GEOLOGINEN TUTKIMUSLAITOS — GEOLOGICAL SURVEY OF FINLAND

Opas — Guide 11

Exogenic processes and related metallogeny in the Svecokarelian geosynclinal complex

Edited by Kauko Laajoki and Juhani Paakkola

Guide to field trips for the IGCP projects 91 and 160 in eastern, central and southern Finland, August 17—26, 1983

Espoo 1983

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1.

PREFACE

This paper is aimed to serve as a guidebook on the field excursion with a theme "Exogenic processes and related metallogeny in the Svecokarelian geosynclinal complex" organized by the IGCP projects 91 "Precambrian metallogeny" and 160 "Precambrian exogenic processes" from 17th to 26th August, 1983. The guidebook is supplemented with a separate paper by K. Laajoki, 1983, "Outlines of the Precambrian exogenic geology of Finland", Res Terrae, Ser. C, No. 3.

As the editors of this guidebook we wish to express our thanks to all the authors, who have planned the routes and selected the targets, and who also will act as field guides during the excursion. We also thank Mr. Malcolm Hicks, M.A. for correcting the English of the manuscript and Mrs. Raili Junnila for typing and making up the pages.

Oulu, June 1983

Kauko Laajoki

Juhani Paakkola

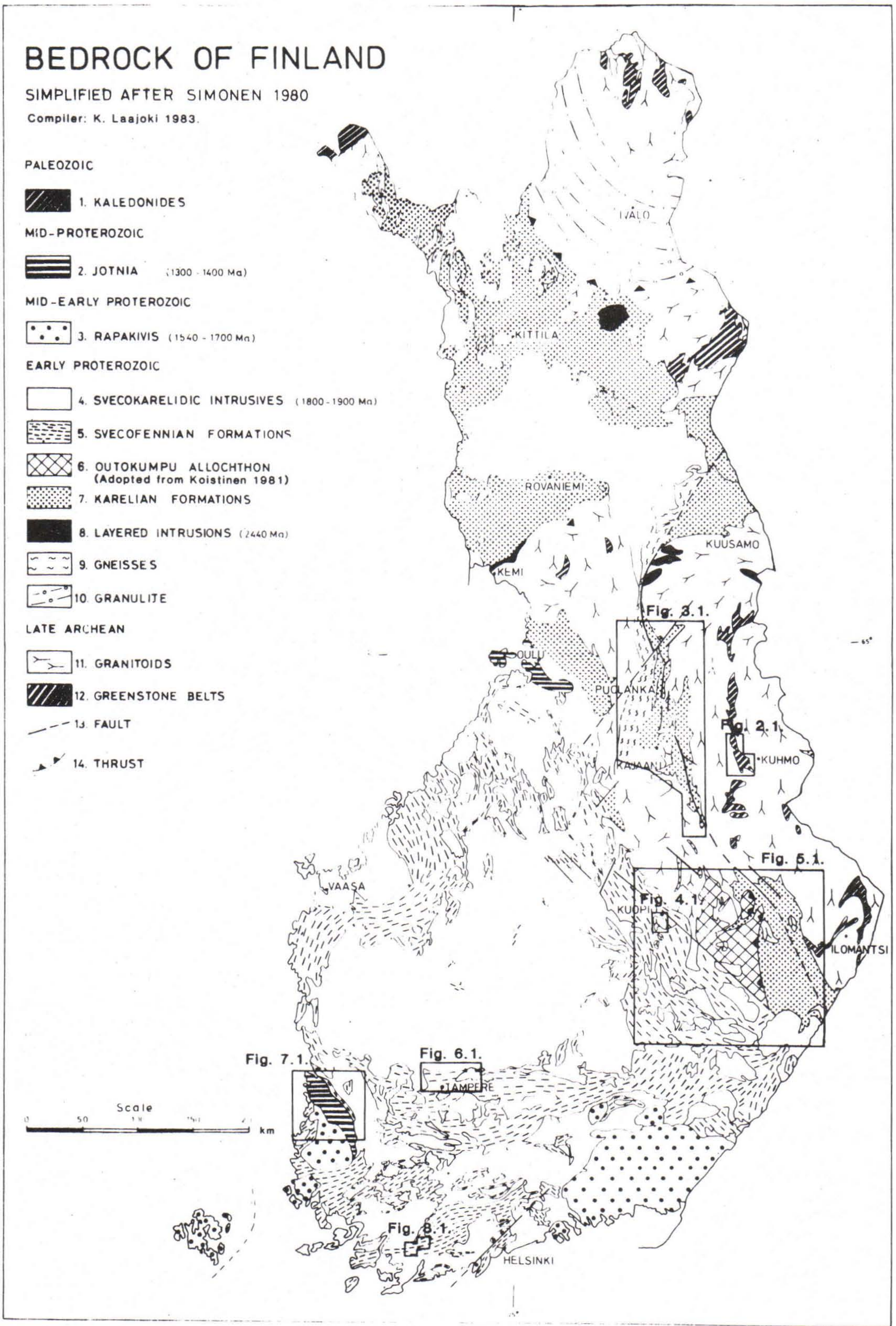

Fig. 1.1. Simplified geological map of Finland with the excursion areas.

2.

THE ARCHAEAN KUHMO GREENSTONE BELT

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INTRODUCTION

The Kuhmo Research Project was started in 1977 at the Department of Geology, University of Oulu. Its aim was to yield geological information on the Archaean Kuhmo greenstone belt for prospecting purposes (Fig. 2.1). As a result of this work an up-to-date geological map of the belt now exists, its stratigraphical outlines have been adjusted and the economically interesting rock units have been linked with the stratigraphic schema. The areal distribution of the greenstone belt rocks and their petrographic and geochemical characteristics have also been determined. The results of the work are summarized in a geotectonic model which attempts to explain the geological evolution of the belt.

STRATIGRAPHY AND PETROGRAPHY

A large number of age determinations from the belt, and especially from the granitoids around it, have been carried out by the Geol. Survey of Finland. Most of these are U/Pb ages of zircons (Fig. 2.2). The peak of the frequency distribution falls in the time range 2600 to 2800 Ma. This interval corresponds to the worldwide late Archaean orogeny.

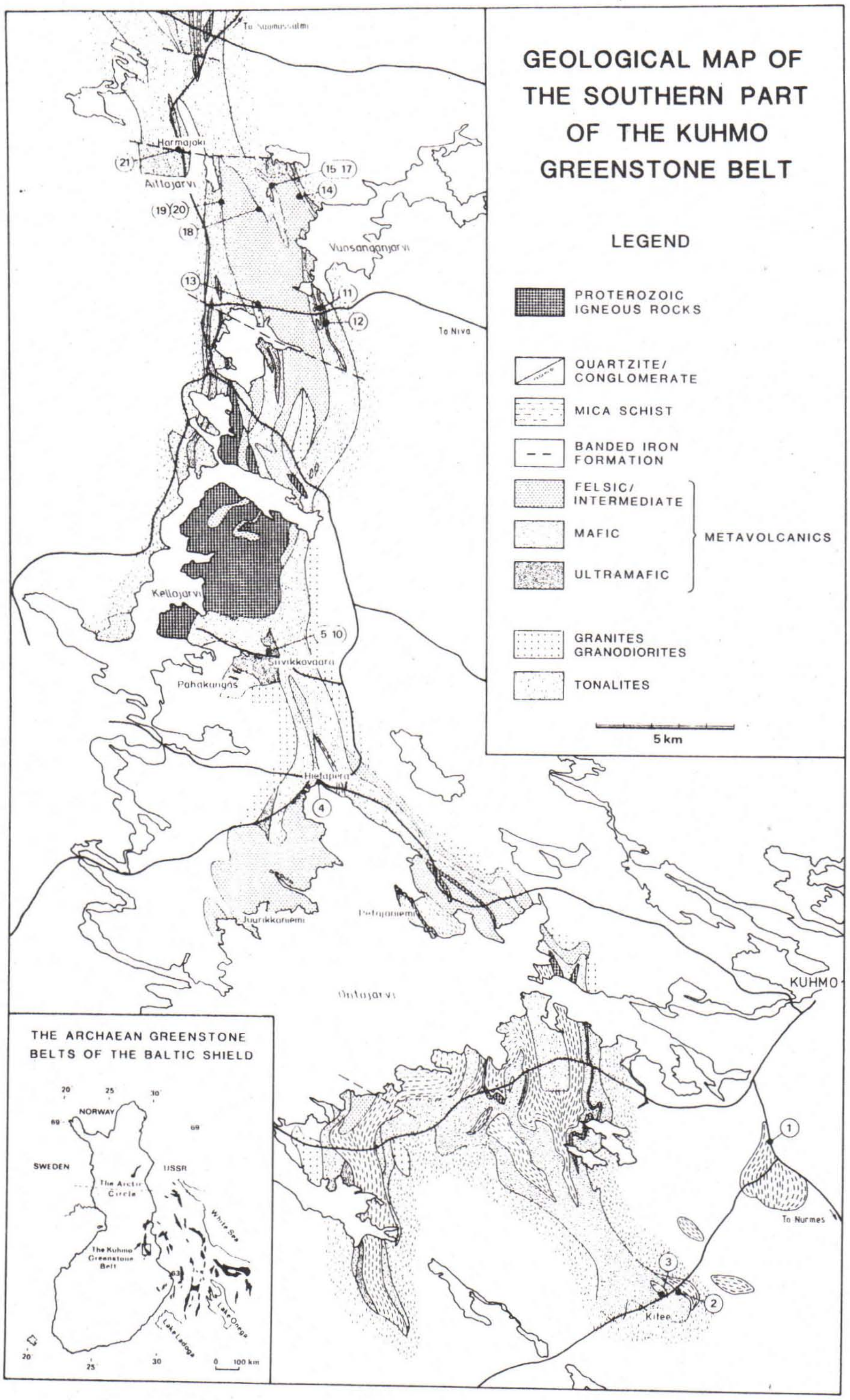

Fig. 2.1. Simplified geological map of the southern part of the Kuhmo greenstone belt. Encircled numbers denote excursion locations.

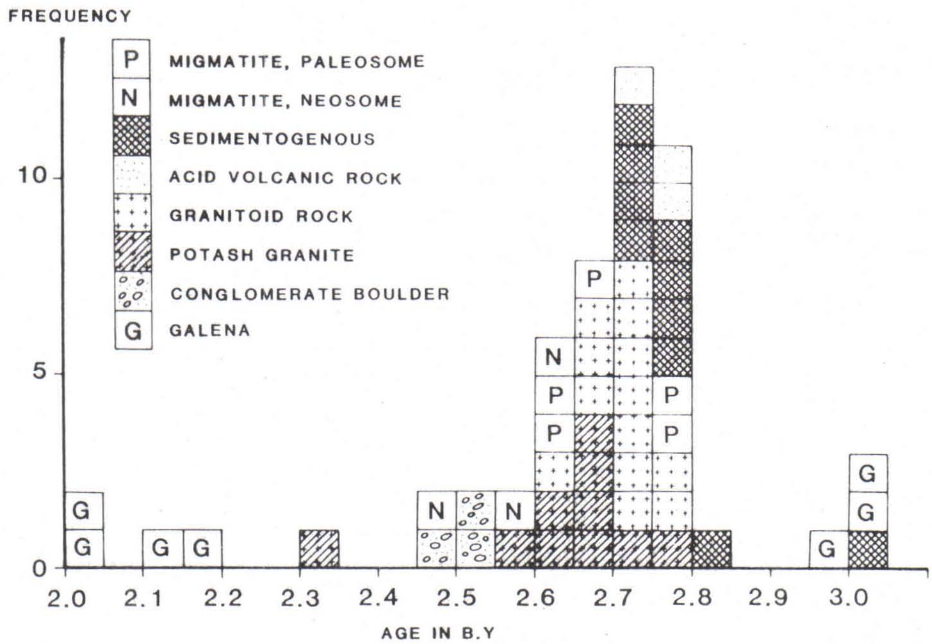

Fig. 2.2. Frequency diagram of ages from the Kuhmo belt and its vicinity as published by Geological Survey of Finland. The determinations were carried out by the U/Pb-method on zircons, except for some common lead datings on galenas.

The Kuhmo schist belt is divided into three stratigraphic units, which are, from the oldest to the youngest, the Luoma, Kellojärvi and Ontojärvi Groups (Fig. 2.3). Proterozoic mafic and ultramafic intrusive rocks also occur in the belt.

The Luoma Group is composed of intermediate and acid metavolcanics and greywacke-like metasediments.

The majority of the metavolcanics are pyroclastic rocks, i.e. breccias, lapilli tuffs and tuffs. The greywacke-like schists in the uppermost part of the unit also contain large amounts of volcanic material.

The Kellojärvi Group comprises tholeiitic and komatiitic metavolcanics, which are thought on the basis of various primary structures to be products of submarine

	Group	Formation	Lithology	Ages. Excursion locations
Proterozoic	Jatulian		Mafic & Ultramafic intrusives	← 2100, Albite diabase (Zircon) U/PB
Proterozoic	Sariolan		Conglomerates	← 2500, Granitoid boulder (Zircon) U/PB; (3)
Upper Archaean	Ontojärvi	Petäjä-niemi	Mica schists Komatiites Fe-tholeiites	(11,12) (2)
Upper Archaean	Ontojärvi	Juurikka-niemi	Mica schist Quartzite Felsic volcanics Conglomerate	(1) (4) ← 2750, Felsic volcanics (Zircon) U/PB (13-20)
Upper Archaean	Kellojärvi	Siivikko-vaara	Komatiites	(5-10)
Upper Archaean	Kellojärvi	Paha-kangas	Tholeiitic meta-basalts + Bif - intercalations	(21)
Upper Archaean	Luoma		Mica schists Felsic & Intermediate volcanics	← 3030, Galena from A Zn-Pb-Ag-mineralization

Fig. 2.3. Stratigraphic schema of the Kuhmo greenstone belt.

volcanism. The lowermost part of the Kellojärvi Group, the Pahakangas Formation, is composed of tholeiitic metalavas, some massive and some pillowed. The flows are intercalated with thin banded iron formations. The upper subunit, the Siivikkovaara Formation, contains komatiitic metalavas and metatuffs. Spinifex textures, polygonal jointing, flow breccias and pillow structures are fairly well preserved, even though completely altered in mineral composition.

A polymictic conglomerate with pebbles of granitoids and mafic and felsic schists is situated lowermost in the Ontojärvi Group. This conglomerate is overlain by acid metavolcanics, which are 2760 Ma old (Samples A511 and 511b; Geol. Survey of Finland Annual Reports 1975 and 1978, respectively) and covered by a quartzite and mica schist. Iron-rich tholeiitic and some komatiitic metalavas occur higher up in the Ontojärvi Group. The uppermost parts are composed of mica schists containing volcanic debris.

Proterozoic mafic and ultramafic intrusives about 2100 Ma old are common in the Kuhmo belt. A characteristic feature of these rocks is a cumulus sequence ol, ol+cpx, cpx, cpx+mt, plag+cpx+mt. Edenitic hornblende occurs as an intercumulus mineral in the early cumulates and plagioclase in the middle part of the sequence.

STRUCTURE AND METAMORPHISM

The structure of the Kuhmo greenstone belt is characterized by vertical or subvertical structural elements, bedding,schistosity and linear parameters.

The schist belt has undergone a polyphase deformation and metamorphic history. The folds of the first phase were isoclinal, their axial planes vertical or subvertical and the fold axes gently plunging north or south. The later phases of deformation produced superposed structures. The axial planes of the second-phase folds mostly strike NW-SE. They are also subvertical. The youngest visible deformations are Proterozoic NW-SE -striking faults.

The most intense metamorphic event during the Archaean was about 2650 Ma ago, when the peak of the metamorphism was reached. The prevailing PT conditions during the metamorphism were equal to the amphibolite facies. The highest metamorphic grade has been detected in the southernmost part of the belt, at Tipasjärvi, where the mineral paragenesis sillimanite-kyanite-staurolite is common in some aluminous schists. The last metamorphic event was Proterozoic, as shown by the Rb/Sr-ages of some biotites and potash feldspar samples.

GEOCHEMISTRY

The metavolcanics of the schist belt are chemically contrasting, with both basic and acid rocks are common, although intermediate compositions are almost entirely absent (Fig. 2.4). Some of the tholeiitic rocks are comparable to the ocean floor basalts (Kellojärvi Group), while others are Fe-rich tholeiites (Ontojärvi Group).

The komatiites are not particularly rich in MgO, their MgO content varying according to their stratigraphic position. The komatiitic rocks of the Kellojärvi Group are for the most part komatiitic basalts (Mg < 18 %) and form a complete series with the tholeiites on the Al_2O_3 vs (FeO^*/FeO^*+MgO) diagram (Fig. 2.5). Komatiites with a MgO content between 24 and 27 % occur in the Ontojärvi Group. Here a gap exists between the Fe tholeiites and the komatiites (Fig. 2.5). The majority of the felsic metavolcanics are Na-rich, like the corresponding plutonic rocks (Table 2.1).

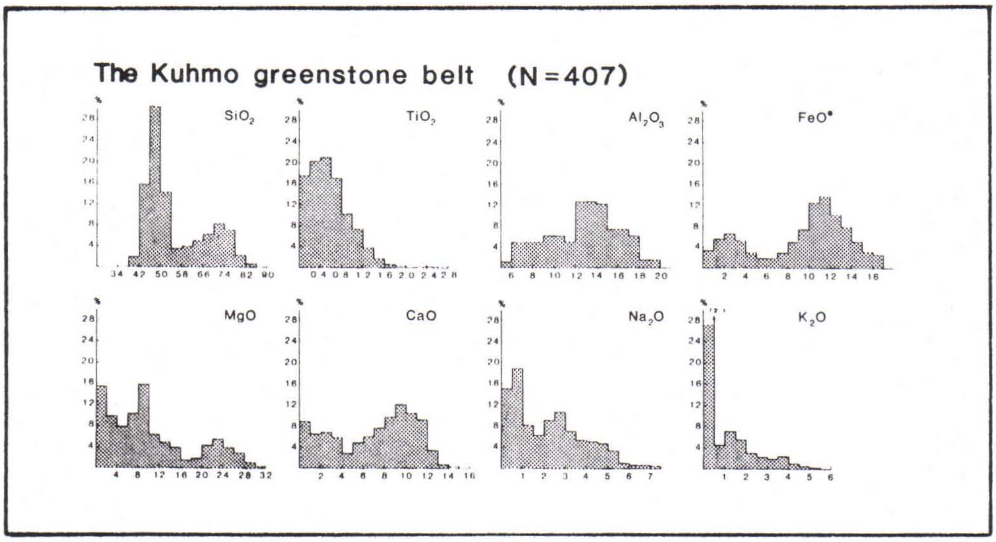

Fig. 2.4. Frequency distributions of eight major oxides of the belt metavolcanics showing their bimodal character. The data are from 407 major element analyses.

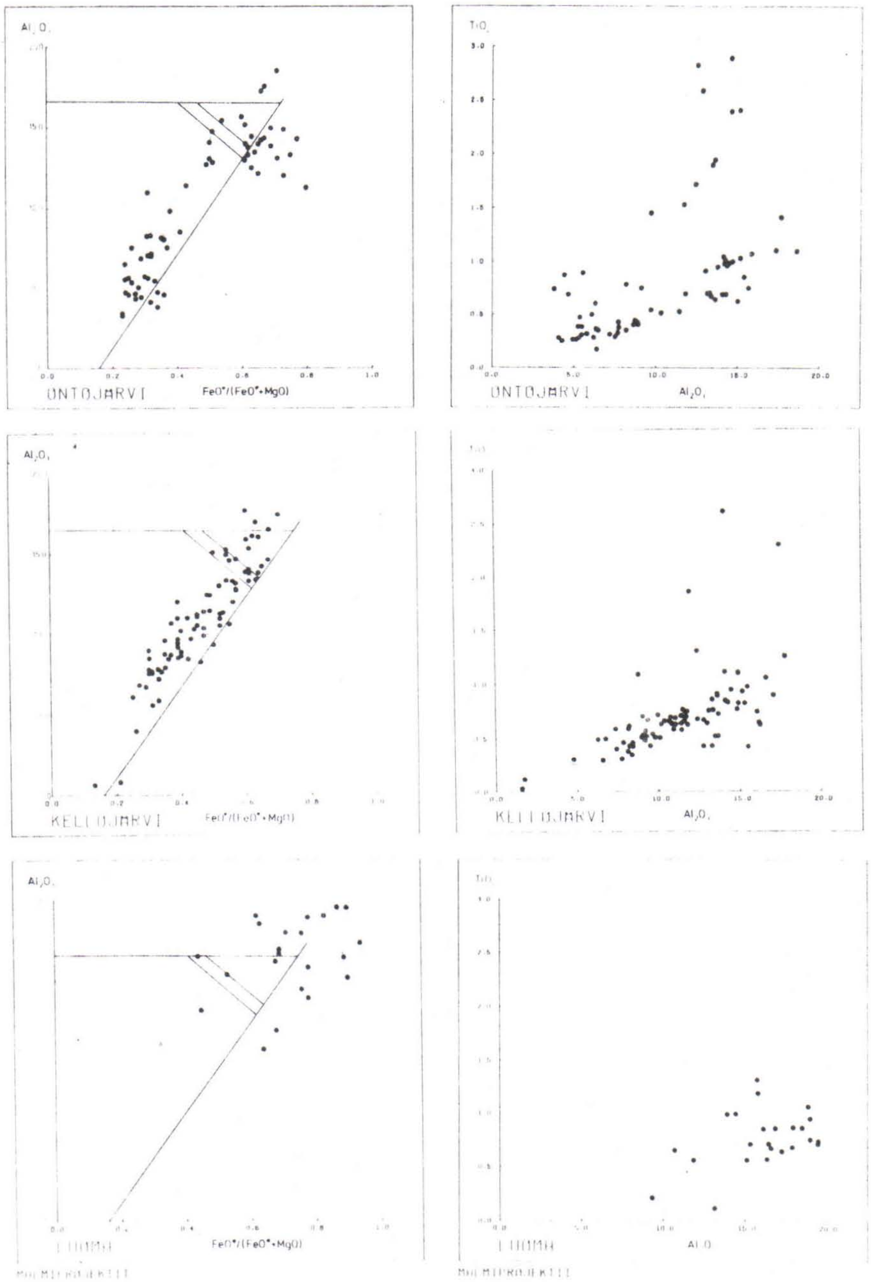

Fig. 2.5. Distributions of the compositions of mafic and ultramafic metavolcanics from different groups on Al_2O_3 vs $FeO^*/(FeO^*+MgO)$ and TiO_2 vs Al_2O_3 diagrams. The differences, especially in the former diagrams are striking.

Table 2.1. Chemical compositions of some volcanic rocks of the Kuhmo greenstone belt.

GROUP	LUOMA			KELLOJÄRVI						ONTOJÄRVI						
FORMATION				PAHA-KANGAS	SIIVIKKOVAARA					JUURIKKANIEMI			PETÄJÄNIEMI			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SiO_2	58.60	68.10	73.10	51.02	47.70	48.80	42.50	45.50	48.90	67.01	68.50	77.50	48.69	51.66	43.64	41.30
TiO_2	0.89	0.38	0.19	0.80	0.80	0.71	0.53	0.60	0.68	0.28	0.29	0.21	0.95	0.63	0.24	0.55
Al_2O_3	15.04	15.23	15.72	15.59	12.54	12.73	10.38	9.71	10.90	15.55	14.16	12.61	14.05	13.43	8.41	5.78
Fe_2O_3	7.28	3.79	1.37	2.53	14.43	13.45	14.59	13.55	13.90	0.94	0.94	0.56	2.69	1.90	2.28	3.52
FeO	-	-	-	8.15	-	-	-	-	-	3.28	2.37	0.23	10.47	11.12	8.91	6.29
MnO	0.12	0.09	0.05	0.19	0.21	0.21	0.21	0.24	0.28	0.04	0.04	0.01	0.25	0.23	0.18	0.14
MgO	3.58	2.16	0.70	6.85	11.80	11.10	18.10	18.70	11.80	1.77	1.51	0.09	6.55	8.00	24.12	30.73
CaO	5.84	3.52	1.51	10.76	7.27	7.72	7.55	8.54	9.32	2.40	2.79	1.40	10.31	9.13	6.57	3.31
Na_2O	3.96	5.40	6.05	2.12	2.94	3.15	0.40	0.38	2.18	3.26	0.88	4.98	2.56	2.48	0.08	0.07
K_2O	1.91	0.40	1.30	0.22	0.08	0.09	0.03	0.02	0.26	1.40	6.37	1.56	0.39	0.13	0.02	0.01
P_2O_5	0.33	0.10	0.10	0.11	0.07	0.07	0.05	0.05	0.09	0.14	0.00	0.00	0.05	0.00	0.00	0.00
HH	0.83	1.41	0.68	1.13	2.99	2.50	3.21	6.31	1.96	1.53	0.80	0.56	1.59	1.69	6.07	8.44
TOT.	98.58	100.38	100.77	99.47	100.83	100.63	99.33	101.60	100.27	99.30	98.65	99.71	98.61	100.49	100.52	100.14
Ni		22	< 10	175	230	180	550	800	600	23	19	20	110	90	1080	1630
Co	< 10	27	18		60	50	90	70	70	10	-	2	50	60	100	99
Cr	120	71	297	598	870	580	4960	2250	1010	117	134	218	220	190	2320	2620
Sc					46.9				40.8	7.55	4.24	3.77				26
Rb	48	5	35							37	122	62				
Ba										338	308	440				
La	33.9	42.9	24.4		1.79				1.27	11.6	13.4	6.2				0.433
Sm	6.85	2.69	1.84		1.49				1.25	1.62	2.5	1.2				0.487
Yb	1.825	0.607	0.227		1.75				1.25	0.52	0.73					

1. S162. Intermediate metavolcanite. Suomussalmi.
2. S29. Felsic metavolcanite. Suomussalmi.
3. S98. Felsic metavolcanite. Suomussalmi.
4. Average of 5 analyses. Pahakangas, Kuhmo.
5. 604.1.-EJH. Ultramafic metalava. String-beef spinifex. Siivikkovaara, Kuhmo.
6. 604.4.-EJH. Ultramafic metalava. Randomly oriented spinifex. Siivikkovaara, Kuhmo.
7. 604.3.-EJH. Ultramafic metalava. B_1-zone. Siivikkovaara, Kuhmo.
8. 604.5.-EJH. Ultramafic metalava. B_2-zone. Siivikkovaara, Kuhmo.
9. 300-EJH. Massive metalava. Mäkinen, Kuhmo.
10. 112-HOK. Felsic metavolcanite. Juurikkaniemi, Kuhmo.
11. 352-HOK. Felsic metavolcanite. Vuosanka, Kuhmo.
12. 254-HOK. Felsic metavolcanite. Vuosanka, Kuhmo.
13. 4-IKT. Mafic metalava (Fe-tholeiite). Kitee, Kuhmo.
14. 38-KJT. Mafic metalava. (Fe-tholeiite). S of Ontojärvi, Kuhmo.
15. 20-KJT. Ultramafic metalava. Hornasenvaara, Kuhmo.
16. 312-HOK. Ultramafic pillow lava. Vuosanka, Kuhmo.

GEOLOGICAL EVOLUTION OF THE KUHMO GREENSTONE BELT

The field and laboratory data obtained from the Kuhmo greenstone belt are best explained by a geotectonic model which contains a volcanic island arc with its subduction zone and an active marginal sea.

The cyclic volcanism of the schist belt always begins with an acid stage (the Luoma Group; the Juurikkaniemi Formation of the Ontojärvi Group). The REE model calculations suggest that the acid magma could be derived from the partial melting of wet amphibolites. These melts originated from the subduction zone at a depth of about 40-50 kilometres. The tholeiitic and komatiitic magmas were produced at greater depths as a result of gradually increasing melting of the mantle. They were extruded on the floor of the active marginal sea. The basic volcanism could have been at least to some extent contemporaneous with the acid island arc volcanism.

The granodiorites surrounding the belt are chemically similar to the acid metavolcanics. Probably both of them belong to the same magmatism, representing its plutonic and volcanic products. This is also supported by the age determinations.

The majority of the greywacke-like schists associated with the Kuhmo greenstones are the weathering products of the volcanics.

It is not impossible that the basement of the Archaean Kuhmo greenstone may not have been the sialic Belomorian craton, which would have been mobilized for the most part in the Kuhmoan orogeny during the late Archaean.

EXCURSION SITES

For the geographical and stratigraphic location of the excursion sites, see Figs. 2.1 and 2.3.

Stop 1

Cutting on the road to Nurmes, 5 km from Kuhmo

A migmatized metagreywacke with fairly well-preserved graded bedding. The light parts of the beds contain quartz, plagioclase and a little biotite, while biotite is the most common mineral in the dark parts. The present-day texture of the rock is crystalloblastic, but the original clastic features of the quartz and feldspar grains can be seen in the middle parts of many metamorphic grains.

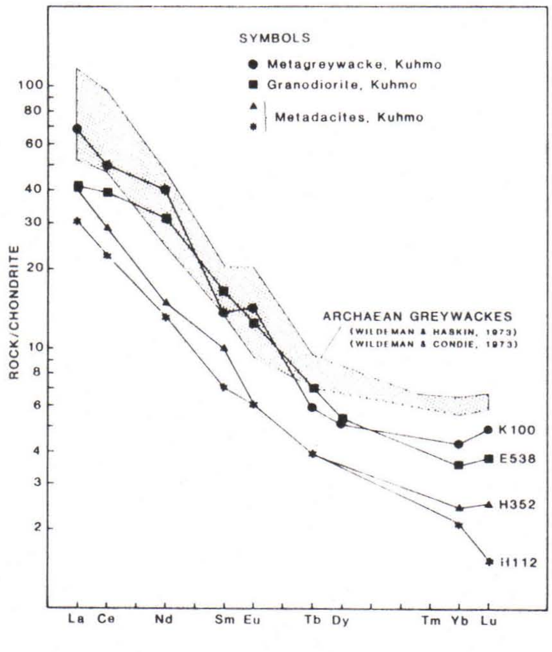

Fig. 2.6. REE patterns for a metagreywacke, a granodiorite and some felsic metavolcanics from the Kuhmo greenstone belt. For comparison, some data from other Archaean areas are included in the same diagram. Sample K100 represents the outcrop studied here, sample H112 is from NW shore of Lake Ontojärvi and samples E538 and H352 from the Siivikko and Vuosanka areas respectively.

Table 2.2. Major oxide and some trace element averages of some Precambrian metagreywackes.

	1	2	3	4	5
SiO_2	62.0	64.4	66.2	59.8	64.7
TiO_2	0.74	0.62	0.52	0.55	0.57
Al_2O_3	17.1	15.5	10.2	12.9	13.4
FeO*	7.62	5.9	6.3	5.9	6.3
MgO	3.40	3.1	4.5	4.4	3.2
CaO	2.55	2.2	2.0	3.2	3.0
Na_2O	3.90	3.7	1.8	2.8	3.0
K_2O	2.92	2.4	1.6	2.2	2.0
Ba	600	-	319	626	-
Ni	50	91	290	160	108
Rb	78	88	54	90	-
Sr	-	424	98	354	-
Na_2O/K_2O	1.34	1.5	1.1	1.3	-
Al_2O_3/Na_2O	4.38	4.2	5.7	4.6	-
K/Rb	224	230	216	204	-

1. Sample K100, this outcrop.
2. Average of Wyoming greywackes*.
3. Average of Sheba-greywackes*.
4. Average of Belvue Road greywackes*.
5. Average of Precambrian greywackes*.

* Data from: Condie, K.C., Macke, J.E. & Reimer, T.O. (1970) Petrology and geochemistry of early Precambrian greywackes from the Fig Tree Group, South Africa. Geol. Soc. America Bull. 81, 2759-2775. Tables 2 and 3.

The major element chemical composition of the metagreywacke is close to that of the Wyoming greywackes (Table 2.2), although the Ni content is somewhat lower. This might suggest a smaller amount of mafic material in the source area of the sediment.

The REE distribution of the metagreywacke seen in the outcrop does not differ notably from the corresponding distributions of the other Archaean greywackes (Fig. 2.6). The possible source material for the greywackes consists of the surrounding granitoids, at least some of which are chemically quite similar to the rock of the outcrop.

The other possible source is the felsic volcanics of the Ontojärvi Group, whose stratigraphic position is the same as that of the greywackes. Mixing of some mafic material with the felsic volcanogenous debris could well produce the REE pattern and Ni content observed here.

Stop 2

500 m NE of the Kitee farmhouse, Kuhmo

At the eastern edge of the outcrop there is a mica schist which is composed almost solely of quartz and biotite (Fig. 2.7). This mica schist is greywacke-like and even graded in many outcrops. There is no essential difference between this rock and the rock type in the previous outcrop.

The mica schist is cut by a seemingly conformable plagioclase porphyry dyke. The matrix of the porphyry are well-preserved euhedral plagioclase phenocrysts, the originally zonal texture of which is seen as relicts in thin sections.

The majority of the outcrops are formed of mafic to ultramafic metalava. The flow faces westwards suggesting that the metavolcanics are situated upon the metasediments.

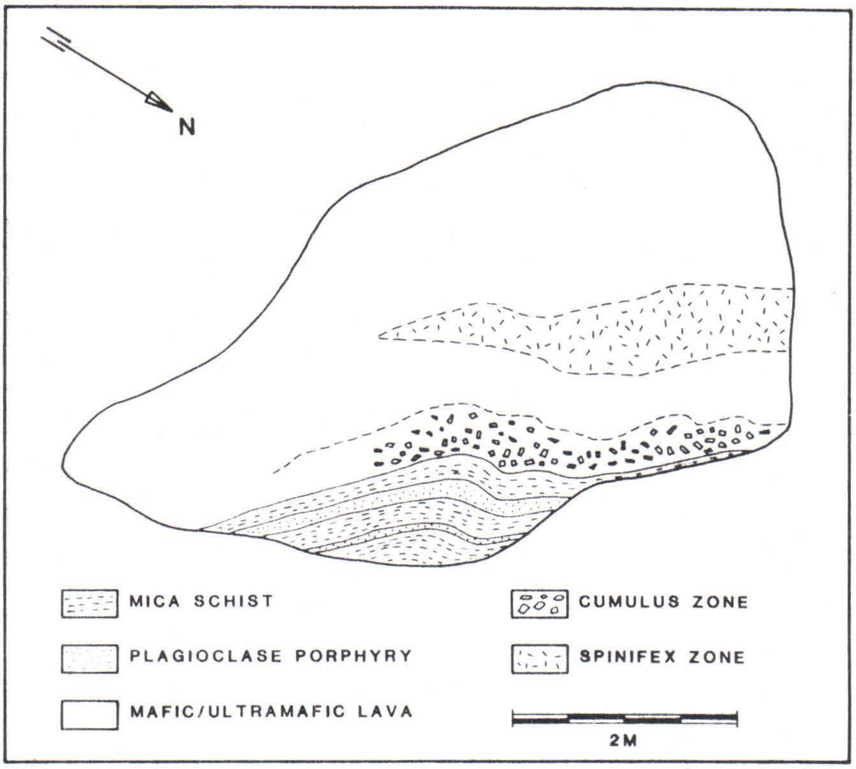

Fig. 2.7. Sketch map of site 2.

The cumulus zone of the flow in its recent form is composed of block-like colourless amphiboles, which are probably pseudomorphs after pyroxene. The minerals are randomly oriented and form a fairly homogeneous mass. Biotite occurs in the interstices between the amphiboles.

About 1 m up from the base of the flow there is a zone 10 cm in width in which light green hornblende forms a randomly oriented spinifex-texture. Grains of plagioclase, quartz and biotite occur between the amphibole needles. The cumulus zone of the flow is ultramafic and the upper parts mafic.

Stop 3

The conglomerate of Kitee and its surroundings

The most common rock type in the locality is the Fe-rich tholeiitic metalava (Fig. 2.8). The occurrence of pillow structures in these rocks suggests submarine origin. Agglomerates and amygdaloidal-like lavas also occur. The lava flows are intercalated with thin, rusty quartzose layers, which are interpreted as being originally chemical silica precipitates.

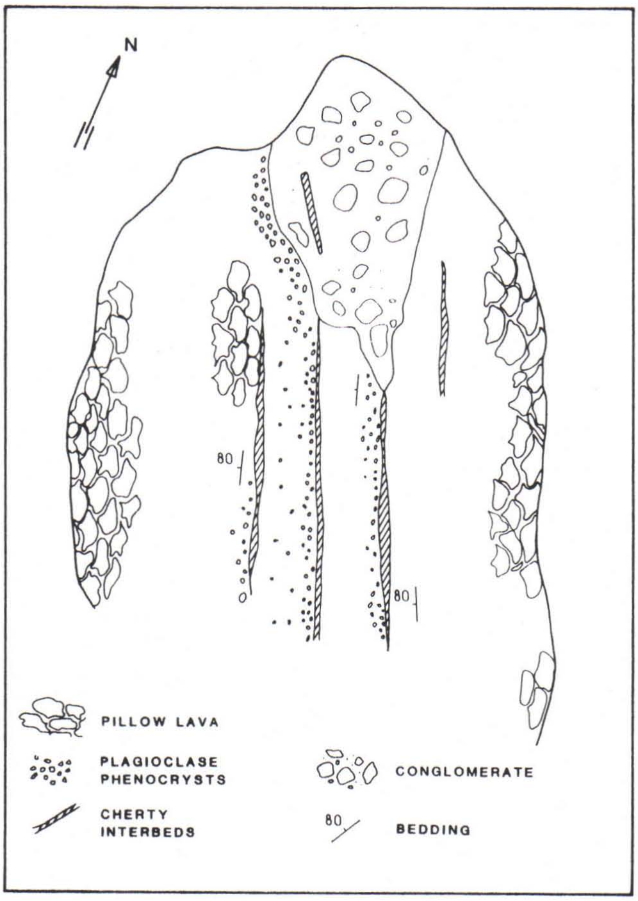

Fig. 2.8. Sketch map of the Kitee conglomerate and its surroundings.

The mafic metavolcanics are composed of green hornblende (> 80 %) and plagioclase. They are weakly oriented and the texture is massive in the pillow lavas. The quartz-rich interbeds contain abundant iron sulphides and some graphite locally. Chalcopyrite has also been found.

At the northern edge of the area there is a polymictic conglomerate of extraordinary character. Measuring some 8 x 15 m, the occurrence is surrounded by volcanics on every side. The contacts between the volcanics and the conglomerate are sharp and the conglomerate seems to "cross-cut" the volcanics.

The pebbles of the conglomerate are granitoids and metavolcanics, mica schists and cherts from the belt. The granitoids are tonalites and granodiorites or quartz diorites. No potash granites or migmatites have been found. The granitoid pebbles and boulders are well-rounded and mostly sizable, the largest ones exceeding one metre in diameter.

The rock fragments originating from the belt are smaller and chiefly sharp-edged. The rock types of the greenstone belt are represented by felsic, mafic and ultramafic metavolcanics. Fragments of mica schist abound. It is significant that many rock fragments were foliated before intermingling with the conglomerate.

The large size of the conglomerate boulders suggests a rough topography during sedimentation. The granitoids were probably carried from further away than the sharp-edged fragments of the schist belt. It is possible, though, that the differences in the roundness of the pebbles may result from differences in the textures of the rocks, the homogeneous granitoids being rounded while the schists remained angular.

On boulder of granitoid was dated by the U/Pb method from zircons, yielding an age of about 2500 Ma. The surrounding metavolcanics have been correlated with the rocks that are penetrated by the 2700 Ma-old granitoids elsewhere in the belt.

Since the conglomerate is also found to be situated in a discordant position with regard to the surrounding metavolcanics, it is thought to be early Proterozoic in age. Rocks of this kind are known to occur in a number of places in Finland and Soviet Karelia in association with other Proterozoic metasediments and metavolcanics. These early Proterozoic formations are known as Sariola conglomerates. No similar conglomerates have been found to be exposed elsewhere in the belt.

Stop 4

The Kivivaara quartzite

The Kivivaara quartzite is composed of quartz grains and grain accumulations surrounded by sericite. Some epidote, zircon and opaque minerals also occur. Feldspars have not been observed. Zircons appear in two generations, one 3000 Ma old, consisting of eroded, dim grains, and another 2700 Ma old, with fresh, and well-preserved grains.

Cross-bedding can be recognized locally in the outcrops. The microscopic texture of the sericite quartzite is cataclastic. The chemical composition of the Kivivaara quartzite is the following: SiO_2 - 84.17, TiO_2 - 0.17, Al_2O_3 - 9.98, Fe_2O_3 - 0.28, FeO - 0.29, MnO - 0.00, MgO - 0.29, CaO - 0.02, Na_2O - 0.06, K_2O - 2.98, P_2O_5 - 0.01, CO_2 - 0.00, H_2O^+ - 1.34, H_2O^- - 0.02.

The Siivikkovaara area

Well-preserved volcanic structures can be seen in the Siivikkovaara area (Fig. 2.9), even though the primary mineral composition has been totally replaced by secondary minerals.

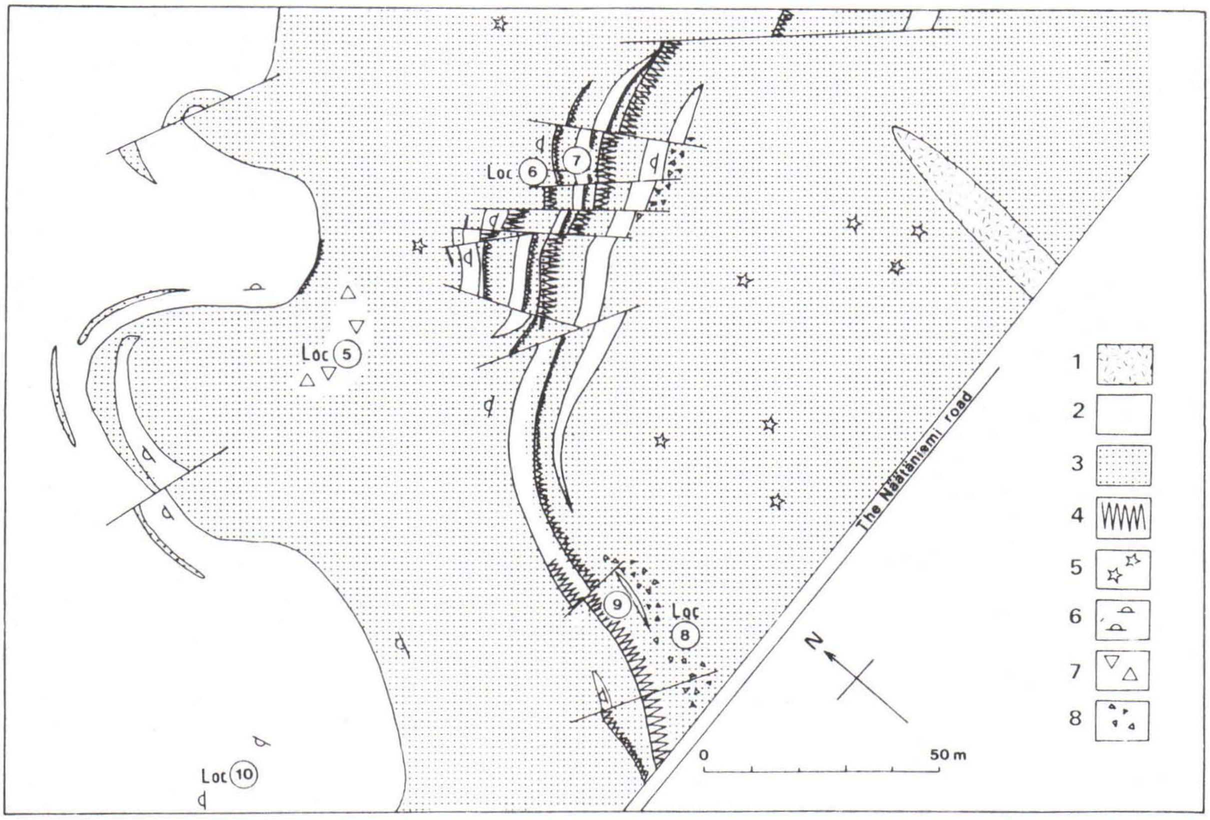

Fig. 2.9. Detailed map showing volcanogenic structures and the contact between the Siivikko and Mäkinen Members of the Siivikkovaara Formation. Key: 1 = plagioclase porphyry, 2 = komatiitic basalts, 3 = komatiite, 4 = spinifex texture, 5 = microspinifex texture, 6 = pillow lava, 7 = coarse volcanic breccia, 8 = autoclastic volcanic breccia.

Stop 5

Coarse volcanic breccia

The fragments are of ultramafic rock composed of felted actinolite, and a matrix mafic rock composed of fine-grained chlorite, a granoblastic plagioclase-quartz mass and long hornblende porphyroblasts. The possible genesis of this rock is thought to involve the mixing of flowing ultramafic lava with unconsolidated mafic tuff material.

Stop 6

Polygonal jointing and pillow structures in komatiite

The rock is composed of actinolite and chlorite, the former sometimes exhibiting dendritic forms. Accessory minerals are ilmenite, pyrrhotite, pyrite and chalcopyrite. Chemical analysis of a pillow (volatile-free): SiO_2 - 48.24 wt-%, Al_2O_3 - 9.18, FeO* - 12.80, MgO - 19.20, CaO - 8.38, Na_2O - 0.45, K_2O - 0.16, P_2O_5 - 0.05, Ni - 1120 ppm and Cr - 2370 ppm.

Stop 7

Two thick spinifex-textured lava flows of thickness 10 m and 17 m and intervening thin flows composed of komatiitic basalt (Fig. 2.10).

Zones A_1 (flow top breccia), A_2 (spinifex zone), B_1 (upper foliated part of the cumulate zone) and B_2 (main cumulate zone) can be distinguished in the spinifex-textured lava flows. Fig. 2.11 illustrates an idealized cross-section of one flow unit.

The flow top breccia is composed of fine-grained actinolite and chlorite, the latter forming pseudomorphs of olivine phenocrysts (0.2 to 1 mm in diameter). The spinifex zone can be divided into three subunits. The dendrite zone and the randomly oriented spinifex zone are formed by dendritic or acicular hornblende pseudomorphs after clinopyroxene respectively. The middle part of the spinifex zone is dominated by a plate spinifex

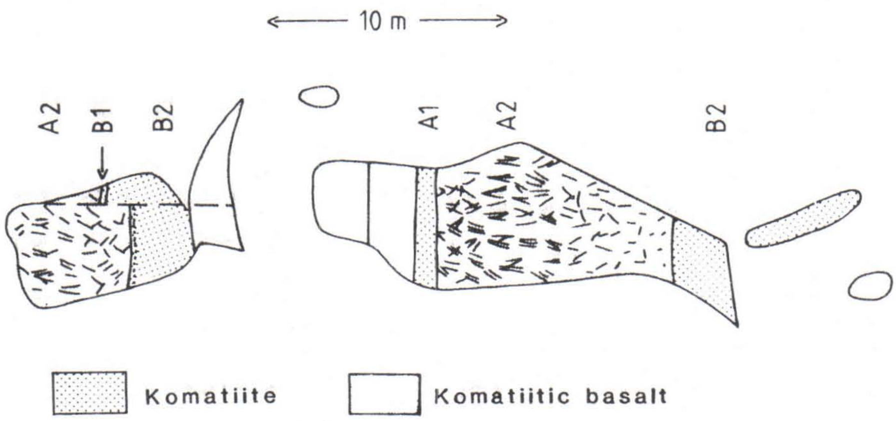

Fig. 2.10. Outcrop map for certain spinifex-textured lava flows.

texture formed by hornblende plates after olivine and clinopyroxene. The interstices between the plates and needles, which sometimes have chloritic cores, are occupied by fan-like spherulitic intergrowths of albite and hornblende.

The cumulate zone is light-coloured wholly ultramafic rock composed of actinolite (or tremolite) and chlorite. The amphibole occurs as skeletal, acicular grains (= 2.5 mm in length) and fan-like spherules, pseudomorphs after clinopyroxene, while the chlorite forms euhedral pseudomorphs of olivine, 0.2 to 1.4 mm in size (< 30 % of the rock). Accessory minerals in the spinifex textured flows are prisms of ilmenite, sulphides at the bottom and euhedral chromite grains particularly in zone B_1.

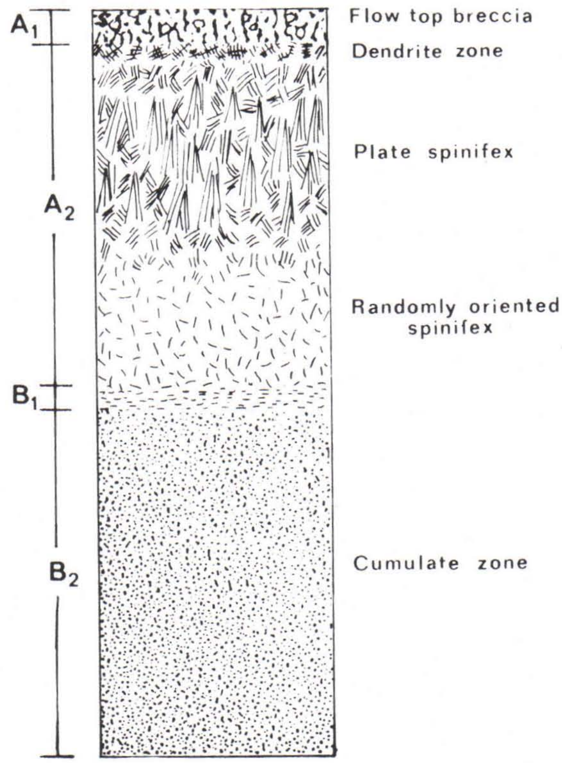

Fig. 2.11. Idealized cross-section of a spinifex-textured lava flow.

Analyses of both the spinifex and cumulate zones are given in Table 2.1. columns 5 to 8.

Stop 8

Spinifex-textured lava flow

The flow is about 15 m thick. Under the flow top breccia there is a 1.5 m thick dendrite zone. The rest of the spinifex zone has randomly oriented spinifex texture formed by hornblende needles after clinopyroxene. The boundary between the spinifex and cumulate zones is gradual and some polygonal jointing can be seen in the latter zone. The chemical profile of the flow is shown in

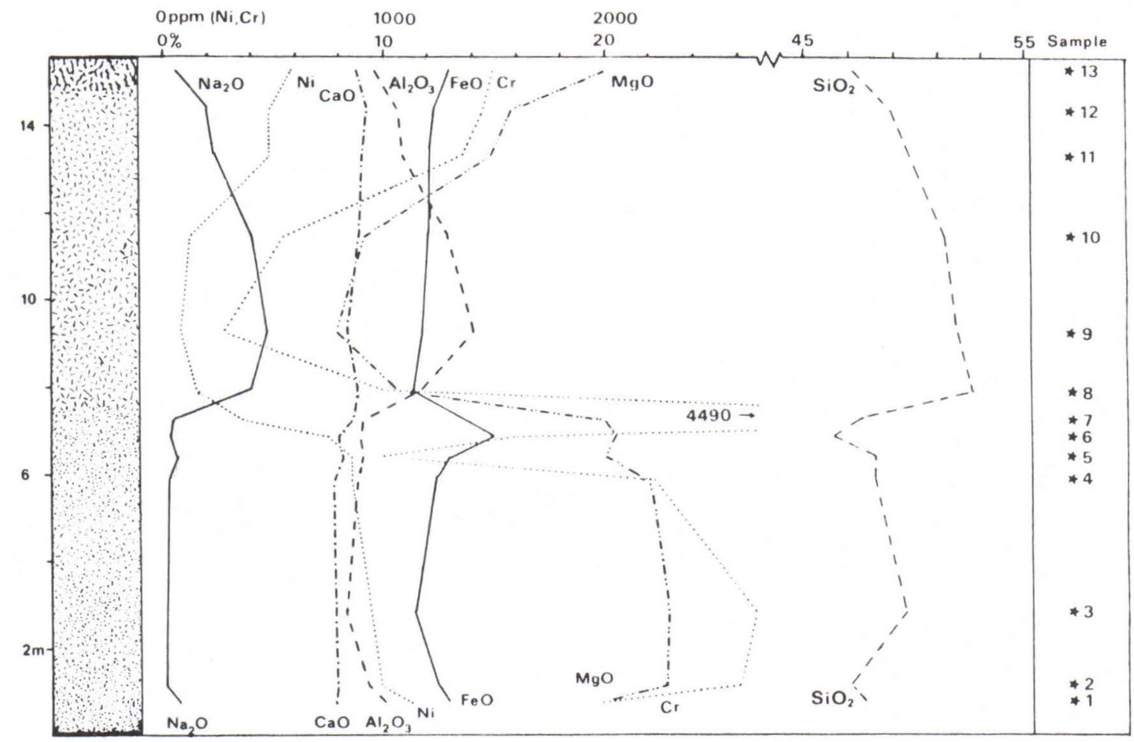

Fig. 2.12. Chemical profile across a spinifex-textured lava flow.

Fig. 2.12. The MgO content of the spinifex zone ranges from about 15 % in the dendrite zone to about 8 % in the lower part of the spinifex zone.

Stop 9

Autoclastic volcanic breccia

Peridotitic komatiite composed mainly of amphibole and chlorite. The edges of the angular or subangular fragments are talc-rich.

Stop 10

Variolitic pillow lava in komatiitic basalt

The light-coloured centre of the pillow typically grades through a variole zone to a darker outer zone. Sometimes the varioles are distributed evenly throughout the pillow. A variole is composed mainly of a granoblastic plagioclase mass which can be in the form of narrow, randomly oriented needles, with additional varying amounts of hornblende, clinozoisite and ilmenite. The varioles frequently have a hornblende-rich nucleus at the centre, or less often a hornblende-rich zone near their outer edge (Fig. 2.13). The interstitial material between the varioles is ultramafic hornblende rock or mafic hornblende-plagioclase (An_{30}) rock. The origin of the varioles could be:

- devitrification of glass
- spherulitic crystallization of the plagioclase
- liquid immiscibility.

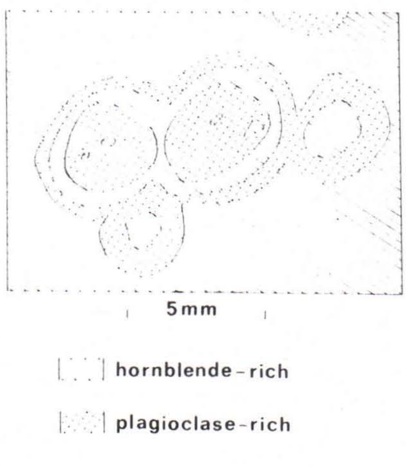

Fig. 2.13. Sketch of varioles having a hornblende-rich nucleus or a hornblende-rich zone near the edge.

The Southern Vuosanka area

The dominating geological feature of the Vuosanka area is a large unit composed of felsic metavolcanics, which form an ancient volcanic centre. Mafic and ultramafic metavolcanics are also represented in this area.

Stop 11

Mafic metatuff

The mafic metatuffs are banded and fine to medium-grained rocks which consist of hornblende, epidote and plagioclase. The banding is caused by variations in the amounts of the minerals, with the light bands rich in epidote and the dark ones in hornblende and plagioclase. The amount of garnet increases sporadically. Chemically the rocks are tholeiitic basalts.

Stop 12

Ultramafic metavolcanite

The ultramafic metavolcanics are dark greenish or brownish rocks resembling serpentinites locally. In most places they are foliated and folded rocks without any preserved primary structures, even though outcrops with fairly well-preserved pillows, polygonal jointing and breccias are known. Light or brownish olivine porphyroblasts are common.

Thin sections show the ultramafic metavolcanics to be fine-grained and composed of amphibole and chlorite. Their olivine porphyroblasts (Fo_{63-71}) are more or less altered to iddingsite and/or serpentine. The chemical composition corresponds to that of komatiites ($MgO > 20$ %, low Ti etc.).

Stop 13

Felsic metavolcanics and pegmatite granite

The felsic metavolcanics are light, homogeneous quartz-feldspar schists composed of albite, quartz, potash feldspar and micas. Deformed quartz eyes also occur. In this outcrop the felsic volcanics gradually change to a pegmatite granite.

The mineral composition of the pegmatite resembles that of the felsic metavolcanics. The grain size of the minerals, especially potassium feldspar, begins to increase in the transition zone, and the strongly altered plagioclase of the felsic metavolcanics becomes clearer towards the pegmatite.

The Northern Vuosanka area

Stop 14

Intermediate metatuffite

The intermediate metatuffites in their present form are heterogeneous, stratified mica schists often showing graded bedding and consisting of quartz, plagioclase, biotite and sometimes hornblende. North of the road there are banded quartz-rich beds, whose lighter parts consist of medium grained quartz (recrystallized chert) and grunerite. The dark beds are rich in grunerite and magnetite. Closest to them are garnet-biotite-hornblende and plagioclase-quartz-biotite-garnet rocks.

The Ruutanalampi area (Fig. 2.14)

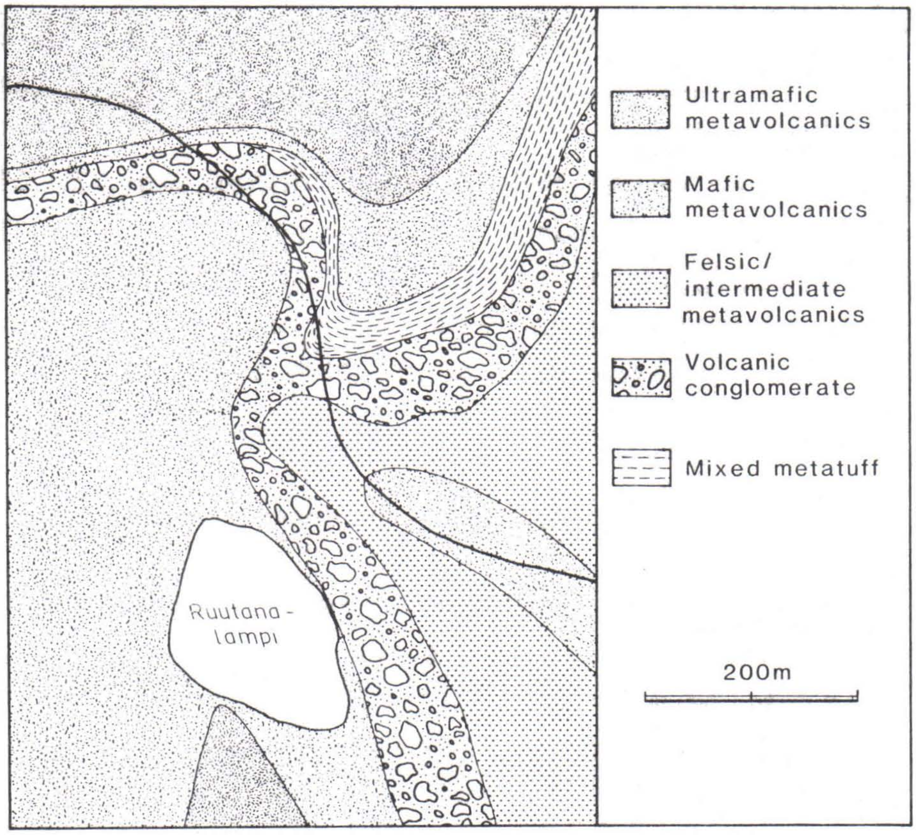

Fig. 2.14. Geological map of the Ruutanalampi area.

The Ruutanalampi area constitutes a part of the contact zone between the felsic metavolcanics and the overlying mafic volcanic unit. This zone is easy to follow because of certain distinct characteristics. The contact zone contains a volcanic conglomerate in many places, and a special type of rock called a mafic-felsic mixed tuff. A sulphide-rich horizon is also associated with the contact zone.

Stop 15

Felsic tuffite

The stratified, graded and intensely folded intermediate tuffite consists of quartz, plagioclase and biotite. Potassium feldspar is present as an accessory mineral.

Stop 16

Volcanic conglomerate

A volcanic conglomerate is exposed in a long, narrow zone close to the contact between the felsic and mafic volcanics. It is often folded and the pebbles are strongly elongated.

The matrix consists of plagioclase, quartz and biotite in this outcrop, although its composition can vary from mafic to felsic within the conglomerate unit. The pebbles are composed of felsic volcanics and more coarse-grained acid rocks resembling small-grained granitoids, or in some cases felsic porphyries.

Stop 17

Felsic-mafic mixed tuff

This is a peculiar rock type associated with the contact zone between the mafic and felsic metavolcanics which is common throughout the Kuhmo belt.

In the outcrops to be inspected here (Fig. 2.15) the felsic metatuff contains thin mafic bands (3 to 5 cm) and conglomerate interbeds. The felsic rock consists of quartz, plagioclase and micas and also contains quartz

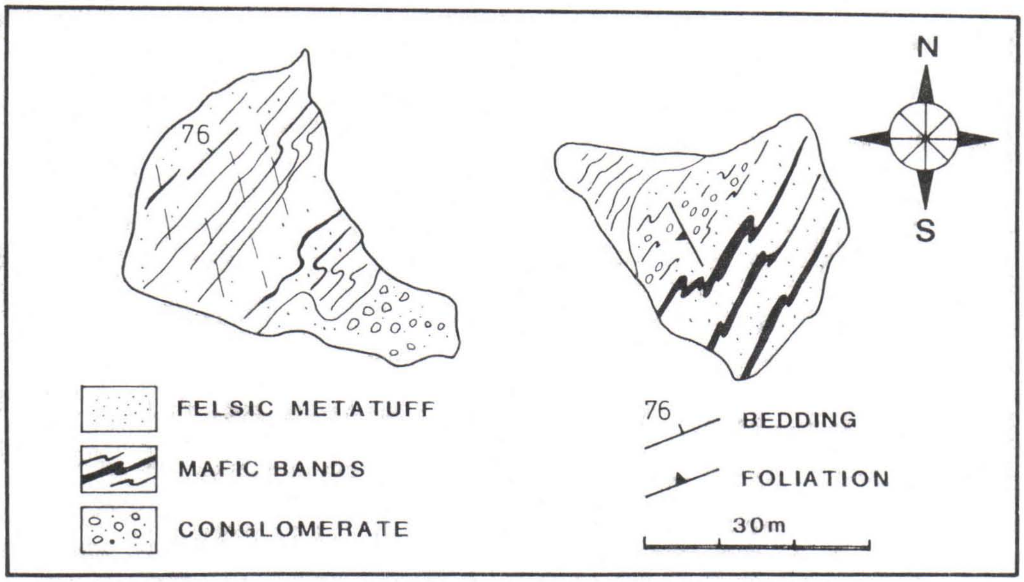

Fig. 2.15. Outcrop map for a felsic-mafic mixed tuff.

and plagioclase phenocrysts. The mafic bands are composed of hornblende, plagioclase and quartz.

Stop 18

Felsic tuffite

The felsic tuffite is a stratified, sometimes graded rock which contains conformable lit-par-lit granite dykes (10-20 cm). It is a heterogeneous schist consisting of quartz, plagioclase and biotite and often graphite. There are layers rich in garnet and biotite porphyroblasts in places.

Stop 19

Intermediate/felsic metatuff. East of Pieni Aittojärvi

At the western edge of the outcrop the felsic metatuff is a stratified and turmaline-bearing quartz-plagioclase biotite schist. In the middle part of the outcrop there is an interbed whose eastern part consists of mafic metatuff and western part of chlorite-talc schist. The mafic metatuff contains a thin arsenopyrite mineralization. In the eastern part of the outcrop there is an intermediate metatuff, which becomes felsic towards the east. There is an arsenopyrite mineralization in the intermediate metatuff.

Stop 20

Felsic metatuff

The felsic metatuff is stratified and schistose, consisting of quartz, plagioclase, potassium feldspar and micas and possessing a thin, mineralized interlayer. In the western part of the mineralization there is a graphite-bearing felsic metatuff followed by banded quartz-grunerite rock and a sulphide-rich felsic metatuff. Sulphides, pyrite and minor chalcopyrite occur in compact lenses.

The same mineralization continues southwards for several kilometres in the upper part of the felsic volcanite unit.

Stop 21

Härmäjoki iron formation

A banded iron formation is exposed in the trough of a NNW-plunging fold (Fig. 2.16). The surrounding rocks are for the most part mafic fine-grained amphibole-plagioclase metavolcanics, but with some ultramafics.

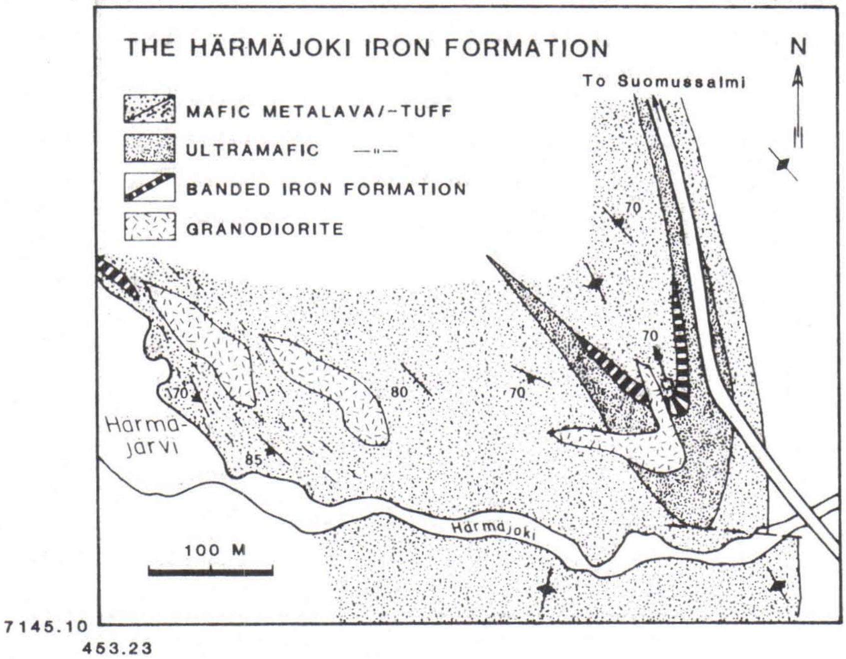

Fig. 2.16. Geological sketch-map showing the Härmäjoki iron formation and its surroundings.

The dimensions of the BIF are not exactly known, but its maximum length probably does not exeed 200 m. The width is usually less than 10 m. The iron-bearing bands are composed of ferroactinolite, grunerite, magnetite and some chlorite. Some of the bands are sulphide-rich and may contain abundant pyrite and sphalerite and some chalcopyrite and pyrrhotite. The average SiO_2 content of the BIF is about 52 %, total Fe, as FeO, about 38 % and P_2O_5 0.2 %. The Fe^{3+}/Fe^{2+} ratio is 1.9.

The supracrustal rocks are penetrated by a granodiorite of age 2700 Ma. Some cross-cutting granodiorite dykes can also be seen in the locality.

3.

THE PROTEROZOIC KAINUU SCHIST BELT

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INTRODUCTION (K. Laajoki)

The Kainuu Schist Belt consists of Lower Proterozoic metasediments pressed between two cratonic blocks, the Kuhmo-Iisalmi province in the east and the Iisalmi-Pudasjärvi province in the west (Fig. 3.1). The central part of the belt is one of the key areas on which Wegman (1928) based his ideas on the Alpine-type tectonics of the Karelides, while the Puolanka area is where Väyrynen (1928) laid the foundation for his concepts of the stratigraphy of the Karelides, which are still widely accepted in Finland.

Structurally, the belt form a synclinorium about 200 km in length with an axial plane which is almost vertical or slightly overturned to the east. This huge fold structure is pierced by many faults, the most important of which are shown in Fig. 3.1. The following three main structural subunits may be distinguished: 1) the Nuasjärvi-Ristijärvi Basin, which comprises the major southern and western part of the belt, 2) the Paltamo area, where the bedrock is characterized by tectonic quartzite blocks and basement wedges in a metapelitic

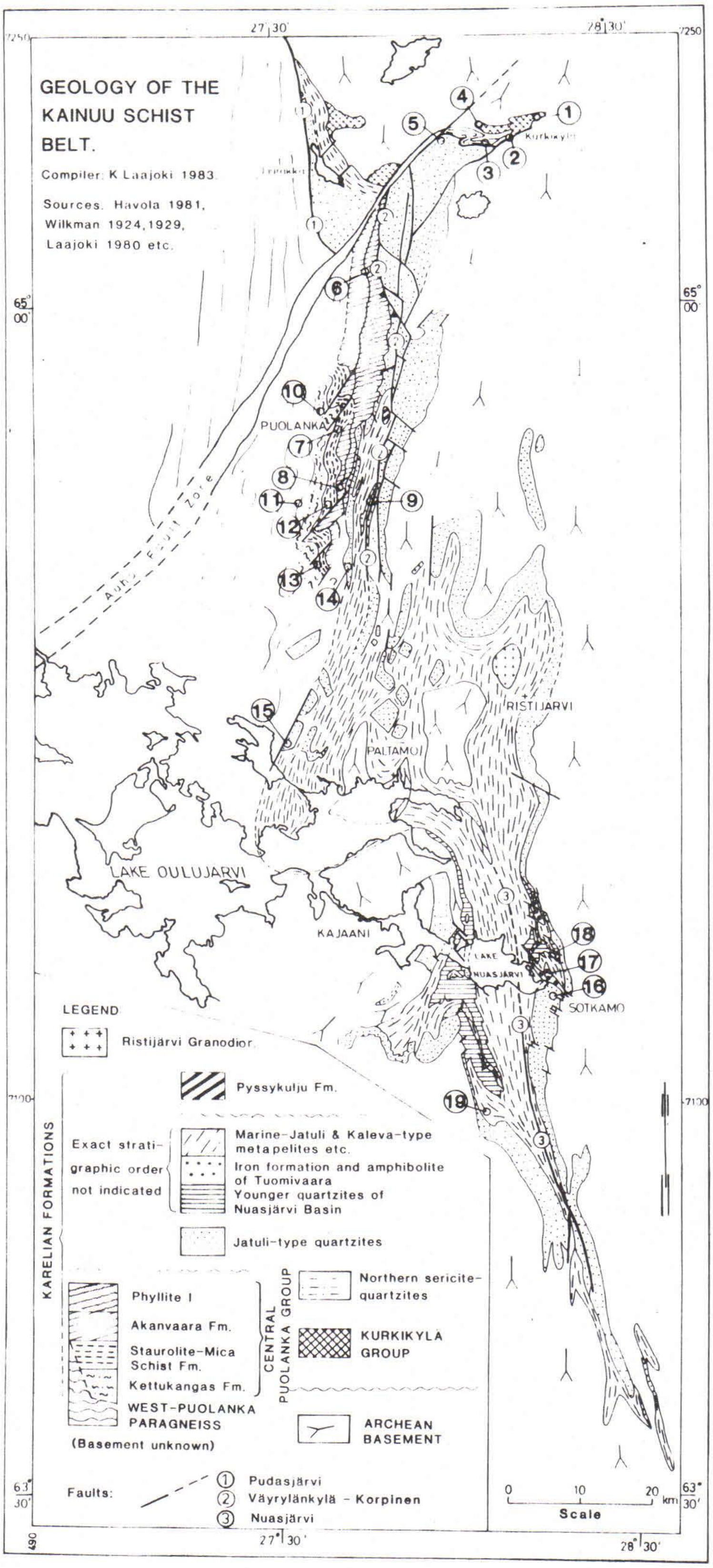

Fig. 3.1. Simplified geological map of the Kainuu Schist Belt. Excursion sites are shown by numbers.

matrix, and 3) the main northern end, divided into two parts, the Puolanka and the Jaurakka areas, by the Auho Fault Zone. The middle part of the belt is also crossed by three fault zones trending almost N-S (Nos. 1, 2 and 3 on Fig. 3.1) and dividing it into eastern and western parts, in which the Karelian formations face mostly to the west or east respectively. The western east-facing part is absent from the Jaurakka area.

The complicated structure and lack of outcrops make intra-belt stratigraphic correlations difficult, especially regarding connections between the more autochthonous eastern formations and the western ones. Starting from the north, the lithostratigraphy of the eastern part is as follows: 1) the Kurkikylä Group, including Sariola-type metasediments and Sumi-type metalavas, which are encountered only in the very north, 2) the northern sericite-rich quartzites with vein quartz pebble conglomerates of Paljakkavaara and the Jaurakka area, 3) the Jatuli-type quartzites proper, which can be followed along whole of the eastern margin, always facing away from the Archaean basement, and 4) Marine Jatuli-type dolomites, metapelites, quartzites and iron formations and the Kaleva-type metapelites. Since it is not possible to map these two groups separately they are mostly included under the same symbol on Fig. 3.1. It is, however, obvious that the Kaleva-type rocks were deposited unconformably on the former rocks.

Excluding the southwestern flank of the Nuasjärvi-Ristijärvi basin, where the formations are allochtonous and consist of Jatuli-Kaleva-type rocks, the geology of the western margin of the belt is more complicated. Firstly, instead of the indisputable Archaean basement there are strongly metamorphosed and migmatized paragneisses north of Lake Oulujärvi whose age is not known, but at least some of which represent highly metamorphosed Karelian rocks. Eastwards the paragneisses gradually grade into, and are stratigraphically overlain by, the east-facing rocks of the Central Puolanka Group, which are divided into the arkositic metaturbidites of the Kettukangas Formation (lowermost), the Staurolite-Mica Schist Formation, the Akanvaara Formation and the Phyllite Formation I (see legend in Fig. 3.1). These rocks are again overlain by the quartzites and metapelites, etc. correlated with the Jatuli and Kaleva-type rocks of the eastern margin, but which face mostly to the east.

In addition to these main formations, at least two minor relics of younger quartzites with quartzite-phenoclast conglomerates in their basal parts occur at Pyssykulju and Jokijyrkkä, while a problematic conglomerate-quartzite occurrence is found at Kivesvaara (see p. 69).

The West-Puolanka paragneiss area in particular is heavily migmatized and intruded by Karelidic synorogenic granites and pegmatites (approx. 1860 Ma). One larger granodiorite intrusion is encountered in the midst of the metapelites at Ristijärvi.

LAKE SUPERIOR-TYPE IRON FORMATION IN KAINUU (K. Laajoki)

The minor iron formations encountered here and there on the eastern margin of the Kainuu Schist Belt have been studied in more detail at Puolanka and Sotkamo.

At Puolanka, small iron formation lenses are found in close association with dolomites, black schists, mica schists and quartzite in a faulted synclinorium known as the Salmijärvi Basin (Laajoki and Saikkonen 1977). The highly complicated structure and the poor outcrops make stratigraphical reconstruction difficult, but it can be concluded on the basis of drilling and large-scale structural interpretations that the iron formations occupying the eastern margin of the Salmijärvi Basin, e.g. those close to the margin of the Archaean basement (Pääkkö, Iso Vuorijärvi and Körölä), are mainly of mixed oxide-silicate type with minor carbonate or sulphide iron formation interbeds, while the more western occurrences, known collectively as the Seppola iron formation and located farther from the basement, are composed mainly of a manganiferous sulphide iron formation.

The mixed oxide-silicate iron formations of Pääkkö, Iso Vuorijärvi and Körölä consist mainly of quartz-magnetite-banded rocks with variable amounts of grunerite in the magnetite-rich bands. A typical accessory mineral is apatite, which follows iron minerals but also occurs in discrete phosphorite bands some millimetres thick (Laajoki and Saikkonen 1977, Fig. 33). Another interbanded lithology consists of a non-cherty garnet-bearing iron-silicate rock, which chemically resembles ironstones rather than the quartz-banded grunerite rocks which are the typical silicate iron-formation rocks at Puolanka. The carbonate and sulphide iron formations on the eastern margin of the Salmijärvi Basin consist of quartz-banded siderite rocks and iron-rich black schists or phyllites respectively. At Seppola, on the western margin of the Salmijärvi Basin, the iron formation consists mainly of manganiferous and iron-rich black schists and phyllites with minor carbonate interbeds. The texture of these occurrences is characterized by micro-ooliths (Laajoki and Saikkonen 1977, Figs. 23 and 24), whereas none have been detected in the eastern occurrences. Mineralogically, the Seppola occurrences are distinguished from the eastern ones by the abundance of spessartine-almandine, manganosiderite and mangaoan cummingtonite. The main iron sulphide is pyrrhotite.

In comparison with Lake Superior-type iron formations in general, the Puolanka occurrences, whose total iron content is about 27 %, are distinguished by exceptionally high P_2O_5 (approx. 2.5 %) and CaO (~ 3.5 %), due to the apatite, and also by the comparatively high S (~ 2 %) and C (~ 1 %) due to frequent iron-rich black schist and phyllite interbeds. On the whole, they can be regarded geochemically as multicomponent formations consisting mainly of true iron-formation components (Fe, Si) with black schist/phyllite (Fe, S, Ti, Al, Ca, K) and minor phosphorite (Ca + P), with additions of ironstone (Fe, Ti, Al, Ca, Na, K; cf. Laajoki and Saikkonen 1977, Fig. 68).

At Tuomivaara, Sotkamo, an iron formation about 200 m thick and over 10 km long occurs on the eastern margin of the Nuasjärvi Basin, whose core is occupied by Kalevian-type metapelites and the rims by Jatulian-type quartzites. According to Mäkelä (1976, Fig. 3) the succession at Tuomivaara from the Archaean basement upwards, as follows: Jatulian-type quartzite (several 100 m), phyllite (100 m) with local dolomite, silicate iron formation (150 m), silicate-magnetite iron formation (10-20 m), black schist (20-30 m) and phyllite with local conglomerate. As the iron is bound mainly in the silicates (grünerite and garnet) this occurrence is uneconomic. Geochemically, it resembles the Puolanka occurrences, being rather rich in phosphorus (0.2-2.0 % $P_2 O_5$) and even in manganese (grunerite rocks have been reported to contain up to 4.2 % MnO, Mäkelä 1976).

The other iron-formation occurrences in Kainuu are also characterized by unusually high phosphorus and often also by high manganese (Lehto and Niiniskorpi 1977). Thus it is quite possible that they represent an originally more or less coherent lithostratigraphic unit which has been folded and faulted in a complicated manner, a major near-shore ("oxide facies") part of which has unfortunately been eroded away. We can therefore conclude that about 2080 Ma ago (Sakko and Laajoki 1975) there was a sedimentary basin at least 100-150 km long in Kainuu, into which large quantities of iron, silicon and phosphorus were deposited.

GEOLOGY OF THE NORTHERN PART OF THE KAINUU SCHIST BELT

(K. Laajoki, K. Strand and R. Kangas)

Main geological features

Simplified maps of the lithostratigraphy and structure of the Kainuu Schist Belt at Puolanka, Kurkikylä (Suomussalmi) and Jaurakka (Pudasjärvi) are given in Figs. 3.2 and 3.3 respectively. Fig. 3.4 gives a lithostratigraphic schema.

The bedrock of the area of Fig. 3.2 is built up of four major lithological units: 1) the Eastern Basement Gneiss Complex in the east, which consists of the Archaean granitoidic gneisses on which the Karelian rocks were deposited, 2) the West Puolanka Paragneiss, which is divided into the lithologically analogous North-western and South-western Paragneiss Complexes by the left-lateral Auho Fault Zone, 3) the Kurkikylä Group of Sumi-Sariola-type rocks lying subhorizontally on the Eastern basement. 4) the Karelides proper, which occupy the quartzite and schist area between the units 1 and 2. Structurally this is again divided by the Väyrylänkylä basement wedge, the Väyrylänkylä-Korpinen fault zone and the Pudasjärvi Fault into an eastern autochthonous - parautochthonous part known as the Eastern Karelides, and a western part, thrust towards the NE, belonging to the Puolanka Shear Allochthon (Fig. 3.3). There are also two small erosion remants of relatively young Karelian formations.

The four major structural units (Fig. 3.3) are:

1) the eastern basement area, which served as a foreland for the Karelidic deformation and on which relics of Sumi-Sariola-type rocks are encountered,

2) the Eastern Karelides, which comprise the west-facing autochthonous-parautochtohonous parts of the Karelides proper and are pressed against the former unit,

3) the Puolanka Shear Allochthon, which comprises the South-western Paragneiss Complex, the east-facing

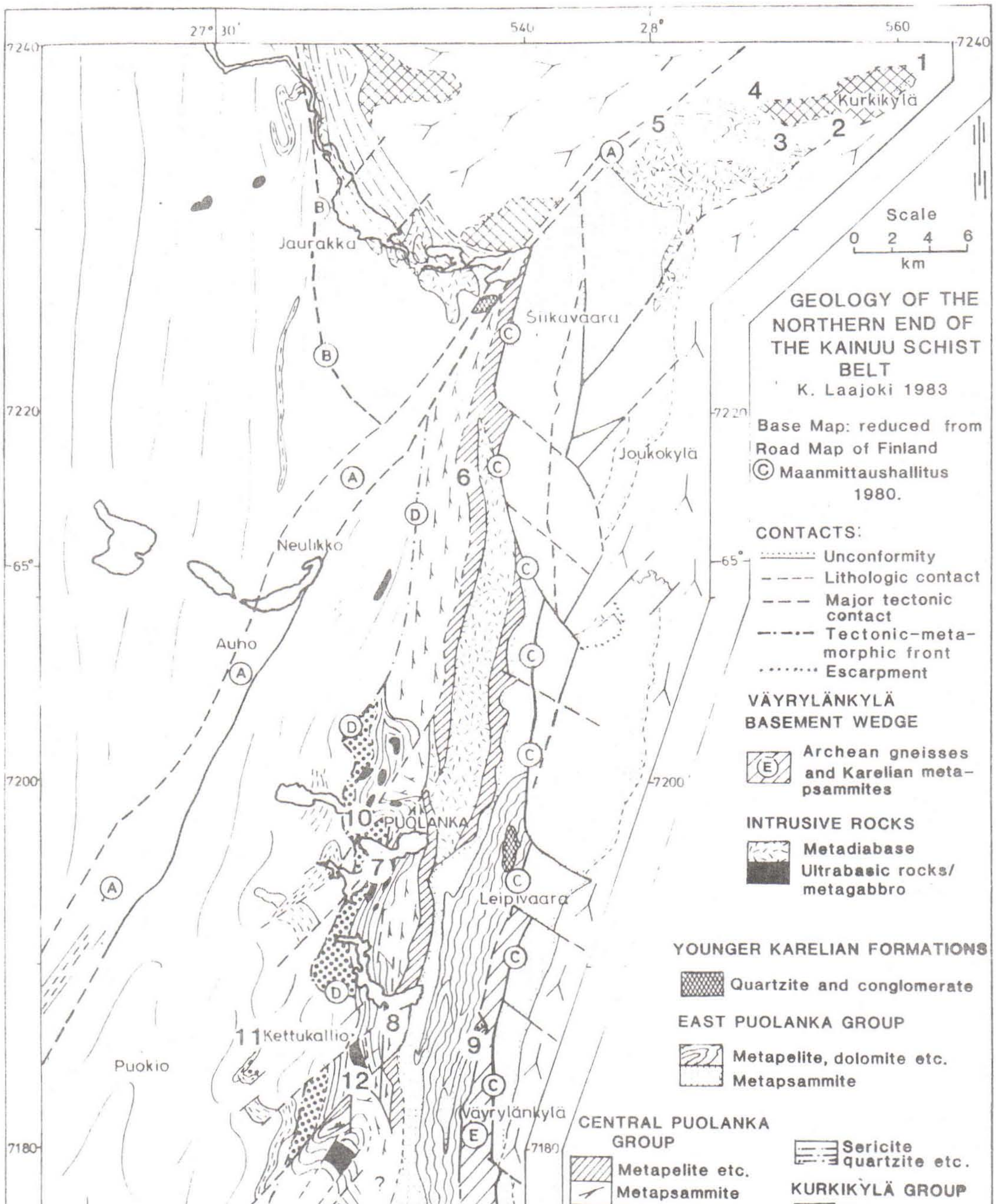

Fig. 3.2. Simplified geological map of the northern part of the Kainuu Schist Belt at Puolanka, Suomussalmi and Pudasjärvi. Tectonic zones: A) Auho Fault Zone. B) Pudasjärvi Fault. C) Väyrylänkylä-Korpinen fault zone. D) Puolanka tektonic-metamorphic zone. Excursion sites are shown by numbers 1-14.

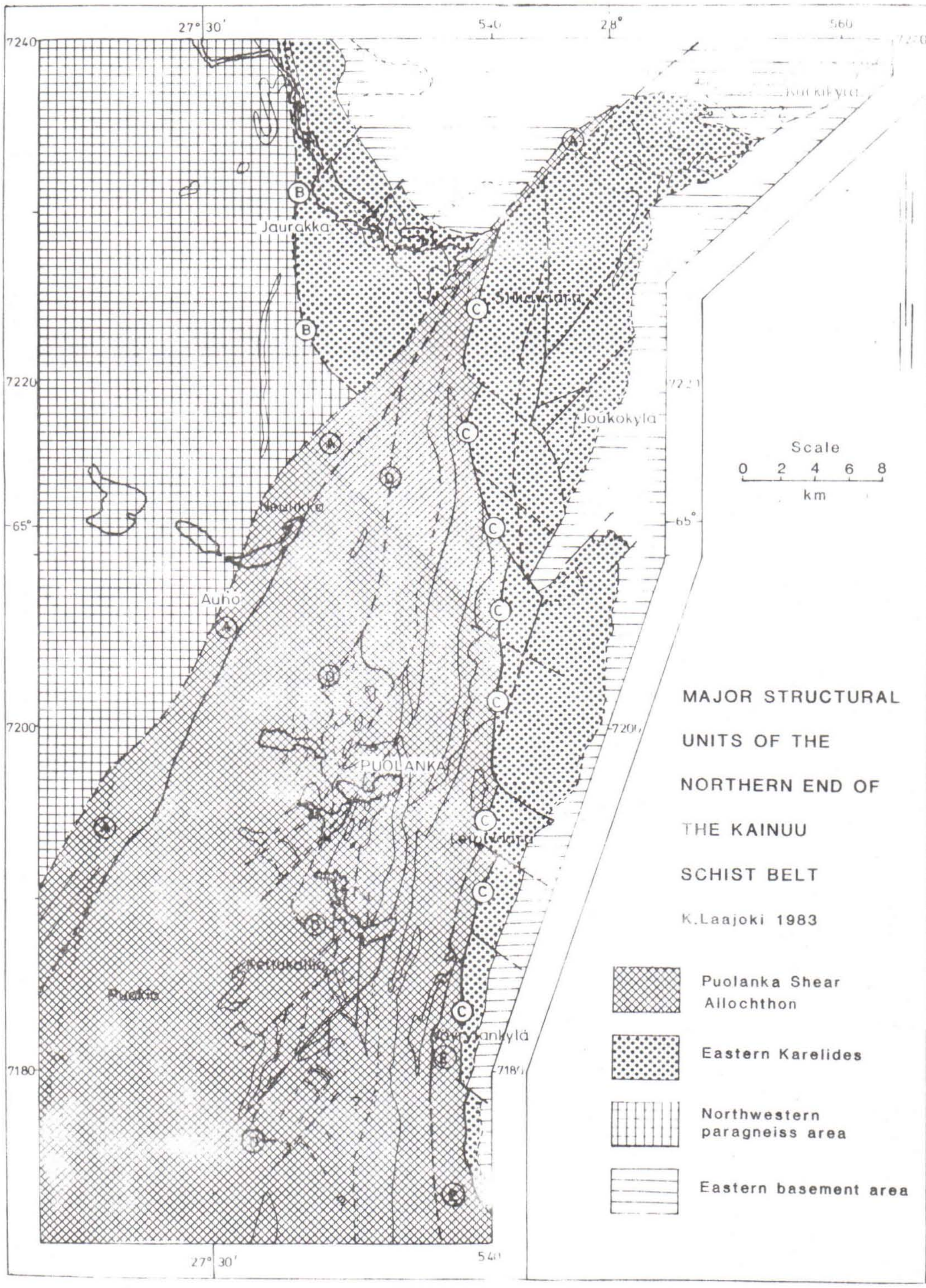

Fig. 3.3. Major structural units of the northern end of the Kainuu Schist Belt.

Central Puolanka Group and the slightly overturned and mostly east-facing part of the East Puolanka Group in central Puolanka and the Salmijärvi basin, and also the tectonic basement wedge of Väyrylänkylä. The Southwestern Paragneiss Complex can be considered a northeastern part of the hinterland block, which carried and pushed the Karelian rocks of central and eastern Puolanka northeastwards against the eastern basement gneiss area.

4) the northwestern paragneiss area, separated from the Karelian rocks of the Jaurakka area by the Pudasjärvi Fault and from the Puolanka Shear Allochthon by the Auho Fault Zone. This represents the southeasternmost margin of the Pudasjärvi basement gneiss, its platform cover having been deformed and migmatized during the Svecokarelidic orogeny.

Lithostratigraphy

Fig. 3.4 depicts the reconstructed stratigraphic scheme for the area. It should be borne in mind that there is a major tectonic zone between the western and eastern Karelian formations (Fig. 3.3). The description that follows starts from the Archaean basement and proceeds to the eastern Karelian formations in stratigraphic order. It then jumps to the lowermost western rocks (paragneisses) and again follows the stratigraphic order upwards ending with the youngest rocks of the Salmijärvi Basin.

The Eastern basement: The eastern basement has not yet been mapped in detail. It is composed mainly of granodioritic-throndhjemitic orthogneisses and migmatic granitoids. K-rich granites or pegmatites are only met with locally.

The Kurkikylä Group: The Kurkikylä Group includes the Laanhongikko, Matinvaara and Ahvenkivilampi formations (Fig. 3.5). In its type area (Figs.3.6 and 3.7), the Laanhongikko Formation, resting nonconformably on the Archaean granodioritic-tonalitic orthogneisses, starts with a basal

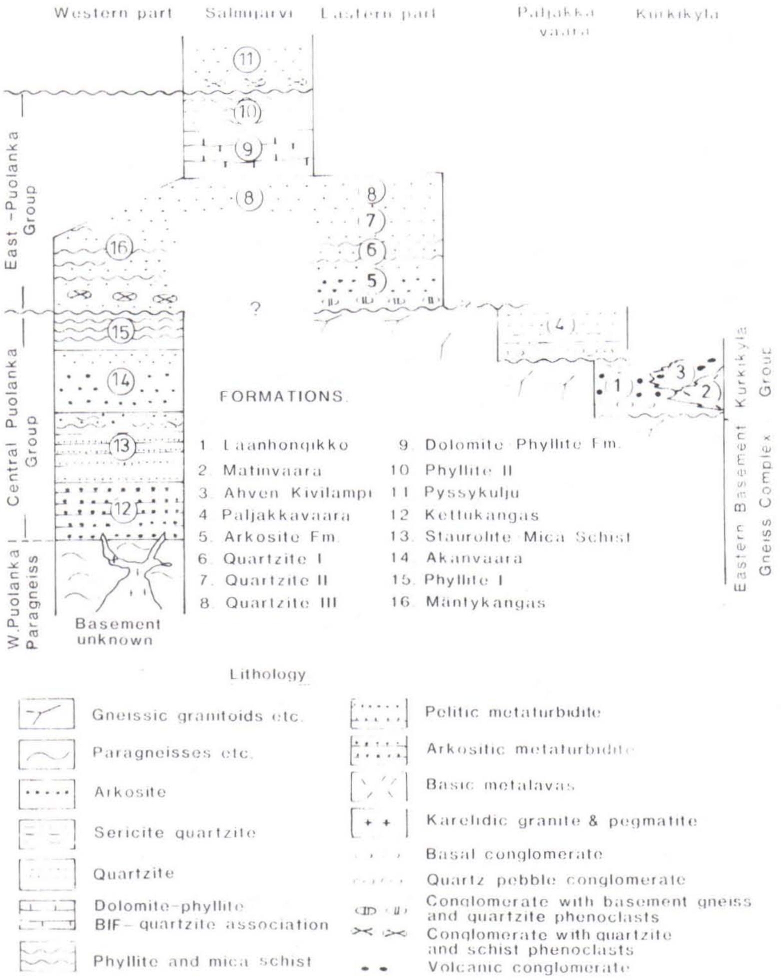

Fig. 3.4. Schema for the lithostratigraphy of the northern part of the Kainuu Schist Belt. Note that the correlation between the eastern and western parts is open and that the Mäntykangas Formation (No. 16) may consist of two or three major units.

breccia (5-30 m) and breccia conglomerate (20-40 m) with abundant angular fragments derived solely from the underlying orthogneisses in small amounts of sericite-rich quartz-feldspar matrix. The next member consists of greenish coarse-grained gravel-like arkosite up to 80 metres thick containing conglomerate beds in its lower parts. This unit is overlain by arkosite and arkosite conglomerate members comprising the bulk of the Laanhongikko Formation.

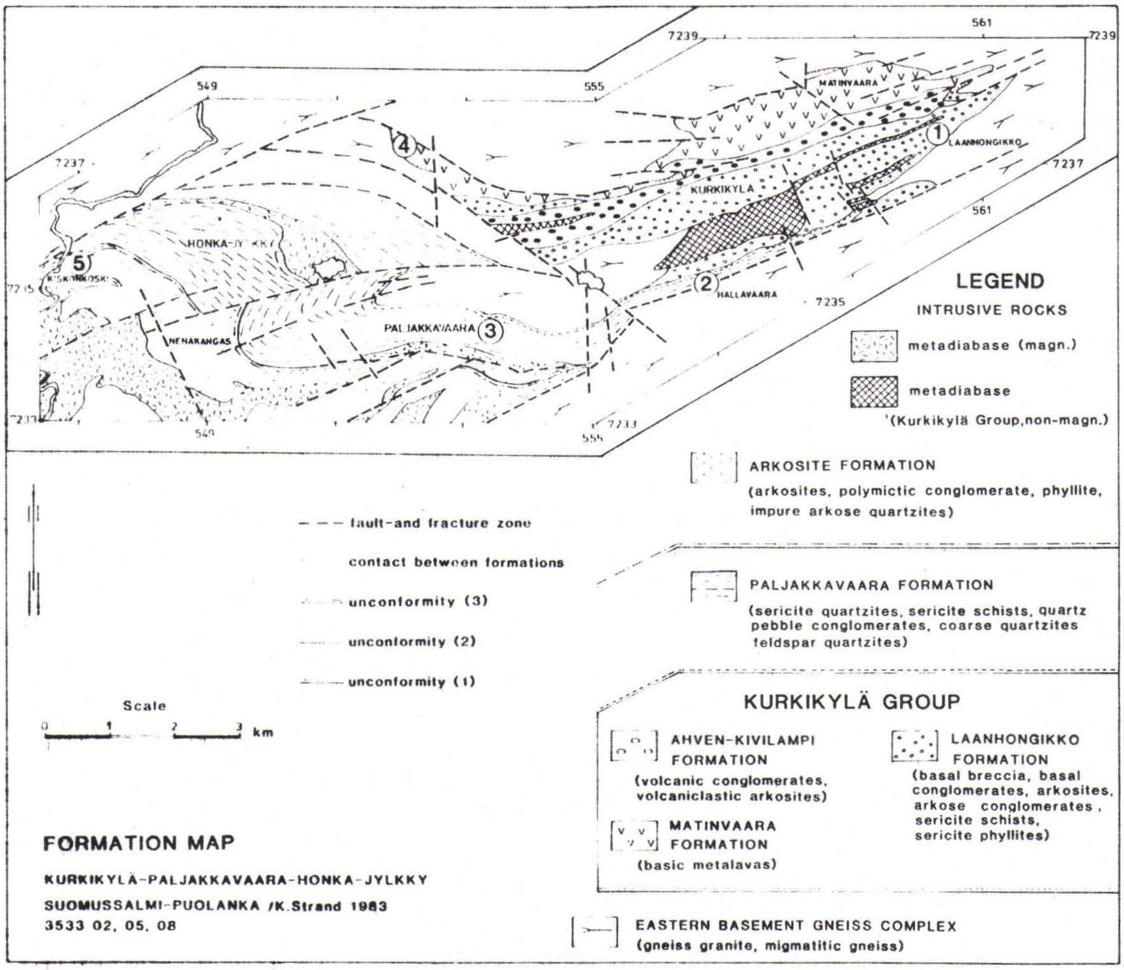

Fig. 3.5. Geology of the Kurkikylä-Paljakkavaara area, as described by K. Strand. Excursion sites are shown by numbers 1-5.

The main rock type is a light-coloured sericite-rich quartz-feldspar rock. The phenoclasts of the conglomerate beds are mainly Archaean orthogneiss, but rare greenish sericite-schist fragments are distinctive for this member. This is also the first member in which a few vein-quartz pebbles are encountered. Upwards it grades into a fine-grained sericite schist, which forms the topmost part of the formation. The total thickness of the formation is hard to estimate, due to pronounced deformation and the lack of primary structures, but may be about 300 m.

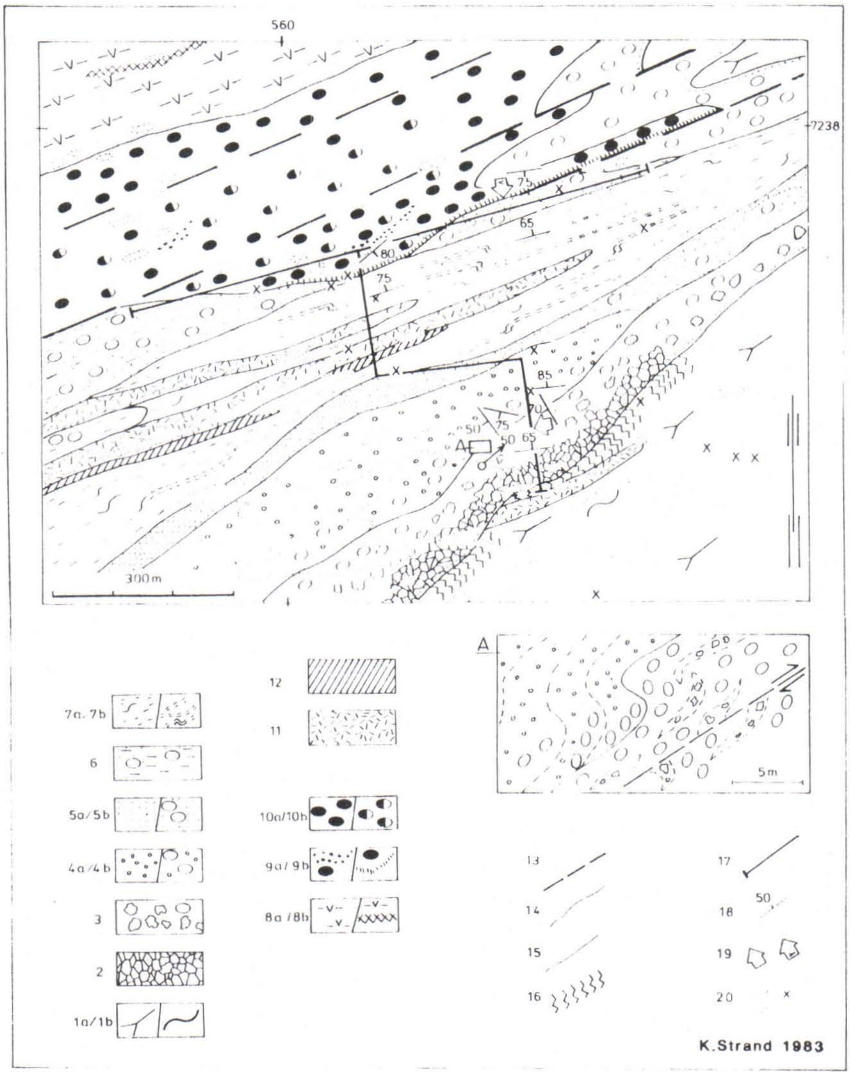

Fig. 3.6. Detailed map of the Laanhongikko area. Symbols: 1. Eastern Basement Gneiss Complex: 1a) gneiss granite, 1b) migmatitic gneiss. 2-7. Laanhongikko Formation: 2) basal breccia, 3) breccia conglomerate, 4a) coarse arkosite, 4b) coarse arkosite with conglomeratic interbeds, 5a) arkosite, 5b) arkose conglomerate (containing sericite-rich fragments), 6) arkose conglomerate (containing sericite-phyllite and sericite-rich fragments), 7a) sericite schist, 7b) sericite phyllite interbeds. 8. Matinvaara Formation: 8a) mainly massive metalavas (strongly foliated), 8b) massive metalavas with Fe-bearing minerals. 9-10. Ahven-Kivilampi Formation: 9a) volcanic conglomerate with volcaniclastic arkosite interbeds, 9b) contact zone of volcanic conglomerate, which contains mainly tuffogenous schists, 10a) volcanic conglomerate, 10b) volcanic conglomerate with numerous phenoclasts of basement gneisses. Others: 11) metadiabase (non-magnetic), 12) quartz vein, 13) fault and fracture zone, 14) contact, 15) unconformity, 16) Prekarelidic jointing, 17) section, 18) bedding, 19) direction of top, 20) outcrop.

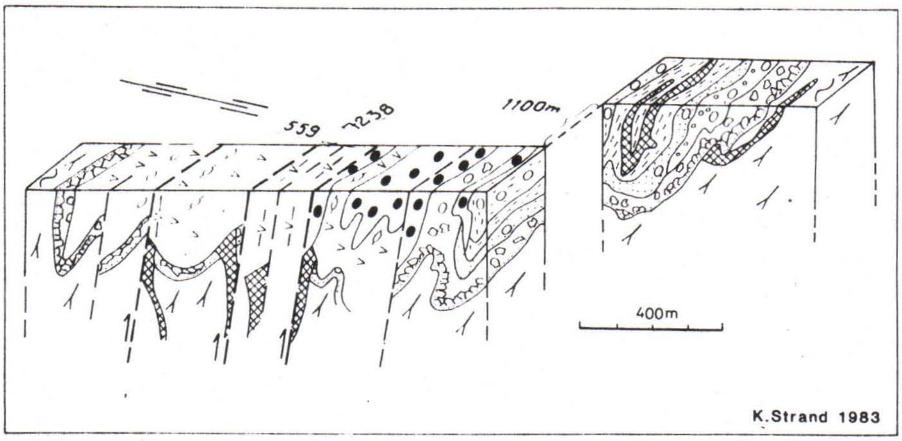

Fig. 3.7. Cross section through the Kurkikylä Group from Laanhongikko to Matinvaara. Symbols as in Fig. 3.6.

The Matinvaara Formation lies on a thin breccia conglomerate of the Laanhongikko Formation or may lie directly on the Archaean basement. It is made up mainly of mafic/spilitic metalavas which are either massive, variolitic or amygdaloidal. The formation is composed of many different lava beds, whose mutual relationships cannot be established. The minimum thickness of the formation at Matinvaara is probably about 300-400 m.

The Ahven-Kivilampi Formation consits almost solely of volcanic conglomerate containing abundant phenoclasts in a small amount of chloritic matrix. The phenoclasts are mostly of different metalavas derived from the Matinvaara Formation, with Archaean orthogneiss phenoclasts also encountered in the upper parts of the formation. The phenoclasts vary greatly in size, being mostly of cobble size, although with large, well-rounded orthogneiss and albite-carbonate rock boulders up to 80 cm in diametre to be encountered locally.

The Eastern Karelides: The eastern autochthonous-parautochthonous Karelian formations comprise the Paljakka-vaara-type sericite-rich quartzites and the East Puolanka Group.

The hill of Paljakkavaara, 4 km southwest of Kurkikylä, consists mainly of sericite-rich quartzites with variable amounts of quartz-pebble conglomerate interbeds. The amount of sericite decreases upwards and the rock becomes ortho-quartzitic (Fig. 3.8). Although the contact against the Kurkikylä Group is not exposed, it seems probable that the Paljakkavaara quartzite was deposited unconformably on the Laanhongikko Formation. A similar sequence is encountered at the hills of Turpeisenvaara and Tolpanvaara in the Jaurakka area, where a gradual change from coarse clastic or conglomeratic sericite-quartzite to rather pure quartzite can be demonstrated. The thickness of the sequence is many hundred metres (Meriläinen 1977).

Unfortunately, the upper contact of the Paljakkavaara-type quartzites is not exposed anywhere, but recent observations by K. Strand indicate that the quartzite phenoclasts of the Nenäkangas-type conglomerates may be derived from these formations. If this is true, the Paljak-kavaara quartzites must underlie the East Puolanka Group unconformably.

The East Puolanka Group begins with the Arkosite Formation, whose lower parts consist mainly of arkosites in which the afore-mentioned Nenäkangas-type conglomerate is encountered in one or more interbeds some metres thick. The well-rounded phenoclasts of the conglomerate are mainly fairly pure quartzites containing variable amounts of sericite and carbonate, vein-quartz and basement gneiss. Both the arkosites and conglomerate are cross-bedded and are very probably of fluvial origin. Upwards the arkosites give way into more mature Jatuli-type quartzites mapped as Quartzite formations I, II and III. The first of these is characterized by alternating orthoquartzite and sericite phyllite intermembers, the second is composed of more

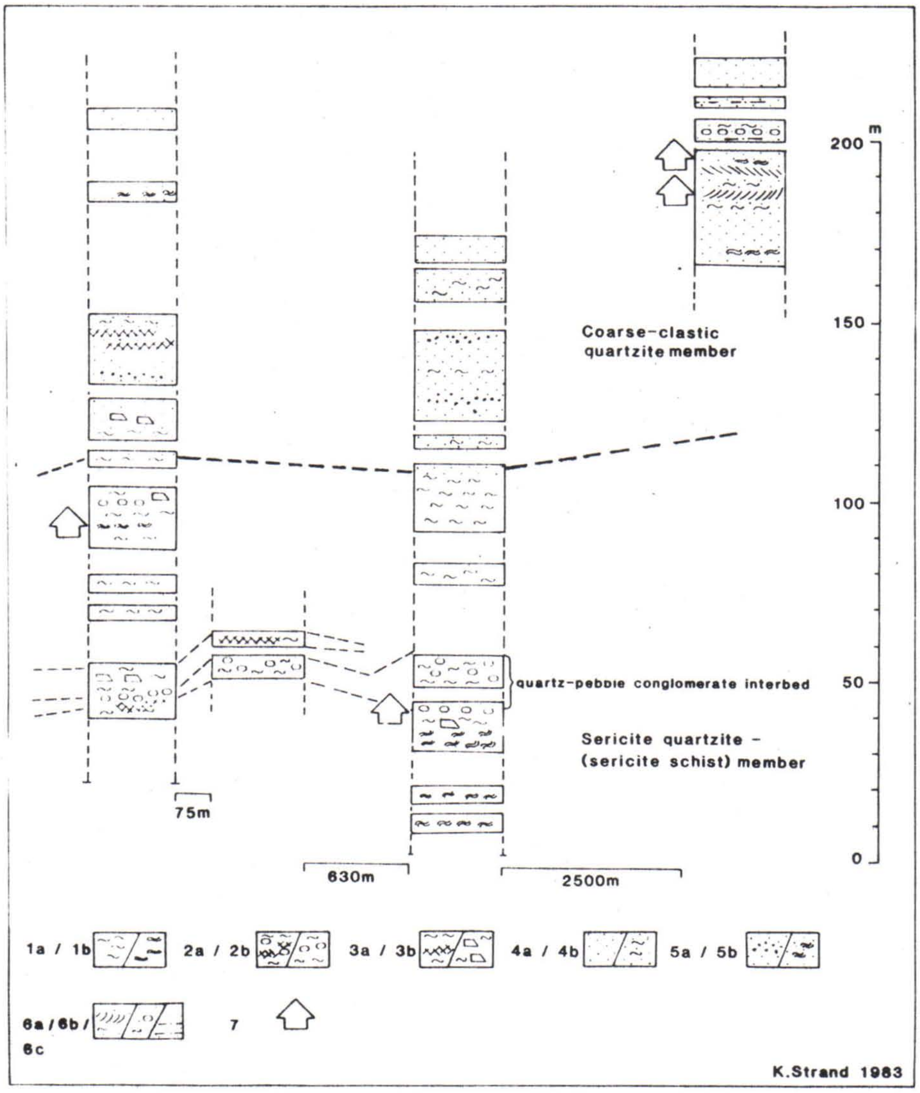

Fig. 3.8. Lithostratigraphic sections through the Paljakkavaara Formation in Paljakkavaara. Symbols: 1-3. Sericite quartzite (sericite schist) member: 1a) sericite quartzite, 1b) sericite schist, 2a) quartz pebble conglomerate with haematite-rich sericite quartzite matrix, 2b) quartz pebble conglomerate with sericite quartzite matrix, 3a) haematite stripes in sericite quartzite, 3b) kyanite in sericite quartzite. 4-6. Coarse-clastic quartzite member: 4a) coarse-clastic quartzite, 4b) sericite-bearing coarse-clastic quartzite, 5a) haematite dots in coarse-clastic quartzite, 5b) sericite schists in coarse-clastic quartzite, 6a) cross-bedding in coarse-clastic quartzite, 6b) quartz pebble conglomerate in coarse-clastic quartzite, 7) top of beds.

sericitic metapsammite, and the third consists of variable quartzite types, giving way at the top to the rocks of the Dolomite-Phyllite Formation, which belong structurally to the Puolanka Shear Allochthon. The total thickness of the eastern part of the East Puolanka Group is at least 1000 m, of which the Jatuli-type quartzites account for the major part.

The West Puolanka Paragneiss: Due to the intense migmatization caused by the Karelidic granites and pegmatites, together with the open folding and limited outcrops, the stratigraphy of the West Puolanka Paragneiss is poorly known. Lithologically both sub-complexes consist mainly of quartzo-feldspathic and mica-rich paragneisses characterized by frequent amphibolite interlayers and quartzite interformations and interbeds. Banded or migmatic gneisses, which may be at least partly of Archaean age, are abundant.

The quartzites are mostly arkositic or mica-rich and often contain quartz-sillimanite knots, alhtough ortho-quartzic varieties are also encountered (Taikina-aho 1982). These are planarbedded and do not seem to contain any cross-bedding, a fact which together with the frequent banded amphibolite interbeds, distinguishes them from typical Karelian quartzites.

As a whole, the West Puolanka Paragneiss seems to represent a part of the Archaean basement and its Proterozoic cover west of the Kainuu Schist Belt involved in the Svecokarelidic orogeny. We have not yet located the probable unconformity surface anywhere, however.

The Western Karelides: The Western Karelides consist of the Central Puolanka Group and that part of the East Puolanka Group lying west of the Väyrylänkylä-Peräkorpinen fault zone. They end tectonically at the Auho Fault Zone in the north.

The Central Puolanka Group, whose lower contact with the West Puolanka Paragneiss is metamorphic, begins with the arkositic metaturbides of the Kettukangas Formation.

Probably as much as 1000 m thick, these rocks grade into the Staurolite-Mica Schist Formation. The metasediments of this ancient deep-water fan complex are classified into five main sedimentary facies (Fig. 3.9): Facies 1 consists of massive or slightly graded sandstone in individual beds of over 1 m in thickness. Facies 2 is a thin-bedded pelite showing graded bedding. The thickness of each graded unit is generally 2-3 cm. Facies 3 includes semipelitic rocks showing frequent cross-bedding and ripple lamination. Facies 4 consists of the non-porphyroblastic Huosiuslampi metapelites, which are so strongly deformed that no primary structures can be seen inside the layers. Facies 5 comprises arkositic sandstone showing large-scale cross-bedding.

Briefly, the Kettukangas Formation consists mainly of facies 1, while in the lower part of the Staurolite Mica Schist Formation facies 1 and 2 alternate, being dominant in the south and north respectively (Fig. 3.9). Upon this facies association rocks of facies 2 and 3 alternate, the latter becoming dominant towards the top. Facies 4 and 5 are exposed only locally and represent a gradation to the Akanvaara Formation. Since the formation is unevenly exposed, an exact facies analysis is hard to make, but it can be stated in general terms that we have here a turbiditic deep-water fan which is prograded by a fluviodelta. Facies 3 and (?)4 may represent offshore/ upper basin slope facies, while facies 5 is a true distal delta front/bar finger sandstone.

The Akanvaara Formation is a monotonous unit at least 1000 m thick composed of cross-bedded brownish arkosite or feldspar quartzite, grading upwards to purer quartzites. It represent the fluviodelta which was prograded upon the Staurolite Mica Schist Formation.

The uppermost unit of the Central Puolanka Group is the Phyllite I, the lower part of which consists of shallow-water metapelites and quartzite interbeds. The middle and upper parts are poorly exposed, but on the whole the formations seems to consist of metapelites and metadiabases intruded into these, with minor quartzite interbeds and a metatuff member.

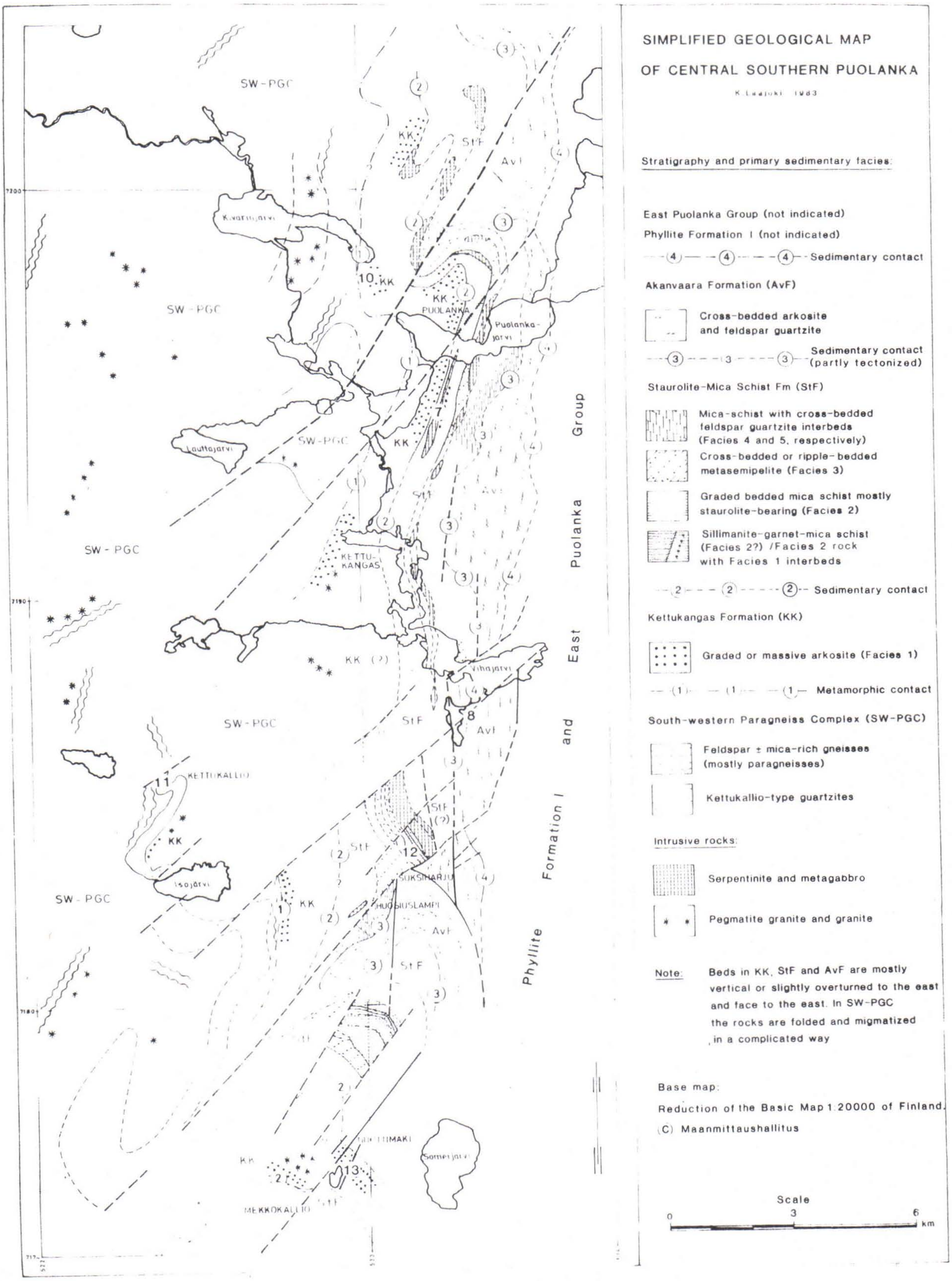

Fig. 3.9. Distribution of the primary sedimentary facies of the Staurolite-Mica Schist Formation and associated formations in Central Puolanka. Numbers 7, 8,10, 11 and 12 denote excursion sites.

The Mäntykangas Formation, the lowermost western formation of the East Puolanka Group, starts either with quartzite or the Mäntykangas-type interformational conglomerate containing large numbers of well-rounded quartzite, metapelite and metadiabase phenoclasts. Most of the phenoclasts are obviously derived from the Central Puolanka Group, but some may represent intra-group material. In any case, this conglomerate marks a major erosion period between these two groups. It is an open question whether this unconformity is the same as that marked by the Nenäkangas conglomerates in the east. This conglomeratic part, which also includes fairly thick metapelite intermembers, is overlain by at least 200-500 m of quartzites of the Jatuli-type very similar to the corresponding rocks in the Eastern Karelides. The studies being carried out by R. Kangas indicate that the Mäntykangas formation may in fact consist of two transgressive sequences.

The formation is overlain by Marine Jatuli-type dolomites, black schists, quartzites and iron formations mapped as the Dolomite-Phyllite Formation and the Phyllite Formation II, occupying the Salmijärvi Basin. This basin contains only very few outcrops, but drilling results suggest that dolomites and Lake Superior-type mixed oxide-silicate iron-formations are distinctive for its eastern margin, while the latter are replaced by Mn-bearing sulphide-facies rocks in the west (Laajoki and Saikkonen 1977).

The younger Karelian formations: There are two solitary quartzite formations, the phenoclasts in the basal conglomerate members of which suggest are younger than the East Puolanka Group. One is the Pyssykulju Formation, which consists mainly of very pure quartzites, but whose lower parts features conglomerate beds containing quartzite and schist fragments in a orthoquartzitic matrix. The lowermost unit exposed nevertheless consists of alternating orthoquartzite and metapelite members, both characterized by a distinctively reddish colour. Another occurrence with quartzite-phenoclast conglomerate is found at Jokijyrkkä in the Jaurakka area (Väyrynen 1928).

EXCURSION SITES AT KURKIKYLÄ AND PUOLANKA

(K. Laajoki, K. Strand and R. Kangas)

The Kurkikylä area: The first five stops (Fig. 3.5) will give a general view of the Sumi-Sariola-type rocks of the Kurkikylä Group, the type section for the Paljakkavaara Formation (Fig. 3.8) and one of the type outcrops for the Nenäkangas-type conglomerates of the East Puolanka Group. All these rocks were mapped in detail by K. Strand.

Stop 1

Laanhongikko, Kurkikylä, Suomussalmi
(3533 08, x = 7237.45, y = 560.43)

Type outcrops for the Laanhongikko Formation and typical examples of the volcanic conglomerate of the Ahven-Kivilampi Formation

The section to be visited (Figs. 3.6 and 3.7) starts from the Archaean basement and gives a complete cross-section of the Laanhongikko Formation described on p. 43-46.

The volcanic conglomerate is of the most common type, with both abundant metalava and orthogneiss phenoclasts of pebble to boulder size.

Stop 2

Hallavaara, Suomussalmi (3533 05, x = 7235.20, y = 556.80)

Kyanite quartzite belonging lithostratigraphically to the lowermost sericite quartzite-quartz-pebble conglomerate deposited unconformably on the Kurkikylä Group

The kyanite quartzite is a bluish or pinkish, strongly deformed rock containing about 10-30 % kyanite. This kyanite defines the foliation planes and imparts a thin streaked appearance to the rock. Primary bedding can be observed only locally.

Stop 3

Paljakkavaara, Puolanka (3533 05, x = 7234.40, y = 553.43)

The type section for the Paljakkavaara formation (Fig. 3.8).

The section starts with a light yellowish sericite-quartzite with quartz pebble (Ø 1-5 cm) conglomerate and haematite stripes. This is followed in a upward direction by a strongly foliated light sericite quartzite overlain by relatively coarse-grained quartzite with quartz grains (Ø 1-2 mm, in general) in a small amount of sericite matrix. The rock becomes more mature quartzite with local sericite-rich or quartz pebble interbeds towards the top.

Stop 4

Aittola, Kurkikylä, Suomussalmi
(3533 05, x = 7237.36, y = 551.97)

A typical amydgaloidal rock of the Matinvaara Formation

The rock is a green, non-phenocrystic amphibole-albite metalava ("spilite") which is almost completely undeformed. The well-preserved amygdales are usually filled with quartz or have an outer zone of epidote and carbonate and a core of quartz. The outcrops provide good tuffs of greenschist-facies metalavas for petrographic courses.

Stop 5

Kiskonkoski, Puolanka (3533 02, x = 7835.45, y = 546.80)

Nenäkangas-type conglomerate interbeds of the Arkosite Formation and associated metasediments of the East Puolanka Group (Fig. 3.10).

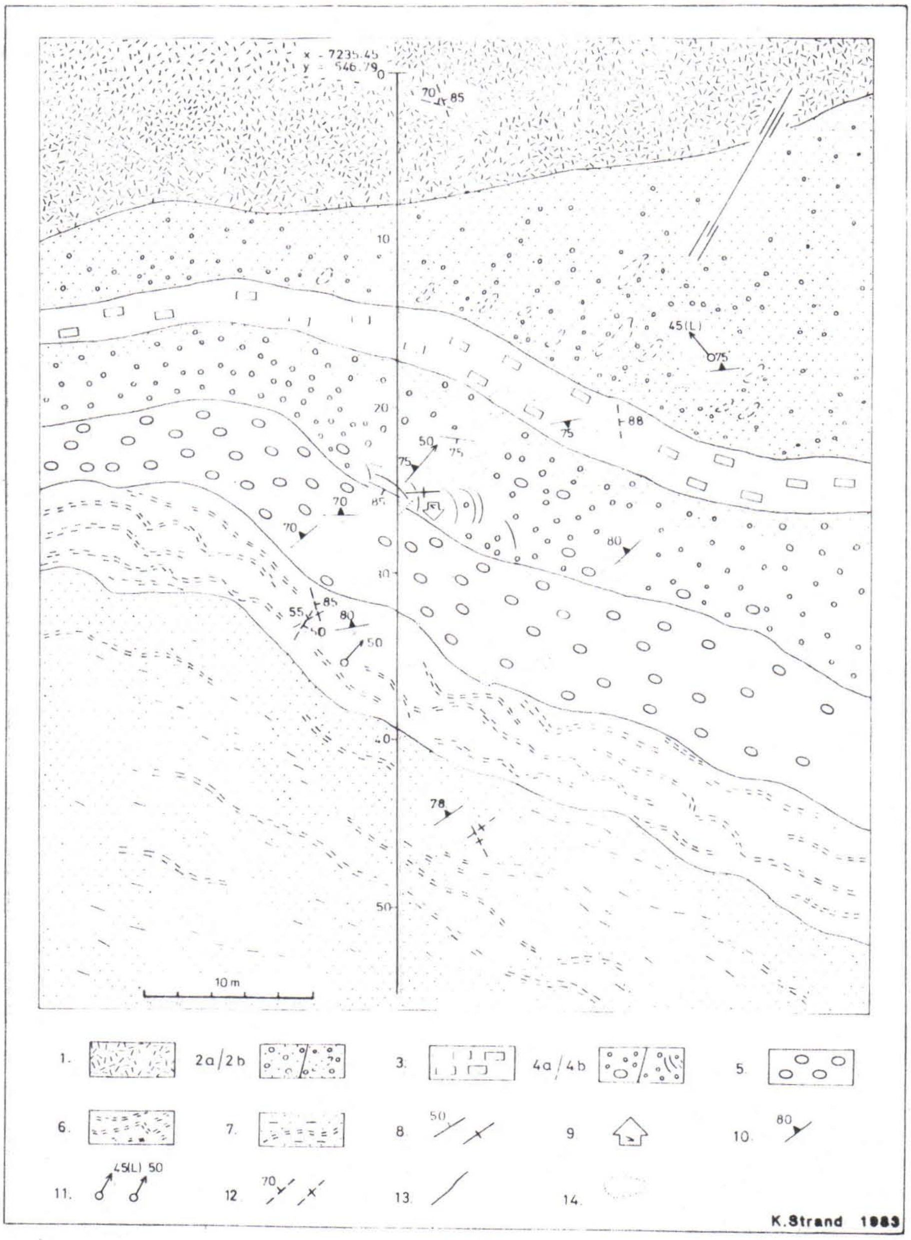

Fig. 3.10. Detailed map of the Kiskonkoski area. Symbols: 1-7. Arkosite Formation: 1) metadiabase (magnetic), 2a) arkosite, 2b) carbonate-bearing fragments in arkosite, 3) dolomitic interbed, 4a) conglomeratic, coarse-clastic arkosite, 4b) cross-bedding in arkosite, 5) Nenäkangas-type conglomerate, containing mainly phenoclasts of quartzites, vein quartz and basement gneiss in arkosite matrix, 6) phyllite, 7) arkosite with phyllite interbeds, 8) bedding, 9) direction of top, 10) foliation, 11) fold axes (L = foliation), 12) jointing, 13) contact, 14) outcrop.

The conglomerate bed is about 2-3 metres thick and is characterized by large quantities of well-rounded phenoclasts in an arkositic matrix. The phenoclasts are mainly of cobble size and consist of vein-quartz, various quartzites and basement orthogneiss.

Central and Southern Puolanka: Sites 6-14 give a general cross-section of the Western Karelides and an example of the quartzites of the West Puolanka Paragneiss (Stop 11). Due to outcrop and road conditions the logical stratigraphic order cannot be followed. The different facies of the Central Puolanka Group can be seen on stops 7, 10, 12, 13 (deep-water fan/upper basin slope), 6 (shallow-water plain) and 8 (delta). Stops 14 and 9 give examples of the Jatuli and Marine Jatuli-type rocks of the East Puolanka Group, respectively.

Stop 6

Pärekangas, Aittokylä, Puolanka
(3442 12, x = 7216.6, y = 536.6)

This outcrop with metasediments inverted into a vertical position forms the type section for the topmost 50 metres of the Akanvaara Formation and the lowermost 200 metres of the Phyllite Formation I (Fig. 3.11). It is one of the very few places where the contact relations between metasedimentary formations of contrasting lithology can be studied directly in Puolanka.

Apart from its very few and rather thin sericite-schist interbeds, the Akanvaara Formation consists of light-coloured sericite-bearing or feldspar-bearing quartzite showing mostly parallel bedding, but there is also cross-bedding here and there.

The abrupt contact between the two formations seems to be conformable, but the metamorphically grown amphibole and epidote hinder direct observations. The metasediments

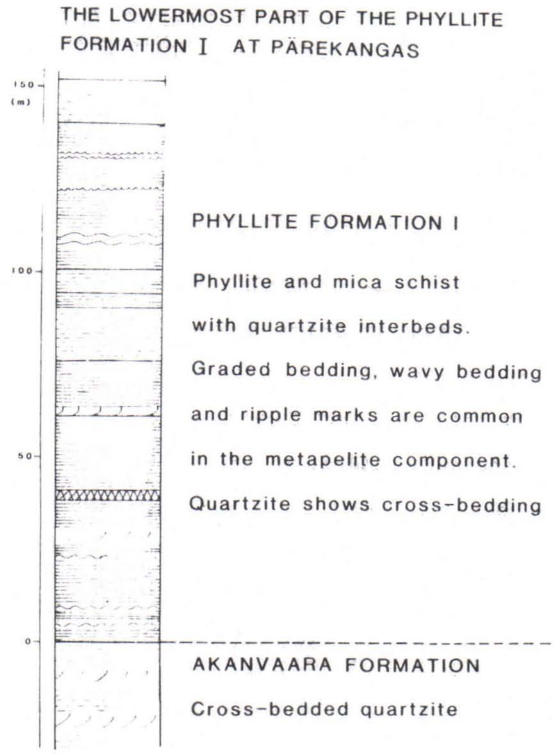

Fig. 3.11. Stratigraphy of the lowermost part of the Phyllite Formation I at Pärekangas.

of the Phyllite I are varied both in their mineralogy and in their primary sedimentary structures. The dominant type is thin-bedded metapelite showing either graded or wavy beddings. The second most common are metasemipelites, which show wavy or lowangle cross-bedding. Contrasting with these two classes are quartzite interbeds up to 5 m thick, many of which show large-scale cross-bedding and resemble Jatuli-type quartzites.

Metamorphically the most important feature is the abundant development of scapolite, which seems to be strata-bound, amphibole and epidote.

Stop 7

Honkaniemi, Puolanka (3442 10, x = 7194.6, y = 532.0)

This measured prophile No. 3 is the type section for the upper and middle northern parts of the Staurolite Mica Schist Formation (Fig. 3.12).

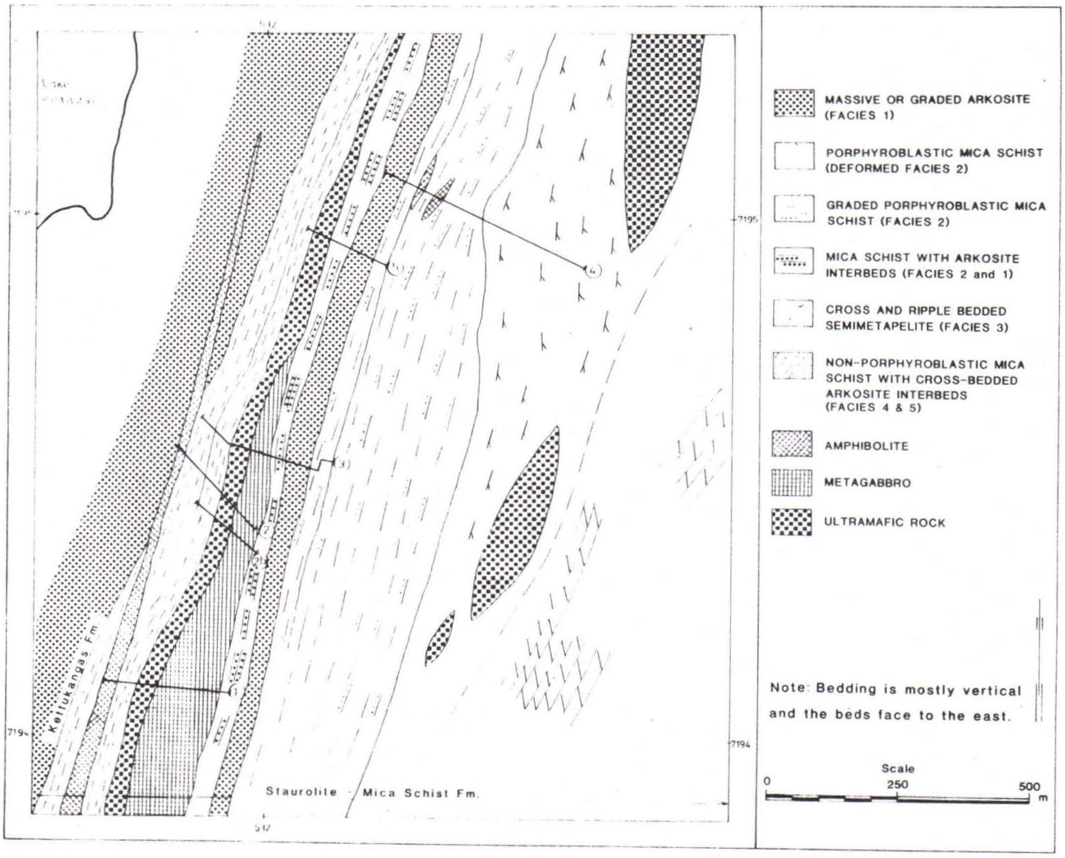

Fig. 3.12. Geological map of the Honkaniemi area. The profiles measured are shown by numbers 1-5. Modified from Korkiakoski (1981, Fig. 3).

The section begins with a strongly foliated staurolite-garnet mica schist whose primary structures are no longer visible. The differentiated amphibole rock - metagabbro body is overlain by an arkosite-dominated member consisting mainly of massive or lightly graded metasandstone of facies 1 with a thin-bedded staurolite-mica schist of the facies 2. The facies 2 rocks show graded bedding in which the lower parts of the strata are of sand grain-size and graded, while the upper parts are pelitic and much thinner. Units starting with small-scaled cross-bedding (Bouma's C-unit) are encountered only locally.

The proportions of metasandstone decrease upwards and facies 2 becomes dominant.

Stop 8

Western flank of Akanvaara, 200 m south of the farm of Lampela (3441 12, x = 7187.70, y = 532.05)

Type section for the 600 lower metres of the Akanvaara Formation

The fairly well-exposed section consists entirely of light brownish or pinkish feldspar quartzite or arkosite with very few pelitic interbeds n x 1-10 cm thin. As well as parallel bedding, the quartzite shows frequent large or medium-scale cross-bedding indicative of sedimentary transportation from somewhere to the south.

Stop 9

The Pääkkö iron formation, Väyrylänkylä
(3441 12, x = 7185.70, y = 537.20)

Type outcrops for the Pääkkö iron formation and associated dolomites and quartzite of the Dolomite-Phyllite Formation

The geology, mineralogy and geochemistry of the Pääkkö iron formation have been described by Laajoki and his coworkers (Laajoki 1975; Sakko and Laajoki 1975; Laajoki and Saikkonen 1977; Laajoki and Ervamaa 1977, see also p. 39). Although uneconomic, the iron-formation lense of Pääkkö contains 13.4 million tons of mineralized rock averaging Fe_{tot} = 26.6 %, Fe_{HCl} = 20.5 %, Ti = 0.06 %, Mn = 0.06 %, V = 0.03 %, P = 1.09 % and S = 2.02 % (Ervamaa and Laajoki 1977).

Figs. 3.13 and 3.14 depict the detailed geology of the outcrop area to be visited and a stratigraphic section through the Pääkkö iron formation, respectively.

The rocks to be seen at this locality are: the dolomite of the Salmijärvi Dolomite Member, a typical quartz-magnetite-banded rock with variable amounts of grunerite from the Pääkkö iron-formation (Laajoki and Saikkonen 1977, Figs. 6 and 7, Table 4), and the dark quartzite of the Pääkkö Quartzite Member.

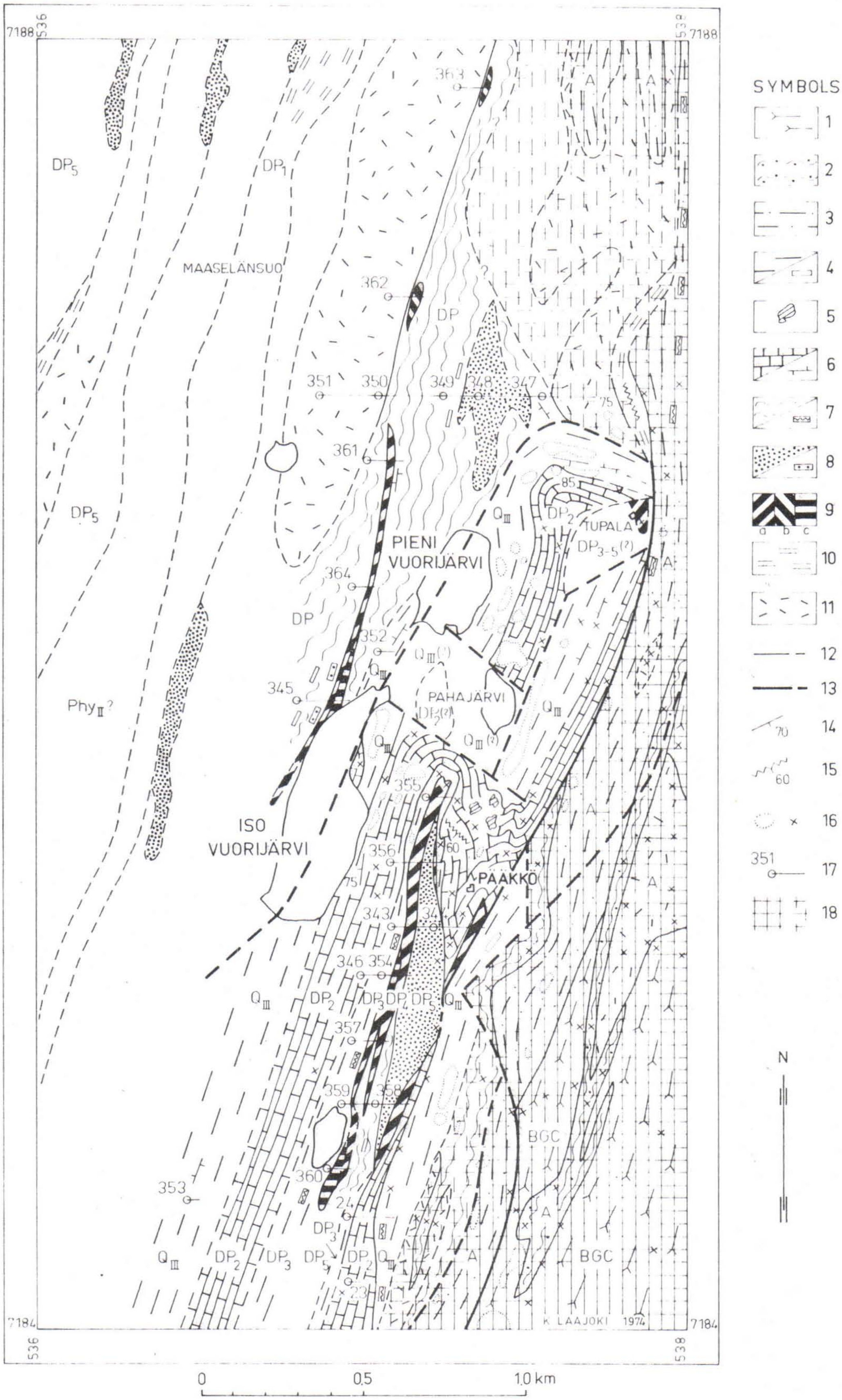

Fig. 3.13. (Explanation on next page).

Fig. 3.13. Stratigraphic-lithological map of the surroundings of the Pääkkö iron formation (in the middle lower part) and the Iso Vuorijärvi iron formation (in the middle). Lithological symbols: 1) Prekarelidic basement gneiss. 2) Conglomeratic mica schist. 3) Arkosite and feldspar and/or sericite-bearing quartzite. 4) Quartzite-orthoquartzite/the same as intercalations. 5) Tectonic inclusions of quartzite. 6) Dolomite/the same as intercalations. 7) Phyllite/the same as intercalations. 8) Black schist/the same as intercalations. 9) Iron formation: a) mixed oxide-silicate facies, b) mixed silicate-oxide facies, c) carbonate facies. 10) Basic tuffite. 11) Metadiabase and/or metavolcanics. 12) Stratigraphic-lithological contact. 13) Fault or tectonic contact. 14) Bedding and dip. 15) Approximate strike and dip of shear-folded beds. 16) Outcrop. 17) Drill hole and number. 18) Allochthonous formations. Stratigraphic units: BGC) Basement Gneiss Complex. A) Arkosite Formation, QIII) Quartzite Formation III. DP) Dolomite-Phyllite Formation: DP_1) Seppola Tuffite Member. DP_2) Salmijärvi Dolomite Member. DP_3) Pääkkö Quartzite Member. DP_4) Pääkkö Iron-Formation Member. DP_5) Salmijärvi Phyllite Member. PhyII) Phyllite Formation II. From Laajoki and Saikkonen (1977, Fig. 3).

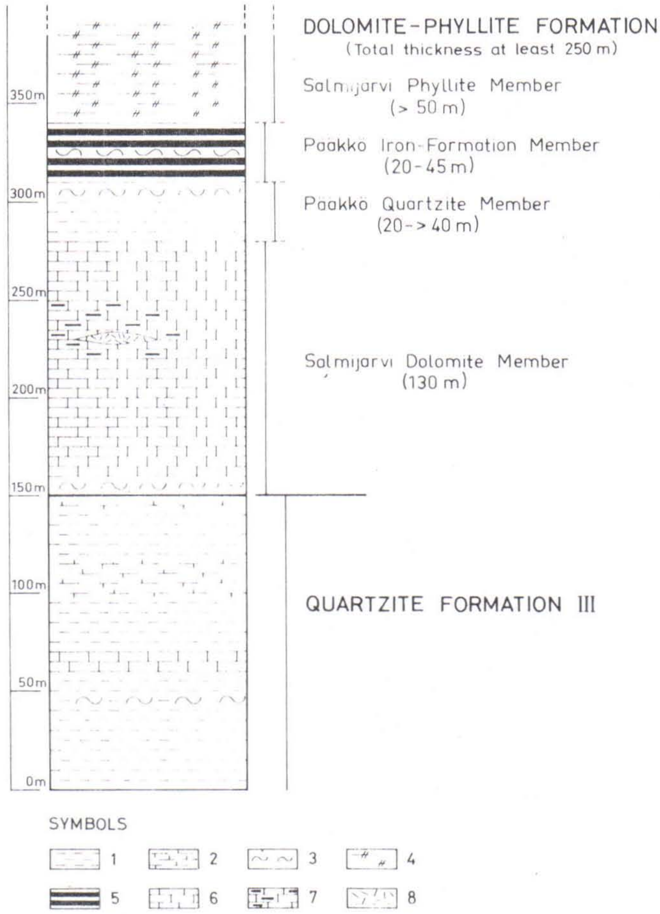

Fig. 3.14. Stratigraphic column from Pääkkö. 1) quartzite, 2) carbonate-bearing quartzite, 3) phyllite, 4) black schist, 5) iron formation, 6) dolomite, 7) amphibole-bearing dolomite, 8) metadiabase.

Stop 10

Nurkkakallio, Puolanka (3442 10, x = 7197.8, y = 530.4)

Arkosite gneiss of the Kettukangas Formation

The outcrop consists of strongly folded and migmatized arkositic paragneiss showing distinctive banding. It can be demonstrated in places that the rock was originally graded-bedded arkose, and consequently the outcrop represents a highly metamorphic turbidite unit. In the western part of the outcrop the increasing degree of recrystallization causes the rock to grade to a fairly homogeneous feldspar gneiss greatly resembling the even-grained Karelidic granites.

Stop 11

Kettukallio, Kalpio (3441 09, x = 7185.4, y = 525.2)

Type outcrop for the quartzites encountered as interformations in the paragneisses of West Puolanka (Taikina-aho 1982, p. 13)

The prevailing quartzite is somewhat impure, containing large amounts of micas (5-20 %) and feldspar (5-25 %), but purer varieties occur in places. In spite of pronounced folding, the primary bedding is still easily visible. The bedding is of a parallel type, and cross-bedding does not seem to have been formed originally.

Metamorphically, the rock is characterized by white sillimanite-quartz knots and light green muscovite aggregates. Amphibolite layers occur here and there, and may be distinguished from "ordinary" amphibolites by their banded structure and highly Ca-rich plagioclase (An content up to 90-96 %) and abundant accessory titanite (age 1785 Ma). The age of the zircon of the banded amphibolite layer is 2540 Ma. If the rock is sedimentary, as indicated by its banded structure, and if the zircon has not been resetted, this age could indicate, that the Kettukallio-type quartzites do not belong to the Presvecokarelidic basement proper.

Stop 12

Suksiharju, Kalpio (3441 12, x = 7183.8, y = 531.0)

The outcrops show the alteration of facies 2 and 3 typical of the southern part of the Staurolite Mica Schist Formation (Fig. 3.9). Facies 2 consists of thin-bedded (n x 1 cm) pelitic metaturbidite showing well-preserved graded bedding. The lower part of each grade consists of quartz and feldspar, mainly plagioclase, which increases in size towards the top. In a few examples, this part contain very faint wavy lamination. The upper parts are rich in biotite and staurolite, although the latter is often pseudomorphosed by coarse muscovite and the pelitic part as a whole is more or less completely andalusitized.

Facies 3 is a semipelitic one with little, if any, staurolite. It shows sedimentary structures indicative of traction transportation, e.g. medium-scale cross-bedding, and ripple-cross lamination is frequently encountered. Here again the staurolite is almost completely muscovitized, but the formation of andalusite is rare. Cordierite-rich knots 5-10 cm in diametre are abundant in places.

Stop 13

Nuottimäki, Somerjärvi (3441 08, x = 7176.22, y = 529.40)

This rather large outcrop forms the type reference site for facies 1 of the Staurolite-Mica Schist Formation. This facies consists of massive or faintly graded meta-sandstone beds, whose thickness is mostly n x 10 cm. Being composed mainly of quartz and plagioclase, they are known as arkositic metaturbidites. Some of the beds have a thin, muscovite-rich upper part. Often the beds are amalgamated to form apparently homogeneous meta-arenite units many metres in thickness. Facies 2 is also represented in this outcrop.

Structurally, the outcrop shows exceptionally well-developed faulting and foliation parallel to the Auho Fault Zone and younger N-S-trending faults. This intense faulting makes it impossible to measure the stratigraphy of the section exactly.

Stop 14

Eskosenvaara (3441 11, x = 7174.7, y = 533.7)

Type section for the Jatuli-type quartzites of the East Puolanka Group at Eskosenvaara

The total thickness of this section is about 200 metres. Starting from the lowermost beds exposed, the following units are defined (Fig. 3.15):

1) The quartzite underlying the Mäntykangas-type conglomerate is a slightly reddish, pure orthoquartzite or a foliated orthoquartzite with very thin, dark mica-laminae.

2) The metaconglomerate-arkosite member can be divided into a lower arkosite bed (a) and an upper metaconglomerate bed (b). The arkosite bed consists of grey, coarse clastic, partly conglomeratic (granule size) and cross-bedded arkose-quartzite/arkosite with magnetite and/or dark mica laminae. The metaconglomerate bed consists of polymictic ortho-conglomerate in which the very variable, well-rounded, severely deformed pebble material includes, in decreasing order, various orthoquartzites, arkosites, vein quartz, greenish sericite quartzites and schists, black chert and argillaceous/volcanic pebbles and fragments. The matrix is of the same magnetite-bearing arkosite material as the lower arkosite bed.

3) The thinly laminated metasiltstone-phyllite member consists of various semipelitic, pelitic and, in lesser proportions, arkosic laminae. The lower parts of the member contain an arkosic bed sequence with very thin pelitic

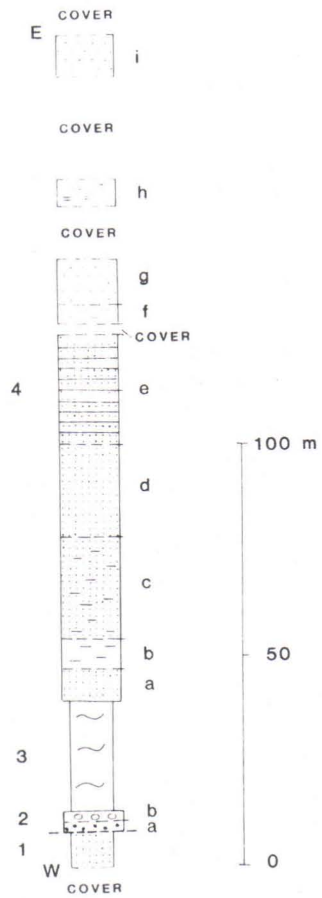

Fig. 3.15. Lithostratigraphic section of the central part of Eskosenvaara, measured by R. Kangas. 1) orthoquartzite, 2) metaconglomerate-arkosite member, a) arkosite bed, b) metaconglomerate bed, 3) metasiltstone-phyllite member, 4) Eskosenvaara quartzite, a) heterogeneous orthoquartzite member, b) lower sericite quartzite member, c) heterogeneous quartzite member, d) orthoquartzite member, e) laminated orthoquartzite-arkose-quartzite member, f) upper sericite quartzite member, g) arkose-quartzite member, h) sericite quartzite - sericite schist member, i) quartz-clastic arkose-quartzite member.

intercalations, but the numbers of arkosic laminae decrease upwards. The continuity of the laminae is fairly good, especially in the upper parts, although some primary lenticular bedding and/or tectonic pinch-and-swell-type compression structures does occur.

4) The major upper quartzite is divided into nine members on the basis of their composition, stratification and bed associations. They are, in stratigraphic order: heterogeneous orthoquartzite (a), lower sericite quartzite (b), heterogeneous quartzite (c), orthoquartzite (d), laminated orthoquartzite - arkose-quartzite (e), upper sericite quartzite (f), arkose-quartzite (g), sericite quartzite - sericite schist (h) and quartz-clastic arkose-quartzite (i). The great variety of quartzites of differing composition is a typical feature. The carbonate-bearing intercalations are associated mainly with sericite-bearing types. In addition to different kinds of stratifications and planar-type cross-beds, other sedimentary structures also occur, e.g. certain types of ripple marks.

KIVESVAARA BEDROCK SECTION AT PALTAMO (T. Heino)

Stop 15

Kivesvaara, Paltamo (3432, x = 7149.85, y = 525.25)

The Kivesvaara bedrock section lies beside the main Oulu - Kajaani road (Route 22), about 20 km west of Paltamo. The rocks of the area are visible in a road cutting face about 500 m in length and 17 metres high at its maximum (Fig. 3.16).

Geologically, the site is located on the western margin of the Kainuu Schist Belt, although correlation of its rocks with those of other Kainuu Schist Belt formations would be impossible without more extensive knowledge of the surroundings of the section.

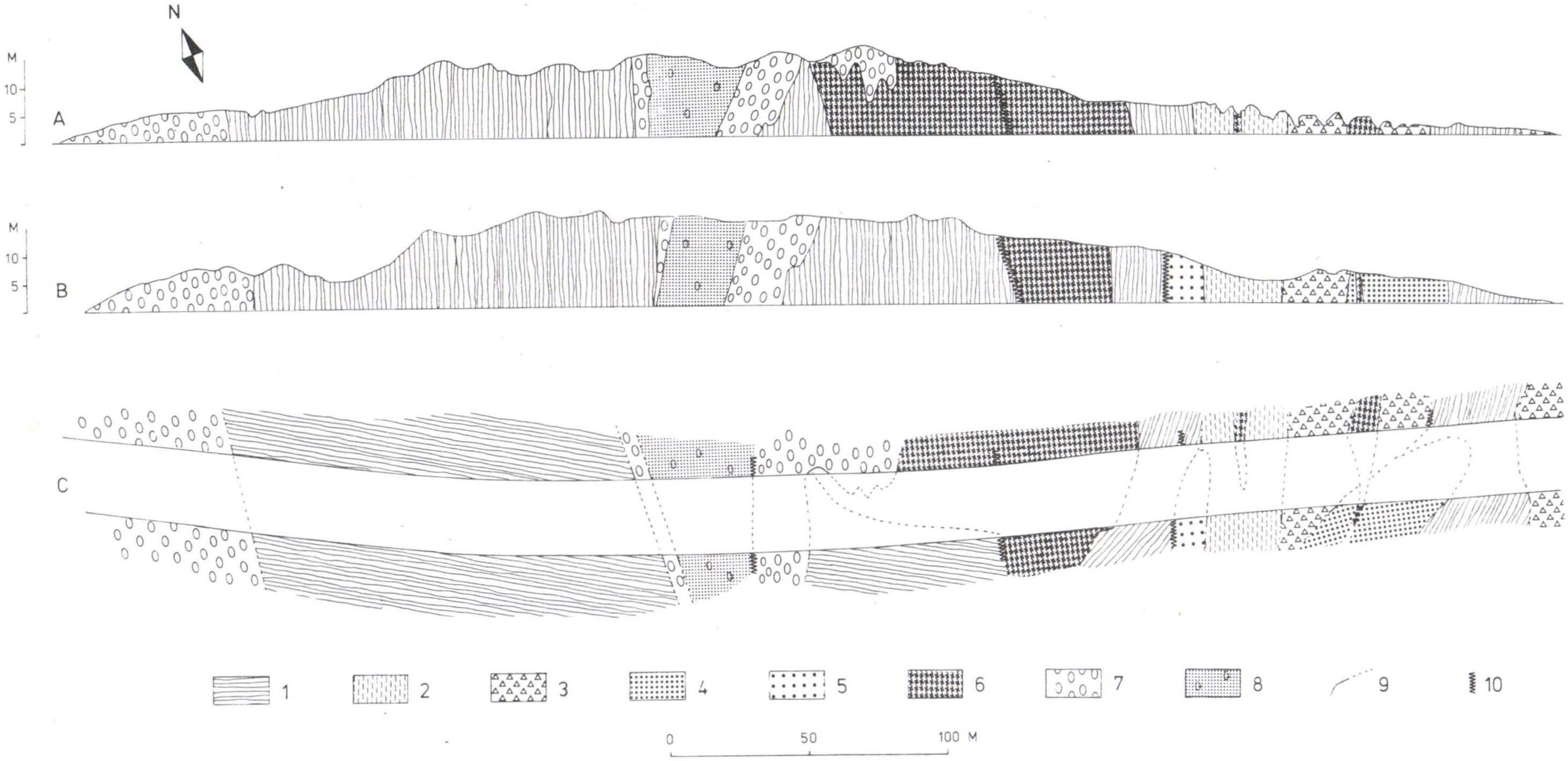

Fig. 3.16. Kivesvaara bedrock section. A) Northern wall, B) Southern wall, C) Horizontal section. Symbols: 1) phyllite, 2) tuff/tuffite, 3) tuff, 4) arkose quartzite, 5) sericite quartzite, 6) metadiabase, 7) conglomerate, 8) conglomerate poor in phenoclasts, 9) contact/inferred, 10) shear zone.

The various contacts and sections suggest that the oldest rocks present are intermediate volcanics, largely metamorphic tuffs and pyroclastic rocks (Fig. 3.16). The eastern part of the section contains tuffs and tuffites, with major fluctuations occurring in rock type and mineral composition.

The majority of the section consists of phyllite composed of very fine-grained quartz, albite and varying amounts of sericite, biotite and chlorite, with large amounts of accessory magnetite, haematite and zircon, especially in the base of each horizon. The phyllite is usually of a grain-size of less than 0.02 mm, although coarser horizons, chiefly of clastic quartz, are found as narrow interlayers, and presents a distinct stratification pattern, with layers varying in thickness from a few millimetres to several centimetres. The direction of stratification is almost parallel to the section itself, and the dips are practically vertical. The schistocity runs N - S and dips approx. 80 ^{o}W. The schistocity is very much more clearly visible on the surface of the section than is the stratification.

The volcanic rocks, the phyllite and the arkosite deposited on top of this are all intersected by veins of metadiabase composed of hornblende, plagioclase, quartz and opaque, all of which are blasto-ophitic in structure. The veins vary in thickness from a few metres up to a hundred metres or so.

The conglomerates encountered in the western part of the section and in the centre have been interpreted as being the youngest rocks in the area. The western edge of the section features a polymictic conglomerate with phenoclasts varying in size from a few millimetres to 50-60 centimetres and composed of quartzites (ortho-quartzite, sericite quartzite, arkose quartzite and arkose), greywackes, phyllites, vein quartz, tourmaline-quartz rock and magnetite-quartz rock or magnetite phenoclasts. The phenoclasts are elongated and flattened to varying degrees, the large quartzite phenoclasts being relatively little deformed, while the arkose and phyllite phenoclasts are highly elongated. The fine-grained matrix of the conglomerate consists of sericite, quartz and magnetite.

The conglomerate in the central part of the section lies unconformably upon the phyllite and metadiabase, the contact being relatively clearly visible in the northern wall of the section. Symbols 7 and 8 in Fig. 3.16 denote the conglomerates, the difference lying in the incidence of phenoclats, with the latter type having only a few compared with the former. The phenoclasts here are very much smaller than those found in the conglomerate of the western edge of the section, although they are similar in composition, containing various types of quartzite and also phyllite, sericite schist, magnetite-quartz rock, vein quartz, metadiabase and jasper. The fine-grained matrix is composed of quartz, sericite and varying quantities of magnetite, which can reach considerable proportions in places.

EXCURSION SITES AT SOTKAMO (M. Havola)

Stop 16

Vuokatti, Sotkamo (3433, x = 7114.82, y = 561.94)

Jatuli-type quartzites at an altitude of a 188 metres from Lake Nuasjärvi

The rocks are completely recrystallized orthoquartzite, sericite quartzite and sericite-kyanite schist with a grain size of 1.0-2.5 mm (Table 3.1). The kyanite porphyroblasts present may be several centimetres long, and the tourmaline is both of detrital and metamorphic origin. Vein quartz with haematite flakes and small haematite cavities in the quartzites are also encountered.

Table 3.1. Mineral compositions of the Vuokatti quartzite, determined by the point counting method.

Minerals	1	2
Quartz	97.8	86.4
Sericite	1.7	13.4
Tourmaline	0.2	0.1
Chlorite	0.1	+
Apatite	+	+
Titanite	+	+
Zircon	+	+
Opaque	0.1	+
Total	100.0	100.0

1. Orthoquartzite (180-MIH-74), Iso-Pölly, Sotkamo.
2. Sericite quartzite (203-MIH-74), Pieni-Pölly, Sotkamo.

The ghost-like quartzite laminae are 1-4 cm thick and white, white-grey, pink, greenish or bluish in colour. The sericite schist interbeds are 5 cm - 3 m thick. A well-preserved large-scale cross-bedding structure can be seen (Fig. 3.17). Other sedimentary structures encountered in the quartzite are ripple marks and graded bedding and conglomerates in several horizons. The conglomerate beds contain pebbles of quartzite and vein quartz, and fragments of sericite schist also occur in places.

The primary bedding follows the head of the hill of Vuokatti and dips 55°-75° to the NW, N or NE. The main fold axis is about $320^{\circ}/65^{\circ}$, and the minor axes are in the area 350°-$10^{\circ}/30^{\circ}$, as measured from the sericite-kyanite schist interbeds. The whole hill of Vuokatti Hill seems to form a large-scale richt-hand fold system.

NW and NNW-trending faults or fracture lines typical of the area can be detected on the outcrops in the form of minor faults or tectonic breccia zones.

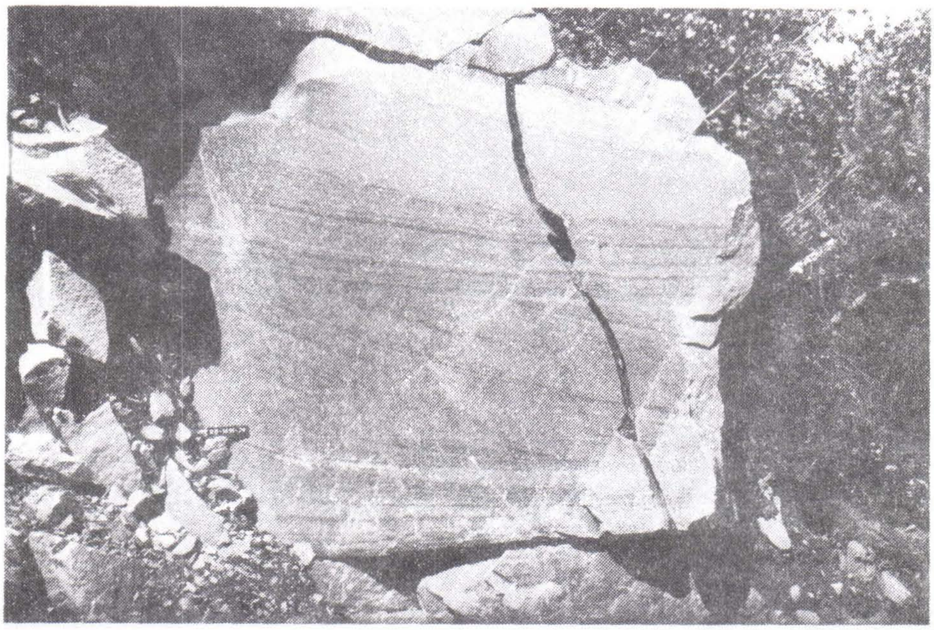

Fig. 3.17. Cross-bedding structure in recrystallized quartzite in a road cutting on the hill of Vuokatti (x = 7114.91, y = 561.75). Photograph by M. Havola.

The Vuokatti area was regionally metamorphosed under conditions of amphibolite facies (kyanite-almandine-muscovite subfacies) by the Svecokarelian orogeny.

Stop 17

Tenetti, Sotkamo (3433, x = 7118.42, y = 561.43)

Silicate-facies rocks of the Tuomivaara iron formation

The formation consists of both chemical and clastic sedimentary components. The rocks are banded, with 0.1-5 m thick beds of varying lithologies. The dominant rock type is a garnet-hornblende rock, the main minerals of which are almandine, hornblende and/or grunerite and carbonate, with some quartz, opaque, biotite, chlorite and dust-like carbon pigment. The second major rock type is garnet-bearing phyllite having as its main minerals quartz, biotite and garnet with some opaque and apatite. Next in abundance is a biotite-quartzite consisting mainly of quartz, biotite and lesser quantities of both K-feldspar and plagioclase with some garnet, opaque, apatite and zircon. There is also a rare amphibole-bearing quartzite containing quartz, chlorite and apatite. Some chemical analyses are given in Table 3.2.

Table 3.2. Chemical composition (wt %) of the two main rock types in the iron formation. Analyst: V. Hoffren, by the XRF method.

	1	2
SiO_2	61.18	61.77
Al_2O_3	10.08	13.12
Fe_2O_3*	21.02	13.64
MgO	2.34	2.84
CaO	2.85	1.67
Na_2O	0.46	2.59
K_2O	0.09	1.95
MnO	1.95	0.27
TiO_2	1.10	1.06
P_2O_5	0.11	0.12
	101.18	99.03

*) total iron as Fe_2O_3.

1. Garnet-hornblende rock (4-MIH-75), Tenetti, Sotkamo.
2. Garnet bearing phyllite (4B-MIH-75), Tenetti, Sotkamo.

The rocks are granoblastic or slightly blastoclastic and weakly foliated, with a grain-size varying from fine to medium. The amount and size (up to 10 cm) of the garnet varies markedly from one bed to another (Fig. 3.18).

The main fold axis runs practically in a N-S direction and plunges about 10° to the north. The folds are tight, isoclinal or in some places chevron-like. The second fold axis is $340^\circ/50^\circ$-80°. The folds are more open than those of of the first generation.

The degree of metamorphism is amphibolite facies (staurolite-almandine subfacies).

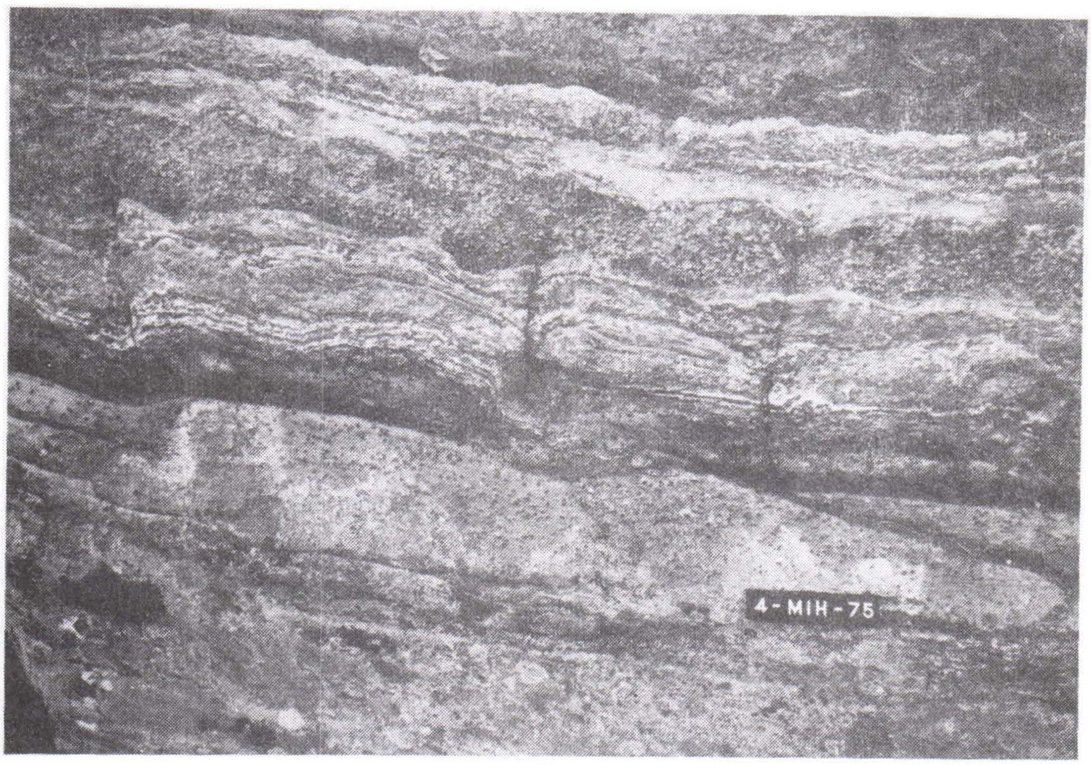

Fig. 3.18. A typical laminated and bedded structure in the silicate iron formation. Garnet-hornblende rock (grey), garnet-bearing phyllite (dark) and chert (white)(x = 7118.42, y = 561.43). Photograph by M. Havola.

Stop 18

Rieskavaara, Sotkamo (3433, x = 7120.44, y = 561.64)

A lenticular occurrence of interformational sharpstone conglomerate belonging to the turbidite conglomerate-quartzite formation

The fragments of the breccia are mostly Vuokatti-type quartzites, with some aplite granite, coarse granite, granodiorite, hornblende gneiss, diabase, limestone and phyllite. The quartzite fragments are mostly angular, while the others are well-rounded and or pebble, cobble and boulder size. Some quartzite fragments are sub-rounded or rounded (Figs. 3.19 and 3.20). The largest fragments or boulders are about 1 m in diameter.

Fig. 3.19. Turbidite conglomerate. The fragments and pebbles are quartzites and phyllite in a clayey-sandy matrix. Scale is 12 cm. (x = 7120.87, y = 561.26). Photo by M. Havola.

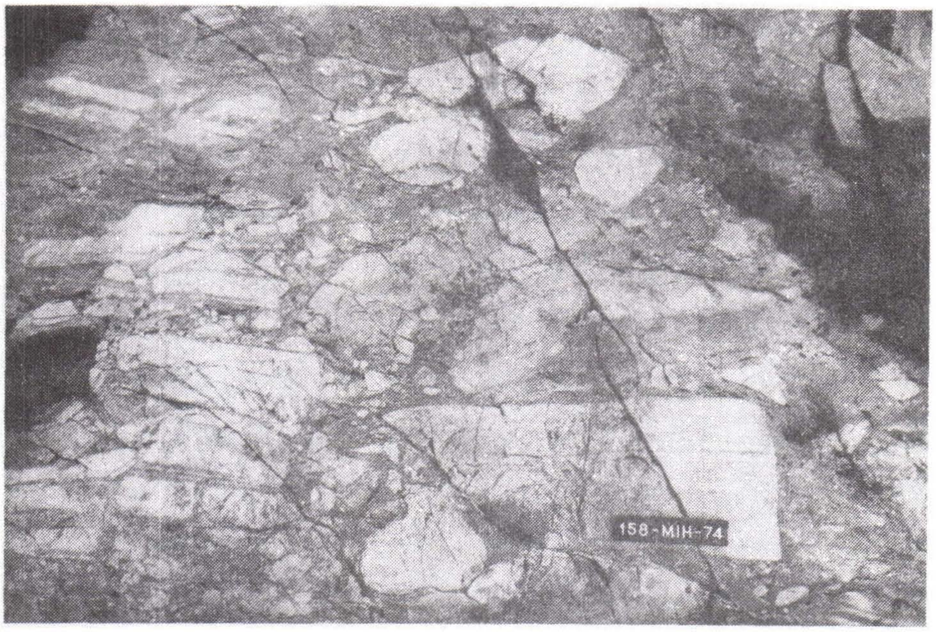

Fig. 3.20. The "breccia of Rieskavaara", a sharpstone conglomerate. The fragments are white quartzite and the matrix white-grey calcareous quartzite. Scale is 12 cm. (x = 7120.41, y = 561.68). Photo by M. Havola.

The matrix may be quartzitic or phyllitic and the clasts/matrix ratio varies greatly. The quartzite matrix is composed of quartz with lesser quantities of biotite, muscovite, chlorite, carbonate and in places tremolite and accessory apatite, zircon, titanite, feldspars and opaque. The phyllitic matrix is composed of quartz, biotite, sericite, opaque and dust-like opaque pigment.

The grain-sizes of the quartzite and the phyllite matrix are 1.5-2.5 mm and 0.3-0.6 mm respectively, and their texture is granoblastic or weakly blastoclastic and slightly foliated. In some places near Rieskavaara grey quartzite layers alternate with phyllite and conglomerate. Cross-bedding and graded bedding structures are also encountered in a few outcrops. The beds vary greatly in thickness but are generally 0.5 cm - 2.5 m. The sharpstone conglomerate on Rieskavaara is approximately 120 m thick.

The bedding is $130^{o}/60^{o}$-$80^{o}/40^{o}$, and NW and NNW-trending fractures and faults are common (Fig. 3.20). Intersecting younger pure glassy quartz veins are typical. These are 2-3 m broad and run about $30^{o}/80^{o}/120^{o}$. Fold-like structures with axis $345^{o}/70^{o}$ are encountered, but some of these may represent primary sub-aqueous gliding or slump structures (Fig. 3.19).

The time span of fragmentation and redeposition is a minor interlude in the deposition of this formation, which may really be sub-aqueous in character. Obviously processes such as fragmentation, collapses and resedimentation have repeated themselves many times, so that you can find conglomerate pebbles or fragments, for example, in a re-deposited conglomerate in some places.

The degree of metamorphism is hard to establish, but may be somewhat lower than at the other places visited.

THE Ni-Cu-Zn MINERALIZATION OF TALVIVAARA, SOTKAMO
(P. Ervamaa and T. Heino)

Geology

Exploration undertaken recently by the Geological Survey of Finland has revealed a large but low-grade Ni-Cu-Zn deposit at Talvivaara, Eastern Finland. The mineralized rock type is black schist, which lies stratigraphically in the upper part (Marine Jatulian) of the Early Proterozoic Jatulian Group. The lead-lead age of the galena separated from one mineralized black schist is 2148 Ma.

The Proterozoic rocks of the area consist mainly of quartzites, black schists and mica schists. Minor serpentinite bodies are also present. The metasedimentary sequence rests unconformably on the Archaean basement. The stratigraphy of the area is presented schematically in Table 3.3. A simplified lithological map and a cross-section through the schist belt are shown in Figures 3.21 and 3.22 respectively.

Table 3.3. Stratigraphy of the Talvivaara area.

PROTEROZOIC	Kalevian	- metaturbitites and mica schist	
PROTEROZOIC	Jatulian	- black schist, normal	
PROTEROZOIC	Jatulian	- black schist, rich in Fe and Mn sulphides	
PROTEROZOIC	Jatulian	- black schist, intercalated by tremolite skarn, enriched with Ni, Cu, Zn and Mn	
PROTEROZOIC	Jatulian	- black schist, normal	
PROTEROZOIC	Jatulian	- diopside skarn	
PROTEROZOIC	Jatulian	- quartzite, alternating with mica schist and black schist	metadiabase dykes
PROTEROZOIC	Jatulian	- orthoquartzite	metadiabase dykes
PROTEROZOIC	Jatulian	- arkose quartzite	metadiabase dykes
		Major Unconformity	
ARCHAEAN		- sericite schist	
ARCHAEAN		- basement gneiss	

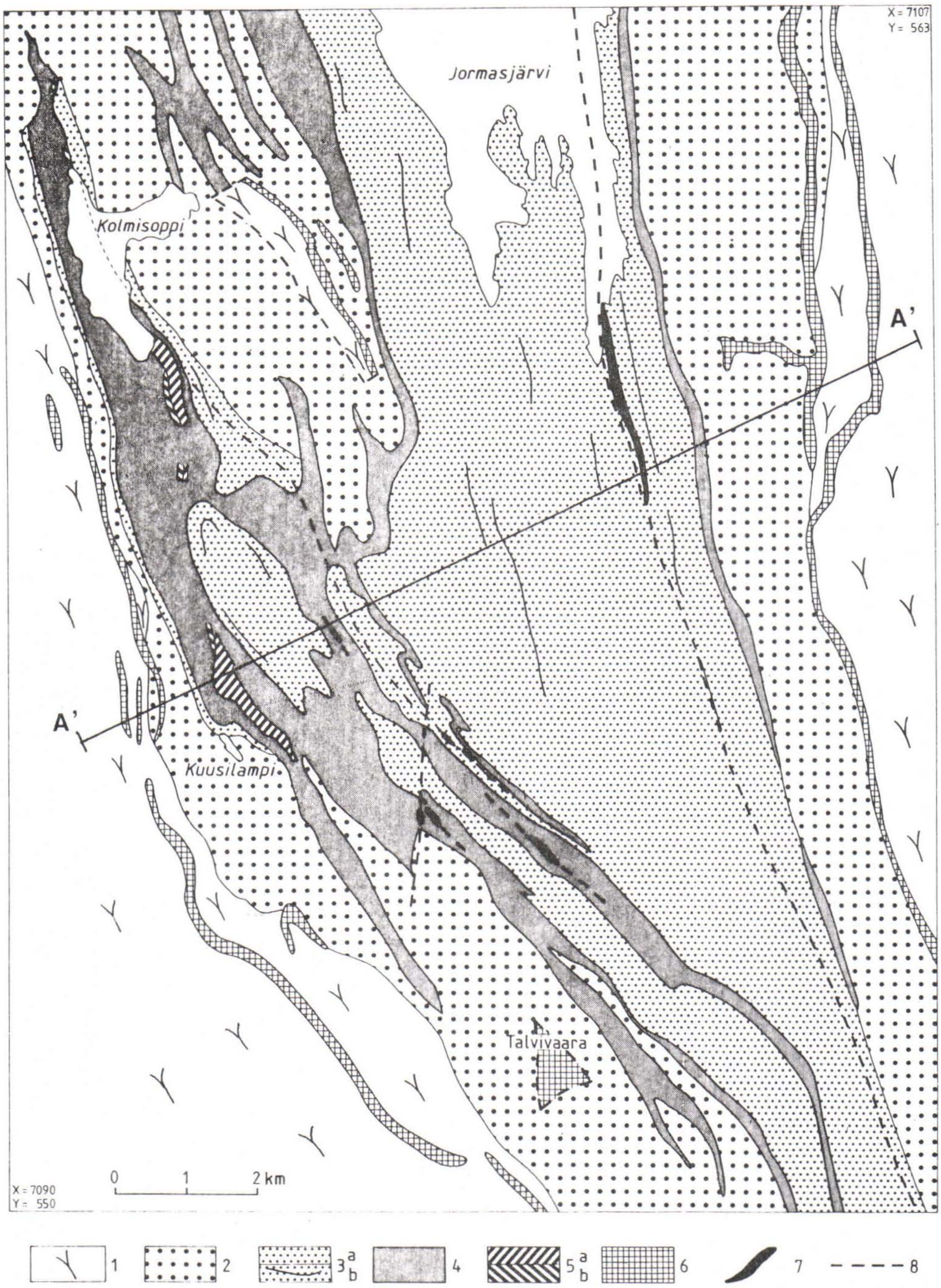

Fig. 3.21. Geological map of the Talvivaara Area. 1. Prekarelidic basement gneiss, 2. quartzite, 3a. mica schist, 3b. black schist intercalates in mica schist, 4. black schist, 5a. Ni-Cu-Zn bearing-black schist, 5b. MnS-bearing black schist, 6. metagabbro and metadiabase, 7. ultramafic rocks, 8. fault.

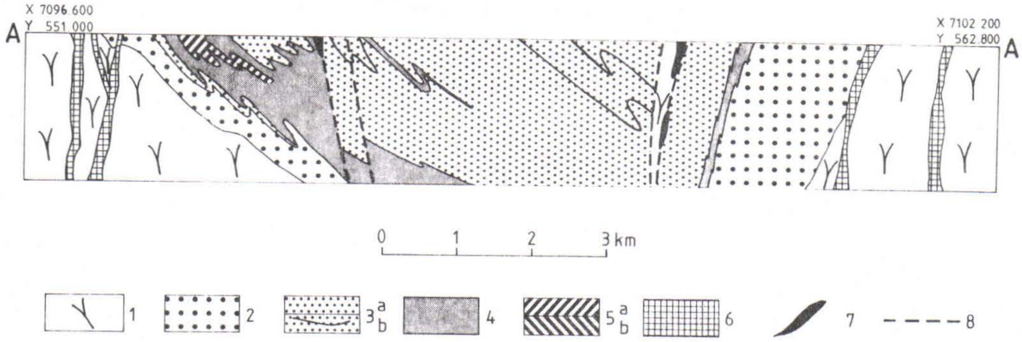

Fig. 3.22. Vertical cross section along line A-A' in Fig. 3.21. For symbols see explanation in Fig. 3.21.

Geochemically, the mineralization is characterized by a strong enrichment of nickel, manganese, zinc, copper and cobalt, whereas the concentrations of many other elements such as iron, carbon, sulphur, vanadium, molybdenum and silver are at the same level as in the surrounding barren black schists (Table 3.4). The enrichment of dolomitic material in the mineralized black schists is clearly indicated by high concentrations of magnesium and calcium as compared with the barren types. On the other hand, the mineralized black schist is characterized by small amounts of feldspars and other detrital clastic material. This observation is sustained also by the low concentration of sodium.

The mineralization in these black schists appears to be generally syngenetic, although the elevated values in the ratios Se/S, S_{34}/S_{32} and U/Th in the mineralized rock as compared with the corresponding values in the barren type indicate that the excess of nickel and associated elements is due to an input of magmatic-hydrothermal solutions poured out into sea water in the original depositional basin.

The Talvivaara black schist contains some 300 million tons of mineralized rock averaging 0.26 % Ni, 0.15 % Cu, 0.54 % Zn, 1.0 % Mn and 8 % graphitic carbon. The main

Table 3.4. Main constituents and some minor elements in the barren black schist (1) and the mineralized black schist (2) at Talvivaara. All figures are percentages.

Element	1	2	Element	1	2
Si	24.2	22.4	Ni	.05	.26
Al	6.4	5.2	Zn	.22	.53
Fe	9.0	9.9	Cu	.05	.14
Mg	1.7	2.5	Co	.003	.02
Ca	1.6	2.7	Pb	.004	.008
Na	1.1	.2	Mo	.011	.010
K	2.4	2.7	V	.061	.063
Mn	.04	.9	Ba	.058	.019
C	6.8	7.5	Cr	.013	.013
S	7.1	9.3	Se	.003	.006
Ti	.39	.41	B	.003	.001
P	.1	.1	As	.010	.003
			Sb	.0004	.0002
			Th	.0008	.0005
			U	.0009	.0023
			Hg	.00010	.00014
			Ag	.0002	.0003
			Au	.0000010	.0000004

sulphides are, in order of decreasing abundance, pyrite, pyrrhotite, Mn-rich sphalerite, pentlandite and chalcopyrite. Alabandite and galena are occasionally also present. The only oxide minerals are rutile and, in minor quantities, uraninite.

Stop 19

One site on the excursion is a small quarry from which rock material has been removed for enrichment tests by the Outokumpu Co. The rock types are mineralized black schist and skarn interbeds.

REFERENCES

Ervamaa, P. & Laajoki, K. 1977, Puolangan prekambristen rautamuodostumien geologiasta. Abstract: On the geology of the Precambrian iron formations in Väyrylänkylä, Puolanka. Geol. Surv. Finland. Rep. Invest. 27, 66 p.

Havola, M. 1980, On the Geology of the Tuomivaara area north of Vuokatti in Sotkamo. Pp. 39-48 in Silvennoinen, A. (ed.) Jatulian geology in the eastern part of the Baltic Shield. Proceedings of a Finnish-Soviet Symposium held in Finland, 21st-26th August, 1979. The Committee for Scientific and Technical Co-operation between Finland and the Soviet Union. Rovaniemi.

Havola, M. 1981, Suomen geologinen kartta 1:100 000, kallioperäkartta, lehti 3433-Sotkamo (Geological Map of Finland 1:100 000, sheet 3433-Sotkamo). Geologinen tutkimuslaitos/Geological Survey of Finland.

Korkiakoski, E. 1981, Puolangan stauroliittikiilleliuskemuodostuman litostratigrafia ja rakenne. Res Terrae, Ser. B, No. 2. 41 p.

Laajoki, K. 1975, Rare-earth elements in Precambrian iron formations in Väyrylänkylä, South Puolanka area, Finland. Bull. Geol. Soc. Finland 47, 93-107.

Laajoki, K. 1980, Outlines of the Precambrian geology of the North Puolanka area, Finland. Res Terrae, Ser. A.1. 11 p.

Laajoki, K. & Saikkonen, R. 1977, On the geology and geochemistry of the Precambrian iron formations in Väyrylänkylä, South Puolanka area, Finland. Geol. Surv. Finland, Bull. 293, 137 p.

Lehto, T. & Niiniskorpi, V. 1977, Pohjois- ja Itä-Suomen rautamuodostumat. Summary: The iron formations of northern and eastern Finland. Geol. Surv. Finland. Rep. Invest. 22, 49 p.

Mäkelä, K. 1976, On the stratigraphy and petrography of the Tuomivaara iron formation in Sotkamo, northern Finland. Bull. Geol. Soc. Finland 48, 71-86.

Meriläinen, K. 1977, Suomen geologinen kartta 1:100 000, kallioperäkartta, lehti 3531-Jonku. (Geological Map of Finland 1:100 000, Pre-Quaternary rocks, sheet 3531-Jonku). Geologinen tutkimuslaitos/Geological Survey of Finland.

Sakko, M. & Laajoki, K. 1975, Whole rock Pb-Pb isochron age for the Pääkkö iron formation in Väyrylänkylä, South Puolanka area, Finland. Geol. Soc. Finland Bull. 47, 113-116.

Taikina-aho, O. 1982, Puolangan lounaisen paragneissi-kompleksin kvartsiittiesiintymien litologia ja rakenne. Res Terrae, Ser. B. No. 4. 44 p.

Väyrynen, H. 1928, Geologische und petrographische Untersuchungen im Kainuugebiete. Bull. Comm. géol. Finlande 78, 127 p.

Wegmann, C.E. 1928, Über die Tektonik der jüngeren Faltung in Ostfinnland. Fennia 50, No. 16, 20 p.

Wilkman, W.W. 1924, Suomen geologinen yleiskartta (General geological map of Finland), 1:400 000, lehti D4, Nurmes.

Wilkman, W.W. 1929, Suomen geologinen yleiskartta (General geological map of Finland), 1:400 000, lehti C4, Kajaani.

4.

THE PROTEROZOIC METASEDIMENTARY AND METAVOLCANIC MANTLE OF THE KUOPIO DOMES

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INTRODUCTION

Kuopio, a town of 80 000 inhabitants, is the commercial and administrative centre of the Savo province in eastern Finland. The terrain in the Kuopio area is intersected by low hills and valleys, the highest hills being about 160 m above sea level. The hills are usually very well exposed, but the valleys with prevailing NW-SE strike are often covered by small lakes, bays of Lake Kallavesi or Quaternary deposits.

The Kuopio area has for a long time been the object of geological interest because of its Archaean gneiss domes mantled by Proterozoic schists. A number of investigations have been published concerning the mantled gneiss domes, the most famous of them being P. Eskola's "The problem of mantled gneiss domes" (1949).

This excursion is directed towards southern Kuopio and is concetrated on the Proterozoic schists overlying the Archaean basement.

GENERAL GEOLOGICAL SETTING

Geologically, Kuopio is located roughly between the Archaean area of eastern Finland and the Proterozoic schists of Central Finland. The bedrock is composed of

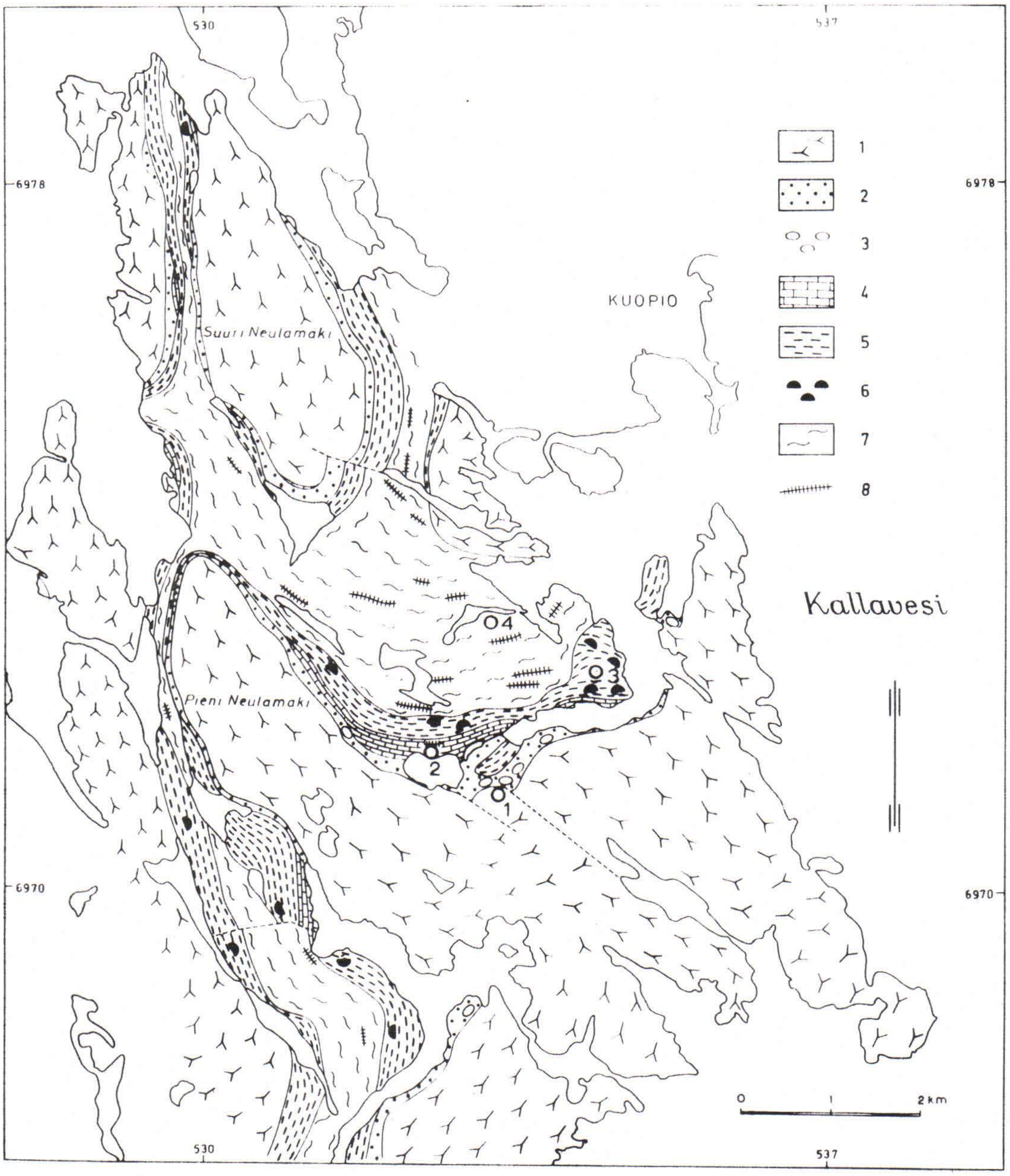

Fig. 4.1. Geological map of the southern Kuopio area. 1 = basement gneiss, 2 = quartzite, 3 = conglomerate, 4 = dolomite and skarn, 5 = basic metalava and amphibolite, 6 = pillow lava, 7 = mica gneiss, 8 = graphite- and iron sulphide-bearing interbeds. The excursion targets are marked with circles.

two major units: 1) the Archaean basement, which takes the form of NW-SE-oriented oval-shaped domes, and 2) the Proterozoic, or more precisely Karelidic, schists occurring between the domes (Fig. 4.1).

The stratigraphy of the schists in the Kuopio area mainly follows the general stratigraphy of the Karelidic schist belt (Fig. 4.2). The Karelian sediments were deposited unconformably on the Archaean basement and were deformed and metamorphosed during the Svecokarelidic orogeny about 1800-1900 Ma ago.

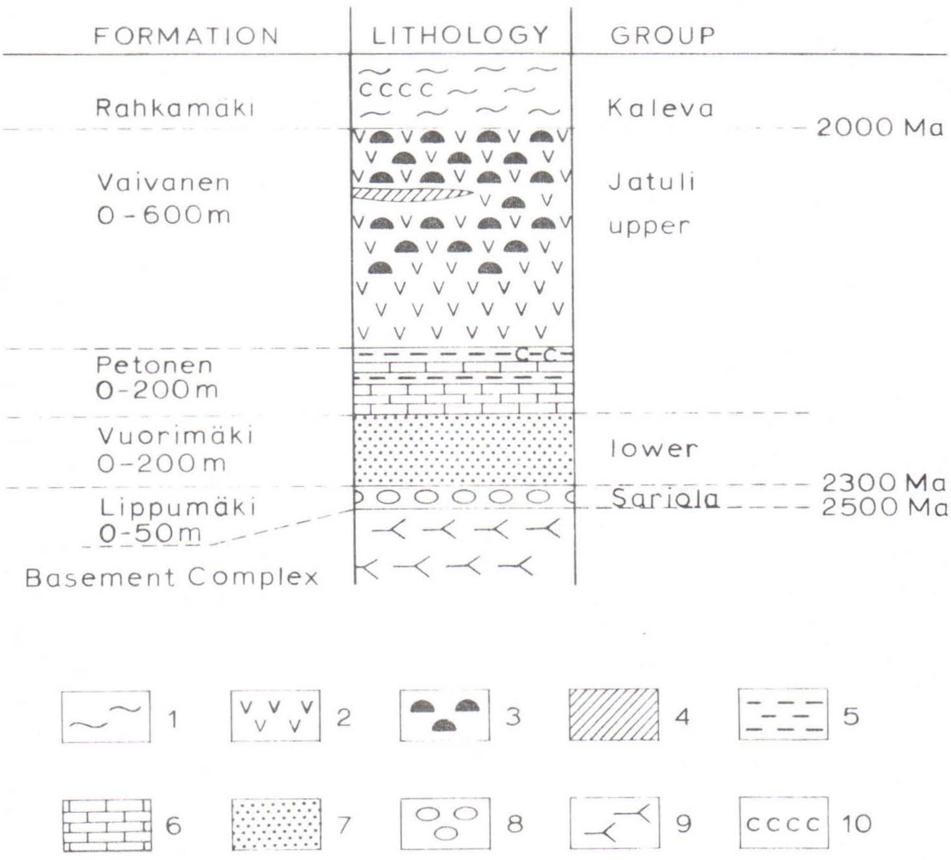

Fig. 4.2. Stratigraphic sequence of the Kuopio area. 1 = mica gneiss, 2 = basic metalava, 3 = pillow lava, 4 = chert, 5 = mica schist, 6 = dolomite and skarn, 7 = quartzite, 8 = conglomerate, 9 = basement gneiss, 10 = black schist interbeds. The boundaries between the groups are according to Luukkonen and Lukkarinen (1983).

ARCHAEAN BASEMENT

For the most part, the Archaean basement consists of light grey or pink migmatite, generally granodioritic but sometimes quartz dioritic in composition. Locally the gneiss is granitic because of later granitization. Schlieren, stromatic and augen structures are common.

The main minerals of the gneiss are oligoclase, quartz, microcline, biotite and sometimes hornblende. Apatite, sphene, zircon, epidote and opaque minerals occur in small quantities.

The basement is cut by numerous veins of granite, granodiorite, tonalite and metadiabase. Amphibolite inclusions are also common.

PROTEROZOIC SCHISTS

The Lippumäki Formation

The lowest unit of the Karelian sequence in the area is the Lippumäki Formation of Sariolan Group, which consists of conglomerate with arkosic and carbonate-rich interbeds. This formation is restricted in extent, being only 50-60 m thick at its maximum.

The conglomerate is polymictic and moderately sorted, and the pebbles are well rounded, although somewhat deformed locally. The pebbles are mostly leucogranitic, but there are also some migmatite and vein quartz fragments. The matrix is composed of arkosite and skarn.

Considering that the material of the conglomerate is derived from the basement, the proportion of leucogranitic pebbles to dark migmatitic pebbles is quite large. The source area must have been mostly granitic or else granitic material has become enriched during the weathering process. The Sariolan conglomerates were most probably deposited in a fluvial environment. The occurrence of carbonate as cement and intercalations suggests that the climate was arid during the deposition.

The Vuorimäki Formation

The Lippumäki Formation is overlain by the Vuorimäki Formation of the Jatulian Group, consisting of quartzite. In many places, however, the quartzite lies directly on the basement. The thickness of the quartzite unit is at most only about 200 m.

As a rule the quartzite is completely recrystallized and shows primary bedding only locally. It contains 80-100 % quartz with impurities of sillimanite, sericite, potassium feldspar, oligoclase, garnet, carbonate, zircon, biotite, apatite, magnetite and occasionally also fuchsite. The potassium feldspar is in the form of microcline and mostly secondary, while the quartzites are strongly granitized, especially near the granitic pegmatites.

The occurrence of zircon suggests a detrital origin for the quartzites. Their depositional environment is obscure, however, because of the scarcity of primary sedimentary structures.

The Petonen Formation

The Petonen Formation, overlying the Vuorimäki Formation, is a nonhomogeneous sequence of mostly carbonate-rich rocks and skarns. The unit is discontinuous and measures only 100-200 m at its thickest. The boundary between the Vuorimäki and Petonen Formations is a gradual one with thin carbonate-bearing interbeds occuring in the upper part of the quartzite.

The carbonate sediments are usually dolomitic and impure. The skarns contain mostly diopside and tremolite. Mica schist, connected locally with black schist, is the most common of the interbeds. The carbon content of the black schist may reach 30-50 %. In the upper part of the Petonen Formation there are amphibole-bearing schists in which the amphibole is either antophyllite, cummingtonite or hornblende. Some thin chert intercalations occur locally.

The Vaivanen Formation

The Petonen Formation is overlain by the Vaivanen Formation, which consists mainly of basic metalava. The formation is fairly continuous, and varies in thickness between 10 and 700 m. In places there are chert interbeds 2 to 10 m thick.

The lowest part of the metalava unit is massive and homogeneous. In the upper part pillow structures are common and there are also pillow breccia structures locally. There is little matrix between the pillows. Sometimes pillows contain small amygdules. The flattened pillows observed in some outcrops show that the lava has been deformed, and the outcrops of the most deformed pillow lava look like banded amphibolite.

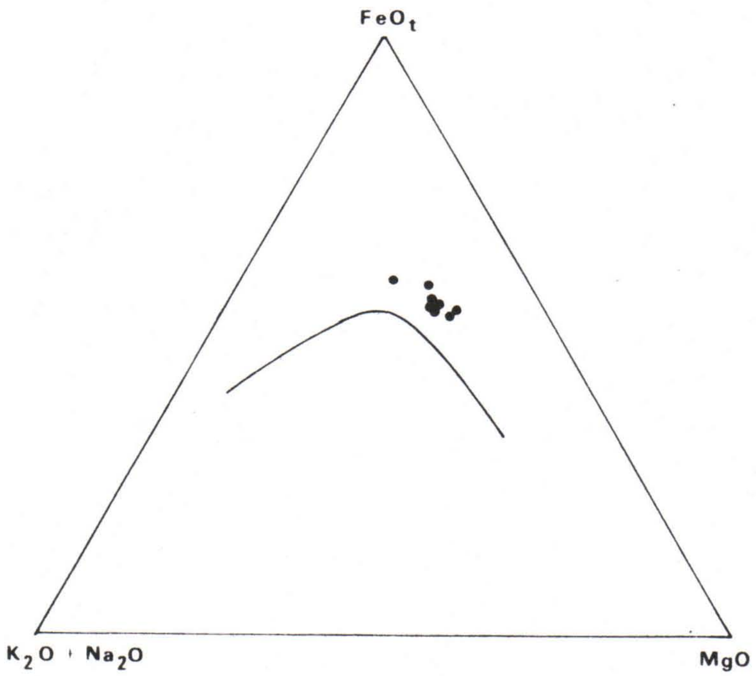

Fig. 4.3. Basic metalavas of the Kuopio area on the AFM diagram. Analyses are as in Table 4.1.

Table 4.1. Chemical composition of various basic lavas in the Kuopio area (weight per cent). t = total iron.

	1a	1b	1c	2	3	4	5	6
SiO_2	51.12	51.72	47.85	51.00	51.55	49.16	53.19	49.12
TiO_2	1.39	1.32	1.50	1.06	1.26	1.51	1.84	0.98
Al_2O_3	14.30	13.72	14.63	13.63	13.66	13.82	14.12	13.48
FeO_t	11.81	10.70	12.88	11.50	12.12	13.66	11.94	11.69
MnO	0.19	0.19	0.20	0.19	0.17	0.20	0.18	0.19
MgO	6.59	5.78	7.13	7.14	6.27	6.46	4.44	7.31
CaO	9.69	10.35	10.60	11.82	10.08	10.23	8.50	12.44
Na_2O	2.61	2.60	2.31	2.49	2.98	3.11	3.39	2.50
K_2O	0.85	0.50	1.04	0.22	0.37	0.32	0.46	0.53
P_2O_5	0.17	0.18	0.20	0.11	0.16	0.15	0.23	0.11
	98.72	97.06	98.34	99.16	98.62	98.62	98.29	98.35

1. Pillow lava, Vaivanen, Kuopio. 1a = lower part of the pillow, 1b = the centre of the pillow, 1c = the upper part of the pillow. Analyst: V. Hoffren.
2. Pillow lava, Jynkkä, Kuopio. Analyst: V. Hoffren.
3. Pillow lava, Pieni Neulamäki, Kuopio. Analyst: V. Hoffren.
4. Pillow lava, Valkealampi, Kuopio. Analyst: V. Hoffren.
5. Pillow lava, Pitkälahti, Kuopio. Analyst: V. Hoffren.
6. Basic lava, Väärälahti, Kuopio. Analyst: V. Hoffren.

The basic metalava consists mainly of hornblende and plagioclase (An 40-50 %), and is tholeiitic in chemical composition (Table 4.1, Fig. 4.3). The matrix of the pillow lava is diopside skarn.

The eruption of the pillow lava was submarine and took place along fractures. Silica dissolved from hot lava and precipitated as chert.

The Rahkamäki Formation

Uppermost in the Karelian sequence in the Kuopio area is the Rahkamäki Formation of the Kalevian Group, which mainly consists of mica gneiss. The thickness of this unit is unknown.

The mica gneiss shows distinct bedding and generally also graded bedding. There are convolute bedding structures locally. The beds of mica gneiss consist of a pelitic upper part and a psammitic lower part. The thickness of the beds varies from ten centimetres to about one metre, the pelitic parts usually being the thicker of the two. Graphite and iron sulphide-bearing interbeds are common and may be several metres thick. Carbonate and amphibole-bearing intercalations 2 to 10 cm thick also occur locally.

The pelitic layers contain mainly biotite, plagioclase, quartz, cordierite, sillimanite, staurolite and andalusite. The psammitic layers are made up of quartz, plagioclase and biotite and sometimes garnet. Tourmaline is a common accessory mineral in the mica gneiss.

The material of the mica gneiss was deposited by turbidity currents in deep water. The graphite and iron sulphide-bearing interbeds were deposited under anoxygenic deep-sea conditions.

DYKES CROSSCUTTING THE KARELIAN SEQUENCE

Granite pegmatite dykes are the most common, being encountered in all the Karelian formations. Quartz dioritic dykes occur in the Vaivanen and Rahkamäki Formations. Metadiabase dykes are found only in the formations underlying the Vaivanen Formation. Their chemical composition greatly resembles that of the basic metalava and a genetic connection with the basic metalava seems evident.

METAMORPHISM

The Archaean basement was metamorphosed under the conditions of the amphibolite facies. Afterwards it has undergone a slight retrogressive metamorphism.

The Karelidic schists were metamorphosed in amphibolite facies during the Svecokarelidic orogeny 1800-1900 Ma ago. Their metamorphism can be examined more closely on the basis of the mineral assemblage of the mica gneiss. The staurolite of the pelitic parts is replaced by sillimanite. Thus their metamorphism must have taken place near the P-T conditions of the breakdown reaction of staurolite. The metamorphic conditions must also have been near the breakdown reaction of muscovite. Hence, the metamorphism of the pelites will have taken place at a temperature of 620-670 ^{o}C and a pressure of 3-4 kb. The Karelidic schists have also undergone slight retrogressive metamorphism.

EXCURSION SITES

Stop 1

An unconformity between the Archaean basement and the Lippumäki Formation

Lippumäki, Kuopio (3242, x = 6971.2, y = 533.3)

The basement gneiss at Lippumäki is granodioritic, except near the unconformity, where it is granitic because of granitization. The basement gneiss shows augen gneiss structures in which the augens are secondary potassium feldspar. In the immediate vicinity of the unconformity the basement contains fairly abundant secondary epidote due to shearing.

The Lippumäki Formation consists of alternating conglomerate and arkosite beds upon the basement (Fig. 4.4).

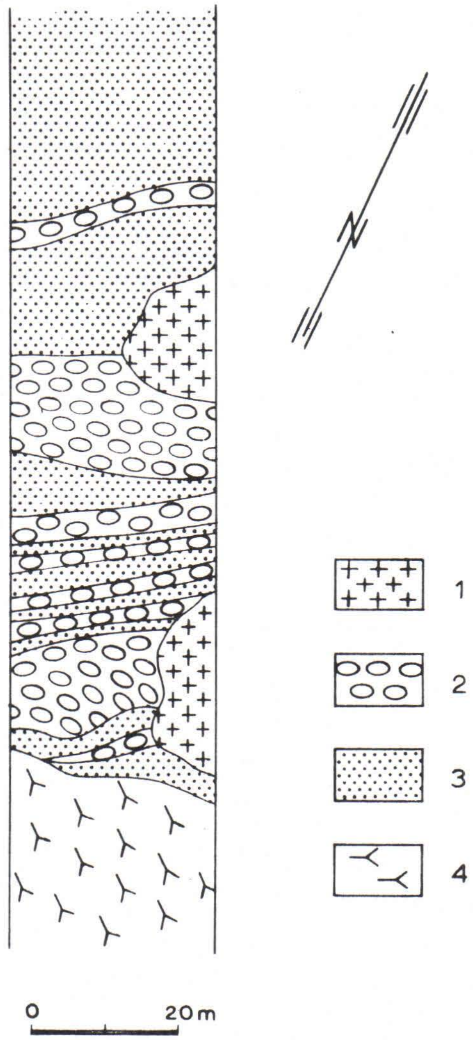

Fig. 4.4. Section of the Lippumäki Formation at Lippumäki. 1 = granite pegmatite dykes, 2 = conglomerate, 3 = arkosite, 4 = Archaean basement gneiss.

The basal part is composed mostly of conglomerate, which grades upwards into more arkositic material. Some pegmatite dykes crosscut the unconformity.

The diameter of the fragments in the conglomerate is usually less than 10 cm, but some are bigger, up to 10-20 cm. The pebbles and cobbles are very well rounded.

Some of them have a thin weathering crust. The material in the conglomeratic beds is fairly well sorted, and the fragments mostly touch one another. The little matrix present consists of arkosite with calcium-bearing material.

The conglomerate of Lippumäki is polymictic, the fragments are for the most part leucogranitic, but there are also some darker migmatitic pebbles and a few of vein quartz. The leucogranitic fragments contain mainly microcline, quartz and oligoclase, with smaller amounts of biotite, sphene, apatite and epidote. The darker migmatitic pebbles have biotite among the main minerals. The potassium feldspar grains are relatively large and fresh and contain smaller sericitized plagioclase grains as inclusions. Thus the potassium feldspar is mostly secondary. The matrix of the conglomerate is made up of quartz, epidote, oligoclase and sphene.

The arkosic interbeds contain quartz, microcline and oligoclase with occasional biotite. The accessory minerals are apatite, sphene and hornblende. Some of the beds are calcareous, being composed of quartz, microcline, oligoclase, epidote, carbonate and either tremolite or diopside. The boundary between the skarn beds and arkosic beds is a gradual one. The thickness of the skarn interbeds, which show boudinage structures locally, is 20 to 100 cm.

Stop 2

Diopside tremolite skarn with dolomite interbeds

Petosenlampi, Kuopio (3242, x = 6971.6, y = 532.5)

This outcrop belongs to the Petonen Formation. The rock is skarn with dolomite intercalations 2 to 10 cm thick and one mica schist interbed a few metres in thickness. The skarn is intensively folded and shows prominent axial plane schistosity. The dolomite interbeds are sometimes broken up into boudins.

The major minerals of the skarn are tremolite, diopside, andesine and biotite. Carbonate and sphene occur in smaller amounts. The skarn contains alternating tremolite, diopside and biotite-rich layers.

The mica schist interbed is composed mainly of andesine, biotite and quartz. Some of the mica schist contains sillimanite porphyroblasts, although these are almost completely sericitized. The accessory minerals of the mica schist are tourmaline, apatite and zircon.

Stop 3

Basic metalava with pillow structures

Vaivanen, Kuopio (3242, x = 6972.5, y = 534.4)

This outcrop belongs to the Vaivanen Formation of the upper part of the Jatulian Group.

The largest pillows of metalava are 1 to 2 metres long and approximately half a metre thick. The top direction is to the north. The pillows are close to one another, and the small amount of matrix between them is skarn in composition and deeply eroded. Calcium silicate-bearing material also occurs in the joints in the middles of the pillows. It is plausible that the joints may have been created as a consequence of cooling and shrinking of the lava. There are some small amygdules, and also some varioles in places, in the marginal portions of the pillows.

The main minerals of the basic metalava are hornblende and plagioclase (An 40-50 %), the former being partly altered to biotite. Sphene is also fairly abundant as an accessory mineral. The amygdules are filled with epidote, carbonate and quartz. The varioles consist of plagioclase. The interstitial skarn is composed of diopside, carbonate and plagioclase. The chemical composition of the basic metalava is tholeiitic (Table 4.1).

There is no significant difference in composition between the centres and the margins of the pillows.

Stop 4

Mica gneiss

Kivilampi, Kuopio (3242, x = 6973.1, y = 533.2)

This outcrop belongs to the uppermost stratigraphic unit of the Kuopio area, the Rahkamäki Formation of the Kalevian Group. Though the mica gneiss is relatively strongly metamorphosed it shows distinct bedding and also graded bedding. The beds consist of psammitic lower parts and pelitic upper parts, the thickness of which is 20 to 50 cm. Having initially been fine-grained, the pelitic parts are now coarser than the psammitic parts because of metamorphism. A convolute bedding structure that has developed in one psammitic bed can also be seen in this outcrop.

The main minerals of the psammitic parts are quartz, plagiocalse (An 20-40 %) and biotite, and the accessory minerals tourmaline, garnet, apatite, zircon and opaque. Garnet and tourmaline occur as porphyroblasts. The opaque minerals are pyrite, pyrrhotite and graphite. Some psammitic beds, e.g. the bed showing convolute structure, are fairly quartz-rich and their composition is almost quartzitic.

The pelitic parts contain mainly biotite, plagioclase (An 15-25 %), quartz, cordierite, sillimanite, andalusite and staurolite. Tourmaline, opaque, apatite and anto-phyllite occur as accessory minerals.

REFERENCES AND FURTHER READING

Eskola, P. 1949, The problem of mantled gneiss domes. Quart. J. Geol. Soc. London 104, 461-476.

Luukkonen, E. & Lukkarinen, H. 1983, Stratigraphic map of Middle Finland. (in preparation).

Preston, J. 1954, The geology of the Pre-Cambrian rocks of the Kuopio district. Ann. Acad. Sci. Fennicae, Ser. A III, 40. 111 p.

Wilkman, W.W. 1938, Kivilajikartan selitys C 3, Kuopio. English summary. (Explanation to the general geological map of Finland, 1:400 000.) 171 p.

5.

EXOGENIC FEATURES IN THE STRATABOUND Cu-Co-Zn ORE DEPOSIT OF OUTOKUMPU; A SHORT REVIEW

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INTRODUCTION

The Outokumpu ore deposit (62°46'N, 29°E) is composed of two stratabound, metamorphosed ruler-shaped ore bodies almost 4 km long, Keretti (28MT) and Vuonos (6MT). The metal contents are usually in the range: Cu 2-4 %, Zn 0.5-2 %, Fe 20-30 %, and S 15-30 %. There is some Co, Au and Ag. The ore mineralogy is simple: Pyrite + pyrrhotite or pyrrhotite ± pyrite, chalcopyrite, sphalerite and cobalt pentlandite are commonly the main minerals. Significant accessories, some of which may be considerable in places, are cubanite, magnetite, stannite and argentian pentlandite.

More than 70 years after their discovery, in 1910, the ore reserves will soon be exhausted.

GEOLOGICAL SETTING

The host rock assemblage of the ore deposit and the minor sulphide occurrences elsewhere in the province is dominated by the presence of serpentinite, frequently accompanied by metacarbonate rock, skarn and quartzite - the host rock of the ore at Outokumpu. This assemblage is usually bordered by black schist and regionally enclosed by mica schist. Basic volcanic rocks have recently been identified as belonging to the assemblage (Park & Bowes 1981), and also gabbro (Koistinen 1981). The serpentinites have been referred as ophiolites by various authors, e.g. Wegmann (1928), Huhma (1975, 1976), Gaál et al. (1975), Koistinen (1981), or as 'serpentinized mantle peridotites' (Bowes & Gaál 1981). On the other hand, some authors have drawn attention to certain differences compared with well-documented examples of ophiolites from elsewhere (later) in the geological record. These include the absence of sheeted dyke complexes in the area (Parkkinen & Reino, in press), and the nontectonic emplacement of the ultramafic material into the metasediments as magma or crystal mush (Park, in press). According to Park, this took place considerably earlier than the development of the thrust nappe which transported the rocks and ore of the assemblage into the region (Koistinen 1981).

The ore was laid down in a submarine basin in an early phase during the Svecokarelian orogenic cycle. Later, during the crustal shortering, approx. 1.9-1.85 b.y. ago, the ore deposit became deformed, metamorphosed and in parts mobilized.

Fig. 5.1 (Koistinen 1981, Fig. 22) shows the regional position of the Outokumpu Ore District, an area where Cu-Co-Zn ore deposits and minor related sulphide masses are found. The district lies in the junction area between the Archaean basement (B) and the younger crust composed of Svecofennian sedimentary-volcanogenic assemblages SW of the major suture (Bowes et al., in press).

EXOGENIC FEATURES IN THE ORE

The ore and rocks at Outokumpu have been subject to a number of detailed descriptions. Among the earlier authors, mention should be made of Haapala (1936), Vähätalo (1953) and Peltola (1960, 1968). Our ideas on the genesis of the ore deposit have developed with the increasing

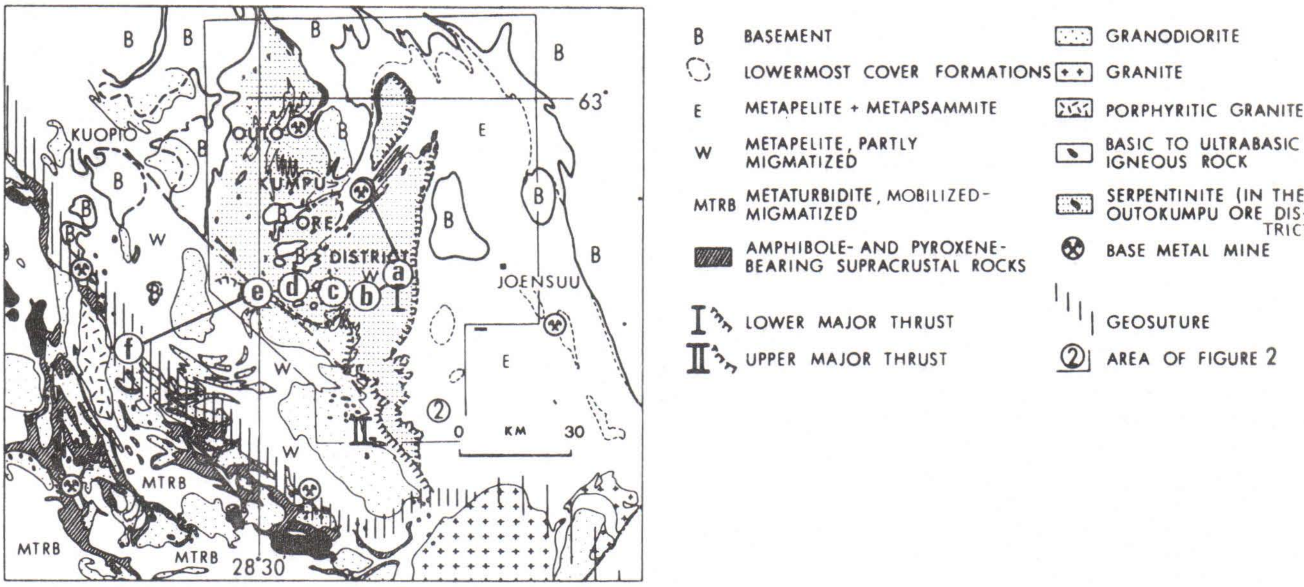

Fig. 5.1. Major tectonic features of the Outokumpu Ore District and surrounding areas. Excursion route: Mine = Stop 1, a = stop 2, b = stop 3, c = stop 4, d = stop 5, e = stop 6, f = stop 7.

data. It is evidently polyphase deformation and metamorphic modification of the deposit which has made it laborious to trace its original characteristics. Evidence of the submarine exhalative mode of deposition of the ore has also emerged gradually (Borchert 1954; Mäkelä 1974; Huhma 1976; Peltola 1978; Koistinen 1981; Treloar et al. 1981; Park, in press). The present characteristics of the ore are inherited partly from the time of deposition (Mäkelä 1974; Peltola 1978; Koistinen 1981) and partly from different times during its structural and metamorphic evolution (Mikkola & Väisänen 1972; Gaál et al. 1975; Gaál 1977; Koistinen 1981).

The original setting of the ore with respect to the adjacent sediments and the ultramafic unit is revealed as the minor and major tectonic thrusts, extensive F_1 folds and less extensive post-D_1 structures are reduced (Koistinen 1981). As this is done, the ore deposit is shown to be originally a wide layer of massive sulphides underlain by a low-grade stockwork deposit in the sediments. This major feature relates ore deposition to processes active early in the geological evolution of the region. A prerequisite for the generation of the stratabound layer of sulphides and the associated stockwork deposit is understood to be the availability of a heat source initiating a convection cell and of units from which metals could have been extracted.

Most of the chert (now quartzite) lies below the original layer of massive sulphides, but a minor, carbonaceous part of the chert postdates the ore (Koistinen 1981), and hence the ore deposition is syngenetic to the chert deposition. The origin of the chert and the serpentinisation are related (Huhma & Huhma 1970). There is also evidence of a close relationship between the serpentinisation and the exhalation of the ore (Park, in press).

As a result of the structural evolution of the ore and the surrounding lithology, the low-grade stockwork deposit now forms an elongated, disseminated zone inverted above the massive ore. This is encountered at Keretti and Vuonos, and in the latter locality the highest grade part has been used for nickel production from an open pit (Gaál et al. 1975; Koistinen 1981; Parkkinen & Reino, in press). Characteristic of the zone is the enrichment of Ni, Cu and Co, and other metals also present in the massive ore. Also characteristic is the presence of Ca-deficient silicate minerals, e.g. cummingtonite and orthoamphibole, whereas calcic silicates such as chrome diopside and chrome tremolite occur elsewhere. The composition of the non-calcic zone is interpreted as being derived from the time of exhalation, and the rocks there are regarded as metamorphic equivalents of sediments (chert with limestone layers) altered by gas and fluid leaching agents (Treloar et al. 1981).

Due to the extensive mobilisation of the massive ore during the polyphase deformation and regional metamorphism, it is the lowest strain areas that contain layers of ore in their original stratabound position. The layers of ore, like the layers of the adjacent rocks, have been intensely folded. The thickness of the individual layers has been modified by deformation, particularly by F_1 flow folds, and hence the original thickness is hard to demonstrate. The beds are expressed in the form of compositional layering, now from minute bands to beds several decimetres thick. The early metamorphic segregation banding is well visible in the non-mobilized parts, the distinction from the sedimentary banding being obvious, as observed at the fold noses, where the cutting relations can be demonstrated. No structures resembling framboids have been found, and such structures are unlikely to have been preserved under the metamorphic conditions which prevailed ($600 \pm 50^{\circ}C$, 3.5 ± 1 kbar, Treloar et. al. 1981; Treloar & Putnis 1982).

The extensive mobilisation of ore certainly poses problems for the study of the primary zoning, although positive results may be expected in the non-mobilized parts of ore, as the layers are traced around the fold noses (Warrender, personal communication). At the moment it is only known that both horizontal and vertical primary zoning do exist. One feature of the vertical zoning is the position of the pyritic ore originally overlying the pyrrhotitic layer, while one feature of the horizontal zoning is the variable extension of the pyrrhotitic ore with respect to the margin of the pyritic ore in the original basin.

EXCURSION SITES

Stop 1

Outokumpu, Vuonos mine

Visit underground. Cu-Co-Zn ore.

The open pit of Vuonos:

Some rocks of the Outokumpu association are seen in the open pit (no longer worked): serpentinite, metadolomite rock, chrome diopside skarn, chrome tremolite skarn, quartzite (quartz rock) with skarn layers, carbonaceous quartzite, black schist and mica schist. The nickeliferous zone is poorly exposed in the presently accessible parts of the quarry.

Road cuttings, Svecokarelian schists (except c), Outokumpu-Varkaus

This part of the excursion demonstrates the gradual increase in neosome development from ENE to WSW, beginning from mica schist underlain by Archaean gneisses and ending mica migmatite near the major suture. Generally the metamorphic modification of the sedimentary layering also increases towards the suture. More than one set of structures and metamorphic fabrics is shown by each outcrop.

Stop 2

Viinijärvi

Mica schist (quartz + plagioclase + biotite ± muscovite ± garnet). Calc-silicatic layers/lenses, sedimentary layering.

Stop 3

Juojärvi

Mica schist as a), a microtonalite dyke, granite-granodiorite dykes.

Stop 4

Papinniemi (Valamo monastery)

Basement gneiss (approx. 2.7 b.y. granitoid) of a small, local window.

Stop 5

Humalajärvi

Veined gneiss. More than one pulse of neosome.

Stop 6

5-7 km W of Karvio

Veined gneiss. Kuopio - Suvasvesi - Savonranta wrench fault zone (see Halden 1982).

Stop 7

Town of Varkaus, BP station

Schollenmigmatite.

REFERENCES

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

Bowes, D.R. & Gaál, G. 1981, Precambrian record of the eastern North Atlantic borderlands. In: Kerr, J.W. & Ferguson, A.J. (eds.) Geology of the North Atlantic Borderlands 31-55. Mem. Can. Soc. Pet. Geol.

Bowes, D.R., Halden, N.M., Koistinen, T.J. & Park, A.F. in press, Structural features of basement and cover rocks in the eastern Svecokarelides. In: Kröner, A. & Greiling, R. (eds.) Precambrian Tectonics Illustrated. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

Gaál, G. 1977, Structural features of Precambrian, strata-bound sulphide ore deposits of Finland. Geol. Fören. Stockholm Förh. 99, 118-126.

Gaál, G., Koistinen, T. & Mattila, E. 1975, Tectonics and stratigraphy of the vicinity of Outokumpu, North Karelia, Finland. Bull. Geol. Surv. Finland 271, 1-67.

Halden, N.M. 1982, Structural, metamorphic and igneous history of migmatites in the deep levels of a wrench fault regime, Savonranta, eastern Finland. Trans. of the Royal Soc. of Edinburgh, Earth Sci. 73, 15-30.

Huhma, A. 1975, Geological map of Finland 1:100 000, sheets 4222, 4224, 4311. Explanation to the map. English summary: Precambrian rocks of the Outokumpu, Polvijärvi, and Sivakkavaara map sheet areas. Geological Survey of Finland, Otaniemi.

Huhma, A. 1976, New aspects to the geology of the Outokumpu region. Bull. Geol. Soc. Finland 48, 5-24.

Huhma, A. & Huhma, M. 1970, Contribution to the geology and geochemistry of the Outokumpu region. Bull. Geol. Soc. Finland 42, 57-88.

Koistinen, T.J. 1981, Structural evolution of an early Proterozoic strata-bound Cu-Co-Zn deposit, Outokumpu, Finland. Trans. of the Royal Soc. of Edinburgh, Earth Sci. 72, 115-158.

Mäkelä, M. 1974, A study of sulfur isotopes in the Outokumpu ore deposit, Finland. Bull. Geol. Soc. Finland 267, 1-45.

Mikkola, A.K. & Väisänen, S. 1972, Remobilization of sulphides in the Outokumpu and Vihanti ore deposits, Finland. 24th Int. Geol. Congr. 4, 488-497.

Park, A.F. 1983, in press, Sequential development of metamorphic fabric and structural elements in polyphase deformed serpentinites in the Svecokarelides of eastern Finland. Trans. of the Royal Soc. of Edinburgh, Earth Sci. 74.

Park, A.F. & Bowes, D.R. 1981, Metamorphosed and deformed pillows from Losomäki: evidence of sub-aqueous volcanism in the Outokumpu association, eastern Finland. Bull. Geol. Soc. Finland 53, 135-145.

Parkkinen, O. & Reino, J. in press, Running heading: Outokumpu-type Ni-occurrences, Vuonos and Keretti.

Peltola, E. 1960, On the black schists in the Outokumpu region in Eastern Finland. Bull. Comm. géol. Finlande 192, 1-107.

Peltola, E. 1968, On some geochemical features in the black schists of the Outokumpu area, Finland. Bull. Geol. Soc. Finland 40, 39-50.

Peltola, E. 1978, Origin of Precambrian copper sulfides of the Outokumpu District, Finland. Econ. Geol. 73, 461-477.

Treloar, P.J., Koistinen, T.J. & Bowes, D.R. 1981, Metamorphic development of cordierite-amphibole rocks and mica schists in the vicinity of the Outokumpu ore deposit, Finland. Trans. of the Royal Soc. of Edinburgh, Earth Sci. 72, 201-215.

Treloar, P.J. & Putnis, A. 1982, Chemistry and microstructure of orthoamphiboles from cordierite-amphibole rocks at Outokumpu, North Karelia, Finland. Mineral. Mag. (Deer, Howie and Zussman Volume - in press).

Vähätalo, V. 1953, On the geology of the Outokumpu ore deposit in Finland. Bull. Comm. géol. Finlande 164, 1-98.

Warrender, J. (in preparation).

Wegmann, C.E. 1928, über die Tektonik der jüngeren Faltung in Ostfinnland. Fennia 50, 1-22.

6.

METAVOLCANICS AND METASEDIMENTS OF THE PROTEROZOIC TAMPERE SCHIST BELT

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GENERAL

The Tampere schist belt (Fig. 6.1) is one of the key areas of the Proterozoic Svecofennian zones of Finland and Sweden. It was made famous by J.J. Sederholm, who published his classical study with its actualistic concepts in 1897.

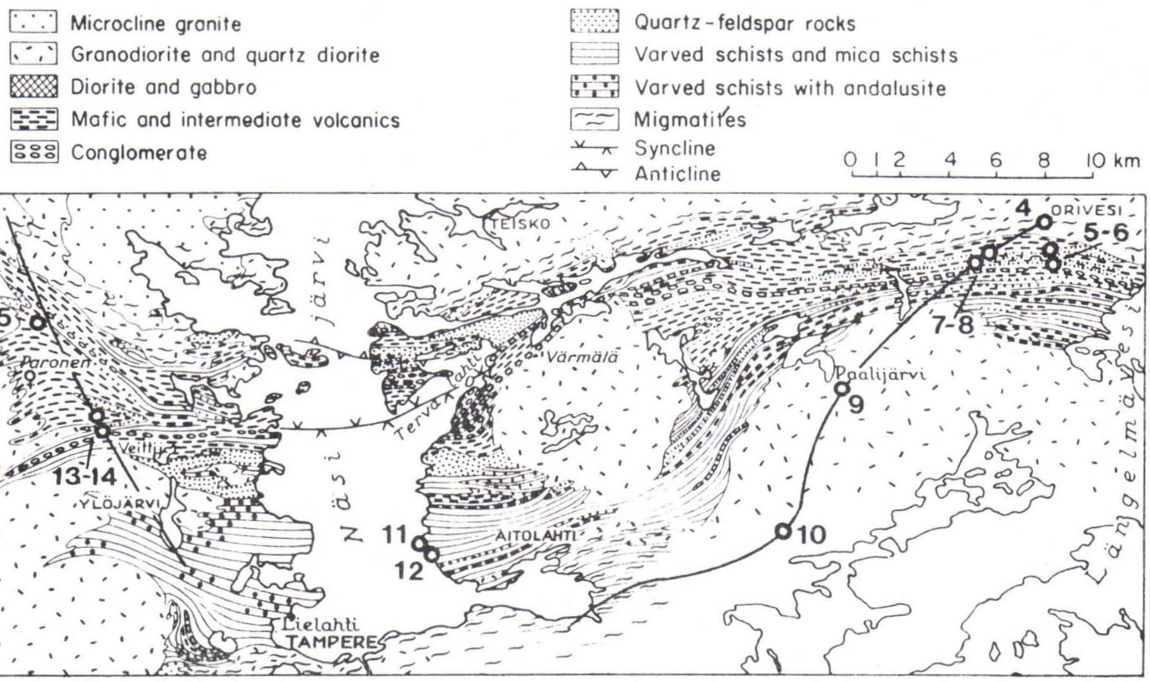

Fig. 6.1. Geological map of the Tampere schist belt according to Simonen and Seitsaari (Eskola 1963).

The belt is over 200 km long in an E-W direction and some 20 km across at its widest. It is composed of many kinds of metasedimentary and metavolcanic rocks (referred to here without the prefix meta-). The sediments are mostly greywackes and pelites, but there are also conglomerates, arkoses and black schists. Calcareous rocks are rare and quartzites are almost entirely absent. The basement of deposition is unknown. The volcanic rocks are mainly pyroclastic in origin, but there are also some lavas and subvolcanic rocks, ranging in composition from basaltic to rhyolitic, but with the intermediate types most frequent. The regional metamorphism had commonly peaked under low pressure amphibolite facies conditions. The schists are cut by granitoids of approx. 1880 Ma in age. To the south the schist belt grades to mica gneisses and migmatites. Sederholm regarded these "Svionian" gneisses as older than the "Bothnian" schist belt of Tampere, but nowadays the difference between these two groups is generally regarded as one of metamorphic grade and sedimentary façies. To the north the bedrock borders on the granitoid complex of Central Finland.

STRUCTURE

There is no thorough study on the structure of the Tampere schist belt as a whole. Most authors discussing the belt have suggested practically horizontal fold axes striking approx. E-W and vertical or subvertical axial planes for the "main folding" (Neuvonen and Matisto 1948; Seitsaari 1951; Simonen 1953a, b).

Polyphase deformation of the Tampere schist belt was obvious from the studies of Seitsaari (1951) and Simonen and Kouvo (1951). Campbell (1978 and 1980), in his study at Ylöjärvi, identified five generations of folding. The earliest, the F_1 folds, are problematic and could also be the result of penecontemporaneous sedimentary folding. F_2 folds (the "main folding", as it is called) and an associated axial planar fabric are the dominant tectonic elements of the belt. According to Campbell, there is commonly a steeply oriented mineral lineation parallel to the F_2 fold axes. As a rule, however, the continuity of the beds as marked on lithological and geophysical maps of the belt suggests a gently rather than steeply plunging fold axis for this dominant fold generation. The F_3 folds of Campbell have gently dipping axial planes and are only locally developed. The F_4 folds are flattened flexural folds with dextral vergence. F_5 deformation is a large-scale folding responsible for the curvature of the strike of the schist belt.

STRATIGRAPHY

The stratigraphic scheme of the belt (Table 6.1) is based on strata top observations in roughly N-S-trending profiles east and west of Lake Näsijärvi and along a profile at Viljakkala, about 35 km NW of Tampere. There are some reservations concerning this scheme. Campbell (1978) regards volcanic activity as contemporaneous with greywacke deposition, and stresses the difficulties for stratigraphic reconstruction caused by polyphase deformation. Mäkelä (1980) suggests that the basic volcanics at Viljakkala lie at the lateral extensions of greywackes. In any case, the observations from strata tops by Gaál et al. (1981) and Kähkönen (1981) support the idea of dividing the volcanics of Ylöjärvi into two groups separated by conglomerates and other associated sediments.

Quartzite xenoliths in diabase dikes (stop 3; Laitakari 1969) indicate the possiblity that there may exist, under the layers mentioned above, quartzite layers of some kind which do not reach the present erosion level.

Table 6.1. Stratigraphic sequence of the supracrustal rocks in the Tampere schist belt (Simonen 1980).

		thickness in metres
Middle	mafic volcanics	1000
Sveco-	conglomerates and associated	700 - 800
fennian	beds of greywacke slates and arkoses	
	mafic and intermediate volcanics	800 - 1500
Lower	quartz-feldspar rocks (arkoses,	
Sveco-	greywackes and pyroclastics)	1500 - 2200
fennian	greywacke slates	3000

The age of detrital zircon from the greywackes is approx. 2400 Ma, whereas that of the Svecofennian volcanics is in the range 1920-1880 Ma (Simonen 1980). The conglomerates contain some pebbles of plutonic (and hypabyssal) rocks whose zircon shows an age of 1880 Ma, which is almost the same as the age of the granitoids intrusive to the schists. A similar age (approx. 1900 Ma) is also indicated by the detrital zircon in the arkose of Mauri, some 30 km W of Tampere (Matisto 1968), which obviously belongs to Simonen's Middle Svecofennian group. Thus, the sediments of the schist belt contain two zircon groups. That in the greywackes is old (approx. 2400 Ma, from the unknown basement) whereas that in the sediments higher in the stratigraphy is of a younger generation (approx. 1900 Ma).

The evolution of the belt occurred between 2400 Ma and 1880 Ma. The time of commencement of sedimentation is not known, but the period of magmatic activity was very short, from around 1900 Ma ago for the volcanic rocks to around 1880 Ma ago for the plutonic rocks. In this respect, too, the belt is highly similar to many Archaean greenstone belts.

SEDIMENTARY ROCKS

Greywackes and slates

The greywackes and slates of the Tampere schist belt are mostly turbidites. Graded bedding is a common feature, and small-scale cross-bedding (Bouma C), load casts and soft sediment deformation have also been observed in places (Sederholm 1911; Matisto 1977). Most of the greywacke beds are Bouma A or Bouma AB beds (Ojakangas, oral communication).

There is a large area close to Tampere consisting of greywackes and slates, most of which obviously belong to the Lower Svecofennian. This area is perhaps the best-known area of sedimentary origin in the belt, due to excellent outcrops on both shores of Lake Näsijärvi. It is also in this area that the greywacke beds reach their maximum thickness (3-5 m), in the southern parts of the belt at Nokia. In the northern parts of the greywacke - slate area the thickness of the strata is typically less than 0.5 cm (Matisto 1977), although there are some "mega-varves" with a thickness of 60-200 cm (Simonen and Kouvo 1951). The palaeoccurrents of the turbidites at Nokia and Aitoniemi typically ran from SE to NW (Ojakangas, oral communication).

The clasts of the greywackes include mineral grains of quartz, plagioclase and some microcline. Rock fragments include quartzite, slate, fine-grained quartz-feldspar rock and occasionally basic igneous rocks with a blasto-ophitic texture (Simonen and Kouvo 1951). The 2400 Ma-old detrital zircon and the abundance of quartzite clasts, as well as the presence of quartzite conglomerates within the greywackes (Seitsaari 1951; Stop 9, this guide) suggest that the greywackes were at least partly derived from rocks of greater age than those within the schist belt. Nevertheless, the pyroclastic interbeds and the presence of the volcanic conglomerate at Tohloppi (approx. 5 km west of the city of Tampere) indicate that there was volcanic activity of some stage during the sedimentation of the greywackes (Simonen and Kouvo 1951; Matisto 1977).

The mica gneisses and migmatites south of the schist belt proper do not in general display any well-preserved primary structures. They are characterized by numerous black schist intercalations, abundant calcium concretions, and more intense weathering and sorting than the greywackes near Tampere (Matisto 1977).

Conglomerates

The conglomerates of the Tampere schist belt can be divided into three types, volcanic, plutonic and quartzitic according to the dominant phenoclast material.

Typically they belong to the group in which the pebbles are mostly of volcanic (and less commonly of sedimentary) origin. The type unit is the Veittijärvi conglomerate (stop 13, this guide), which is situated between the lower and upper volcanic unit of Ylöjärvi. The conglomerate can be traced for many kilometres on lithological and geophysical maps, and is up to 900 m thick 10-15 km east of Lake Näsijärvi. The proportions of volcanic and sedimentary pebbles in the Veittijärvi conglomerate vary, as do the ratios between mafic, intermediate and felsic volcanics. Pebbles of true plutonic origin are extremely rare. The matrix and interbeds in the conglomerate consist of greywackes and slates which vary in composition from mafic volcaniclastic to felsic sandstones. The associated greywackes often show graded bedding.

Conglomerates with large numbers plutonic and hypabyssal pebbles are typical of the Suodenniemi-Lavia area (50-60 km west of Tampere). These are interbedded with mica schists and mica gneisses and are not intimately associated with volcanics as are the conglomerates near

Lake Näsijärvi (Simonen 1953a). Perttula (1982), however, has observed that there are also intermediate volcanics associated with conglomerates in the Suodenniemi area.

Conglomerates consisting mainly of quartzite pebbles are rare. So far these have been observed only as narrow beds in the region SW of the Värmälä granite (Seitsaari 1951; see also Stop 9, this guide), where there are also pebbles of phyllite, fine-grained volcanics, quartz-feldspar rocks and fragments of feldspar. Some pebbles could be of plutonic, probably granodioritic, origin. Conglomerates of this kind typically occur as interbeds in greywackes and slates.

Arkoses

There is a large arkosic unit near Mauri, some 25 km west of Tampere (Matisto 1968, 1977). It is up to 2.5 km thick and some 15-20 km long. The arkose shows large-scale cross-bedding, and there are scattered fine-grained pebbles of the same material in places. The tops of the strata typically point to the south, and the direction of flow was roughly from west to east.

The texture of the rock is blastoclastic, the clasts observed including mainly quartz and feldspars. The clasts are angular and amount to only some 20 % by vol. Due to deformation and metamorphism it is difficult to say, whether there had originally been more mineral grains and rocks fragments.

Accessory minerals include tourmaline, zircon (approx. 1900 Ma old) and monazite.

Matisto (1968, 1977) suggestes that the arkose was derived from nearby granites and deposited in a fluvial environment.

Volcanic rocks

The volcanic rocks of the Tampere schist belt are mostly pyroclastic; tuffs (including crystal tuffs and hyaloclastic tuffs), lapilli tuffs, agglomerates and volcanic breccias. There are large amounts of volcanic conglomerates, volcanic greywackes and tuffites. Many types of dykes, sills and lavas are associated with the pyroclastic rocks, and it is often difficult to distinguish the volcanic and hypabyssal rocks of the various categories one from another. Pillow lavas of indisputable origin have so far been observed only in the Haveri formation at Viljakkala (approx. 35 km NW of Tampere; Stigzelius 1944; Mäkelä 1980).

We have no thorough palaeovolcanic analyses available at present, and therefore we have no exact idea of the volcanic centres.

The mineral composition of the basic volcanics is characterized by hornblende (amphiboles in general) and plagioclase (andesine to oligoclase). The shoshonitic basalts and andesites also contain large amounts of biotite. The intermediate rocks typically contain plagioclase, quartz, biotite, hornblende and chlorite. The original phenocryst phases include clinopyroxene (currently uralite) and plagioclase in the basic rocks, and plagioclase in the intermediate rocks.

The chemical composition of the volcanic rocks is highly variable; from basaltic to rhyolitic, from subalkaline to alkaline, from low-K to shoshonitic, and from tholeiitic to calc-alkaline (Kähkönen 1981). The most typical cases are intermediate rocks with calc-alkaline affinities. The TiO_2 content of the basaltic rocks is typically, though not entirely, low (less than 1.3 %). Most of the volcanics in the Tampere area resemble lavas and tephras of modern arc volcanoes in their composition.

EXCURSION SITES

Most stops are indicated in Fig. 6.1.

Stops 1 and 2 will concern the Hirsilä-Korkeakoski area, which is a northerly equivalent of the Tampere schist belt proper (situated 5-10 km north of it).

Stop 1

Korkeakoski (2142 06; x = 6856.20, y = 515.88)

Gabbro

Autobreccia structures in a hornblende-gabbro which is possibly associated with the volcanic rocks of the Hirsilä-Korkeakoski area. Autobrecciation is obviously due to processes in the magma chamber.

Stop 2

Hirsilä, Orivesi (2142 06; x = 6852.47, y = 516.20)

Greywackes with volcanic interbeds

Greywackes often display graded bedding and are probably turbidites. The thickness of the individual beds varies greatly, from laminations of 1-2 mm to beds more than 1 m thick.

There are interbeds of basic tuffites (Fig. 6.2) and an intermediate hyaloclastite. There are also basic (uralite porphyrite) and intermediate sills which may be comagmatic with the volcanic rocks of the area.

The noses of tight to isoclinal folds are often clearly discernable. The ptygmatic folding and feather joints represent different types of plastic and brittle

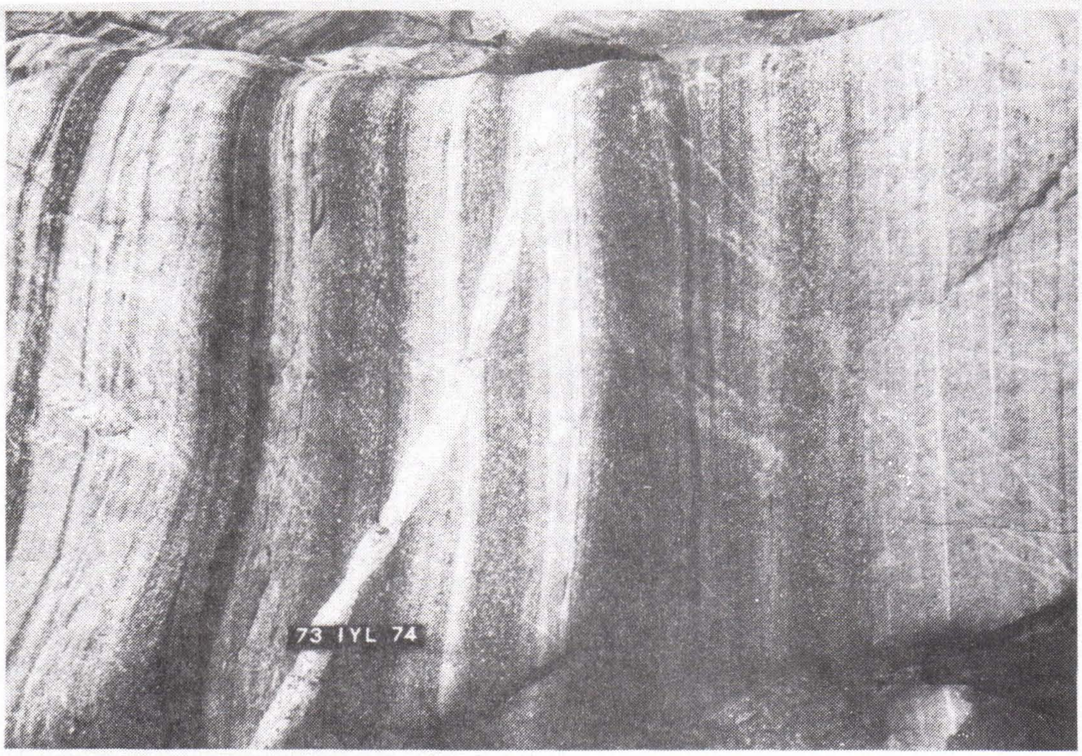

Fig. 6.2. Basic volcanic intercalations in greywacke. Stop 2, Hirsilä, Orivesi. Length of the scale bar 12 cm. Photo I. Laitakari.

deformation. The cutting granitic dykes show nice boudinage.

Stops 3 and 4 concern some peculiarities of the olivine diabase dykes of Häme (Laitakari 1969). The set of dykes is at least 150 km long. About 150 dykes are known, some of them measuring over 10 km in length and over 100 m in width. They are of an age of about 1650 Ma, and thus belong to the same age group as the rapakivi granites.

Stop 3

Jouttijärvi, Orivesi (2142 05, x = 6844.53, y = 514.15)

Quartzite xenoliths in diabase

An olivine diabase dyke containing large fragments of plagioclase and xenoliths of blastoclastic quartzite. As mentioned before, quartzites are very rare in the Tampere schist belt. The xenoliths, however, suggest that even the Svecofennian belt may contain some quartzite, at least in its deeper parts.

Stop 4

Oritupa, Orivesi (2142 05, x = 6840,10, y = 514.90)

Precambrian glass

Glass in narrow apophyses of diabase dykes (Lindqvist and Laitakari 1980). Precambrian glass is exceptionally uncommon. The presence of glass in the rock shows that the present erosion level is very near to that of 1650 Ma ago, since devitrification of glass rich in water takes place very rapidly even at 300° C. Thus the temperature can never have exceeded that value during the last 1600 Ma.

At stops 5-8 we will study the volcanic rocks of Orivesi near Teerijärvi and in road cuttings on highway 9.

Stop 5

Teerijärvi, Orivesi (2142 04, x = 6839.70, y = 515.83)

Volcanic conglomerate (?)

The pebbles are mostly basic, but with some ultrabasic and acid ones. The matrix is basic. The pebbles are mostly roundish, but some are angular. The occurrence of pebbles rich in epidote (originally pumice filled with carbonates?) indicates subaerial origin for this possibly catastrophic deposit.

Stop 6

Teerijärvi, Orivesi (2142 04, x = 6839.23, y = 516.00)

Basic agglomerate

The "bombs" often contain pale amygdalas, 1-2 cm in diameter. The rocks in the surroundings of stops 5 and 6 are mainly intermediate volcanics. According to magnetic maps, it is estimated that these two basic units are less than 200 m thick, while the thickness of the surrounding intermediate unit (described at stop 7) approaches 1000 m.

Stop 7

Road cuts of highway 9, Orivesi

The rocks at this stop represent the intermediate unit of thickness approx. 1 km. The rocks of the unit are typically calc-alkaline pyroclastic dacites and andesites, and there are also some rhyolites. Also there are narrow metamorphic basaltic dykes with a high potassium content, but these are younger than the intermediate unit.

a. 2142.04, x = 6839.34, y = 513.92

Plagioclase porphyritic crystal tuff

The rock is relatively homogeneous and typically shows no stratification, although these are fragments

Fig. 6.3. Conglomerate "dyke" in intermediate crystal tuff. Stop 7a, Orivesi. Length of the scale bar 12 cm. Photo I. Laitakari.

of lapilli size in variable amounts. One "bed" is possibly a sill.

One peculiarity is a conglomerate "dyke" about 30 cm wide (Fig. 6.3), the fragments in which mainly resemble the surrounding volcanics and are equally deformed.

b. 2142 04, x = 6839.10, y = 513.70

Ignimbrite and crystal tuff

The ignimbrite dispalys a "fiamme" (flame) structure (Fig. 6.4). The epidote spots may originate from pumice fragments. Possible channeling suggests that the top of the strata is S. An homogeneous crystal tuff contains

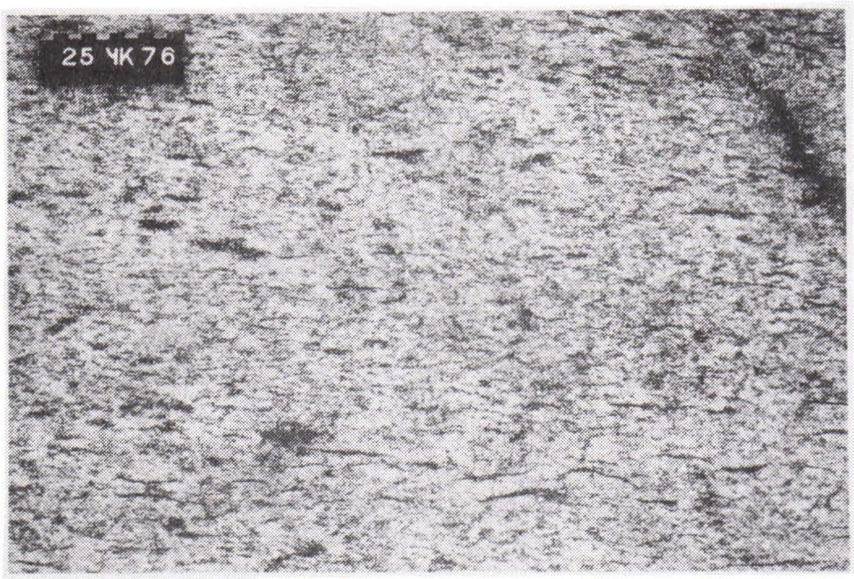

Fig. 6.4. Ignimbrite with fiammes. Stop 7b, Orivesi. Length of the scale bar 10 cm. Photo Y. Kähkönen.

large amounts of angular fragments of plagioclase phenocrysts (approx. 35 % by vol.).

Stop 8

Road cuttings on highway 9, Orivesi (2142 04, from x = 6838.60, y = 513.20 to x = 6838.10, y = 512.70)

The NE part of the area is composed of a unit of subalkaline basalts-to-rhyolites, and the SE part of shoshonitic and high-K basalts-andesites-dacites, with overlying conglomerates, greywackes and pelites (Kähkönen 1981).

a. The subalkaline basaltic-to-rhyolitic unit is about 150 m thick. The rocks are volcaniclastic in general; agglomerates, lapilli tuffs, tuffs, tuffites and volcanic greywackes. They seem to be mainly water-laid rocks.

In addition there is one uralite-plagioclase-porphyrite sill. The compositions of the strata vary from basaltic to ryolitic. Some strata include deformed mud balls. The graded bedding youngs to the south.

b. The shoshonitic and high-K unit is approx. 250 m thick in this profile, and comprises an older basaltic-to-andesitic unit and a younger dacitic (or trachytic) unit. The rocks of the former are mainly pyroclastic; agglomerates, lapilli tuffs, tuffs and tuffites (Fig. 6.5). There is discussion on whether some plagioclase-porphyritic rocks are flow-breccias or hyaloclastites. The rocks of the dacitic unit display a peculiar pillow-like structure (Fig. 6.6).

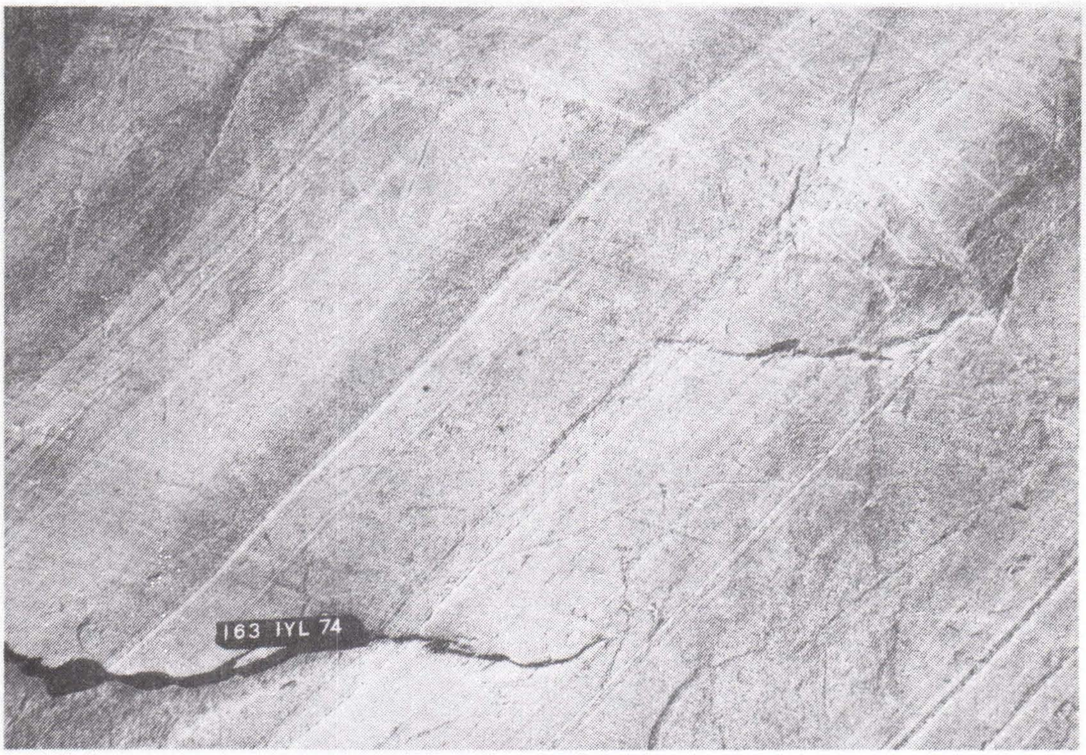

Fig. 6.5. Stratification in a tuffite of the shoshonitic to high-K unit. Stop 8, Orivesi. Length of the scale bar 12 cm. Photo I. Laitakari.

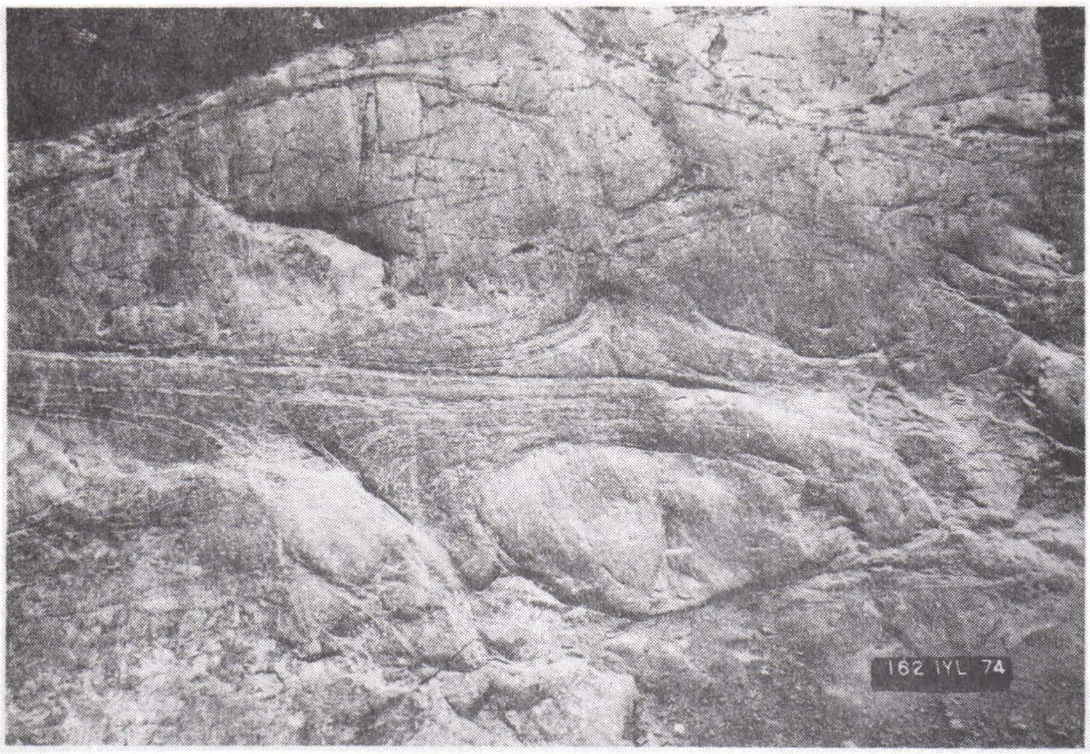

Fig. 6.6. Pillow-like structure in a shoshonitic dacite. Stop 8, Orivesi. Length of the scale bar 12 cm. Photo I. Laitakari.

c. Volcanic conglomerates, greywackes and pelites overlie the shoshonitic and high-K unit, which can also be observed on the SW side of the conglomerate-pelites due to folding. The conglomerate is clast-supported in its NE parts. Pebbles from the dacitic unit below are clearly discernable. These pebbles mostly differ from the volcanics of the Orivesi area, however, in having a higher Ni content. Towards the SW (higher in the stratigraphy) the conglomerates contain more pelitic matrix and pelitic intercalations. Finally there are pelites (partly greywackes), which often show graded bedding.

Stop 9

Road cutting at the boundary of Orivesi
and Kangasala (2142 01, x = 6833.92, y = 507.98)

Greywacke with interbeds of quartzite conglomerate

The thickness of the strata in the greywackes varies from several metres to lamination of some millimetres (Fig. 6.7). There is graded bedding in places. Some interlayers are pelitic, and many conglomeratic (Fig. 6.8). Their thickness seldom exceeds 1 m. There are pebbles of pelites and fine-grained plutonic rocks, but most of the pebbles consist of quartzites of unknown origin (see also Seitsaari 1951, p. 42). The presence of roundish zircon and rare streaked features in the quartzite pebbles suggest a clastic-sedimentary origin. The conglomerates are mostly clast-supported but there are single pebbles within the greywackes, too. The outcrop is an inclusion within granodiorites.

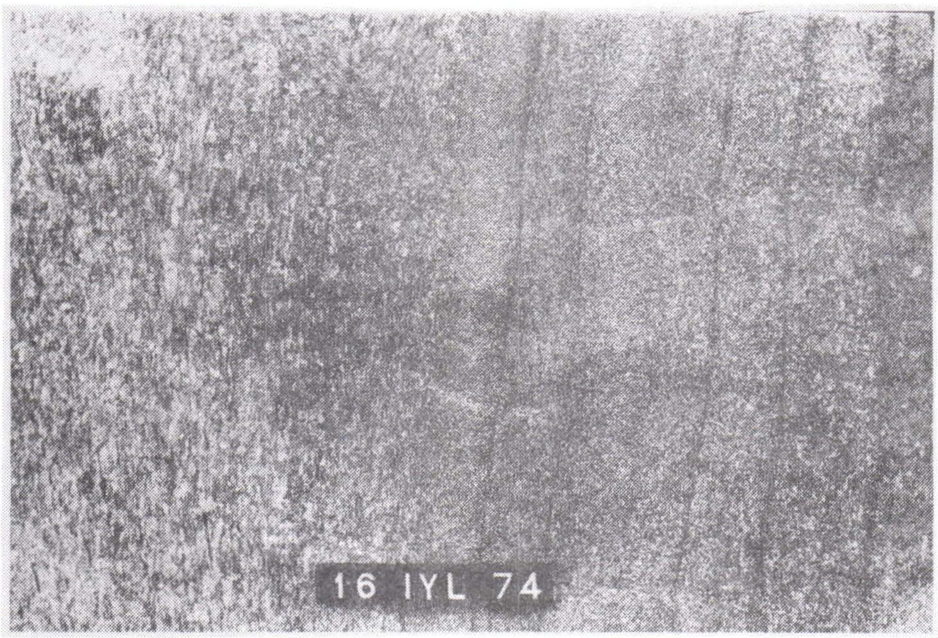

Fig. 6.7. Stratification in greywacke. Stop 9, Kangasala. Length of the scale bar 12 cm. Photo I. Laitakari.

Fig. 6.8. Conglomerate with quartzitic pebbles. Stop 9, Kangasala. Length of the scale bar 12 cm. Photo I. Laitakari.

Stop 10

Suinula, Kangasala (2141 03, x = 6827.15, y = 504.45)

Veined gneiss with interbeds of hyaloclastic crystal tuffs. If the interbeds are real hyaloclastites, as the present authors think, this would indicate shallow water sedimentation for the gneiss material.

Stop 11

Aitoniemi, Tampere (2123 09, x = 6826.80, y = 489.70)

Greywackes and slates with Corycium enigmaticum

Graded bedding and load casts can be observed. The greywackes and slates on both sides of Lake Näsijärvi contain phyllite inclusions enveloped by graphitic seems (Matisto 1963, 1969, 1974, 1977). Their carbon is of biogenic origin and they also contain microfossils resembling algae. The inclusions were originally regarded as true fossils and named Corycium enigmaticum by Sederholm (1911). Matisto, however, regards them as secondary in origin, loosened and deformed from newly deposited beds by turbidity currents.

Stop 12

Aitoniemi, Tampere (2123 12, x = 6826.00, y = 490.30)

Greywackes and slates

Here we can observe graded bedding, load casts and soft sediment deformation. Bouma A, AB and occasionally ABC beds are seen in this area (Ojakangas, oral communication).

Stop 13

Railway cutting, Takamaa, Ylöjärvi
(2124 04, x = 6831.10, y = 476.40)

Veittijärvi conglomerate (Fig. 6.9)

The conglomerate is approx. 100 m thick at this point.

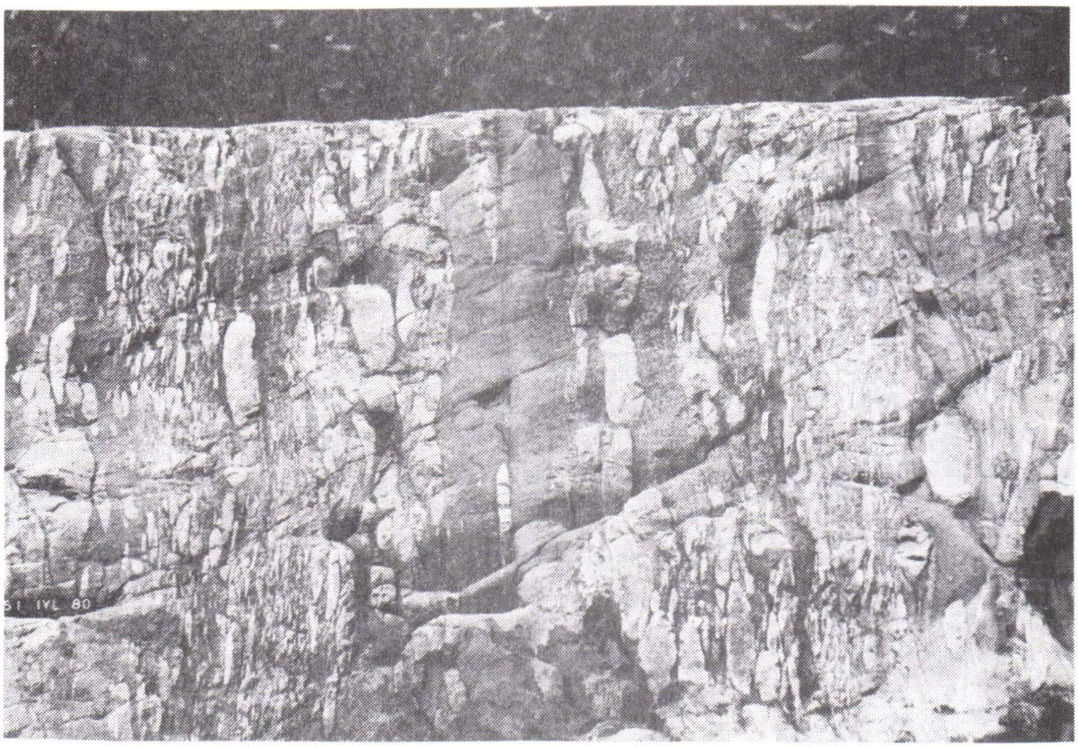

Fig. 6.9. Veittijärvi conglomerate with interbeds. Vertical section. Stop 13, Ylöjärvi. Length of the scale bar 12 cm. Photo I. Laitakari.

The pebbles consist of different types of acid, intermediate and, less commonly, basic volcanic rocks. There are also pelitic pebbles. Some pebbles have a hypabyssal texture, but true plutonic rocks are rare. The pebbles are well-rounded but strongly deformed, their maximum elongation being almost vertical. The composition of the matrix and interbeds varies from pelitic to greywacke and tuffitic. The S part of the outcrop consists of greywackes of basaltic composition. The conglomerate is cut by intermediate dykes, possibly associated with the granitoids to the NE.

Stop 14

Railway cutting, Takamaa, Ylöjärvi (2124 04, from x = 6831.40, y = 476.35 to x = 6831.50, y = 476.30)

Greywackes and volcanics overlying the Veittijärvi conglomerate

The greywackes (typically Bouma AB beds) display graded bedding (top of strata N). The thickness of the strata typically varies from 0.5 to 40 cm. One homogeneous stratum (a Bouma A bed ?) is up to 3 m thick. The clasts of these greywackes consist mainly of plagioclase and volcanic rock fragments instead of the abundant quartz so typical of the greywackes at Aitoniemi (stops 11 and 12). Some strata have a high potassium content. These were probably derived from the shoshonitic volcanics known near Lake Vahantajärvi (approx. 6 km SEE of this point).

The volcanics of the area include rhyolitic tuffs and tuffites, a fragmented basaltic andesite (obviously of hyaloclastic origin), uralite-plagioclase porphyrite sills, and a subvolcanic dacite intrusive to the schists.

Stop 15

Lakiala, Ylöjärvi (2124 04, x = 6835.70, y = 474.90)

Pelites, greywackes and volcanics

The rocks are typically pelitic, but there are some clastic portions, too. The thickness of the beds is mostly less than 5 cm. Tabular cross-bedding and synsedimentary faulting can be observed.

The rock in the S part of the outcrop are acid and intermediate pyroclastics, typically lapilli tuffs. They are strongly deformed. There is the nose of a tight fold at the transition zone from sediments to volcanics. These volcanics belong to the lowermost parts of the upper volcanic unit in the stratigraphic scheme of the Ylöjärvi area (Table 6.1).

Stop 16

Vihola, Nokia (2123 05, x = 6817.90, y = 474.50)

Greywacke and slate

The beds are up to 5 m thick. Bouma A, AB, ABC, possibly ABCD beds are present. Load casts, calcareous concretions and boudinage can be seen. The age of the detrital zircon is approx. 2400 Ma.

Stop 17

Mauri, Suoniemi (2123 03, x = 6821.70, y = 460.60)

Arkose

The blastoclastic arkose displays large-scale cross-bedding, with parallel lamination in some places and scattered pebbles in others. Deposition from a high velocity current in a fluvial environment is evident. The age of the detrital zircon is approx. 1900 Ma. A detailed cescription of this rock was published by Matisto (1968).

REFERENCES

Campbell, D.S. 1978, Structural and metamorphic studies in the Svecokarelides, Tampere, Finland. Unpublished Ph.D. thesis, Glasgow University, 146 p.

Campbell, D.S. 1980, Structural and metamorphic development of migmatites in the Svecokarelides, near Tampere, Finland. Trans. R. Soc. Edinburgh: Earth Sci. 71, 185-200.

Eskola, P. 1963, The Precambrian of Finland. Pp. 145-263 in The Precambrian. Vol. 1, ed. by K. Rankama. Interscience Publ., New York-London-Sydney.

Gaál, G., Front, K. & Aro, K. 1981, Geochemical exploration of a Precambrian batholith, source of a Cu-W mineralization of the tourmaline breccia in southern Finland. J. Geochem. Explor. 15, 683-698.

Kähkönen, Y. 1981, Oriveden ja Ylöjärven proterotsooiset vulkaaniset vyöhykkeet; erityisesti niiden geokemia. Unpublished thesis, University of Helsinki, 210 p.

Laitakari, I. 1969, On the set of olivine diabase dykes in Häme, Finland. Bull. Comm. géol. Finlande 241, 65 p.

Lindqvist, K. & Laitakari, I. 1980, Glass and amygdules in Precambrian diabases from Orivesi, southern Finland. Bull. Geol. Soc. Finland 52-2, 221-229.

Matisto, A. 1963, Über den Ursprung des Kohlanstoffs in Corycium. Neues Jahrb. Geol. u. Paläontol., Monatsh. 8, 433-441.

Matisto, A. 1968, Die Meta-arkose von Mauri bei Tampere. Bull. Comm. géol. Finlande 235, 21 p.

Matisto, A. 1969, On the microfossils of Corycium enigmaticum. Bull. Geol. Soc. Finland 41, 199-202.

Matisto, A. 1974, Corycium enigmaticum; Beschaffenheit und Herkunft des problematischen Gebildes. Geol. Surv. Finland Bull. 268, 30 p.

Matisto, A. 1977, Tampereen kartta-alueen kallioperä. Summary: Precambrian rocks of the Tampere map-sheet area. Suomen geologinen kartta 1:100 000, kallioperäkartan selitys, 2123 Tampere, 50 p.

Mäkelä, K. 1980, Geochemistry and origin of Haveri and Kiipu, Proterozoic strata-bound volcanogenic gold-copper and zinc mineralizations from southwestern Finland. Geol. Surv. Finland Bull. 310, 79 p.

Neuvonen, K.J. & Matisto, A.S.I. 1948, Some observations on the tectonics in the Tampere schist area. Compt. Rend. Soc. Géol. Finlande 21, 79-86, also Bull. Comm. géol. Finlande 142.

Perttula, J.-P. 1982, Suodenniemen geologiasta. Unpublished thesis, University of Turku, 92 p.

Sederholm, J.J. 1897, Über eine archäische Sedimentformation im südwestlichen Finnland und ihre Bedeutung für die Erklärung der Entstehungsweise des Grundgebirges. Bull. Comm. géol. Finlande 6, 254 p.

Sederholm, J.J. 1911, Geologisk öfversiktskarta öfver Finland. B2, Tammerfors. Beskrifning till bergartskartan (Résumé en francais), 110 p.

Seitsaari, J. 1951, The schist belt northeast of Tampere in Finland. Bull. Comm. géol. Finlande 153, 120 p.

Simonen, A. 1953a, Stratigraphy and sedimentation of the Svecofennidic early Archean supracrustal rocks in southwestern Finland. Bull. Comm. géol. Finlande 160, 64 p.

Simonen, A. 1953b, Kallioperäkartan selitys - Explanation to the map of rocks, Lehti - Sheet - 2124, Viljakkala-Teisko. Suomen geologinen kartta - Geological map of Finland, 1:100 000, 74 p.

Simonen, A. 1980, The Precambrian in Finland. Geol. Surv. Finland Bull. 304, 58 p.

Simonen, A. & Kouvo, O. 1951, Archean varved schists north of Tampere in Finland. Compt. Rend. Soc. Géol. Finlande 24, 93-114, also Bull. Comm. géol. Finlande 154.

Stigzelius, H. 1944, Über die Erzgeologie des Viljakkala-Gebiets im südwestlichen Finnland. Compt. Rend. Soc. Géol. Finlande 17, 1-91, also Bull. Comm. géol. Finlande 134.

7.

THE JOTNIAN (UPPER PROTEROZOIC) SANDSTONE OF SATAKUNTA

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The Jotnian area in Satakunta (Fig. 7.1), located south of the town of Pori, consists of non-metamorphic rocks including rapakivi granite, sandstone and olivine diabase. The area measures some 50 x 80 km and the sandstone follows its NE contact in a belt approx. 15 km wide. The Laitila rapakivi massif immediately to the SW of the sandstone is about 1580 Ma old (Vaasjoki 1977) and olivine diabases cutting the sandstone give ages between 1250 and 1275 Ma (Simonen 1980). Field observations suggest that the age of the sandstone lies somewhere between these values.

The material of the sandstone is derived from the Svecofennian metamorphic complex (Simonen and Kouvo 1955). According to paleoccurrent analyses the source area should be in the south (Marttila 1969), that is in the Laitila rapakivi area. Thus erosion probably did not reach the rapakivi until the sedimentation of sandstone began. Bedrock windows in the sandstone area also show that the sedimentation base is the Svecofennian metamorphic complex and not the rapakivi.

Geological observations show that the sandstone lies in a long graben which, at least in the NE, is bordered by a fault zone. A drill hole S of Pori (Fig. 7.1) with a depth of 617 m did not reach the base of the sandstone. Estimates based on aeromagnetic surveys (Puranen 1963) in fact set its depth at 1200-1600 m in the central part. Laurén's result obtained by gravimetric studies, is of

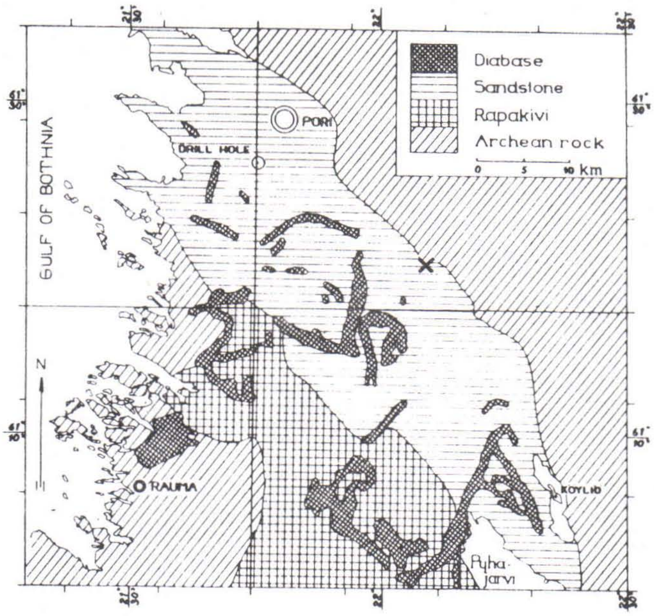

Fig. 7.1. The Jotnian area of Satakunta according to A. Laitakari (Puranen 1963). x = stop 1. "Archaean rock" in the legend of this old map denotes to Svecofennian metamorphic complex, which is now known to be Proterozoic.

the same order, and suggests a still greater depth at the NW end (Marttila 1969). The topography of the sedimentation base seems to have been very rough, however, the bedrock windows representing the hill tops.

The most common rock type in the area is an arkose sandstone containing 15 to 30 % microcline. Quartz is always the principal mineral (usually over 50 %). The proportion of matrix is under 25 %. Interbeds of conglomerate are quite common.

The idea that the material is derived from metamorphic rocks and not from rapakivi, is based on the study of heavy minerals and the type of potash feldspar, orthoclase, so typical of rapakivi, being almost completely absent.

One curiosity that may be mentioned is that iron micrometeorites have been found in many places in the Jotnian sandstone of Satakunta (Marttila 1969).

The sandstone area is very flat and mostly covered by Quaternary deposits. Only about 10 outcrops of sandstone are known. In addition very many wells reach the sandstone. When mapping this area, Aarne Laitakari (1925) dived to the bottom of many of these wells with a hammer and took samples. This enabled him to see that although most outcrops consist of diabase, the area is principally occupied by sandstone, the diabase only forming large dikes and sills cutting this sandstone.

Stop 1

Sandstone, Lammaistenkoski, Harjavalta

Fig. 7.2. The sandstone outcrops of Lammaistenkoski, Harjavalta. Photo I. Marjatta Virkkunen.

The best outcrops of Satakunta sandstone lies down the river from the Harjavalta power station plant (Fig. 7.2). The bedding is very clear. Cross-bedding shows that the deposit was originally formed as a river delta. Intercalations of clay rock are common, and ripple marks have also been found.

The outcrop lies almost exactly on the NE contact of the sandstone graben. The dip of the beds (about 35°) shows that the fault was also active after the sedimentation of the sandstone. One possible reason for the sinking of the graben may be the eruption of the large amounts of diabase in the area.

The many potholes in the sandstone tell of more recent exogenic processes.

REFERENCES

Laitakari, A. 1925, Über das Jotnische Gebiet von Satakunta. Bull. Comm. géol. Finlande 73.

Marttila, E. 1969, Satakunnan hiekkakiven sedimentaatio-olosuhteista. Unpublished thesis, University of Turku.

Puranen, M. 1963, A geophysical investigation of the Satakunta sandstone area in South-western Finland. Geoexploration 1, 6-15.

Simonen, A. 1980, The Precambrian in Finland. Geol. Surv. Finland Bull. 304.

Simonen, A. & Kouvo, O. 1955, Sandstone in Finland. Compt. Rend. Soc. géol. Finlande 28, 57-87.

Vaasjoki, M. 1977, Rapakivi granites and other postorogenic rocks in Finland: their age and the lead isotopic composition of certain associated galena mineralizations. Geol. Surv. Finland Bull. 294.

8.

ON THE GEOLOGY OF THE AIJALA-ORIJÄRVI AREA, SOUTHWEST FINLAND

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INTRODUCTION

The Aijala-Orijärvi area, of appr. 400 km^2, is located in Southwest Finland, appr. 100 km west of Helsinki (Fig. 8.1). It is a part of a zone composed principally of acidic metavolcanic rocks, the leptite zone, the main part of which is located in Central Sweden, while its easternmost continuation is found in Southwest Finland, representing a deeper erosional level.

The geology of the Aijala-Orijärvi area was made famous by the publications of Eskola (1914, 1915) in which he discussed the petrology of the area and laid the foundations for metamorphic petrology. Tuominen (1950, 1954, 1957) wrote about the tectonic history of the area, and the origin of cordierite-anthophyllite rocks, and Latvalahti (1979) described the volcanogenic ore deposits of the area.

The present study results from work carried out by Outokumpu Oy, Exploration, in the area in 1974-1980, with the aim of locating new ore bodies based on information obtained from known occurrences.

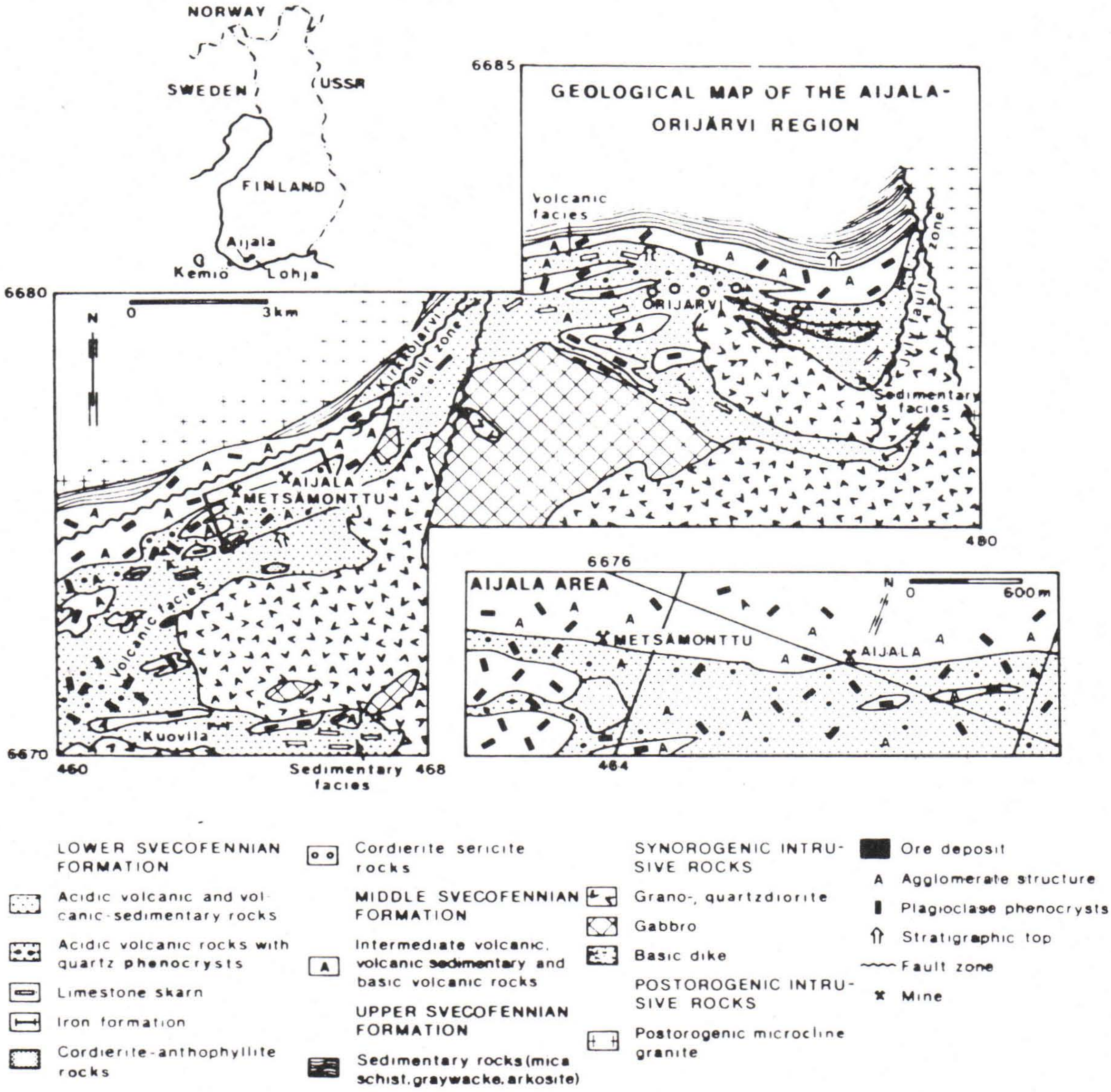


Fig. 8.1. General geological map of the Aijala-Orijärvi area, and detailed map of the environment of the Aijala area (lower right-hand corner).

General geology

The leptite zone, of which the Aijala-Orijärvi area is a part, belongs to the Svecofennian schist zone of the Svecokarelian orogeny, which reached its culmination

1800-1950 Ma ago. Rocks of volcanic origin display a marked concentration in the area compared with the rest of the leptite zone within Finland, while forwards Lohja in the east and Perniö and Kemiö in the west the proportions of rocks of sedimentary origin clearly increase. The primary structures in the metavolcanic rocks and the existence of chemical sediments in the area (limestones, cherts and iron formations) indicate that these rocks were deposited in a relatively shallow, oxidizing water.

In addition to the supracrustal rocks, the Orijärvi batholith is an essential part of the Aijala-Orijärvi area. It is a synorogenic intrusive ranging in composition from hornblendite to granodiorite. The complex also features a small layered intrusion.

Fig. 8.1 gives a general geological map of the Aijala-Orijärvi area.

Structure and metamorphism

Evidence of three separate folding phases is found in the Aijala-Orijärvi area. The oldest, F_1, has caused an isoclinal folding which is 5-10^o overturned to the south in the Orijärvi area. The axial plane schistosity of F_1 parallels the primary bedding. The second phase, F_2, abounds in the Orijärvi area. Its axial plane schistosity is at a 10-20^o angle to the bedding. These two fold axes are flat-lying. The phase F_3 is typically shearing in the Aijala area; and the lineation connected with it is vertical.

The diapirically raised Orijärvi batholith (Eskola 1914) is in an antiform structural position in the Aijala and Orijärvi areas. A triangular geosynclinal basin bordered by NE and NW-striking faults and shear zones exists north of Orijärvi.

The degree of regional metamorphism is that of a low-pressure amphibolite facies and is associated with the peaks of the deformation phases F_2 and F_3. Typical of the mineral parageneses are coexisting muscovite, quartz, potassic feldspar, and sillimanite.

Stratigraphy

The leptite zone is divided stratigraphically into three groups: the lower, middle and the upper Svecofennian supracrustal groups.

The lower group is composed of mainly acidic supracrustal rocks that are either of volcanic origin or are weathering sediments, depending on their original location within the paleo-basin. Both types include chemical sediments, limestones, cherts and intercalated iron formations.

The overlying middle group contains mostly intermediate and/or basic metavolcanites. Narrow skarn and limestone intercalations (0.1-0.5 m) occur in the basal part.

The upper group consists of weathering sediments mixed with material of volcanic origin. As a whole, it represents the vaining stage of volcanic activity.

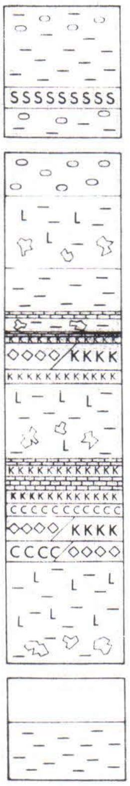
Fig. 8.2 gives the stratigraphy of the leptite zone in the Aijala-Orijärvi area.

The stratigraphic sequence in the Aijala area begins with acidic metavolcanites, which are overlain by intermediate and basic metavolcanites. Metasediments occur at the top.

The stratigraphy of the Orijärvi area is basically similar, with acidic metavolcanites at the bottom that are overlain by a volcanic conglomerate formation 200-300 m thick. The overlying basic metavolcanite formation is composed of several agglomerate and lapilli beds.

STRATIGRAPHY OF THE LEPTITE BELT.

TOP



GRYTHYTTAN	LJUSNARSBERG	AMMEBERG	UTÖ	AIJALA-ORIJÄRVI
CGL META-ARGILLITE, GRF-SLATE, SPILITES	MICA SCHIST		PARAGNEISS GRW, SUBGRW DACITIC TUFFITES	TUFFITES ARENITES VOLCANIC CGL GRW, MICA SCHISTS
GRW, CGL	GRW			BASIC VOLCANIC ROCKS (PYROCL. + LAVAS)
K-HÄLLEFLINTA, LIMESTONE, Mn-RICH IRON ORE	LEPTITE SCHIST, SPILITES, LEPTITE, Mn-RICH IRON ORE, LIMESTONE	SKARN, LIMESTONE, LEPTITE (EPI-CLASTIC SEDI-MENTS + TUFFS + LAVAS)		
Na-HÄLLEFLINTA, LIMESTONE, Mn-POOR IRON ORE, CHERT	LEPTITE, Mn-POOR IRON ORE, LIMESTONE	LEPTITE (EPICLAS-TIC SEDIMENTS + TUFFS + LAVAS) SKARN CHEMICAL SEDI-MENTS (LIME-STONE, QZT)	HÄLLEFLINTA LEPTITE, LIMESTONE, IRON ORE	CGL, LIMESTONE, IRONFORM., CHERT, ACID VOLCANIC ROCKS (PYROCLASTIC)
		LEPTITE - HÄLLE-FLINT (LAVAS + TUFFS)	GRV, SUBGRW	
SUNDIUS (1923)	MAGNUSSON (1940)	HENRIQUES (1964)	GAVELIN et al. (1976)	

Fig. 8.2. Stratigraphic sections across the leptite belt, and the Aijala-Orijärvi area.

Petrology

Plutonic rocks

The synorogenic plutonic rocks of the Orijärvi batholith are located in the central part of the area. The supracrustal rocks, now surrounding the batholith, were deposited directly on the roof of the batholith in the north and northwest. In this case an acidic plutonic rock gradually grades to an acidic metavolcanic rock. In the Orijärvi area the batholith is surrounded by a quartz porphyritic border facies.

The supracrustal rocks are altered to varying degrees at the gradually changing contacts of the batholith. The strongest degrees of alteration are encountered at Björknäs (appr. 1.5 km S of Aijala) and Venetkorpi (appr. 2.5 km SW of Aijala). The composition of the batholith ranges from hornblendite to granodiorite. Silicification is encountered in places, as indicated by quartz eyes in the grano and quartz diorites.

Genetically associated with the batholith are frequently encountered acidic subvolcanic dykes. These dykes, in which large quartz eyes are typical, occur both conformably with, and cutting across the supracrustal rocks.

It is evident that the batholith was originally an acidic dome in the earth's crust, originating from volcanic activity. Present erosion exhibits a deeper level in the southern part of the batholith than in the north.

Table 8.1 gives the chemical compositions of the Orijärvi batholith and an acidic dyke.

Supracrustal rocks

The metavolcanic rocks of the area are tholeiitic and calc-alkalic in composition. Fig. 8.3 shows the chemical compositions of the metavolcanic rocks of the area plotted on an AFM diagram.

Volcanic activity in the area was subaquatic, and took place on, or close to, a sea bed at a depth of 200-300 m.

The metavolcanic rocks in the Aijala and Orijärvi areas display marked differences despite the fact that they may represent same stratigraphic formations. The primary structures and textures of the rocks in the Orijärvi area are better preserved than those in the Aijala area.

Table 8.1. Chemical compositions of rock types in the Orijärvi batholith.

	1	2	3	4	5	6
SiO_2	66.9	72.8	71.36	71.50	50.99	49.15
TiO_2	0.27	0.23	0.34	0.34	0.65	1.52
Al_2O_3	13.7	14.2	13.31	13.79	15.18	17.73
Fe_2O_3	-	-	0.99	0.76	1.87	2.76
FeO	4.1	3.03	3.36	2.07	8.09	7.20
MnO	0.06	0.03	0.10	0.06	0.18	0.14
MgO	1.25	0.47	0.87	1.47	10.0	6.91
CaO	2.80	1.99	2.85	3.54	8.60	9.91
Na_2O	4.31	4.65	3.58	4.48	2.67	2.88
K_2O	2.52	2.34	2.26	1.11	0.38	0.72

1. Acidic dyke with quartz eyes. Kisko, Aikonlahti (x = 6676.05, y = 466.92).
2. Even-grained granodiorite. Kisko, Aikonlahti (x = 6676.05, y = 466.92).
3. Granodiorite. Orijärvi (Eskola 1914).
4. Quartz porphyry, a contact variant of the Orijärvi granodiorite (Eskola 1914).
5. Basic sill. Orijärvi (Eskola 1914).
6. Hornblende gabbro. Appr. 6 km S from Kisko (Eskola 1914).

1-2. XRF analyses, Outokumpu Oy.

Mafic pyroclastic rocks are dominant in the Orijärvi area. These were originally mainly tuffs, lapilli tuffs and agglomerates. Metalavas are also encountered, but metatuffites are rare. Quartz and plagioclase phenocrysts are seldom found in the acidic metavolcanites.

The majority of the rocks in the Aijala area are acidic pyroclastic metavolcanites. These are overlain by intermediate-basic metavolcanites containing moderate amounts of weathering sediments in places.

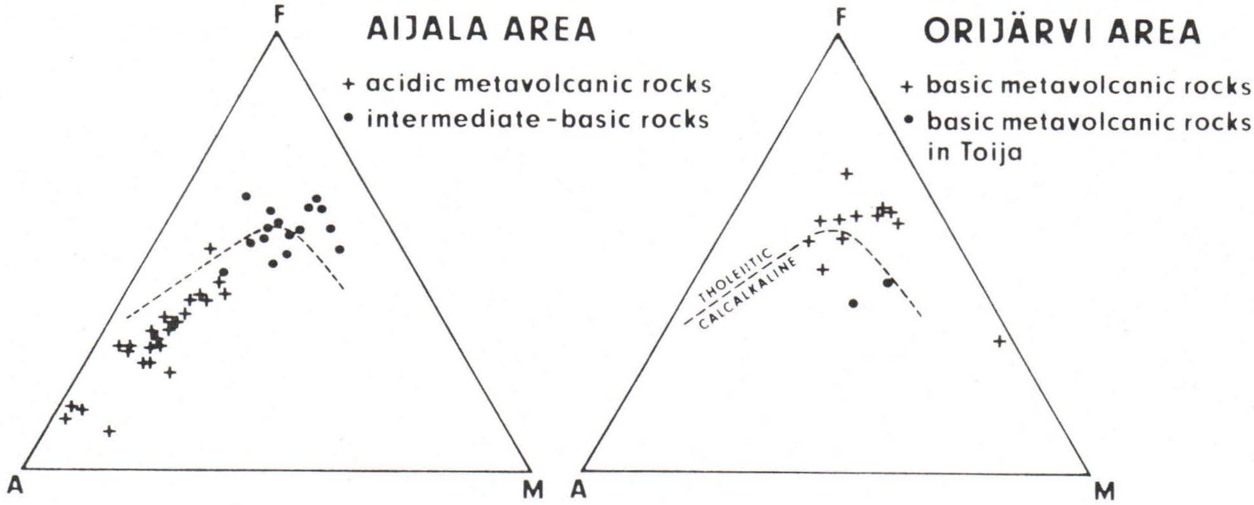


Fig. 8.3. AFM diagram for metavolcanites from the Aijala-Orijärvi area. The broken dividing line between the tholeiitic and calc-alkaline fields is after Irvine and Baragar (1971).

The basic metavolcanite formation is repeated in the Orijärvi area due to isoclinal folding, but the primary volcanic textures are well preserved. The metalavas contain plagioclase phenocrysts, and locally spherules filled with quartz and epidote. The composition of the fragments in the agglomerates and lapilli tuffs ranges from acidic to basic.

Acidic metavolcanic rocks

There are two main types of acidic metavolcanite encountered in the Aijala area. The lower one in the stratigraphy is an even-grained, homogeneous tuff. This is overlain by phenocrystal pyroclastic metavolcanites, which can be classified according to the size, quality and quantity of the phenocrysts, which are composed of quartz and plagioclase (diameter 1-4 mm). It is difficult to differentiate between the quartz phenocrysts and the

Table 8.2. Chemical compositions of acidic metavolcanites.

	1	2	3	4	5	6
SiO_2	70.75	73.85	72.35	74.25	76.20	66.35
TiO_2	0.33	0.20	0.25	0.38	0.34	0.39
Al_2O_3	13.50	12.93	13.96	13.00	12.31	13.84
Fe_2O_3	3.18	3.31	3.04	2.57	0.64	5.86
MnO	0.03	0.04	0.03	0.03	0.02	0.09
MgO	0.94	1.61	1.19	1.14	0.14	2.20
CaO	3.57	3.65	2.85	1.95	2.80	2.54
Na_2O	4.72	2.14	3.08	3.35	3.63	4.92
K_2O	1.80	1.11	2.12	1.89	1.03	1.72
Total	98.1	98.84	98.89	98.56	97.11	97.91

1. Even-grained metavolcanite. Aijala (x = 6675.420, y = 463.810).
2. Acidic metavolcanite with phenocrysts. Aijala (x = 6675.496, y = 464.456).
3. Acidic metavolcanite with quartz eyes. Aijala (x = 6675.256, y = 465.568).
4. Acidic metavolcanite with quartz eyes. Aijala (x = 6675.532, y = 463.866).
5. Quartz-eyed fragment in quartz-eyed metavolcanites. Aijala (x = 6675.530, y = 463.808).
6. Hornblende and biotite bearing fragment in quartz-eyed metavolcanite. Aijala (x = 6675.684, y = 465.318).

1-6. Wet chemical analyses (Lukkarinen 1979).

quartz eyes, since both are deformed and partly recrystallized. The quartz aggregates are 2-10 mm in diameters. The quartz eyes originate from the precipitation of quartz in the pores of acidic pumice from heated, circulating sea-water.

The altered acidic metavolcanites in the Orijärvi area are massive and locally brecciated by skarned fissures. A few acidic agglomerate beds are encountered. The acidic metavolcanites are overlain by beds of chert, limestone, iron formations and a volcanic conglomerate. These mainly chemical sediments indicate a quiet period in the volcanic activity.

Table 8.2 gives the chemical compositions of the acidic metavolcanites.

Intermediate-basic metavolcanites

The intermediate-basic metavolcanites in the Aijala area are heterogenic in composition and habit. The majority are made up of thin, layered (1-10 cm) tuffite beds containing diopside-skarn intercalations. The strongly developed shear-schistosity gives this rock type a banded structure. In addition to tuffites, the intermediate-basic metavolcanites contain agglomerate and tuff beds of a more mafic composition.

There is a basic metavolcanite located at Toija (NW corner of the Orijärvi area) that differs in chemical composition from the rest of the E-W-oriented volcanites in the area. This appears to represent another phase in volcanic activity and may be connected with the emplacement of ultramafic rocks and associated basic volcanites in the area.

Table 8.3 gives the chemical compositions of the intermediate and basic metavolcanites.

Metasediments

Within the leptite zone metasediments are encountered both on the lateral continuation of the metavolcanites and overlying them. The overlying metasediments are in the majority in the Aijala-Orijärvi area.

Table 8.3. Chemical compositions of intermediate-basic metavolcanites.

	1	2	3	4	5	6	7	8	9
SiO_2	60.20	53.70	48.00	50.8	55.50	47.40	45.80	56.50	48.60
TiO_2	0.51	0.59	0.55	0.60	0.68	0.46	0.49	0.37	1.11
Al_2O_3	14.58	15.05	17.76	17.40	15.50	16.30	18.80	14.50	13.70
Fe_2O_3	7.98	9.59	10.54	-	-	-	-	-	-
FeO	-	-	-	10.60	9.20	12.60	12.60	7.55	10.40
MnO	0.13	0.16	0.20	0.19	0.18	0.25	0.19	0.12	0.14
MgO	3.84	5.26	6.51	3.98	2.86	6.10	6.06	2.44	9.15
CaO	7.77	7.69	11.49	10.90	8.69	8.79	8.24	13.6	7.51
Na_2O	1.79	3.37	2.11	3.32	3.41	2.06	1.57	0.25	3.34
K_2O	1.29	1.15	0.21	0.42	0.50	0.10	0.99	0.10	1.06
Total	98.09	98.56	97.37	98.21	96.52	94.06	94.74	95.43	95.01

1. Intermediate metavolcanite. Aijala (x = 6676.392, y = 465.140).
2. Intermediate tuff containing plagioclase and hornblende phenocrysts. Aijala (x = 6675.180, y = 461.420).
3. Basic metavolcanite. Orijärvi (x = 6676.292, y = 465.552).
4. Basic metavolcanite, pillow lava. Orijärvi (x = 6680.35, y = 470.74).
5. Basic metavolcanite, lava. Orijärvi (x = 6680.36, y = 470.75).
6. Basic metavolcanite, tuff. Orijärvi (x = 6681.27, y = 472.93).
7. Basic metavolcanite, cummingtonite bearing tuff. Orijärvi (x = 6681.25, y = 472.93).
8. Epidote skarn fragment in basic metavolcanite (x = 6681.26, y = 472.93).
9. Basic metavolcanite, pillow lava. Toija, appr. 2.5 km NW from Kisko (x = 6684.95, y = 469.02).

1-3. Wet chemical analyses (Lukkarinen 1979).

4-9. XRF analyses, Outokumpu Oy.

Only a narrow band of metasediments, a mica gneiss, is exposed in the Aijala area, and this is intersected in the west by a postorogenic potassic granite, the Perniö granite.

The metavolcanite beds in the Orijärvi area are overlain by metasediments, and the acidic metavolcanites by cherts, limestones, iron formations and a volcanic conglomerate, as mentioned above. The conglomerate mainly contains fragments of acidic metavolcanite, mica gneiss, mica schist and chert. Some of the fragments resemble underlying formations, e.g. the quartz-eyed metavolcanites. This formation is overlain by basic metavolcanites, which are in turn overlain by mica schists, arkosites and, a little higher in the stratigraphy, intercalated intermediate and acidic tuffites.

The chemical sediments, limestones and iron formations are numerous but small in size as compared with those in the areas distal to the volcanic centres, e.g. the Lohja area (20 km east of Orijärvi), where there are operating limestone quarries and exhausted iron ore mines.

The typical iron formations of the Aijala-Orijärvi area are of the Algoma type. These occur in volcanic environments and typically display small horizontal and vertical dimensions as compared with the Superior-type iron formations in sedimentary environments.

The following iron ore types occur in the Aijala-Orijärvi area:

1. Chert-banded iron formations.
2. Banded and massive types of skarn iron ones.
3. Titanium iron ores associated with plutonic rocks.

Comparing the iron formations of the Aijala-Orijärvi area with those of Central Sweden, the following differences can be noted (Sipilä 1981).

1. There are no apatite iron ores in Southwest Finland.
2. Magnetite and hematite coexist in Central Sweden.
3. The iron formations of Central Sweden are located higher in the stratigraphy, i.e. in the potassic leptites.

4. Oxide facies iron formations predominate in Central Sweden while the silicate facies type is the most common in Southwest Finland. (Oxide and sulphide facies of iron formations are also encountered in the Aijala-Orijärvi area.)

Table 8.4 gives the chemical compositions of the metasediments in the Aijala-Orijärvi area.

Ore deposits

There are three exhausted mines in the Aijala-Orijärvi area, the Aijala Cu-S mine, the Metsämonttu Zn-Cu-Pb mine, and the Orijärvi Zu-Cu mine. The mines were operated by Outokumpu Oy. The Aijala and Metsämonttu deposits are in the same stratigraphic horizon, close to the contact between the basic and acidic metavolcanites, on the acidic side. The whole distance between the mines (1.5 km) is mineralized. The Orijärvi deposit is within an acidic metavolcanite formation, slightly lower in the stratigraphy.

The Orijärvi mine is one of the oldest in Finland dating back to 1757. It has yielded appr. 1 million tons of ore containing 0.7 % Cu, and 3.0 % Zn. The ore is locally and genetically associated with an alteration zone. The best quality ore was contained in diopside skarn, and some was also present in sericite schist, quartz rock and cordierite-antophyllite rock. The alteration zone lies appr. 200 m away from the Orijärvi batholith.

The total production of the Aijala mine was 0.8 million tons grading 1.6 % Cu and 14.2 % S, and that of the Metsämonttu mine 1.4 million tons grading 3.5 % Zn, 0.8 % Pb, 25 ppm Ag and 13.3 % S.

All the three ore bodies were relatively small in size and had been badly broken up by tectonic movements and partly remobilized, but they were nevertheless strata-bound. There are distinct hydrothermal alterations associated with the ore deposits producing cordierite-

Table 8.4. Chemical compositions of metasediments.

	1	2	3	4	5	6	7
SiO_2	71.9	24.66	48.89	76.2	75.3	67.3	58.5
TiO_2	-	0.03	0.05	0.20	0.15	0.74	0.54
Al_2O_3	0.40	0.88	0.92	9.58	11.5	12.2	17.5
FeO	19.56	55.98	42.86	4.20	2.28	6.71	8.18
MnO	3.15	0.25	1.32	0.05	0.06	0.08	0.08
MgO	2.36	7.80	2.50	1.48	0.80	2.33	3.15
CaO	4.21	6.41	4.19	0.99	4.62	3.59	2.03
Na_2O	0.01	0.04	0.04	3.09	1.57	1.94	1.18
K_2O	0.12	0.02	0.01	1.39	3.53	2.17	2.78
P_2O_5	0.07	1.72	0.5	0.04	0.05	0.16	0.22
Total	101.5	99.17	102.29	97.22	99.86	97.22	94.16

1. Chert-banded iron formation. Kisko, Marjaniemi (x = 6677.40, y = 467.10).
2. Silicate facies iron formation. Kisko, Marjaniemi (x = 6677.40, y = 467.10).
3. Silicate facies iron formation. Kisko, Marjaniemi (x = 6677.40, y = 467.10).
4. Matrix of a volcanic metaconglomerate (upper). Kisko (x = 6681.16, y = 472.87).
5. Matrix of a volcanic metaconglomerate (lower). Kisko (x = 6680.92, y = 476.75).
6. Graded mica schist. Kisko, Sorvastonlampi (x = 6680.92, y = 476.30).
7. Mica schist with andalusite and cordierite porphyroblasts. Kisko (x = 6681.16, y = 475.00).

1-3. XRF analyses, Rautaruukki Oy (Sipilä 1981).
4-7. XRF analyses, Outokumpu Oy.

antophyllite rocks, sericite and/or cordierite schists, and quartz rocks. The skarns generally hosted high grade ores. The three ore bodies are regarded as proximal volcanic-exhalative, Kuroko-type deposits.

CONCLUSIONS

The mainly calc-alkalic leptite zone is composed largely of supracrustal rocks and extends from Central Sweden into Southwest Finland. This zone is part of a Proterozoic island arc structure. The Finnish side of the zone apparently exhibits a deeper erosional level than the Swedish side. The eastern limits of the leptite zone are found in Southwest Finland.

Metavolcanites make up the majority of the rock types in the Aijala-Orijärvi area. The volcanism in the area is considered to be related to the Orijärvi batholith, which has affected the geological evolution of the area in many ways. After the culmination of the volcanic activity the batholith rose and the contact zone rocks were altered as a consequence of changing PT conditions. Characteristic of the Aijala-Orijärvi area are volcanic-exhalative ore deposits and mineralizations with associated alteration phenomena. This alteration phase probably took place before the next one at the contact zone between the batholith and surrounding supracrustal rocks.

EXCURSION SITES IN THE AIJALA-ORIJÄRVI AREA

Fig. 8.4 gives the excursion route and stops.

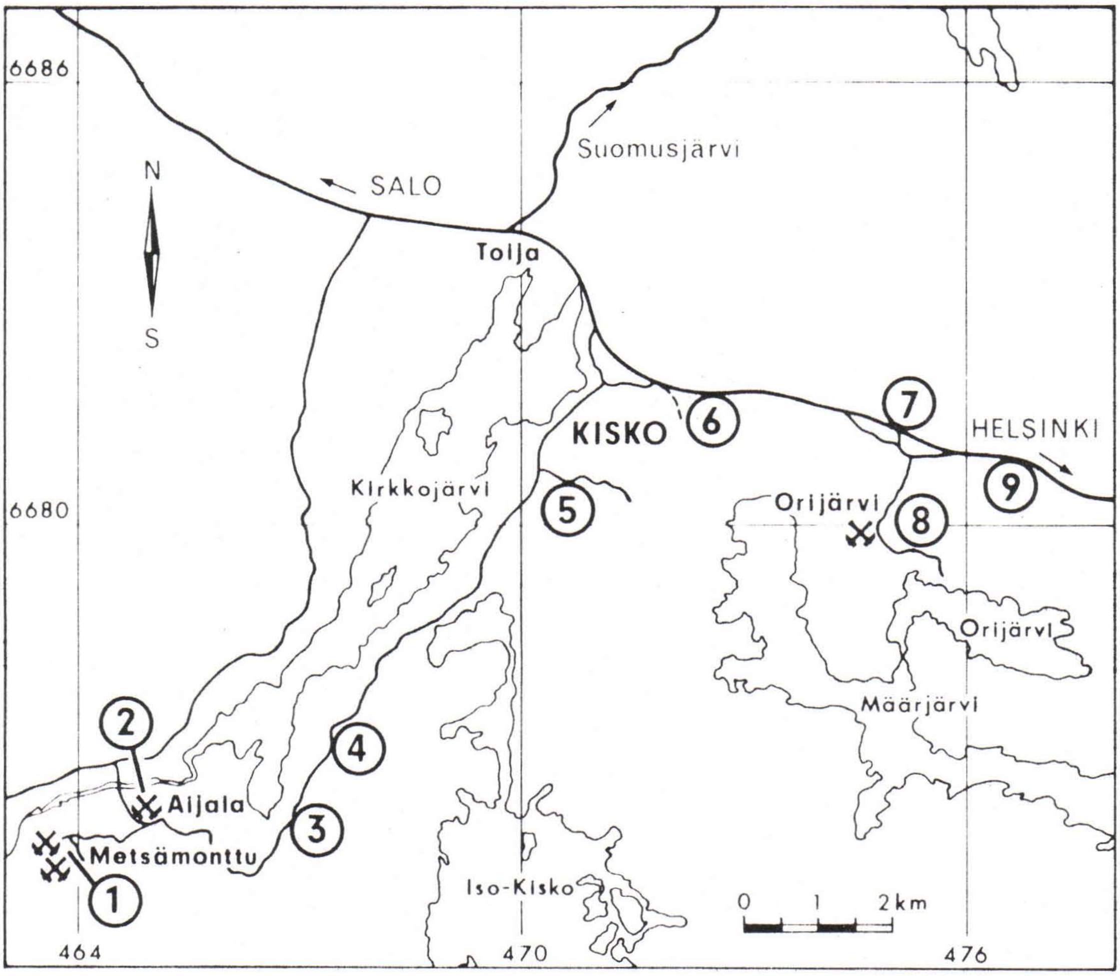


Fig. 8.4. The excursion route and stops in the Aijala-Orijärvi area.

The Aijala area

Stop 1

Metavolcanites at the Metsämonttu mine (x = 6675.78, y = 463.80). 1 km walk.

Intermediate-basic metavolcanites crop out in the vicinity of the Metsämonttu mine, displaying skarn-banded tuffite, lapilli tuff and agglomerate intercalations, and acidic quartz-eyed pyroclastic rocks.

A pronounced shear schistosity and associated vertical lineation are seen.

Two exhausted mines, Metsämonttu and Aijala, are located in the area. These were operated by Outokumpu Oy in 1949-1974. Total production was 2.2 million tons. The mines are in the same stratigraphic horizon, appr. 1.5 km from each other.

Metsämonttu was a Zn-Pb-Ag-Cu mine grading 3.5 % Zn, 0.8 % Pb, 25 ppm Ag, and 0.3 % Cu. Aijala was a Cu-S mine grading 1.6 % Cu, and 14.2 % S.

Stop 2

A micaceous metatuffite at the Aijala sports field (x = 6676.06, y = 465.10).

This metatuffite is stratigraphically between an acidic and an intermediate-basic metavolcanite bed. Primary bedding and a fold are seen in the outcrop.

Stop 3

The contact zone of the Orijärvi batholith at Aikolanlahti, Kisko (x = 6676.05, y = 466.92).

Two acidic rock types of different ages associated with the Orijärvi batholith are seen in the outcrop. The younger one intersects the surrounding older rock, and is an even-grained plutonic rock. It is of a trondhjemitic composition and contains basic inclusions.

The older rock is a coarse-grained, quartz-eyed hypabyssal dyke. These are common in the border zone of the batholith, extending to the metavolcanites. An even-grained granite also brecciates the quartz-eyed acidic dyke in the outcrop. This is considered younger than the metavolcanites but older than the Orijärvi batholith.

Stop 4

Iron formation at Marjaniemi, Kisko (x = 6677.40, y = 467.10).

This stop shows an iron formation with thin intercalating bands of silicate and oxide facies and chert. The formation is plastically deformed and brecciated by a younger plagioclase porphyrite dyke. The iron formations in the Aijala-Orijärvi area occur stratigraphically in several horizons within the acidic metavolcanites.

The Orijärvi area

Stop 5

Basic metavolcanites south of Hyypiänmäki, Kisko (x = 6680.35, y = 470.70). 1 km walk.

The objects of interest are a contact between intermediate and basic metavolcanites, and agglomerate and pillow lava beds in the latter. Typical of the contact zone is a skarned part in the intermediate metavolcanite. Several agglomerate beds are seen, with bombs and sharp-edged fragments of up to 0.2 x 0.3 m^3.

Stop 6

Metavolcanites north of Iilinjärvi, Kisko (x = 6681.24, y = 472.45). 0.5 km walk.

The outcrops display mafic metavolcanite and underlying conglomerate. The two folding phases typical of the Orijärvi area are seen in the conglomerate outcrop.

Stop 7

Mica schist in a cutting in the Salo-Mustio road at Orijärvi (x = 6681.30, y = 475.04).

This site is higher in the stratigraphy than any of the previous ones. At these stratigraphic levels the origin of the weathering material may vary from bed to bed. When it is of volcanic origin the rocks are called intermediate or acidic tuffites. When the material is of sedimentary origin, mica schists result. The road cutting displays a mica schist with alternating andalusite and/or cordierite porphyroblast-bearing beds.

The bedding strikes almost E-W. The outcrop features a drag fold in which the schistosity clearly intersects the bedding.

Stop 8

The Orijärvi mine (x = 6679.76, y = 474.65).

On the north side of the open pit a subvolcanic amphibolite dyke cuts across metavolcanites and ore, while on the south side of the open pit there are altered rock types: skarns, sericite and cordierite-bearing schists and cordierite-antophyllite rocks. Geological observations suggest that there are cordierite-anthophyllite rocks of two different origins in the area:

1. Cordierite-anthophyllite rocks genetically associated with the ore deposits, originally acidic volcanites.

2. Cordierite-anthophyllite rocks originating through alteration from sedimentary rocks. Primary bedding is sometimes seen in these.

Only the open pit, 80 m deep, and the head frame remain of the old Orijärvi mine today.

Stop 9

A metagraywacke in a cutting on the Salo-Mustio road at Sorastonlampi (x = 6680.92, y = 476.30).

Site 9 is stratigraphically at the same level as site 7. The outcrop displays a greywacke schist with bedding, graded bedding, load casts and slumps.

REFERENCES

Eskola, P. 1914, On the petrology of the Orijärvi region in south-western Finland. Bull. Comm. géol. Finlande 40, 279 p.

Eskola, P. 1915, Om sambandet mellan kemisk och mineralogisk sammansättning hos Orijärvi-traktens metamorfa bergarter. Bull. Comm. géol. Finlande 44, 145 p.

Gavelin, S., Lundström, I. & Nordström, S. 1976, Svecofennian stratigraphy on Utö, Stockholm archipelago. Sveriges Geol. Undersökn., Ser. C 719, 44 p.

Henriques, Å. 1964, Geology and Ores of the Åmmeberg Disctrict (Zinkgruvan) Sweden. Ark. Mineral. Geol. 4 (1), 245 p.

Irvine, T.N. & Baragar, W.R.A. 1971, A guide to the chemical classification of the common volcanic rocks. Canadian Journ. Earth Sci. 8, 523-548.

Latvalahti, U. 1979, Cu-Zn-Pb Ores in the Aijala-Orijärvi Area, Southwest Finland. Econ. Geol. 74, 1035-1059.

Lukkarinen, H. 1979, Aijalan ja Metsämontun liuskeista. Unpublished master's thesis, University of Turku, 89 p.

Magnusson, N.H. 1940, Ljusnarsbergs malmtrakt. Beruggrund och malmfyndigheter. Sveriges Geol. Undersökn., Ser. C 30, 188 p.

Sipilä, P. 1981, Lounais-Suomen rautamalmeista. Unpublished master's thesis, University of Turku, 106 p.

Sundius, N. 1923, Grythyttefältets geologi. Sveriges Geol. Undersökn., Ser. C 312.

Tuominen, H.V. 1951, Metamorphic concentration of magnesium and iron in the Orijärvi region. A reply. Bull. Comm. géol. Finlande 154, 234-238.

Tuominen, H.V. 1957, The structure of Archean area, Orijärvi, Finland. Bull. Comm. géol. Finlande 177, 32 p.