cooperative Research Centre (AGSO) Record 1997/44, 103–105.

Saksela, M. 1933. Kokkola. General Geological Map of Finland 1 : 400 000, Explanation to the Map of Rocks, Sheet B 4. Geological Survey of Finland. 55 p.

Saksela, M. 1934. Vaasa. General Geological Map of Finland 1 : 400 000, Pre-Quaternary Rocks, Sheet B 3. Geological Survey of Finland.

Salli, I. 1983. Pielaveden kartta-alueen kallioperä. Summary: Pre-Quaternary rocks of the Pielavesi map-sheet area. Geological Map of Finland 1 : 100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheet 3323. Geological Survey of Finland. 29 p.

Simonen, A. 1960. Plutonic rocks of the Svecofennides in Finland. Bulletin de la Commission géologique de Finlande 189, 1–101.

Simonen, A. 1980. The Precambrian in Finland. Geological Survey of Finland, Bulletin 304. 58 p.

Sipilä, P., Ervamaa, P. & Papunen, H. 1985. The Petolahti nickel-copper occurrence. In: Papunen, H. & Gorbunov, G.I. (eds.) Nickel-copper deposits of the Baltic Shield and Scandinavian Caledonides. Geological Survey of Finland, Bulletin 333, 293–312.

Skiöld, T. 1988. Implications of new U-Pb zircon chronology to Early Proterozoic crustal accretion in northern Sweden. Precambrian Research 38, 147–164.

Skiöld, T. & Öhlander, B. 1989. Chronology and geochemistry of late Svecofennian processes in northern Sweden. Geologiska Föreningens i Stockholm Förhandlingar 111, 347–354.

Suominen, V. 1991. The chronostratigraphy of southwestern Finland with special reference to Postjotnian and Subjotnian diabases. Geological Survey of Finland, Bulletin 356. 100 p.

Tuukki, P. 1984. Simpsiön ja muiden Pohjanmaan liuskealueiden kvartsirikkaiden metasedimenttien petrografia, mineralogia ja geokemia. Unpublished master's thesis, University of Oulu, Department of Geology. 132 p.

Vaarma, M. & Kähkönen, Y. 1994. Geochemistry of the Paleoproterozoic metavolcanic rocks at Evijärvi, western Finland. In: Nironen, M.& Kähkönen, Y. (eds.) Geochemistry of Proterozoic supracrustal rocks in Finland. IGCP Project 179 Stratigraphic methods as applied to the Proterozoic record and IGCP Project 217 Proterozoic geochemistry. Geological Survey of Finland, Special Paper 19, 47–59.

Vaarma, M. & Pipping, F. 1997. Alajärven ja Evijärven kartta-alueiden kallioperä. Summary: Pre-Quaternary rocks of the Alajärvi and Evijärvi map-sheet areas. Geological Map of Finland 1 : 100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheet 2313 and 2314. Geological Survey of Finland. 83 p.

Vaasjoki, M. & Sakko, M. 1988. The evolution of the Raahe-Ladoga zone in Finland: isotopic constraints. In: Korsman, K. (ed.) Tectono-metamorphic evolution of the Raahe-Ladoga zone. Geological Survey of Finland, Bulletin 343, 7–32.

Wasström, A. 1990. Knaftenområdet - en primitiv tidig proterozoisk vulkanisk öbåge söder om Skelleftefältet, norra Sverige. Unpublished master's thesis, Åbo Akademi, Department of Geology and Mineralogy. 128 p.

Wasström, A. 1993. The Knaften granitoids of Västerbotten County, northern Sweden. In: Lundqvist, Th. (ed.) Radiometric dating results, Division of Bedrock Geology, Geological Survey of Sweden, Sveriges geologiska undersökning C 823, 60–64.

Wasström, A. 1996. U-Pb zircon dating of a quartz-feldspar porphyritic dyke in the Knaften area, Västerbotten County, northern Sweden. In: Lundqvist, Th. (ed.) Radiometric dating results 2, Division of Bedrock Geology, Geological Survey of Sweden, Sveriges geologiska undersökning C 828, 34–40.

Västi, K. J. 1989. Geology of the Rauhala stratiform massive Zn-Cu-Pb sulphide deposit. In: Kojonen, K. (ed.) The early Proterozoic Zn-Cu-Pb sulphide deposit of Rauhala in Ylivieska, western Finland. Geological Survey of Finland, Special Paper 11, 5–18.

Weihed, P. & Antal, I. 1998. Bedrock maps 22J Kalvträsk NE and SE, scale 1 : 50 000. Sveriges geologiska undersökning Ai 93 and 95.

Weihed, P., Bergman, J. & Bergström, U. 1992. Metallogeny and tectonic evolution of the Early Proterozoic Skellefte district, northern Sweden. Precambrian Research 58, 143–167.

Welin, E. & Lundqvist, Th. 1975. K-Ar ages of Jotnian dolerites in Västernorrland County, Central Sweden. Geologiska Föreningens i Stockholm Förhandlingar 97, 83–88.

Widenfalk, L., Elming, S.-Å. & Enmark, T. 1985. A multidisciplinary study of the Notträsk Gabbro, northern Sweden. Geologiska Föreningens i Stockholm Förhandlingar 107, 109–126.

Wikström, A. 1993. Berggrundskartan Kalix SV. 1 : 50 000. With a short description in Swedish and an English summary. Sveriges geologiska undersökning Ai 81.

Wikström, A., Mellqvist, C. & Barbarin, B. 1996. The Bälinge conglomerate in northern Sweden reinterpreted as a magmatic, hydraulic breccia. Terra Nova 8, 166–172.

Wikström, A., Mellqvist, C. & Persson, P.-O. 1996. An Archaean megaxenolith and a Proterozoic fragment within the Bälinge magmatic breccia, Luleå, northern Sweden. In: Lundqvist, Th. (ed.) Radiometric dating results 2. Sveriges geologiska undersökning C 828, 48–56.

Wikström, A., Skiöld, T. & Öhlander, B. 1996. The relationship between 1.88 Ga old magmatism and the Baltic-Bothnian shear zone in northern Sweden. In: Brewer, T.S. (ed.) Precambrian Crustal Evolution in the North Atlantic Region. Geological Society Special Publication 112, 249–259.

Wilkman, W.W. 1938. Kuopio. The General Geological Map of Finland 1 : 400 000, Explanation to the Map of

Rocks, Sheet C 3. Geological Survey of Finland. 171 p.
Vilpas, L. 1996. Etelä-Pohjanmaan jalo-, koru- ja koristekivet. Abstract: The gems of Southern Ostrobothnia, western Finland. Geological Survey of Finland, Guide 40. 34 p.
Wilson, M.R., Hamilton, P.J., Fallick, A.E., Aftalion, M. & Michard, A. 1985. Granites and early Proterozoic crustal evolution in Sweden: evidence from Sm-Nd, U-Pb and O isotope systematics. Earth and Planetary Science Letters 72, 376–388.
Wilson, M.R., Sehlstedt, S., Claesson, L.-Å., Smellie, J.A.T., Aftalion, M., Hamilton, P.J. & Fallick, A.E. 1987. Jörn: an early Proterozoic intrusive complex in a volcanic-arc environment, north Sweden. Precambrian Research 36, 201–225.
Witschard, F. 1975. Description of the geological maps Fjällåsen NV, NO, SV, SO. Beskrivning till berggrundskartbladen Fjällåsen NV, NO, SV, SO. With an appendix on geophysical aspects by H. Henkel. With maps to the scale of 1 : 50 000. Sveriges geologiska undersökning Af 17–20. 125 p.
Witschard, F. 1984. The geological and tectonic evolution of the Precambrian of northern Sweden - a case for basement reactivation? Precambrian Research 23, 273–315.
Vivallo, W. & Claesson, L.-Å. 1987. Intra-arc rifting and massive sulphide mineralization in an early Proterozoic volcanic arc, Skellefte district, northern Sweden. In: Pharaoh, T.C., Beckinsale, R.D. & Rickard, D. (eds.) Geochemistry and Mineralization of Proterozoic Volcanic Suites. Geological Society Special Publication 33, 69–79.

3.3 Meso- and Neoproterozoic cover rocks of the Svecofennian Domain

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3.3.1 Geology

Sedimentary cover formations of Mesoproterozoic (Jotnian) age occur in the Svecofennian Domain in the Muhos area and at Lappajärvi in Finland, and at Nordingrå in Sweden. In the western part of the Muhos area deposition also occurred in Neoproterozoic (Vendian) time.

At Nordingrå the plutonic rapakivi rocks as well as the older Svecokarelian complex have been weathered and overlain by an up to 65 m-thick cover sequence of reddish, arkosic, continental sandstone, shale and conglomerate (Fig. 46; Lundqvist et al. 1990). The basal layers are formed by regolithic material reflecting the underlying lithologies. The sequence is termed the Nordingrå Formation (NoF) and is included in the Jotnian formations of Fennoscandia. It is connected with the much more extensive sandstone occurrences in the Gulf of Bothnia. The sandstone formation at Nordingrå has been protected from erosion by the overlying lopolithic sills of the Ulvö Dolerite Complex (see above).

The unmetamorphosed sedimentary rock cover lying on the Palaeoproterozoic crystalline bedrock in Finland is preserved in only a few places on land in the Mid-Norden map area. Such rocks have been observed in a roughly NW–SE-trending, graben-like basin south of Oulu, extending c. 50 km inland from the coast. This roughly 20 km broad basin is filled with a sedimentary succession named the Muhos Formation (MuF), which forms the easternmost part of the basin-fill of the Gulf of Bothnia. The Muhos Formation is quite exotic for Finland. In spite of this, it has not been an important target for re-examination during recent years. This is due to the fact that it is almost totally covered with a rather thick pile of Quaternary sediments. Thus, data on the formation mainly derive from a few diamond drillings made on the island of Hailuoto, c. 40 km west of Oulu, and at Tupos 20 km south of Oulu during the 1950's and 1960's (Simonen & Kouvo 1955, Kalla 1960, Veltheim 1969).

The Muhos Formation is a flat-lying succession of immature sedimentary rocks. The greatest thickness of the formation, 895 m, has been observed at Tupos, c. 20 km south of Oulu (Kalla 1960). The sedimentary rocks that have been detected by drilling are usually red-coloured, interfingering siltstones and shales, deposited in a floodplain environment (Simonen & Kouvo 1955). The lowermost unit of the pile also contains conglomeratic and arkosic sandstone layers, only few metres in thickness. The only known outcrop belonging to the Muhos Formation shows a bed of polymictic conglomerate less than 10 m thick, found at Kieksi, Muhos (Brenner 1941). The Muhos Formation was considered to be correlated with the Jotnian sandstones in Satakunta, southwestern Finland, based on ^{40}K - ^{40}Ar datings of two sandstone samples which indicate a diagenesis event at approximately 1300 Ma (Simonen 1960). Microfossil descriptions, on the other hand, indicate an age of sedimentation which is probably 100 Ma younger than the ^{40}K - ^{40}Ar age (Tynni 1978).

The diamond drillings made on Hailuoto have shown that the unmetamorphosed sedimentary rock cover is here obviously much thinner than at Muhos, being probably less than 300 m in the western part of the island (Veltheim 1969). The sedimentary succession on Hailuoto may be composed of two different units. The lower unit, lying directly on the metamorphosed Svecofennian bedrock, consists of conglomerates, red arkoses and red shales. The upper unit, deposited on the red shale, is composed of inter-fingering beds of arkoses, sandstones, siltstones and shales. Thus,