NEW ASPECTS TO THE GEOLOGY OF THE OUTOKUMPU REGION

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HUHMA, AARTO 1976: New aspects to the geology of the Outokumpu region. *Bull. Geol. Soc. Finland 48, 5—24.*

This study provides a general picture of the geology of the Outokumpu region with no attempt at being a detailed description. Special attention is paid to the areas occupied by Karelian and Prekarelian rocks and the location of the Outokumpu region in relation to the Prekarelian rocks.
Age determinations carried out from the area assign an average age of 2680 Ma to the Prekarelian rocks and 1900 Ma to the Karelian rocks (Maarianvaara granite).
The differences between the rocks of the serpentinite-quartz rock series and the epicontinental series are elucidated on the basis of analytical data and with triangular diagrams.
In the opinion of the present author, the Outokumpu region shows features characteristic of an Alpinotype orogenesis and hence an Alpinotype model is applied to the region. A contrary view has been presented by H. J. Zwart (1967), who considers that the Svecofennian-Karelian area exhibits features typical of Hercynotype orogeny.
Finally the genesis of the Outokumpu ore is discussed, the conclusion being reached that it is of submarine origin.

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Introduction

The Outokumpu region is located in North Karelia, East Finland, as shown on Fig. 1. The area covered by the map is larger than that comprising the Outokumpu region in sensu stricto.

Three active mines are in operation in the region, *i.e.* Keretti (Outokumpu), Vuonos and Luikonlahti. In addition to these, several sulphide mineralisations are known in the area. The theme of this study, however, is not the ores but the general geology of the Outokumpu region, the mapping of which was completed at the beginning of the 1970's. A simplified geologic map is appended (Fig. 3) showing the boundaries between the Prekarelian and Karelian rocks as well as the main tectonic features and the location of the serpentinite-quartz rock series favourable for the occurrence of the ore deposits.

Geologic maps of the area (sheet 4222-Outokumpu, sheet 4224-Kontiolahti and sheet 4311-Sivakkavaara, 1971) and their explanations (Huhma, A. 1975) have already been published and for more detailed information the reader is referred to these publications. I have already discussed the geology of the area in the »Short description of the geology of the Outokumpu district» (Huhma, A. and

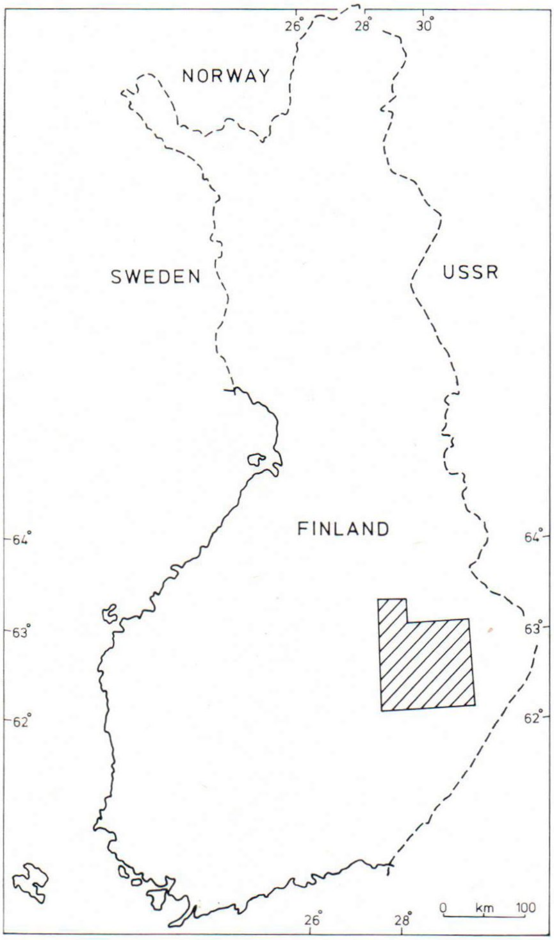

Fig. 1. Location of the area investigated.

Huhma, M. 1970). When this study was published the whole area had not been mapped and the outlines of the geology were not yet mature. Now, however, the mapping is finished and it is my intention in the present paper to describe the area in broad outlines. The forementioned study and the present one emphasize different aspects of the area and are, consequently, not exclusive. Nevertheless, the subject is such that some repetition is unavoidable in the cause of comprehensibility. The theme of my study in Finnish (Huhma, A. 1970) was the Outokumpu serpentinite-quartz rock series and the sedimentary rocks of the epicontinental facies. Some supplementary data from this work, and which have not been published elsewhere, are included in the present paper.

Seven age determinations have been obtained of which two have reported earlier (Kouvo 1958).

A survey of the geology of the area

The Outokumpu region forms part of the Karelian formations, whose plutonic rocks are approximately 1900 Ma old. It is bordered on the north, east and west by older Prekarelian rocks, whose infracrustal rocks have been assigned an age of some 2680 Ma. In the southwest the Outokumpu area comes to an end at the northwest to southeast trending Kermajärvi zone, which includes the Kermajärvi granite.

The Karelian area is marked by several Prekarelian domes; wellknown ones are those of Sotkuma, Kontiolahti, Liperinsalo and Oravisalo. In connection with the mapping a number of additional Prekarelian domes were discovered, *i.e.* the Juojärvi domes and the three small ones south of them: Papinniemi, Humalajärvi and Petrumajärvi.

Figs. 2, 3 and 4 all cover the same area and serve to elucidate the geology of the area. Fig. 3 is a geologic map showing the locations of the ore deposits and the major sulphide mineralisations as well as the sites from which samples were collected for age determinations. Fig. 2 gives some geographic names as an aid to localisation and four sampling sites selected by Dr. Kouvo for dating. Fig. 4 is an aeromagnetic map.

The Karelian-Prekarelian boundary

The Prekarelian rocks are overlain in many places by basal arkoses and conglomerates as well as by sediments of the epicon-

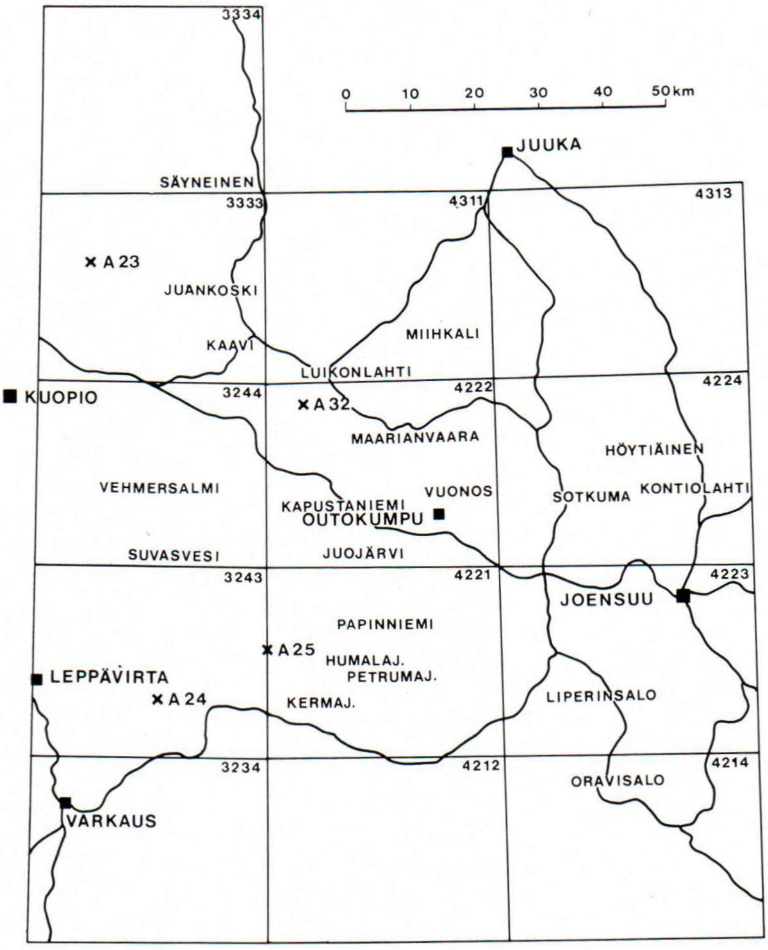

Fig. 2. Outokumpu district.

tinental facies, e.g. quartzites, arkoses, skarns, carbonate rocks and black schists.

The eastern contact, of which only the northern part is visible in map sheet 4313, has been known for decades. It runs almost rectilinearly approximately from northwest to southeast. The northern contact is lobate and the Karelian rocks penetrate in a fingerlike manner on the Prekarelian basement. A novel feature is the fact that the Outokumpu region is also bordered in the west by Prekarelian rocks. This contact trends roughly north to south, although in places it is sinusoidal. In the south the contact turns westwards to Suvasvesi; it has not been traced beyond this lake because in any case the Outokumpu region comes to an end at the Kermajärvi zone. The western contact has certain characteristics that distinguish it from the other contacts and since these represent the latest findings the western contact merits a more lengthy description.

From the north down as far as Juankoski the contact is occupied by a continuous and narrow formation of quartzite with some skarn interbeds that decrease in number southwards. With a few exceptions the quartzites are absent from the contact south of Juankoski and they are not encountered until west of the bulge pointing southwards

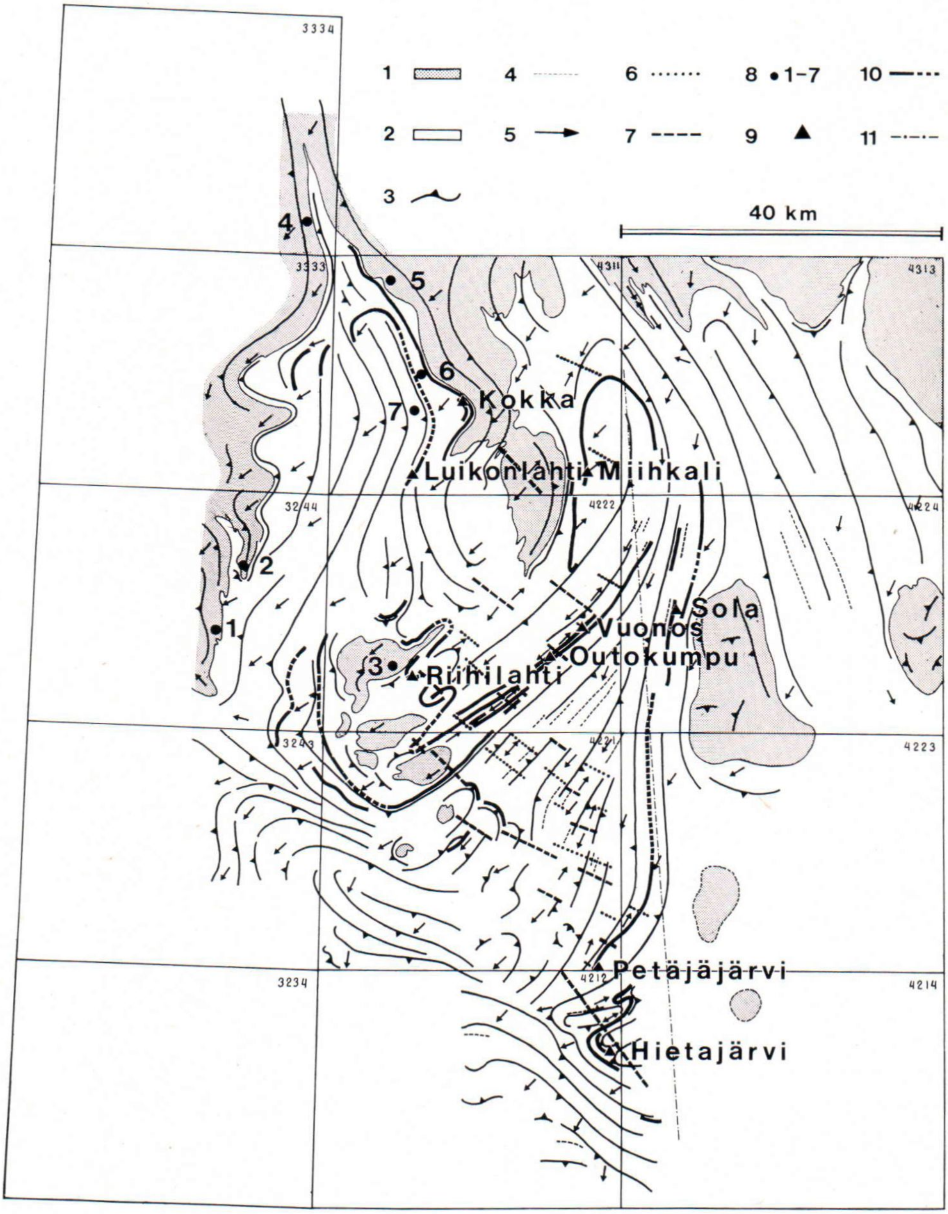

Fig. 3. Simplified geological map. 1. PREKARELIAN rocks 2. KARELIAN rocks 3. Prevailing schistosity 4. Synclines 5. Lineations 6. Axial depressions 7. Axial culminations 8. Datings 9. Ore deposits and mineralisations 10. Serpentinite zones and the assumed continuations 11. West of the boundary the serpentinites are chrysotile serpentinites, the skarns diopsidetremolite skarns and the carbonate rocks dolomites. East of the boundary the serpentinites are antigorite serpentinites, the skarns tremolite skarns and the carbonate rocks magnesite rocks.

in the Vehmersalmi mapsheet (3244) where there is a narrow 10 km long continuous quartzite deposit trending north to south. East of the quartzite, between the quartzite

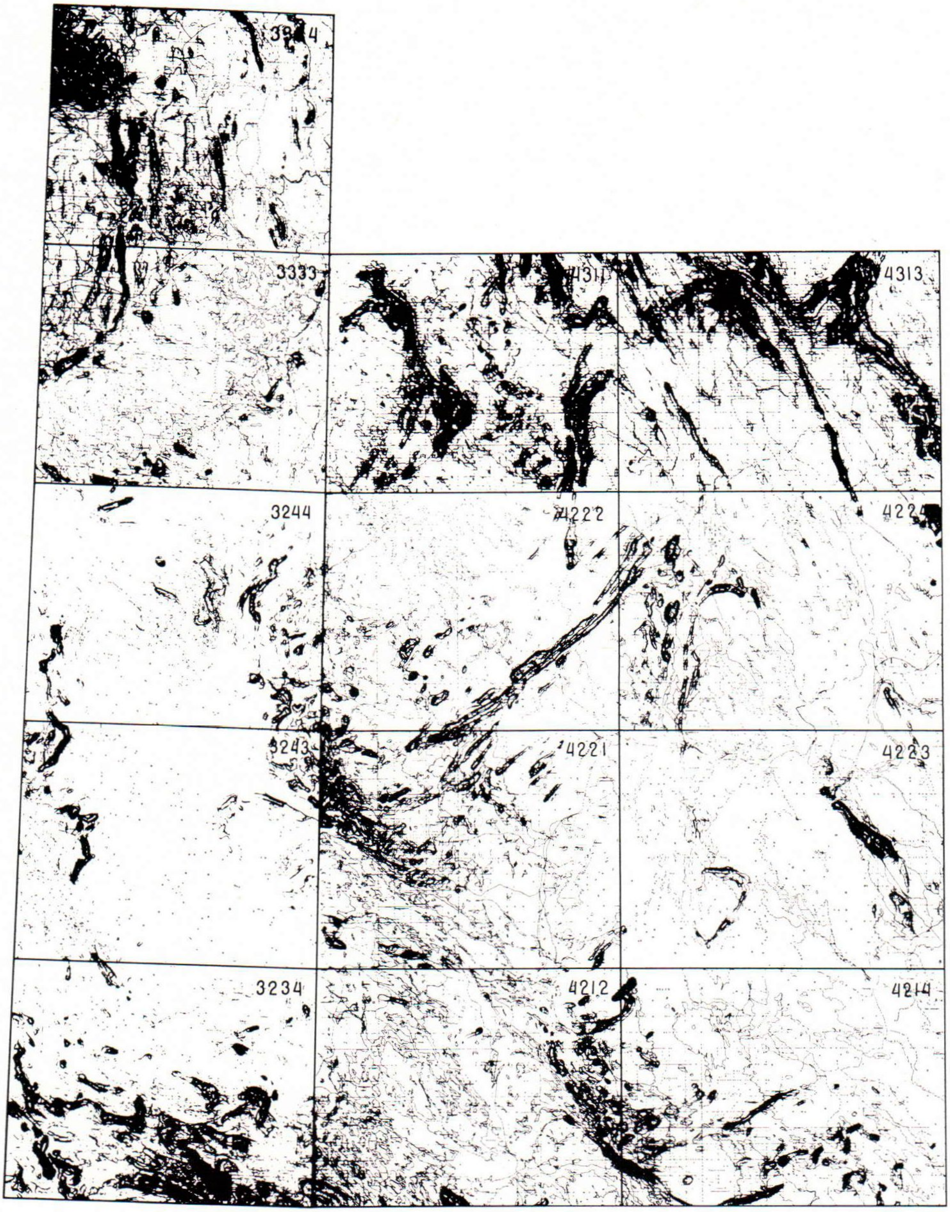

Fig. 4. Aeromagnetic map.

and mica gneiss, there is an occurrence of arkose gneiss that also bends around the southward bulge in the basal formation. The arkose gneiss zone contains interbeds of mica-garnet gneiss with occasional cordierite. Amphibolites with some local tuffitic and agglomeratic features are also encountered in this contact zone. Some skarns and carbonate rocks have been found in the amphibolite zone.

Tectonic macrostructure

Throughout the northern part of the area bedding dips westwards and folding is isoclinal. Farther south there is a large anticline around the Juojärvi domes, with the Maarianvaara granite in the middle. Between the Outokumpu—Miihkali area and the Sotkuma dome there is a synclinorium. Within the Höytiäinen area the dips are fairly monotonously westwards. The Outokumpu region is cut in the south by the Kermajärvi zone in which the bedding dips to southwest. The dominant axial trend is towards southwest, but locally it is reversal, the axes trending northeast owing to the axial depressions and culminations marked on Fig. 3. The Outokumpu and Vuonos ore deposits are located in the axial depressions.

Karelian sediments

The bulk of the Karelian sediments are of the geosynclinal facies, i.e. mica gneisses, mica schists and phyllites with abundant black schist interlayers. The intesity of the metamorphism increases from east to west and, consequently, the rocks in the Höytiäinen furrow are phyllites. Westwards they grade into gneisses and further into veined gneisses in the western and southern parts of the area.

Prekarelian rocks

The Prekarelian rocks are ortho- and paragneisses that exhibit gneissose, migmatitic, slightly foliated and banded (in places also augen gneiss) structure. Granodioritic and granitic rocks predominate in the eastern and northern parts of the Outokumpu region, whereas in its western subareas trondhjemitic and quartz-dioritic rocks prevail. Furthermore, amphibolites and diabases are encountered here and there in the Prekarelian basement.

In my opinion there are two reasons why the Prekarelian rocks have escaped recognition so far:

1) It has been commonly assumed that the Maarianvaara granite produced granitisation and migmatisation in its environment, and hence the Prekarelian rocks were considered as products of these agencies. In fact, however, the Maarianvaara granite had no such effect on its country rocks.

2) The degree of metamorphism increases west- and southwards, making it difficult to distinguish the Prekarelian from the Karelian rocks. For example, in the southern part of the map there are strongly migmatised mica gneisses that are fairly similar to the banded and migmatised rocks in the basal complex. In extreme cases it is almost impossible to say whether a rock is Karelian or Prekarelian in origin. The distinction is further hampered by the fact that the Maarianvaara granite and pegmatite have sent numerous veins and bodies into the Prekarelian rocks, thereby breaking them into pieces. Hence, the domes are by no means so regular in shape as the map would suggest. As a matter of fact, only the boundary within which the Prekarelian rocks occur has been drawn on the map. The abundance of Maarianvaara granite in these domes has further exaggerated the misinterpretation because the Prekarelian rocks were no longer recognizable among the granites.

In the literature mention is also made of Karelian augen gneisses (Väyrynen 1954). However, all the augen gneisses in the Outokumpu region are of Prekarelian origin.

Karelian infracrustal rocks

The geosynclinal sediments in the western part of the region contain initial magmatites, *i.e.* serpentinite-ophiolites that occur in a zone following the basal complexes. Quartz rocks, skarns and carbonate rocks, which the present author calls the serpentinite-quartz rock series (Huhma A. 1970), are associated with the serpentinites. In a paper in Finnish (Huhma, A. 1970), a detailed description is given of the serpentinite-quartz rock series as well as of the sedimentary rocks of the epicontinental facies. The analytical data (Table I) and the triangular diagrams (Figs. 5—7) are from this paper.

Explanation to Table I

$\bar{x}_A$ = arithmetic mean
$\bar{x}_G$ = geometric mean
s_A = standard deviation
s_G = geometric deviation
N = number of analyses

Table I part 1

The arenites of the epicontinental facies
The Sivakkavaara-Kortteinen subarea (map sheet 4311 04—06)

	ppm Cu	ppm Zn	ppm Ni	ppm Co	% S	% Cr_2O_3	% TiO_2
$\bar{x}_A$	11	14	26	11	0.01	0.06	0.29
$\bar{x}_G$	7	11	18	8	0.01	0.06	0.13
s_A	13	11	32	10	0.01	0.21	0.37
s_G	2	2	2	2	2.15	1.40	4.20
N	6	6	6	6	4	4	4

The Rovevaara-Petrovaara subarea (map sheet 4311 08—12)

	Cu	Zn	Ni	Co	S	Cr_2O_3	TiO_2
$\bar{x}_A$	11	14	14	4	0.01	0.04	0.15
$\bar{x}_G$	8	9	12	2	0.01	0.04	0.13
s_A	9	15	7	5	0.07	0.01	0.09
s_G	3	3	2	3	3.26	1.40	4.20
N	15	15	15	15	10	10	10

The Juojärvi domes subarea (map sheets 4221 03, 06 and 4222 01, 04)

	Cu	Zn	Ni	Co	S	Cr_2O_3	TiO_2
$\bar{x}_A$	13	21	18	1	0.01	0.10	0.13
$\bar{x}_G$	11	19	18	1	0.01	0.01	0.12
s_A	9	11	6	1	0.02	0.04	0.06
s_G	2	2	1	1	2.97	1.50	1.70
N	4	4	4	4	4	4	4

Total

	Cu	Zn	Ni	Co	S	Cr_2O_3	TiO_2
$\bar{x}_A$	11	15	18	5	0.01	0.06	0.17
$\bar{x}_G$	8	11	14	1	0.01	0.06	0.13
s_A	10	13	17	7	0.02	0.61	0.18
s_G	2	2	2	1	2.87	1.51	2.09
N	25	25	25	25	18	18	18

Table I part 2

Quartz rocks in association with serpentinites
Vuonos (map sheet 4222 11)

	ppm Cu	ppm Zn	ppm Ni	ppm Co	% S	% Cr_2O_3	% TiO_2
$\bar{x}_A$	33	17	1552	90	0.94	0.59	0.01
$\bar{x}_G$	26	12	1475	86	0.80	0.58	0.01
s_A	23	16	485	25	0.50	0.09	0.01
s_G	2	2	1	1	1.89	1.62	2.17
N	11	11	11	11	11	11	11

Petäjäjärvi (map sheet 4221 10)

	Cu	Zn	Ni	Co	S	Cr_2O_3	TiO_2
$\bar{x}_A$	8	4	1950	83	0.45	0.51	0
$\bar{x}_G$	7	1	1579	71	0.31	0.48	0
s_A	5	2	1437	50	0.44	0.16	0
s_G	2	2	2	2	2.44	1.44	1.18
N	18	18	18	18	18	18	18

Total

	Cu	Zn	Ni	Co	S	Cr_2O_3	TiO_2
$\bar{x}_A$	17	9	1799	86	0.63	0.54	0
$\bar{x}_G$	11	7	1539	76	0.44	0.52	0
s_A	19	11	1173	42	0.51	0.14	0.01
s_G	3	3	2	2	2.50	1.37	1.69
N	29	29	29	29	29	29	29

Table I part 3

Skarns of the epicontinental facies
The Sivakkavaara-Kortteinen subarea (map sheet 4311 04—06)

	ppm Cu	ppm Zn	ppm Ni	ppm Co	% S	% Cr_2O_3	% TiO_2
$\bar{x}_A$	18	29	35	15	0.03	0.02	0.19
$\bar{x}_G$	8	24	23	10	0.02	0.01	0.10
s_A	26	23	38	16	0.02	0.01	0.27
s_G	5	2	3	3	1.90	1.89	4.23
N	3	3	3	3	3	3	3

The Rovevaara-Petrovaara subarea (map sheet 4311 08—12)

	Cu	Zn	Ni	Co	S	Cr_2O_3	TiO_2
$\bar{x}_A$	26	35	29	15	0.05	0.02	0.47
$\bar{x}_G$	18	28	27	13	0.04	0.02	0.32
s_A	24	30	10	8	0.03	0.01	0.38
s_G	3	2	2	2	2.04	1.96	2.77
N	8	8	8	8	8	8	8

The Juojärvi domes subarea (map sheets 4221 03, 06 and 4222 01, 04)

	Cu	Zn	Ni	Co	S	Cr_2O_3	TiO_2
$\bar{x}_A$	7	35	15	9	0.02	0.01	0.36
$\bar{x}_G$	7	33	14	8	0.02	0.01	0.29
s_A	4	11	4	3	0.01	0.01	0.28
s_G	2	2	1	2	1.95	1.57	2.02
N	6	6	6	6	6	6	6

Total

	Cu	Zn	Ni	Co	S	Cr_2O_3	TiO_2
$\bar{x}_A$	18	34	25	13	0.04	0.02	0.38
$\bar{x}_G$	11	31	21	11	0.03	0.02	0.25
s_A	20	22	17	9	0.03	0.01	0.37
s_G	3	2	2	2	2.09	1.81	2.78
N	17	17	17	17	17	17	17

Table I part 4

Skarns in association with serpentinites
Vuonos (map sheet 4222 11)

	ppm Cu	ppm Zn	ppm Ni	ppm Co	% S	% Cr_2O_3	% TiO_2
$\bar{x}_A$	62	20	1328	91	0.90	0.37	0.01
$\bar{x}_G$	50	17	1313	82	0.77	0.36	0.01
s_A	40	16	250	46	0.50	0.08	0.02
s_G	2	2	1	2	1.78	1.25	2.42
N	13	13	13	13	13	13	13

Petäjäjärvi (map sheet 4221 10)

	Cu	Zn	Ni	Co	S	Cr_2O_3	TiO_2
$\bar{x}_A$	7	4	2076	87	0.44	0.63	0.01
$\bar{x}_G$	5	4	1714	75	0.32	0.60	0.01
s_A	5	1	1209	41	0.38	0.20	0.01
s_G	2	1	2	2	2.54	1.41	1.85
N	9	9	9	9	9	9	9

Total

	Cu	Zn	Ni	Co	S	Cr_2O_3	TiO_2
$\bar{x}_A$	39	14	1634	89	0.71	0.48	0.01
$\bar{x}_G$	20	9	1464	79	0.54	0.45	0.01
s_A	41	15	849	43	0.51	0.19	0.01
s_G	4	3	2	2	2.34	1.45	2.18
N	22	22	22	22	22	22	22

Table 1 part 5

Dolomites in association with serpentinites
Vuonos (map sheet 4222 11)

	ppm Cu	ppm Zn	ppm Ni	ppm Co	% S	% Cr_2O_3	% TiO_2
$\bar{x}_A$	38	21	1513	90	1.36	0.33	0
$\bar{x}_G$	36	16	1494	89	1.33	0.33	0
s_A	15	17	259	13	0.33	0.05	0.01
s_G	2	2	1	1	1.28	1.18	1.41
N	4	4	4	4	4	4	4

Petäjäjärvi (map sheet 4221 10)

	Cu	Zn	Ni	Co	S	Cr_2O_3	TiO_2
$\bar{x}_A$	4	8	1305	58	0.45	0.48	0.05
$\bar{x}_G$	4	8	1270	57	0.35	0.47	0.05
s_A	1	1	404	13	0.40	0.17	0.03
s_G	1	1	1	1	2.80	1.44	1.82
N	2	2	2	2	2	2	2

Total

	Cu	Zn	Ni	Co	S	Cr_2O_3	TiO_2
$\bar{x}_A$	27	16	1443	79	1.06	0.38	0.02
$\bar{x}_G$	17	13	1416	77	0.86	0.37	0.01
s_A	21	15	291	20	0.57	0.12	0.03
s_G	4	2	1	1	2.34	1.32	3.07
N	6	6	6	6	6	6	6

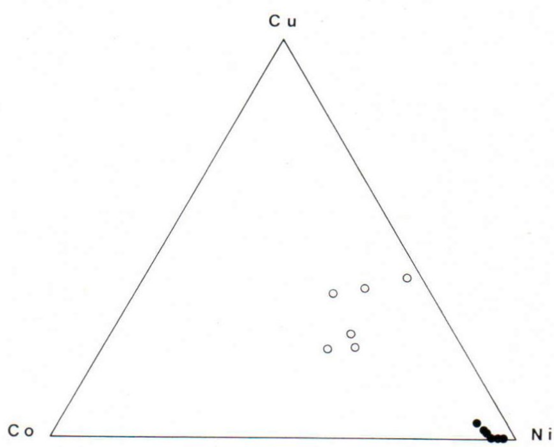

Fig. 5. Cu-Co-Ni triangular diagram. Open circles are for the arenites, skarns and carbonate rocks of the epicontinental facies. Solid circles refer to the quartz rocks, skarns and carbonate rocks associated with the serpentinites. The plots are the means given in the tables.

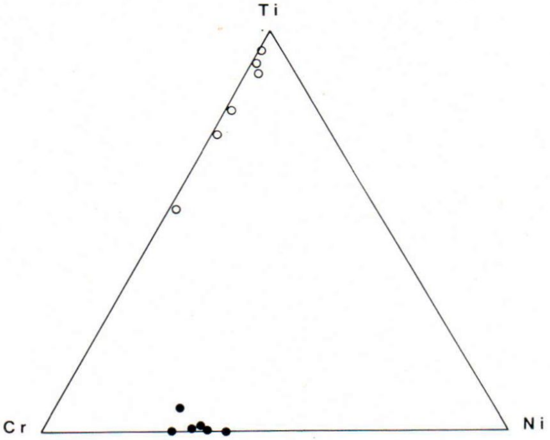

Fig. 6. Ti-Cr-Ni triangular diagram. Open and solid circles as in Fig. 1.

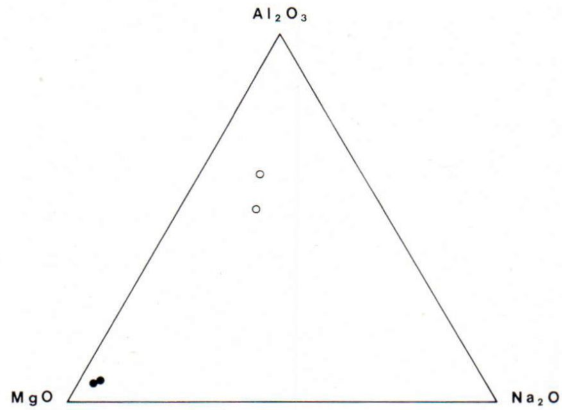

Fig. 7. Al_2O_3-MgO-Na_2O triangular diagram. Open circles refer to the skarns of the epicontinental facies and solid circles to the skarns associated with serpeninites.

The Karelian granite, i.e. the Maarianvaara granite, occurs chiefly in the northern part of map sheet 4222 and the southern part of map sheet 4311. This granite exhibits both synorogenic and lateorogenic features depending on the locality. Thus, the Juojärvi domes are largely penetrated by the Maarianvaara granite, which is an even-grained rock,

Table II. Sample numbers and locations of the rocks dated.

Rocks 1—5 are Prekarelian intrusives.

1 = 26-1-VJP/Vhs-7	Vehmersalmi, Litmaniemi x = 6961.93, y = 563.33	3244 08 A
2 = 263 A-VJP/Vhs-71	Vehmersalmi, Hoikanmäki x = 6969.80, y = 566.23	3244 08 D
3 = 282-ALP/Kjä-59	Outokumpu, Kapustaniemi x = 6958.85, y = 431.90	4222 04 B
4 = 198-AL/Säy-60	Säyneinen, Kirkonkylä x = 7013.8, y = 571.4	3334 10 A
5 = 35-EV/Säy-53	Juuka, Losomäki x = 7006.3, y = 431.55	4311 06 B
Rocks 6—7 are Karelian intrusives (»Maarianvaara granite»).		
6 = 209f-AH/Kvi-54	Kaavi, Mäntyjärvi x = 6996.65, y = 435.05	4311 05 D
7 = 658a-MH/Kvi-54	Kaavi, Vihtajärvi x = 6991.10, y = 434.18	4311 05 A

1 = A449 (Numbers refer to Dr. O. Kouvo's age determinations)
2 = A448
3 = A75
4 = A73
5 = A74
6 = A59
7 = A60

Table III. Mineral compositions of the samples.

	1	2	3	4
Quartz	12.2	15.0	21.3	40.5
Potash feldspar	tr.	0	0	2.8
Plagioclase (An)	61.2 (28)	62.7 (30—35)	58.6 (30)	43.0 (20)
Biotite	14.3	14.9	11.4	12.7
Muscovite	tr.	tr.	tr.	0.9
Hornblende	10.1	6.3	7.7	0.0
Accessories	2.2	1.1	1.0	0.1
	100.0	100.0	100.0	100.0

	5	6	7
Quartz	31.6	24.3	32.3
Potash feldspar	8.4	7.2	22.8
Plagioclase (An)	52.3 (15)	48.9 (31—20)	39.1 (26—18)
Biotite	6.8	17.3	5.7
Muscovite	0	0	tr.
Hornblende	0	1.5	0
Accessories	0.9	0.7	0.1
	100.0	100.0	100.0

	Densities
1 = Quartzdiorite	1 = 2.75
2 = »	2 = 2.77
3 = »	3 = 2.72
4 = » (trondhjemite)	4 = 2.69
5 = Granodiorite	5 = 2.63
6 = »	6 = 2.70
7 = »	7 = 2.64

Table IV. Chemical compositions of the samples.

	1	2	3	4	5	6	7
SiO_2	59.37	60.91	64.67	67.16	72.39	67.78	72.63
TiO_2	0.72	0.49	0.50	0.57	0.30	0.57	0.28
Al_2O_3	16.40	16.66	16.93	15.66	14.52	16.6	15.4
Fe_2O_3	2.32	2.32	1.46	1.35	0.69	0.15	0.05
FeO	3.65	3.13	2.57	2.30	1.58	3.05	1.58
MnO	0.04	0.04	0.02	0.02	0.01	0.08	0.05
MgO	3.90	3.42	2.92	2.45	0.97	1.66	0.51
CaO	5.77	5.70	5.04	2.06	1.96	3.30	1.65
Na_2O	4.48	4.45	4.52	4.92	4.25	3.70	3.62
K_2O	1.57	1.45	1.27	2.23	2.05	2.20	3.75
P_2O_5	0.42	0.38	0.19	0.24	0.11	0.20	0.08
H_2O +	1.30	0.95	0.79	0.89	0.58	0.71	0.45
H_2O —	0.04	0.01	0.03	0.01	0.02	0.06	0.03
	99.98	99.91	100.91	99.86	99.43	100.06	100.08

Analyses 1—5 by U. Penttinen
» 6—7 by A. Heikkinen

grey in colour and granodioritic in composition although it shows differentiation from diorite to granite.

On the southwestern border of the area in the zone, which shows up clearly also on the tectonic map, there occurs the synorogenic Kerma granite, which, unlike the Maarianvaara granite, forms migmatites in its envi-

Table V. U, Th-Pb analytical data and apparent ages for zircon.

Sample no.	Rock	Mineral	Age (million years)		
			$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
1	Quartzdiorite	zircon (100—125 mesh)	2351 ± 55	2506 ± 29	2635 ± 22
2	Quartzdiorite	zircon	2474 ± 49	2577 ± 24	2659 ± 24
3	Homogenous oriented quartzdioritic orthogneiss	zircon (+ 325 mesh)	2556 ± 113	2627 ± 56	2683 ± 32
4	Paragneiss-like rock. Most of the zircon grains distinctly idiomorphic	zircon	2023 ± 94	2317 ± 59	2587 ± 65
5	Granodioritic gneiss. Some zircons are large with inclusions and fine zonality indicating that recrystallization was unlikely	zircon	2304 ± 138	2482 ± 84	2631 ± 118
6	Granodiorite	zircon (—200 mesh)	1064 ± 28	1366 ± 24	1875 ± 21
7	Granodiorite	zircon	1687 ± 65	1759 ± 39	1846 ± 19

Table VI (part 1)
Analytical data (zircon)

Sample no.	U p.p.m.	Radiogenic ^{206}Pb, p.p.m.	Isotopic abundance relative to ^{206}Pb (= 100)		
			204	207	208
1	345.5	130.6	0.0182	18.12	17.27
2	283.2	113.89	0.0077	18.25	15.22
3	193.1	80.77	0.0562	19.12	17.81
4	529.4	167.7	0.0071	17.47	11.81
5	626.9	231.5	0.0667	18.69	11.26
6	538.0	82.9	0.1663	13.82	21.94
7	783.6	201.4	0.0032	11.38	20.64
A23	537.4	133.6	0.0305	12.01	6.33
A24	683.6	159.7	0.0351	11.85	7.36
A25	908.6	170.8	0.0835	12.49	8.66
A32A	596.2	155.7	0.0820	12.53	14.54
A32B	810.3	274.8	0.0588	16.98	9.09
A134	937.5	243.0	0.0095	11.54	14.16

ronment. In general the Kerma granite is porphyric with a composition varying from granitic to granodioritic, although it also includes more basic differentiates.

Radiometric age determinations

Datings were carried out from three sites in the western Prekarelian area: Vehmer-

Table VI (part 2)
U, Th-Pb analytical data and apparent ages for zircons

Sample no.	Location and rock	Mineral	Age (million years)		
			$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
A23	Granodiorite, Pieksänkoski, Muuruvesi	zircon	1639 ± 50	1750 ± 35	1886 ± 59
A24	Granite, Parkkolansaari, Leppävirta	zircon	1551 ± 72	1682 ± 47	1850 ± 46
A25	Granite, Viitalahti, Heinävesi	zircon	1276 ± 91	1505 ± 71	1845 ± 94
A32A	Granodiorite, Kaavinkoski, Tuusniemi	zircon (-200 mesh long prisms)	1711 ± 28	1777 ± 17	1856 ± 21
A32B	Granodiorite, Kaavinkoski, Tuusniemi	zircon (+ 125 mesh dark, round)	2144 ± 227	2315 ± 189	2470 ± 19
A134	Granodiorite, Puijo, Kuopio	zircon (-200 mesh long prisms)	1699 ± 39	1771 ± 26	1856 ± 20

salmi (two) and Säyneinen. One age was determined from Juuka and one from the Juojärvi dome, Kapustaniemi. In addition, ages were assigned to two Karelian granites.

The sample numbers and locations of the rocks dated are given in Table II and Fig. 3. Their mineral compositions are listed in Table III and chemical compositions in Table IV. The dates and isotopic compositions are compiled in Tables V and VI; the concordia diagram is in Fig. 8.

It is a noteworthy fact that the dates of the Prekarelian rocks are consistently about 2680 ± 20 Ma. These ages are somewhat lower than those of the craton area (c. 2800 Ma, *e.g.* Kouvo and Tilton, 1966) and refer to doming. The Maarianvaara granite dates to c. 1900 Ma. Figs. 9 and 10 illustrate the outcrops from which the samples dated (Figs. 11—14) were collected. The microphotos of the samples are depicted in Figs. 15 to 18.

In addition to the samples taken by me, Dr. O. Kouvo has put data at my disposal from five of his samples (A23 to A25, A32 and A134), whose locations are marked on Fig. 2 (expect A134). The dates of these rocks are listed in Table VI.

A set of samples labelled A23, A24, A25, A32, A59 and A60 (Pieksänkoski—Suvasvesi—Kermajärvi—Kaavinkoski—Mäntyjärvi—Vihtajärvi) was collected for comparison with the dates of the rocks marked on the old Joensuu map sheet (Wilkman 1924) by different colours on the basis of their assumed age differences. The results indicate, however, that all these rocks are of the same age, or that the differences, if any, are very small.

The zircons in the samples are strikingly similar in morphology: they are exceptionally long, needle-like and idiomorphic, exhibiting single tetragonal prisms. These seem to be genetic features that they all have in common (O. Kouvo, personal communication). More

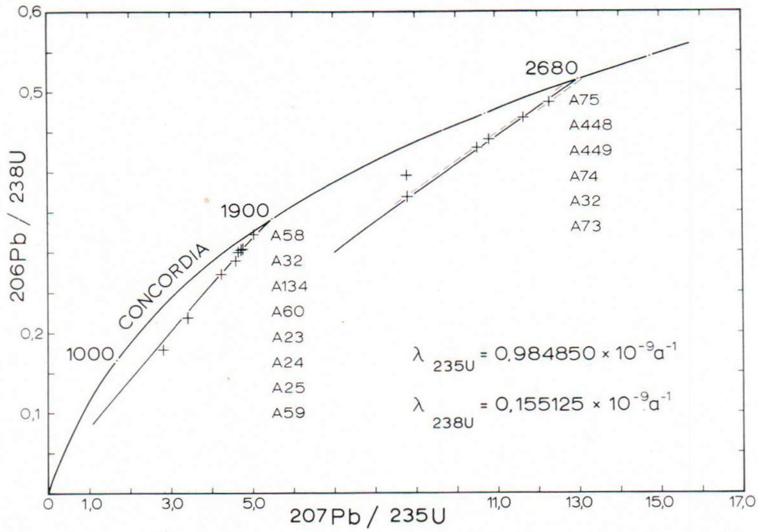

Fig. 8. Concordia diagram for U-Pb ratios of zircons and one uraninite. Chords passing through data-points represent the continuous diffusion trajectories. The upper intersections are 1900 Ma and 2680 ± 20 Ma. The best fit line through the 1900 Ma points intersects the concordia at 0 and 1860 Ma. The Outokumpu uraninite A58 (Kouvo and Tilton 1966), however, has to be considered slightly younger. Zircon from Kaavinkoski granodiorite (A32) is very similar to that in Kuopio granodiorite (A134) (long needles). Both of them include in less quantity darker and shorter zircon crystals. In case of A32 this fraction shows a pre-Karelian age (by O. Kouvo).

information on the geology of the dated samples I collected is given in the explanation to map sheets 4222, 4224 and 4311 (Huhma, A. 1975).

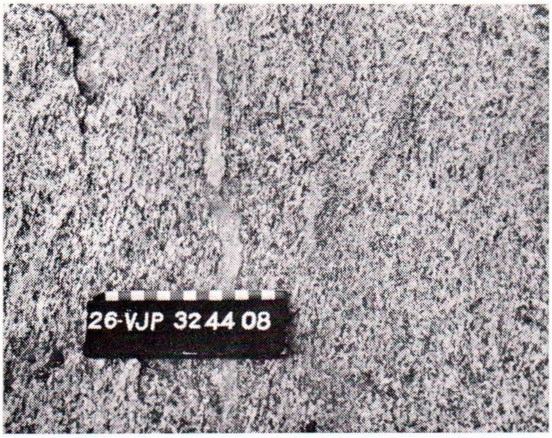

Fig. 9 Prekarelin quartz-diorite. Dating site 1. Photo V. J. Penttilä.

The Outokumpu belt and Alpinotype orogenesis

I would like to suggest a tentative model for the geologic evolution in the area on the basis of the facts presented in the previous chapter. To begin with let us consider the Alpinotype orogeny in its early geosynclinal stage, such as it is known today from the younger Alpine mountain ranges (Aubouin 1965).

The evolution of the eugeosyncline-miogeosyncline couple is marked by four features in the direction of the geosynclinal polarity from internides to externides:

1) eugeanticlinal ridge
2) eugeosynclinal furrow
3) miogeanticlinal ridge
4) miogeosynclinal furrow

At the front of the miogeosynclinal furrow is the foreland.

Fig. 10. Prekarelian quartz-diorite. Dating site 2. Photo V. J. Penttilä.

The eu- and miogeanticline ridges as well as the foreland are composed of old basement and are separated by eu- and miogeosynclinal furrows. The eugeosynclinal furrow is always somewhat allochthonous in character whereas the miogeosynclinal furrow shows autochthonous features.

Without going into the details of the alpinistic theories I would like to emphasize the following salient points:

1) The pre-flysch period is characterized by the emission of ophiolites in the eugeosynclinal furrow but not in the miogeosynclinal furrow.

2) During the flysch period thick beds of flysch sediments are deposited, beginning at the internides with the filling of the eugeosynclinal furrow. Hence the sediments in the miogeosynclinal furrow are younger than the sediments in the eugeosynclinal furrow.

3) Orogenic and tectonic movements take place during the orogenic stage concomitant with the flysch period. The deformation is maximal at the eugeanticlinal ridge, which is pushed towards externides from where the orogenic events decrease in intensity towards the externides and foreland. The eugeosynclinal ridge that emerges supplies the furrows with abundant detrital flysch material.

4) The late geosynclinal period is characterized by intensive magmatic activity producing late orogenic intrusive rocks such as granodiorites. However, the activity is appearing only in the internal zones but not in the external (miogeosynclinal) zones.

5) During the postgeosynclinal stage the vertical movements deform the bedrock into its present state. It should be emphasized, however, that these movements have no polarity, because by then the bedrock has already turned completely into craton.

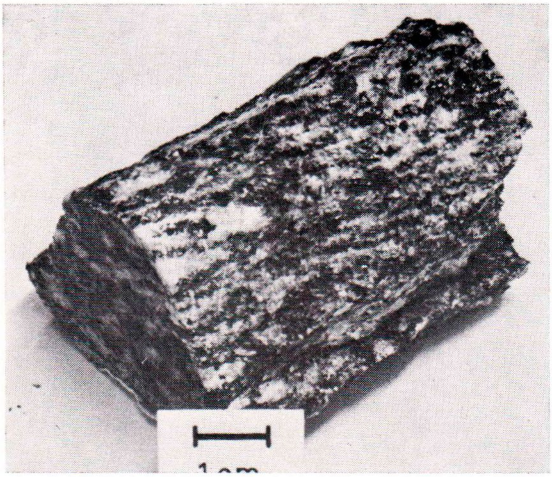

Fig. 11. Prekarelian quartz-diorite. Dating site 2. Photo M. Kokkola.

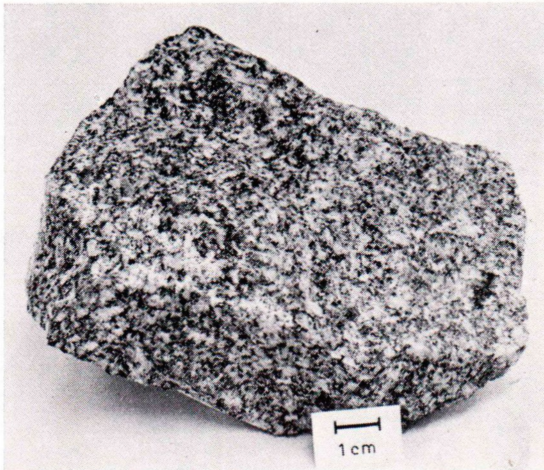

Fig. 13. Karelian granodiorite. Dating site 6. Photo M. Kokkola.

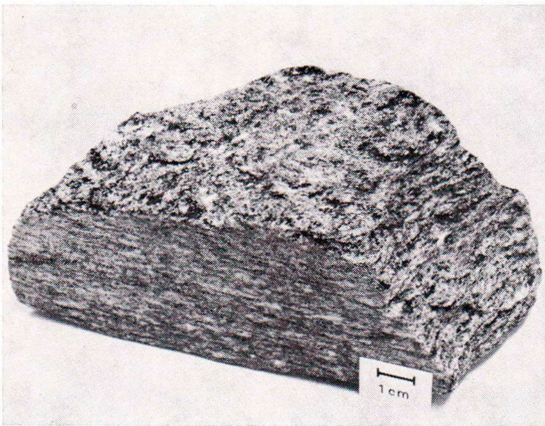

Fig. 12. Prekarelian quartz-diorite (trondhjemite). Dating site 4. Photo M. Kokkola.

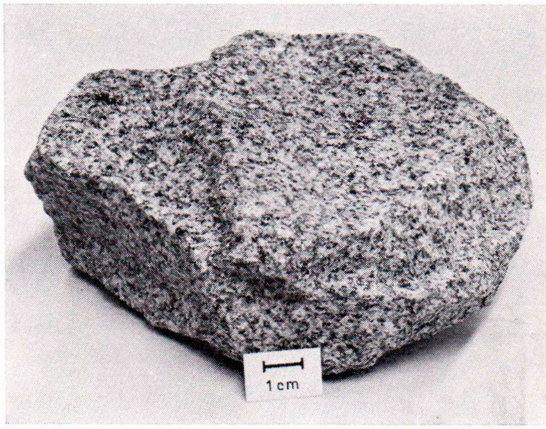

Fig. 14. Karelian granodiorite. Dating site 7. Photo M. Kokkola.

Pre-flysch period. The silica-bearing deposits are common everywhere in the eugeosynclinal furrows, including the radiolarian ooze in the deepest furrows. They occur invariably in association with ophiolites. Most investigators are of the opinion that the ophiolites intruded as submarine eruptions when abundant basaltic (simatic) material discharged through a fracture on the ocean floor. Consequently, ophiolites do not form one petrographic unit but include rocks of different compositions. However, rocks such

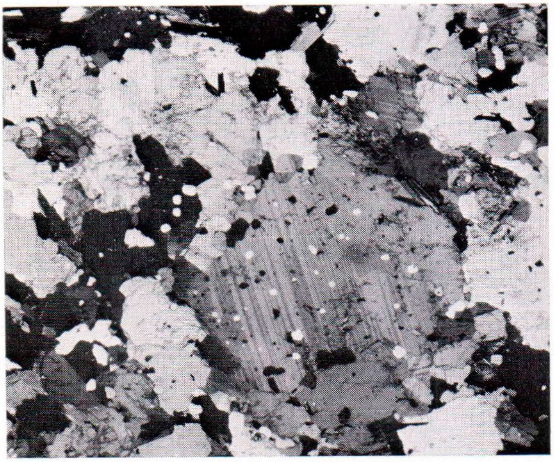

Fig. 15. Prekarelian quartz-diorite. Dating site 2 18 ×. Nic. +. Photo M. Kokkola.

Fig. 17. Karelian granodiorite. Dating site 6. 18 x Nic. + Photo M. Kokkola.

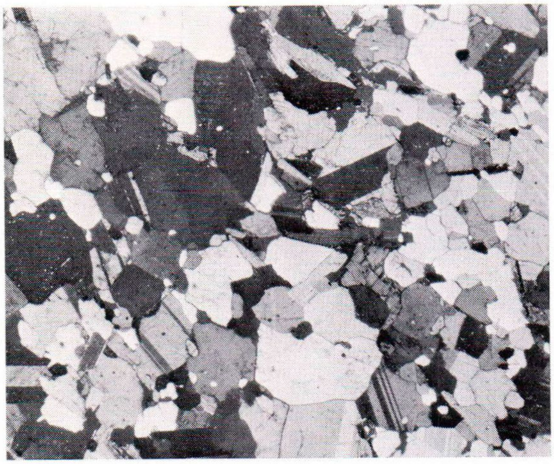

Fig. 16. Prekarelian quartz-diorite. Dating site 3 18 ×. Nic. +. Photo M. Kokkola.

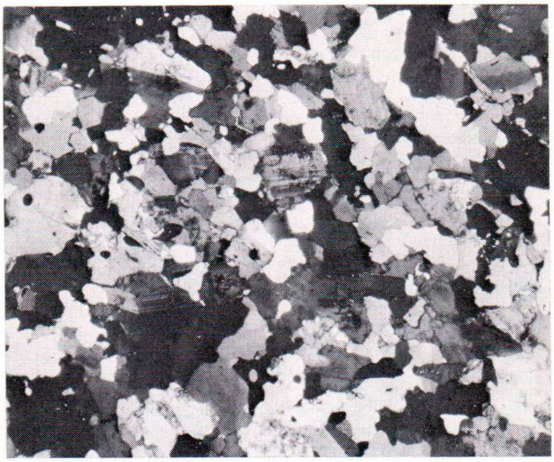

Fig. 18. Karelian granodiorite. Dating site 7. 18 x Nic. + Photo M. Kokkola.

as peridotites and pyroxenites etc. are frequently serpentinised.

The abnormally high silica content in the eugeosynclinal furrows has been attributed to the diffusion of the silica liberated in the serpentinisation process. Several authors have emphasized that it is the heating of water during submarine eruptions that brings about the increase in the solubility of silica. Convection currents propagate silica, which then deposits as chemical sediments. This mechanism would explain why the fine-grained quartz rocks occur in such close association with ophiolites and why the radiolarian deposits are so abundant in the presence of these rocks.

[Radiometric ages available thus far for the Svecokarelian depositional time (2000—2250 Ma) have been summarized by Sakko and Laajoki (1975) in their work on preflysch sedimentation in the restricted marginal basin of the Puolanka area (2080 Ma of the Marine Jatulian Pääkkö iron formation).]

Flysch period. During the flysch period thick beds of weathering products were deposited. Flysch is mainly a product of the orogenic stage and its erosional material always derives from the central zone of the geosyncline couple, with the consequence that the material becomes increasingly younger as the deposition progresses from internides to externides. Flysch denotes the closing stage of the sedimentation.

Magmatic activity. Magmatic activity is a prominent feature of the internal eugeosynclinal zone both before (ophiolites) and after the tectonic deformations (granites, granodiorites).

1) The initial magmatic, simatic ophiolites never occur along the axis of an eugeosynclinal furrow but rather along the margins of a geanticlinal ridge.

2) Sialic, syn-, late- and post-tectonic granite and granodiorite batholiths are not encountered in eugeosynclinal furrows but along the flank of the eugeosynclinal ridge.

3) The post-tectonic period comes to an end with a magmatic stage that produces volcanic rocks with mainly basaltic composition. This terminal volcanism is simatic in origin and closely associated with the vertical movements.

Hence the magmatism begins and ends with simatic material.

Two types of magmatism can be distinguished: a basaltic, simatic type associated with tensional joints, and a granitic, sialic type connected with the compressional stages giving rise to granodioritic plutons.

This brief summary of the Alpinotype orogeny serves as an introduction to the following discussion of the Outokumpu region.

Discussion of the Outokumpu region

I have applied the ideas expressed by Aubouin (1965, Fig. 16, p. 70) to the Outokumpu region and supplemented them with my own comments (Fig. 19). The eugeanticline (the Prekarelian basement at Vehmersalmi) is in the west; then comes the eugeosynclinal furrow (the Outokumpu region with the serpentinite-quartz rock series), followed by the miogeanticlinal ridge (the Sotkuma—Liperinsalo—Oravisalo line), the miogeosynclinal furrow (the Höytiäinen basin) and finally the foreland (the eastern Prekarelian basement). The geosynclinal polarity trends from west to east. The serpentinite-quartz rocks occur in the Outokumpu furrow but not in the Höytiäinen basin.

In the west the flysch has undergone strong metamorphism and is partly altered into veined gneisses. Eastwards the intensity of the metamorphism decreases and in the Höytiäinen furrow the rocks are fine-grained mica gneisses and phyllites that often show well-developed graded bedding and cross bedding.

The mica gneiss in the Outokumpu region contains plagioclase but is free from potash feldspar, possibly because the Prekarelian basement at Vehmersalmi is devoid of granites and, instead, contains trondhjemites and quartz-diorites. No vulcanogeneous rocks such as amphibolites are met with in the eugeosynclinal furrow. However, calcium-bearing concretions are common and in some places at least they are clearly boudins of calcium-bearing interlayers in mica gneiss.

No distinct signs of graded bedding or cross bedding have been observed in the eugeosynclinal furrow, presumably owing to the deleting action of the metamorphism.

The Maarianvaara granite does not occur in a eugeosynclinal furrow but in the margin of a basement area and it is cut by younger dyke rocks.

The eugeosynclinal ridge (the Vehmersalmi basement) has clearly been pushed eastwards,

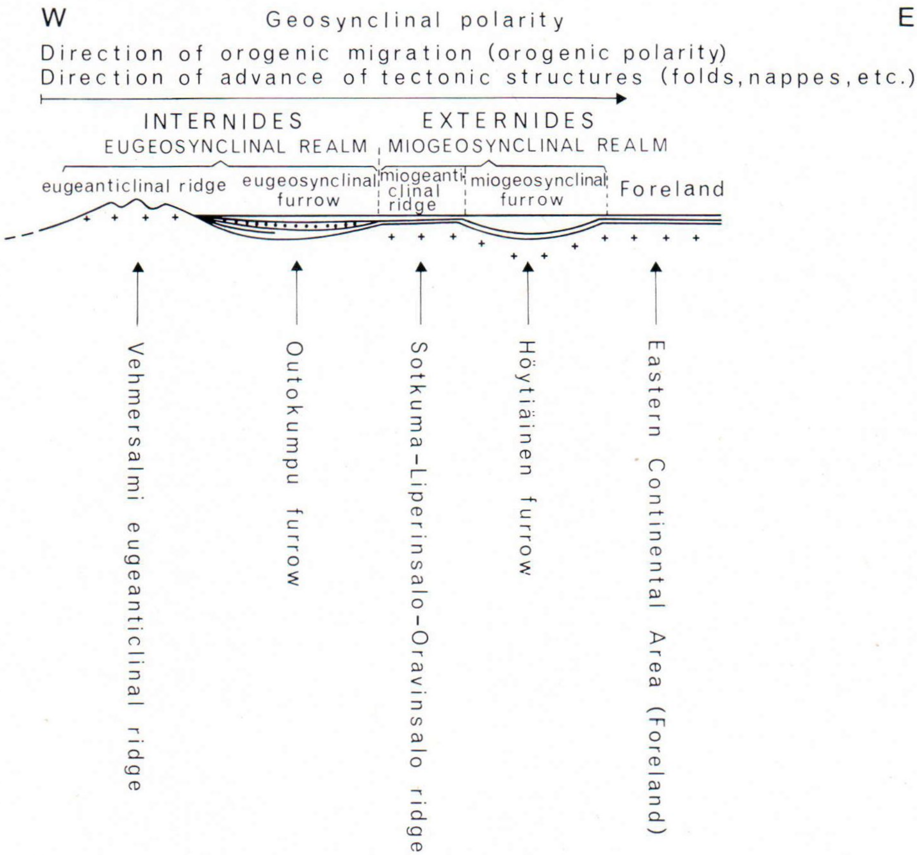

Fig. 19. Figure 16 by Aubouin (1965) applied to the Outokumpu region.

as is also indicated by the persistent westward dips. The overthrust towards the east is visible at numerous localites along the margins of the basement. Thus at Kaavi for instance the quartzite plates have been pushed one over the other in a tile-like fashion.

The Outokumpu belt and Hercynotype orogenesis

In the foregoing chapters I have treated the Outokumpu region as an Alpinotype area (albeit a miniature one). In his paper entitled »The duality of orogene belts», however, H. J. Zwart (1967) maintains that the Svecofennian-Karelian area as a whole is a typical Hercynotype region. His summary is as follows: »Definition of Hercynotype and Alpinotype orogenies. Their main differences warrant the distinction of a Hercynotype and Alpinotype orogeny, with the following characteristics:

Hercynotype:

1) shallow, low pressure metamorphism; thin metamorphic zones
2) plurifacial metamorphism dependent on increase in temperature
3) abundant granite and migmatite
4) few ophiolites, ultrabasites practically absent

5) very wide orogen
6) small and slow uplift
7) nappe structures missing or rare.

Alpinotype:

1) deep, high pressure metamorphism; thick metamorphic zones
2) plurifacial metamorphism dependent on decrease in pressure
3) few granites and migmatites
4) abundant ophiolite with considerable amount of ultrabasite
5) relatively narrow orogen
6) large and rapid uplift
7) nappe structures predominant

The main point that both orogenies have in common is that strong folding and metamorphism took place and that both processes were to a large extent simultaneous.»

The Outokumpu region is restricted in size and hence less suitable for a consideration of large-scale orogenic problems. It is not my intention to discuss the interpretation of the Svecofennian-Karelian areas by Zwart (1967), but in conclusion I should like to point out that in my opinion the geologic data from the Outokumpu region are consistent with the model outlined by Aubouin (1965).

The genesis of the Outokumpu ore

In the light of the studies undertaken in the Outokumpu region I propose that:

1) The quartz rocks (the so-called Outokumpu quartzites) are primary sedimentogeneous rocks (although not products of weathering).
2) The serpentinites and quartz rocks are genetically related to each other.
3) The ore invaded as a gel into the unconsolidated quartz rocks.
4) The ore invaded during a very early flysch period.
5) Hence the Outokumpu ore is to be considered as a product of submarine processes (Borchert 1954).
6) The chronostratigraphic position of the Outokumpu ore material is strengthed by the isotopic composition of lead from ore which indicates an common lead age of 2250 Ma (Kouvo 1958, Kouvo and Kulp 1961, Geol. Surv. of Finland 1973, p. 16). This age equals to that of the oldest basaltic intrusions found thus far within the cratogenic quartzite (Sakko 1971, Sakko and Laajoki 1975).

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