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THE METAVOLCANIC ROCKS OF THE PEURASUVANTO AREA, NORTHERN FINLAND

by
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The Archaean and Early Proterozoic volcanic-sedimentary rock associations overlie the Archaean granite gneiss domes in the Peurasuvanto area, northern Finland. The supracrustal rocks are intruded by the 2435 Ma old Koitelainen layered gabbro, small mafic intrusions of the Jatulian stage (2125 Ma) and the postorogenic Nattanen-type granites (1772 Ma).

The metavolcanic rocks of the area are divided into the Lower and Upper metavolcanic units, which are members of the Tuntsa and Lapponia Supergroups, respectively. The units are separated by various thick piles of Lower Lapponi metasediments.

The Lower metavolcanic unit, probably Archaean in age, consists predominantly of a thick sequence of basaltic to andesitic amygdaloidal lavas with dacitic and rhyolitic interlayers. Tuffitic rocks and a polymict conglomerate with an intermediate tuff matrix probably exists in the upper part of the sequence. The Lapponi arkosic quartzites and aluminous schists that overlie the Lower metavolcanic unit are in turn succeeded by komatiitic basalts, komatiites and peridotites of komatiitic affinity, representing the Upper metavolcanic unit.

Geochemically, the ultramafic rocks of the study area are similar to the mafic and ultramafic rocks of the West Inari schist belt and the Karasjok greenstone belt, probably representing the same extrusive phase of komatiitic rocks.

Key words: metavolcanic rocks, komatiite, tholeiitic composition, geochemistry, genesis, tectonics, Precambrian, Peurasuvanto, Sodankylä, Finland.

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INTRODUCTION

The study area is situated at the eastern margin of the Central Lapland greenstone belt, some 50 km north of the village of Sodankylä (Fig. 1). The geology of the area was outlined by E.Mikkola (1941) in the explanation to the general geological map C7 at a scale of 1:400 000. Geological investigations in the Peurasuvanto area have been carried out since then by several workers including Rastas (1964), Papunen *et al.* (1977), Puustinen (1977), Isomaa (1978), Mutanen (1979), Kröner *et al.* (1981) and Jahn *et al.* (1984). In 1980, the Geological Survey of Finland started regional mapping for the Peurasuvanto map sheet (3723) at a scale of 1:100 000. The present paper examines the petrography and geochemistry of the metavolcanic rocks in the eastern part of the map sheet area.

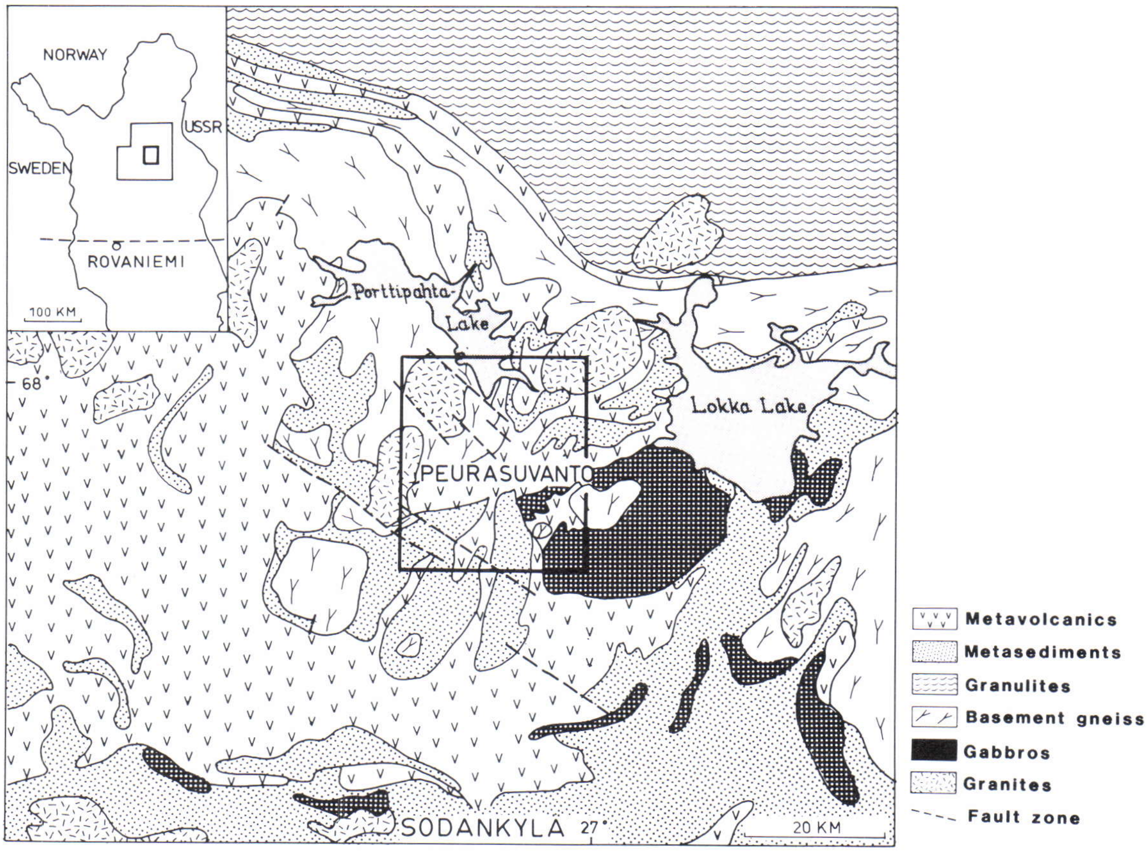

Fig. 1. Location and regional geology of the Peurasuvanto area. General geology modified after the geological map by the Nordkalott Project of the Geological Surveys of Finland, Norway and Sweden.

REGIONAL GEOLOGY

In the Peurasuvanto area, a northeast-trending volcanic-sedimentary rock succession rests unconformably on Archaean basement gneiss domes. Lithologically, the area forms a ''triple junction'', where the rocks of the Central Lapland greenstone belt and the supracrustal rocks bordering the granulite arc all join together (Fig. 2).

The extensive granite gneiss area northwest of Kurittukoski is composed mainly of variously granitized, arkosic paragneisses that resemble the arkose gneisses of the West Inari schist zone described by Meriläinen (1976). The Tojottamaselkä basement gneiss dome consists predominantly of granitoid gneisses of tonalitic to trondhjemitic composition (Kröner *et al.* 1981).

The metavolcanic rocks of the Peurasuvanto area are divided into Lower and Upper metavolcanic units separated by Lower Lapponi metasedimentary rocks. The Lower metavolcanic unit, which is probably part of the Archaean Tuntsa Supergroup, is composed predominantly of mafic and intermediate lavas with minor ultramafic and felsic interlayers. The Lower Lapponi metasediments overlie, possibly unconformably, the lower metavolcanite sequence, forming piles of arkose quartzites, aluminous schists and black schists of various thickness. The Upper metavolcanic unit consists entirely of ultramafic rocks of komatiitic affinity, representing rocks of the Lapponia Supergroup.

Because of poor exposure and insufficient intrusive contacts, the age and field relations of the area are to some extent obscure. The oldest formation, the Tojottamaselkä basement gneiss dome, has yielded a U-Pb age of 3110 Ma (Kröner *et al.* 1981). The Peurasuvanto volcanic conglomerate (see Peltonen *et al.* 1986), which is probably situated in the upper part of the Lower metavolcanic unit, has an acid volcanic breccia interlayer 2526 Ma in age. Some of the clasts of the conglomerate, too, derive from rocks of the lower volcanic sequence, suggesting that they are Archaean in age. The relationship of the 2435 Ma old Koitelainen layered gabbro to the supracrustal rocks of the area is also uncertain, because reliable intrusive contacts

Fig. 2. Simplified geological map of the Peurasuvanto area.

have not been found. Stratigraphic evidence indicates, however, that the Upper metavolcanic unit is younger than the Koitelainen complex, i.e. early Proterozoic in age. The Peurasuvanto volcanic conglomerate is intruded by a 2125 Ma old gabbro, and the Lower Lapponi metasediments by 1772 Ma old Nattanen-type granites.

Most of the metavolcanic rocks of the area are metamorphosed into greenschist facies. Locally, near the contacts of the basement gneiss domes and in the Lohisarriot area, however, lower amphibolite facies prevails. The rocks of the Lower metavolcanic unit are generally affected by retrograde metamorphism.

THE LOWER METAVOLCANIC UNIT

Because of faulting and poor exposure the exact straticraphy of the Lower metavolcanic unit has still not been established. Further, the contact zone between the basement gneisses and the schists is covered by Quaternary deposits, preventing us from being able to observe the basal relations.

Mafic metavolcanic rocks

A heterogeneous sequence of mafic lavas, tuffs and tuffites borders the western gneiss dome in the southeast and east, and trends northwards through the eastern end of the lake Porttipahta. Minor occurrences of mafic lavas, probably part of the same lithostratigraphic unit, exist elsewhere in the study area. In the Kurittukoski area, some outcrops of peridotitic komatiite are also associated with the mafic metavolcanics. The thickness of the formation is unknown, and the contacts with intermediate rocks are gradational and intermingled.

In outcrops, the mafic lavas are usually dark green, finegrained and schistose amphibolitic rocks with occasional quartz and plagioclase lenses interpreted as deformed amygdales. Locally there are massive uralite porphyritic lava flows in which a weakly oriented, medium to coarsegrained and porphyritic central portion passes gradually into a finegrained, amygdale-bearing margin zone. The thickness of the single lava flows varies from a few metres to 10—20 m. Intercalated with massive lava flows are thinly laminated tuff and tuffite beds of various thickness. Some grey, mica-rich layers may be of sedimentary origin, but an acid pyroclastic origin is not excluded. Tuff and tuffite interlayers are met with only in diamond drill cores; no primary structures besides laminar bedding are visible. Sparse rounded and elongated clasts, about 1—10 cm in diameter, of granodiorite and arkose quartzite or felsic volcanite have, however, been observed in a 15—20 m thick tuffite interlayer.

The amphibolitic varieties of mafic lavas are nematoblastic in texture, consisting mainly of well-oriented, green and strongly pleochroic tremolite-actinolite laths ($c \wedge Z = 17°$) and altered, granoblastic plagioclase. The accessories are quartz, secondary epidote and titanite in varying amounts. In the Lohisarriot area, where the lower amphibolite facies prevails, prismatic amphibole is hornblende and the amount of poikiloblastic almandine crystals, 1—3 mm in diameter, exceeds locally 20 % of the rock volume. Porphyritic lavas are composed of anhedral prisms of uralitic amphibole set in a recrystallized mosaic of quartz and plagioclase. The bluish green, stubby prisms (∅ = 1—8 mm) have needle-shaped marginal extensions due to uralitization. Mafic tuffs are finegrained, nematoblastic rocks, consisting predominantly of the same minerals as the amphibolitic lavas. Thinly bedded tuffites have mica-rich layers, and with an elevated biotite content they pass into lepidoblastic mica schists.

In the Kurittukoski area, ultramafic rocks of peridotitic komatiite composition are also associated with the mafic metavolcanics. The mode of the greenish-grey, schistose rocks varies from finegrained, nematoblastic amphibole-chlorite rock to less-oriented talc-serpentine-amphibole rock with sparse remnants of olivine. Any primary structures and textures have been obliterated by intense deformation, preventing the original character of the rock from being identifiable.

Intermediate metavolcanic rocks

Intermediate metavolcanic rocks of andesitic composition predominate in the upper division of the lower metavolcanic sequence. In the Kurittukoski area, they form a coherent lithostratigraphic unit, roughly 500—1 000 m thick, with felsic metavolcanic interlayers. The rocks are mainly well-preserved amygdaloidal lavas, but dense, schistose variants, particularly when they are associated with felsic interlayers, may be pyroclastic in origin. Finegrained, grey tuffitic schists, frequently with distinct laminae about 0.1—2 cm thick, occur around the Tojottamaselkä gneiss dome. Intercalated with these tuffites are more felsic tuffs and also the Peurasuvanto volcanic conglomerate.

The andesitic lavas in the Kurittukoski area are greyish green, turning dark green in the north or northeast of the intermediate rock zone. Texturally, the amygdaloidal lavas are finegrained and nematoblastic, consisting mainly of oriented needles and laths of greenish, weakly pleochroic tremolite-actinolite ($c \wedge Z = 16°$) and strongly altered, albitic plagioclase. The alteration of plagioclase into epidote indicates that the primary composition was more Ca-rich. Diverse amounts of quartz, biotite, chlorite and titanite exist only occasionally. The variously deformed amygdales which are often zoned with a plagioclase or quartz rim surrounding the epidote-rich central zone, range from 2 to 10 mm in size. The composition of the amygdales depends on the degree of deformation and alteration of the rock, quartz usually being the only component when the amygdales are intensely deformed and the lower amphibolite facies prevail. Locally, the amygdale content exeeds 25—30 %, providing evidence for subaerial eruption (Moore 1965).

Felsic metavolcanic rocks

The lower metavolcanic unit of the Peurasuvanto area also includes felsic rocks of dacitic and rhyolitic composition. They are usually intercalated with the intermediate amygdaloidal lavas and are interpreted predominantly as pyroclastic in origin. The dacitic interlayers of the andesitic lavas contain, however, epidote-filled vesicles as evidence of lava flow origin. Near the Tojottamaselkä gneiss dome there is also an acid volcanic breccia. Because of poor exposure, the exact thickness of the acid interlayers is unknown, but it probably does not exceed a few tens of metres.

In the outcrops, the felsic metavolcanics are dense, slightly schistose rocks with a light reddish weathering crust and a reddish grey or brown fresh surface. The pyroclastic interlayers are usually massive, non-sorted crystal tuffs of rhyolitic composition but, occasionally, they are thinly laminated and parallel-bedded, the laminae being only 1—2 mm thick .

Texturally, the felsic pyroclasts are mainly finegrained (0.1—2 mm), consisting of plagioclase with minor quartz phenocrysts set in a matrix of quartz, feldspar, amphibole, mica, epidote and magnetite. Subhedral to euhedral phenocrysts of plagioclase are 0.5—2.5 mm in diameter, varying from resorped to fractured and angular. The mostly Karlsbad-twinned, albitic plagioclase phenocrysts account for up to 20 % of the rock. The matrix of the crystal tuffs is composed predominantly of recrystallized grains of quartz and feldspar with varying proportions of secondary minerals. Recrystallization and alteration have destroyed all the primary textures of the matrix.

Interlayeres of amygdaloidal lavas of dacitic composition occur in the andesitic metavolcanics of the Kurittukoski area. The massive lava flows consist of epidote and quartz-filled amygdales, 2—15 mm in size, and of small plagioclase phenocrysts in a finegrained, weakly oriented groundmass.

The acid volcanic breccia occur as an interlayer in the Peurasuvanto volcanic conglomerate, which is composed primarily of intensely deformed lithic material ranging from small lapilli to angular or subangular fragments up to 10—15 cm in diameter. The fragments consist mainly of poorly sorted, rhyolitic quartz porphyries and andesitic amygdaloidal lavas. The matrix is predominantly a crystal tuff of rhyolitic composition.

Tuffites and volcanic conglomerate

The western basement gneiss complex in the Kurittukoski area is bordered by a highly deformed tuffite. Although the tuffite is exposed only on the banks and bottom of the river Kitinen, the associated aeromagnetic anomalies, cut off by sinistral transcurrent faults, suggest that the formation is continuous. The thickness of the tuffite and the character of the contact with the basement gneiss are unknown. The same rock unit is probably also present in the Kunnasenvaara area, where small, separate occurrences of well-preserved tuffites have been met with in the middle of the basement gneiss area.

Intense deformation has obliterated most of the primary structures in the Kurittukoski area, although phantom fragments exist in the streaky, gneissose rock of intermediate composition, suggesting pyroclastic or volcanoclastic origin. The tuffitic character of the rock is clear in the Kunnasenvaara area. Besides the well-developed stratification, angular to subangular lithic fragments, approximately 1—5 cm in size, are encountered in a massive, intermediate tuff matrix. The composition of the probably volcanogenic fragments varies from mafic to felsic.

Texturally, the tuffites are finegrained, nematoblastic to granoblastic, usually well-oriented rocks, consisting mainly of quartz, oligoclase and bluish green, strongly pleochroic amphibole. Locally, uralitized augite prisms occur in varying proportions. Biotite, epidote, titanite, zircon and magnetite are common accessories.

In the Peurasuvanto area, a volcanic conglomerate surrounds the Tojottamaselkä basement gneiss dome. The most common phenoclasts of the polymictic conglomerate are intermediate lavas, tuffs, tuffites and the gneisses of TTG composition. The clasts also include diabases, quartzites and acid volcanics. The matrix of the conglomerate varies from intermediate tuff to volcaniclastic metasediments.

THE UPPER METAVOLCANIC UNIT

The ultramafics of the upper metavolcanic unit consist mainly of komatiitic amphibole-chlorite rocks, but metaperidotites and basalts of komatiitic affinity are also closely associated with the succession. The ultramafic succession forms a continuous belt, over 20 km long, that parallels the regional northeast-trending fabric of the area, bending eastwards north of the Koitelainen layered intrusion. Another branch of the belt trends northwards through the eastern end of the lake Porttipahta. The same ultramafic, komatiitic metavolcanics also cover a wide area to the west of the western gneiss dome, probably extending to the West Inari schist belt.

Amphibole-chlorite rocks

The amphibole-chlorite rocks are mainly tuffs, lapilli tuffs, agglomerates and pyroclastic breccias in origin. In many places, intense schistosity prevents us from recognizing whether the volcanic material was initially pyroclastic or volcaniclastic. The rocks are usually greenish grey on the eroded surface. Random rounded to subangular lapillis, bombs and fragments are often visible on the weathered surfaces, because the coarse pyroclasts are slightly lighter than the tuffaceous matrix. The minor ultramafic lava occurrences are greenish in colour. The massive or variously oriented rocks are fine or medium grained, occasionally with carbonate or chlorite and amphibole-filled vesicles, suggesting amygdale structure. Characteristic of all amphibole-chlorite rocks is the occurrence of small, rusty cavities caused by weathering of the carbonate grains.

Deformation and alteration in the greenschist facies has tended to obliterate all the primary minerals and textures of the amphibole-chlorite rocks. Texturally, they consist predominantly of a finegrained and variously oriented, nematoblastic mass of colourless tremolite-actinolite ($c \wedge Z = 16°—17°$) and pale greenish, weakly pleochroic chlorite. Magnetite, carbonate, talc and serpentine occur accessorily in varying proportions. In the northern and northwestern part of the area the grade of metamorphism is of lower amphibolite facies, and the rocks have remnants of secondary olivine. On weathered surfaces, the strongly serpentinized porphyroblasts appear as rusty ovoidal patches 5—20 mm in size.

To the east of Peurasuvanto, some ultramafic dykes, 10—20 m in width, intrude the Lower Lapponi arkose quartzite. The chemical composition of the porphyritic, unoriented dykes corresponds to the mean composition of the amphibole-chlorite rocks of the study area, (Figs. 1 A—4 A; Table 1), and thus they probably derive from the same komatiitic parent magma.

Amphibole rocks

The basal part of the amphibole-chlorite rock sequence probably includes intercalations of amphibole rock of komatiitic basalt composition. The massive to slightly oriented, finegrained rock has a bright green weathered surface. Albite or amphibole-filled amygdales and flow top breccia structures have been preserved in some places. Typically, the rock consists almost entirely of randomly oriented, bluish green and strongly pleochroic amphibole needles and laths with a maximum extinction angle of 20. Albitic plagioclase, chlorite and titanite occur only sporadically.

Peridotites

Closely associated with the ultramafic metavolcanics of the Peurasuvanto area there are lenticular peridotite and serpentinite bodies. The long axes of the ultramafic lenses, measuring roughly 50—200 m x 200—1 000 m, parallel the dominant fabric of the region. In places, the bodies exhibit compositional layering, but usually the rocks are massive or only slightly oriented, typically with a reddish brown, 1—10 mm thick weathering crust and a regularly developed fissure system. Mineralogically, the rocks are strongly serpentinized peridotites with only sparse remnants of primary olivine and clinopyroxene remaining. The major minerals are secondary antigorite, chlorite, amphibole and magnetite.

PETROCHEMISTRY

The petrochemical interpretation of the metavolcanics of the Peurasuvanto area is based on 120 major-element analyses. The rocks have been classified as seven major groups, and the komatiite suite has been subdivided into komatiites (MgO > 18 %) and komatiitic basalts (MgO < 18 %) after Arndt & Nisbet (1982). It has also been necessary to form subgroups of the mafic and ultramafic metavolcanics. The ultramafic metavolcanics have been subdivided into peridotitic (MgO > 30 %) and pyroxene peridotitic (18 % < MgO < 30 %) komatiites. The pyroxene peridotitic komatiites (PYPRDKOM) are mainly pyroclastic amphibole-chlorite rocks, but they also include some ultramafic dykes (DKOM) cutting the Lower Lapponi quartzites. The peridotitic komatiites (PRDKOM) are cumulate-textured rocks, constituting conform, lensoidal bodies and layers within the pyroclastic amphibole-chlorite rocks. On the basis of the extensive geochemical and petrographical material, this subdivision seems to be applicable to the ultramafics of Lapland (Papunen 1977, Papunen *et al.* 1977, 1980; Pihlaja, in prep.).

The mafic metavolcanics of the area are tholeiitic and komatiitic basalts. The basalts with 12—18 % MgO have been termed pyroxenitic komatiitic basalts (KOMBAS), corresponding closely to the classifications of Naldrett & Turner (1977), Arndt *et al.* (1977) and Hanski (1980). There are also major groups of mafic, intermediate and felsic metavolcanics. The classification used in this study is shown in Table 1, which gives the means of the seven rock groups.

Table 1. Mean chemical composition of metavolcanics in the Peurasuvanto area.

wt.%	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B
SiO_2	40.78	44.18	44.28	46.83	45.14	47.17	47.14	48.56	50.11	50.72	58.15	58.50	70.39	70.79
TiO_2	0.27	0.30	0.49	0.52	0.68	0.71	0.73	0.75	1.15	1.17	0.99	0.99	0.56	0.56
Al_2O_3	4.26	4.60	6.44	6.81	6.50	6.79	10.95	11.28	14.05	14.22	13.62	13.69	12.60	12.67
Fe_2O_3tot	11.43	12.38	11.99	12.68	13.10	13.69	12.73	13.12	13.68	13.85	10.36	10.42	5.20	5.23
MnO	0.16	0.17	0.18	0.19	0.13	0.13	0.20	0.21	0.18	0.19	0.13	0.13	0.05	0.05
MgO	31.74	34.42	23.06	24.40	23.45	24.47	13.14	13.57	6.32	6.40	3.57	3.58	1.28	1.28
CaO	3.03	3.28	7.62	8.05	5.39	5.64	9.15	9.42	9.48	9.60	7.18	7.22	2.92	2.95
Na_2O	0.65	0.70	0.44	0.46	1.27	1.32	2.81	2.89	3.24	3.27	4.38	4.41	3.72	3.74
K_2O	0.00	0.00	0.02	0.02	0.00	0.00	0.13	0.14	0.43	0.44	0.92	0.93	2.59	2.60
P_2O_5	0.02	0.02	0.03	0.03	0.06	0.06	0.06	0.06	0.14	0.14	0.21	0.22	0.13	0.13
Total	92.01	100.00	94.83	100.00	95.71	100.00	97.15	100.00	99.23	100.00	99.42	100.00	99.52	100.00

1 A: Peridotitic komatiites (12 anal.)
2 A: Pyroxene peridotitic komatiites (27)
3 A: Ultramafic dykes (4)
4 A: Komatiitic basalts (13)
5 A: Mafic metavolcanics (25)
6 A: Intermediate metavolcanics (21)
7 A: Felsic metavolcanics (17)
1 B—7 B: Analyses 1 A—7 A recalculated on a volatile-free basis.

Table 2. Mean chemical composition of metavolcanics from the West Inari schist belt and the Karasjok greenstone belt.

wt. %	1	2	3	4	5	6
SiO_2	41.68	44.39	50.10	39.55	44.00	50.11
TiO_2	0.13	0.45	1.15	0.33	0.67	1.34
Al_2O_3	1.18	5.27	12.85	2.72	5.89	13.77
FeO_{tot}	7.99	9.99	12.14	11.12	10.93	12.34
MnO	0.11	0.20	0.19	0.21	0.19	0.21
MgO	39.27	26.18	8.00	32.71	23.80	6.68
CaO	1.26	6.97	10.25	1.77	8.01	9.68
Na_2O	0.07	0.44	2.68	0.01	0.17	2.45
K_2O	0.05	0.09	0.66	0.06	0.09	0.47
P_2O_5	n.d.	n.d.	n.d.	0.04	0.06	0.13
Total	91.12	93.00	97.04	n.d.	n.d.	n.d.

1: Peridotitic komatiites (9 anal., Pihlaja, in prep.)
2: Pyroxene peridotitic komatiites (49 anal., Pihlaja, in prep.)
3: Mafic metavolcanics (17 anal., Pihlaja, in prep.)
4: Cumulate chlorite-amphibole rocks (4 anal., Henriksen 1983)
5: Metavolcanic chlorite-amphibole rocks (15 anal., Henriksen 1983)
6: Mafic metavolcanics (16 anal., Henriksen 1983)

The rocks of the study area have been compared with the metavolcanics of the West Inari schist belt (WISB, Fig. 7) and the Karasjok greenstone belt (KGB, Fig. 7). The means of the major-element analyses for the WISB and KGB metavolcanics are listed in Table 2.

The ultramafic and mafic metavolcanics of the Peurasuvanto area plot in the tholeiitic field of the AFM diagram, forming a continuous komatiite — tholeiite series; the trend is marked with the dashed line in Fig. 3A. Some of the plots of the intermediate and felsic metavolcanics fall within the field of the tholeiitic rocks, whereas some seem to form a calc-alkali series. This does not necessarily imply, however, that there are two differentiation series differing

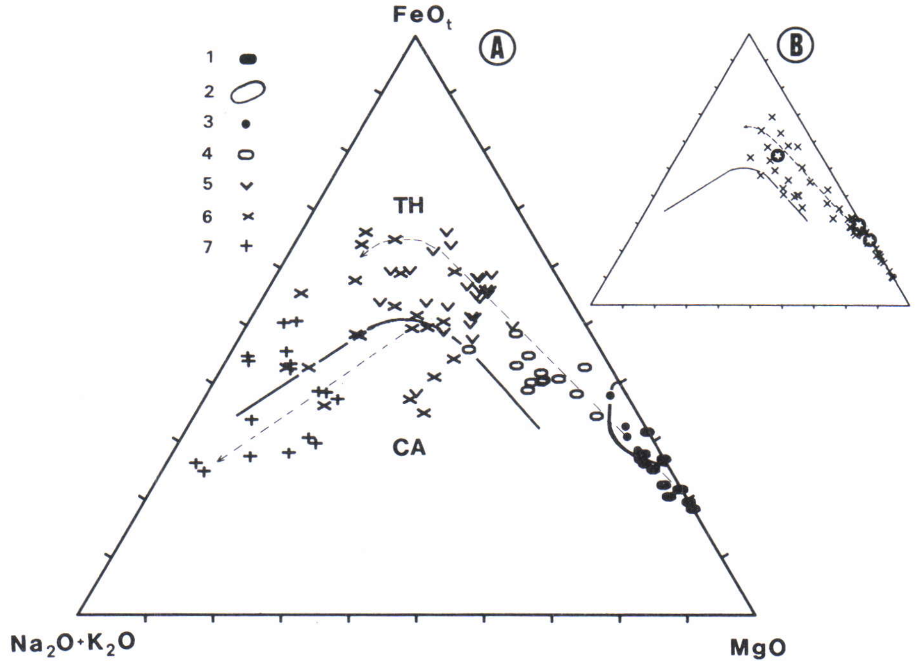

Fig. 3. a) AFM plot for metavolcanics of the Peurasuvanto area. Symbols: 1. peridotites (peridotitic komatiites) 2. amphibole-chlorite rocks (pyroxene peridotitic komatiites) 3. ultramafic dykes 4. amphibole rocks (komatiitic basalts) 5. mafic metavolcanics 6. intermediate metavolcanics 7. felsic metavolcanics. b) AFM plot of metavolcanics from the WISB (Pihlaja, in prep.) and the KGB (Henriksen 1983). Crosses: WISB metavolcanics, Stars: means of the KGB ultramafic metavolcanics and ultramafic cumulates. All analyses are calculated in wt.% on a volatile-free basis. Line separating the tholeiitic (TH) and calc-alkaline (CA) fields after Irvine & Baragar (1971).

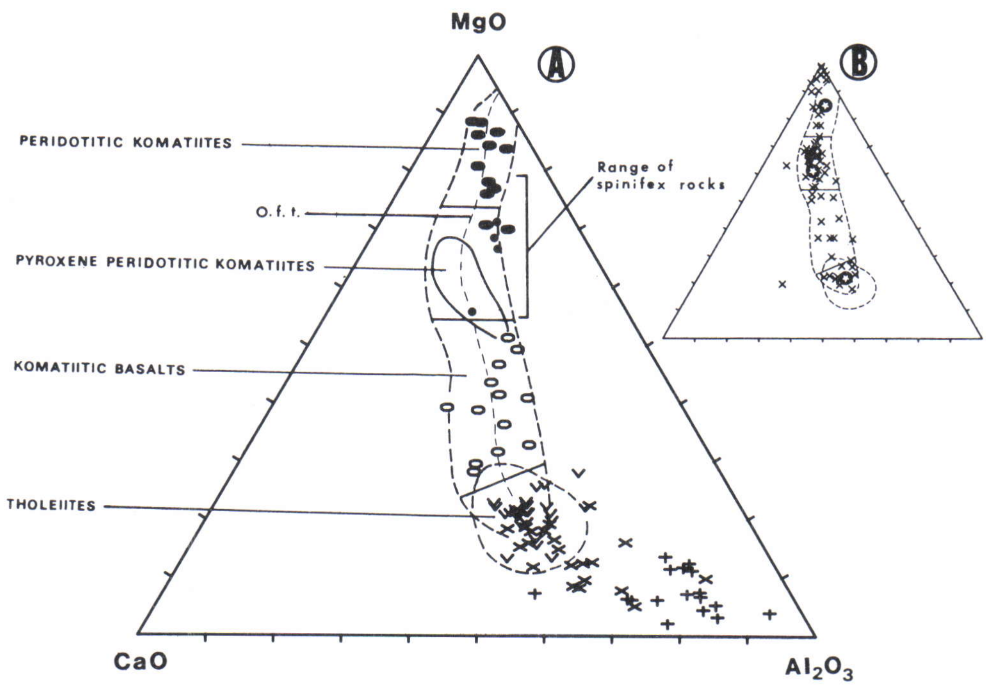

Fig. 4. a) CMA plot for metavolcanics of the Peurasuvanto area. The fields of komatiitic and tholeiitic rocks shown by dashed lines enclose most of the Archaean komatiite and tholeiite analyses from Canada (Arndt 1977, Jensen & Pyke 1982), Western Australia (Naldrett & Turner 1977, Binns *et al.* 1982), South Africa (Viljoen *et al.* 1982), Norway (Henriksen 1983) and Finland (Hanski 1980, Auvray *et al.* 1982, Piirainen 1985, Saverikko 1985). The olivine fractionation trend after Marston & Groves (1981). b) CMA plot of metavolcanics from the WISB (Pihlaja, in prep.) and the KGB (Henriksen 1983). Symbols as in Fig. 3.

in type in the Peurasuvanto area. The AFM diagram is not very reliable for Archaean metavolcanics, because alkalies and also FeO and MgO are mobile components during metamorphism and the associated alteration processes (Davies *et al.* 1979, Condie 1982). The retrogressive metamorphism together with metasomatic processes, visible in most of the metavolcanics in the study area, may cause the plots to move towards the alkalic corner and across the TH — CA line in the AFM diagram. The plagioclase-filled amygdales of the intermediate lavas may also affect the composition of the rocks. The peridotitic and pyroxene peridotitic komatiites and the komatiitic basalts form separate, compact groups in the AFM diagram. The plots of the ultramafic and mafic metavolcanics from the West Inari schist belt and the Karasjok greenstone belt are shown in Figure 3B. The komatiitic basalts are absent from the Karasjok greenstone belt.

In the CMA diagram, the ultramafic and mafic metavolcanics of the Peurasuvanto area form a typical, continuous komatiite — tholeiite trend within the fields where most analyses of the Archaean komatiitic and tholeiitic rocks plot (Fig. 4A). Olivine fractionation controls first the trend characterized by decreasing MgO and near constant CaO/Al_2O_3. The bending of the trend towards the Al_2O_3 corner of the diagram then reflects the effect of olivine and clinopyroxene fractionation.

Spinifex-textured komatiites are thought to represent primary liquid compositions. In the CMA diagram, the range of spinifex-textured rocks (Green & Naldrett 1981, Binns *et al.* 1982) comprises the field of the pyroxene peridotitic komatiites and a part of the field of peridotitic komatiites. Henriksen (1983) suggests a MgO content of about 25 % (volatile free) for the parental liquid of the KGB ultramafic komatiites. Auvray *et al.* (1982) propose about 30 % MgO for the primary magma of komatiitic rocks in the Tipasjärvi area of the Archaean Kuhmo greenstone belt.

Spinifex textures have not been found within the ultramafic metavolcanics of the Peurasuvanto area. The pyroclastic amphibole-chlorite rocks and the komatiitic dykes are, however, located within the range of the spinifex-textured rocks (Fig. 4 A). The most primitive ultramafics of the study area consist of the rocks located at the MgO end of the field of the pyroclastic amphibole-chlorite rocks in the CMA diagram or the komatiitic dykes with about 26—28 % MgO (volatile free). The rocks along the olivine control line are either liquid differentiates resulting from olivine fractionation (less magnesian volcanics) or relatively unfractionated liquids enriched in olivine phenochrysts (high-magnesian cumulates).

The WISB ultramafic and mafic metavolcanics have a continuous komatiite — tholeiite trend as have metavolcanics of the Peurasuvanto area (Fig. 4 B), except that the ultramafic lenses (metadunites and metaperidotites) plot at or near the MgO apex, outside the komatiitic field. The metadunite and metaperidotite lenses

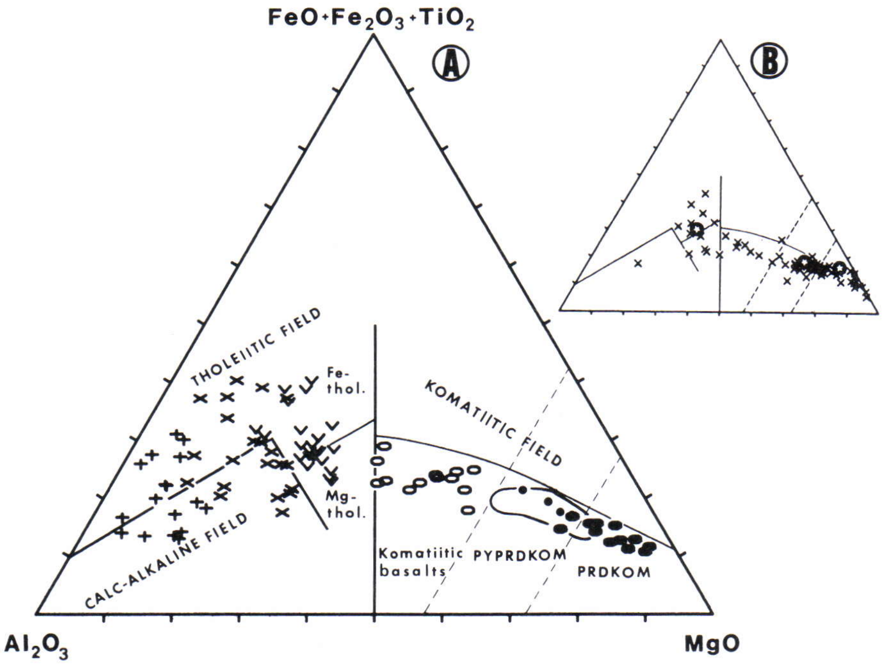

Fig. 5. Jensen cation plot of metavolcanics a) from the Peurasuvanto area. b) from the WISB (Pihlaja, in prep.) and the KGB (Henriksen 1983). Symbols as in Fig. 3.

occurring within the extrusive series and underlying metasediments may well be cogenetic with the komatiitic extrusives.

In the Jensen cation plot (Jensen 1976), which is commonly used to distinguish between tholeiitic and komatiitic metavolcanics, a continuous komatiite-tholeiite trend is obvious and similar to those shown by most komatiite suites. Without any compositional gap, the trend continues with metabasalts in the tholeiite field. The boundary between komatiites and komatiitic basalts is set at an MgO value of 57.5 %, corresponding to a MgO content of about 18 % (volatile free). This boundrary is in good agreement with the ultramafic metavolcanics of Lapland (Papunen *et al.* 1980), especially with the WISB komatiites. The ultramafic pyroclastic metavolcanics and komatiitic dykes merge again in the same field of pyroxene peridotitic komatiites. The composition of the tholeiitic series ranges from Mg-rich basalts to dacites and rhyolites. An apparent calc-alkaline trend is again in sight, but it does not necessarily imply the presence of calc-alkaline components in the area for the reasons discussed above.

In the FeO/(FeO + MgO) vs. Al_2O_3 diagram (Arndt *et al.* 1977), the Peurasuvanto ultramafic metavolcanics are well in the komatiite field, where they form a relatively smooth pattern of increasing Al_2O_3 and decreasing MgO, which is basically an olivine control line (Fig. 6 A). Mafic, intermediate and felsic metavolcanics are in the fields of Fe-rich tholeiites and intermediate basalts suggested by Naldrett & Goodwin (1977). According to this diagram, Al-rich calc-alkaline basalts are absent from the study area.

The use of this diagram to discriminate between komatiitic and tholeiitic rocks, particularly in the basaltic portion, has been criticized by many authors (Naldrett & Doodwin 1977, Nesbitt *et al.* 1979, Viljoen *et al.* 1982). Nesbitt *et al.* (1979) have stated that the intermediate basalts and Fe-rich tholeiites of Naldrett & Goodwin (1977) could just as well merely be more primitive tholeiitic basalts and fractionated tholeiitic basalts, respectively. The Fe-rich tholeiites could be differentiated tholeiitic basalts within the triangular area. But, in the case of sequential partial melting of the upper mantle and lower crust, the simplified trend could be from rhyolitic and dasitic volcanics and Fe-rich tholeiites through intermediate basalts to komatiitic basalts and high-magnesian members of the differentiation series.

In diagrams 6 A and 6 B, the analysis patterns of the Peurasuvanto area are similar to those of WISB and KGB. Komatiitic basalts seem to be absent from the Karasjok greenstone belt.

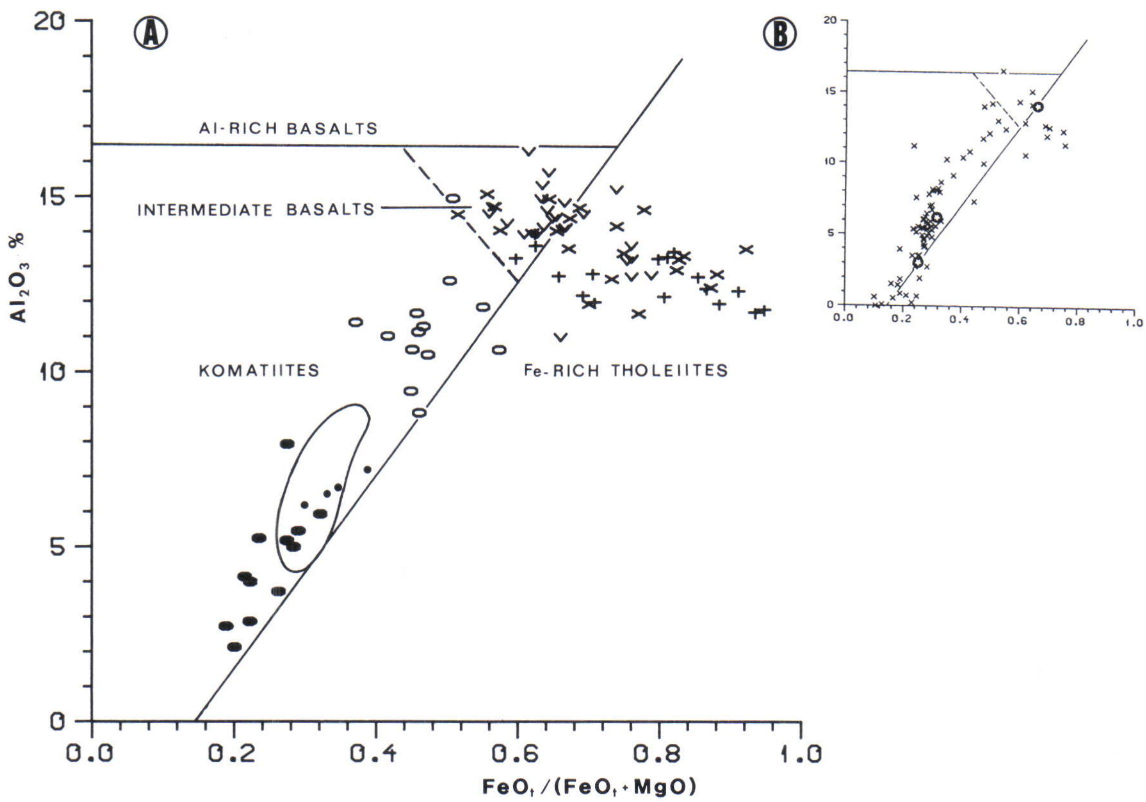

Fig. 6. Al_2O_3 vs. FeO/(FeO + MgO) plot for the metavolcanics of a) the Peurasuvanto area, b) the WISB (Pihlaja, in prep.) and KGB (Henriksen 1983). The fields after Naldrett & Goodwin (1977). Symbols as in Fig. 3.

DISCUSSION

The preceding petrochemical examination indicates the occurrence of both komatiitic and tholeiitic series in the Peurasuvanto area. Komatiitic volcanism occurred here in two phases. The earlier (minor) phase is represented by lavas and ultramafic cumulates, the main phase by huge amounts of ultramafic pyroclasts. In both phases, komatiitic volcanism was preceded by basaltic and felsic volcanism of tholeiitic affinity, suggesting that komatiites and tholeiites may be genetically linked and, in all probability, derive from the same source region but differing in degrees of partial melting.

Archaean greenstone complexes are generally interpreted to have been deposited in tectonically unstable milieus. Hanski (1980) has considered the theories and models for the geotectonic environment of komatiitic volcanics and states that komatiites cannot be associated with a specific geotectonic environment. Taipale (1979) suggests a volcanic island arc and associated back arc basin as the most appropriate geotectonic environment for the Tipasjärvi greenstone belt. The island arc produced large amounts of calc-alkaline volcanics, whereas the back arc produced volcanics of the tholeiite — komatiite series. Schau (1977) has described the occurrence of komatiitic volcanics and dykes within a cratonic sedimentary suite from the Archaean Prince Albert Group in Canada, thus resembling in many ways the milieu described in the present paper.

The volcanic-sedimentary rock associations of the Peurasuvanto area were deposited during a tectonically stable regime. The cratonized Archaean gneiss basement acted as a depositional base for mafic and felsic volcanics of tholeiitic affinity, ultramafic pyroclastic komatiites interlayered with arkose quartzites. The very long (tens to hundreds of kilometres), relatively narrow and parallel belts of pyroclastic komatiites in Peurasuvanto, and especially in the West Inari schist belt and the Karasjok greenstone belt (Henriksen 1983), favour a rift-type environment (Fig. 7). In the rift system, volcanism and sedimentation were subaerial or occurred in shallow-water basins. The large amounts of pyroclastic volcanics, mainly tuffs, agglomerates and pyroclastic breccias but also amygdaloidal lavas, block lavas and volcanic conglomerates are evidence of the prevailing depositional conditions. Furthermore, the erosional periods produced clastic sediments, arkosic quartzites with cross-bedding structures. Intervals between the eruptional phases yielded alumina-rich weathering products of mafic and ultramafic volcanics. The occurrence of large

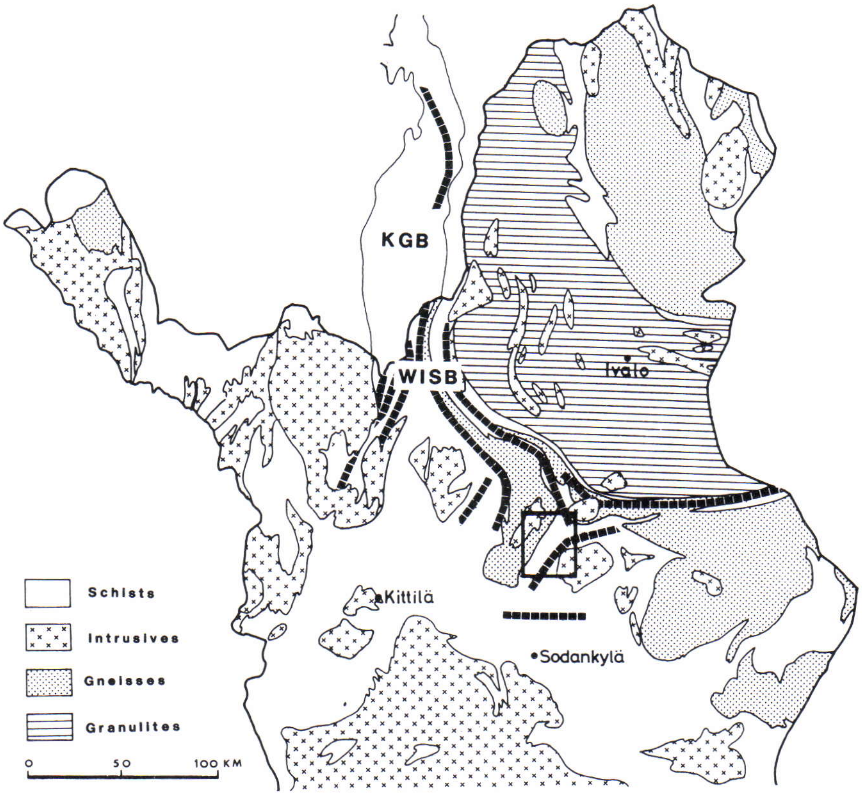

Fig. 7. Location of the komatiitic rocks in the Peurasuvanto area (outlined), West Inari schist belt (WISB) and Karasjok greenstone belt (KGB).

basins, e.g. marginal seas, is excluded by the absence of turbidites and greywacke-like, immature shales and submarine lavas. In addition, the obvious deficiency in calc-alkaline volcanics rules out tectonic environments such as ocean floors or volcanic island arcs.

According to Kröner (1982), the late Archaean crustal segments exceeded several hundreds of kilometres in size. These segments were subjected to crustal attenuation or fissuring above mantle plumes or hot lines, thereby generating elongate basins or sharply bounded, fault-controlled graben systems. These basins collected shallow-water sediments and also mafic to ultramafic volcanics produced by a high degree of melting in a sub-crustal mantle. The continental crust has not remained the same throughout geological time, and changes in its composition and thickness must have appreciably affected the rifting processes and rift structures that developed in the crust as it extended.

In summary, the present authors favour the evolution of Peurasuvanto greenstone basin in rift environments on a relatively stable continental crust.

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