

# Palaeoproterozoic mafic and intermediate metavolcanic rocks in the Turku area, SW Finland



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## Abstract

Twenty two samples were analysed from mafic and intermediate volcanic rocks from the Turku area along ~ 60 km long north-south geotraverse. Geographically and lithologically the samples were divided into the Pargas, Turku and Vahto groups. The Pargas and Turku groups consist of mafic units and intercalations within migmatitic gneisses. Their geochemical compositions are very similar. In average, they show quite flat REE curves and the multielement diagrams show moderate LILE enrichments, minor negative Ta-Nb anomalies and straight HFSE curves. We infer these as transitional between MORB and VAB. The Vahto group consists of thicker volcanic sequences in connection with synorogenic plutonic rocks. The data show enriched LREEs, LILEs, Th and P combined with negative Ta-Nb anomalies, i.e. the Vahto group shows subduction component. We interpret that the Vahto volcanic rocks belong to the Häme belt. The geochemical data indicate that the Pargas and Turku groups were formed in extensional, possibly back-arc or intra-arc setting while the Vahto group was formed at continental volcanic arc.

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**Key words:** metavolcanic rocks, geochemistry, trace elements, tectonics, back-arc basins, volcanic arcs, Paleoproterozoic, Svecofennian, Parainen, Turku, Vahto, Finland

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## 1. Introduction

Geochemical modelling has become one of the most important tools in reconstructing the tectonic settings of ancient volcanic formations. The development of analytical techniques, ICP-MS method in particular, has increased the use of trace element modelling (e.g. Pearce, 1996; Macdonald et al., 2000) in research of Palaeoproterozoic igneous rocks.

Recently, Kähkönen (2005) reviewed the present state of knowledge regarding the Svecofennian supracrustal rocks in Finland. From that review it is apparent that there still are very few volcanic areas that

are well-studied with modern geochemical methods. Evidently, for the orogen-scale modelling, data from new areas with analyses made by the most recent methods are most welcome.

In this contribution we present new geochemical data on Palaeoproterozoic mafic and intermediate volcanic rocks from the Turku area, southwestern Finland. The purpose is to add new modern analyses to geochemical databases of volcanic rocks in Finland and interpret tectonic setting of the studied volcanic units.

## 2. Geological setting

The main volcanic belts in southern Finland are called the Uusimaa belt and the Häme belt. The volcanism in the belts took place both in volcanic arc and in extensional settings (Lindroos & Ehlers, 1994; Väisänen & Mänttari, 2002; Kähkönen, 2005; Lahtinen et al., 2005). The age of volcanism is dated at  $\sim 1.90 - 1.88$  Ga (Vaasjoki, 1995; Reinikainen, 2001; Väisänen & Mänttari, 2002; Ehlers et al., 2004; Skyttä et al., 2005). The belts are separated and surrounded by sedimentary migmatitic mica gneisses and plutonic rocks of varying ages. Late Svecofennian 1.85 – 1.81 Ga granites (e.g. Nironen, 2005, and references therein) are common as well as Mesoproterozoic 1.65 – 1.54 Ga rapakivi granites (e.g. Rämö & Haapala, 2005, and references therein). These rock types are typical to southern Svecofennia, contrary to central Svecofennia (terms after Kähkönen, 2005), where the younger granites are absent. Accordingly, these areas are interpreted as separate terranes (Lahtinen, 1996; Rämö et al., 2001; Fig. 1a).

Our study profile covers volcanic rocks in the Vahto area that apparently in the north is the western extension of the Häme belt. The middle and NW part of the profile (Turku) consisting mainly of migmatitic mica gneisses cannot be straightforwardly connected to either of the main belts (Fig 1a). Lithology in the southern part (Pargas) containing marbles connects it to the Uusimaa belt. All rocks are deformed and metamorphosed in high temperature (700 – 800 °C) and low pressure (4 – 6 kbars) conditions and even the mafic volcanic rocks are partly migmatized (van Duin, 1992; Ehlers et al., 1993; Väisänen & Hölttä, 1999).

## 3. Sampled lithology

Our data were collected from a  $\sim 60$  km long north-south traverse. The samples are divided into three main geographical and lithological groups: the Pargas, Turku and Vahto groups. The sample locations are shown in Fig. 1b.

The mafic rock samples from the Pargas group come from the oval-shaped Pargas synform that

forms a doubly plunging basin structure (Lindberg et al., 1994). The mafic volcanic horizon is  $\sim 500$  m thick in average and is overlain by marbles and mica gneisses. Primary structures were not found.

The Turku group consists of mafic volcanic intercalations within the migmatitic mica gneisses in the central and northwestern part of the study area. Intercalations are mainly narrow, ranging from a few tens of centimetres to a few tens of metres. In the southern part of the Turku group the rocks form several hundred metres thick sequences and pillow structures are encountered locally (Lindberg et al., 1994; 118-MAV-02 in Fig. 1). Marbles are not found to be associated with them.

The Vahto group is located on both southern and northern side of, and partly within, the large synorogenic tonalite-quartzdiorite-granodiorite 1.87 Ga intrusion (van Duin, 1992; Nironen, 1999; Väisänen et al., 2002; Väisänen, 2007). The mafic-intermediate volcanic rocks form up to two kilometres thick sequences which are in places intercalated with sedimentary rocks. Volcanic breccias were locally found (Westerlund, 2005). Felsic rocks also exist, but they were excluded from this study. The geochemical data on volcanic rocks in Van Duin (1992) come from the same area. Therefore, they are shown for comparison.

## 4. Analytical procedures

Twenty two samples on mafic and intermediate meta-volcanic rocks were analysed for major and trace elements (Table 1). Fourteen samples were analysed at Acme Analytical Laboratories Ltd. (Acme) in Vancouver, Canada. Major elements and Cr, Ni and Sc were analysed by inductively coupled plasma emission (ICP). The other trace elements were analysed by inductively coupled plasma-mass spectrometry (ICP-MS). Eight samples were analysed at Geological Survey of Finland (GTK) where major elements and As, Ba, Bi, Cr, Cu, Ga, Mo, Ni, Pb, Rb, S, Sb, Sn, Sr, V, Zn, and Zr were analysed by X-ray fluorescence (XRF). The other trace elements were analysed by ICP-MS.

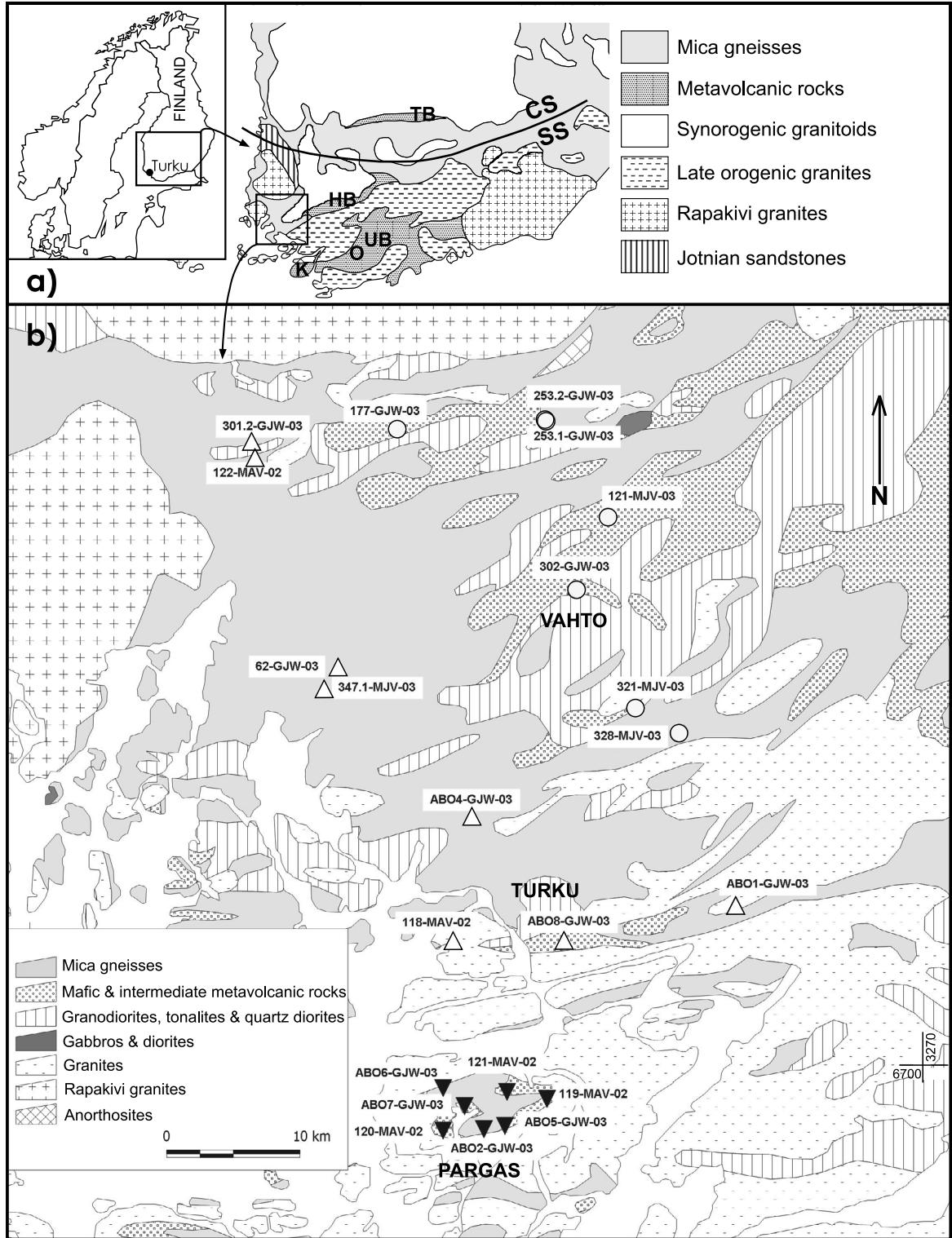


Fig. 1. a) Main lithological units in southern Finland. CS = central Svecofennia; SS= southern Svecofennia; TB = Tampere belt; HB = Häme belt; UB = Uusimaa belt. b) Geological map of southwestern Finland, modified after Korsman et al. (1997). Sample localities are marked with same symbols as samples in Fig. 2.

**Table I.** Chemical whole rock analyses of volcanic rocks from the Turku area (oxides and S in w%, other elements in ppm).

Sample	ABO2- GJW-03	ABO5- GJW-04	ABO6- GJW-04	ABO7- GJW-04	119- MAV-02	120- MAV-02	121- MAV-02	301.2- GJW-03	ABO1- GJW-03	ABO8- GJW-04	ABO4- GJW-03
Group	Pargas	Pargas	Pargas	Pargas	Pargas	Pargas	Pargas	Turku	Turku	Turku	Turku
Laboratory	Acme	Acme	Acme	Acme	Acme	Acme	Acme	GTK	Acme	Acme	Acme
SiO <sub>2</sub>	49.13	50.83	49.64	49.40	47.12	49.72	49.74	48.50	45.79	53.24	47.22
TiO <sub>2</sub>	0.71	1.21	0.79	0.88	0.71	1.24	0.91	0.92	0.68	0.82	1.15
Al <sub>2</sub> O <sub>3</sub>	14.48	14.84	14.77	16.87	17.39	14.38	14.75	12.20	13.69	18.19	14.84
FeO								11.60			
Fe <sub>2</sub> O <sub>3</sub>	11.25	8.75	10.85	11.32	10.82	13.17	11.70		14.04	11.12	12.66
MnO	0.20	0.18	0.16	0.12	0.14	0.14	0.17	0.20	0.19	0.14	0.16
MgO	7.68	4.75	7.48	6.44	7.46	5.93	6.90	10.70	13.64	4.60	9.02
CaO	11.96	15.66	12.85	11.14	12.25	12.34	12.38	10.78	9.16	8.89	11.52
Na <sub>2</sub> O	2.55	2.34	2.26	2.82	1.95	2.61	2.55	0.90	1.47	1.57	1.70
K <sub>2</sub> O	0.97	0.61	0.47	0.36	0.77	0.14	0.16	0.49	0.25	0.81	0.65
P <sub>2</sub> O <sub>5</sub>	0.05	0.12	0.08	0.08	0.04	0.09	0.07	0.12	0.08	0.11	0.14
S	0.02	0.01	0.1	0.01	0.04	0.14	0.01	0.004	0.04	0.01	0.01
Total	99.00	99.30	99.45	99.44	98.69	99.90	99.34	96.42	99.03	99.50	99.07
Cr	68.4	34.2	218.9	136.8	246.3	13.7	205.3	841	41.1	54.7	335.3
Ni	11.4	20	58	27	19.6	6.5	13.5	92	42.6	20	19.6
V	243	301	272	268	210	328	269	284	161	217	248
Zn	24	20	17	12	24	22	13	138	18	31	21
Cu	116.5	6.4	70.3	6.7	362.1	98.6	39.4	<20	133.2	2.3	14
As	66.2	2	2.9	3.4	0.9	0.5	1.7	<30	14.7	9.9	1.9
Ga	14.6	18.2	16.9	17.9	16.6	17.7	16	20	14.4	21	16.8
Rb	107.4	49.6	8.6	26.3	29.8	2.4	9.5	12.6	6.7	82.9	12
Sr	190.9	342.5	142.6	156.4	177.2	156.4	159.7	197	135.1	216.1	244.1
Ba	95	471.4	51.3	72	65	29	33	50	42	270.2	74
Nb	1.5	4.5	2.8	1.6	1.2	2.6	1.8	2.98	2	6	5
Ta	<.1	0.3	0.2	0.1	0.3	0.1	0.1	0.2	<.1	0.4	0.2
Y	16.3	36.1	25	25.2	17.2	32	25.1	16.9	16.6	25.7	26.7
Zr	37.8	102.6	44.5	54.8	33.8	52.5	43.5	48.5	40.1	72.2	65.9
Hf	1	3.1	1.2	1.8	0.9	1.4	1.4	1.32	1.5	2.2	2
U	0.3	1.6	0.2	0.5	<.1	<.1	<.1	0.55	0.2	1.2	0.4
Th	0.9	3	0.5	1.2	0.1	<.1	0.2	0.6	0.4	2.9	0.6
Pb	4.7	3.3	2.9	6.6	3	0.4	0.6	<30	2.5	4.4	3.9
Sn	26	12	3	13	5	2	8	<20	<1	5	1
Sc	52	40	46	44	44	50	55	37.7	27	35	39
La	3.2	8.9	5.4	4.1	2.1	4.5	3.4	4.77	3.9	12.6	7.4
Ce	8.3	22.9	13.2	9.7	5.2	12.5	9.2	11.4	10.3	27	20.7
Pr	1.11	3.31	1.86	1.4	0.79	1.83	1.39	1.52	1.24	3.34	2.78
Nd	5.7	14.7	8.7	7.4	3.7	9.1	7	7.89	5.6	12.5	12.5
Sm	1.7	4.1	2.6	2.4	1.5	2.8	2.2	2.2	1.7	3.1	3.5
Eu	0.73	1.06	0.87	1.01	0.72	1.11	0.75	0.74	0.64	0.86	1.14
Gd	2.14	5	3.44	3.17	1.9	3.87	3.03	2.89	2	3.42	3.5
Tb	0.43	0.9	0.63	0.64	0.44	0.86	0.63	0.45	0.45	0.63	0.72
Dy	2.78	5.39	3.91	4.03	3.09	5.24	4.34	3.1	2.77	3.86	4.6
Ho	0.54	1.28	0.88	0.87	0.65	1.09	0.9	0.63	0.54	0.9	0.86
Er	1.68	3.54	2.72	2.41	1.71	3.12	2.5	1.66	1.72	2.48	2.56
Tm	0.23	0.53	0.36	0.38	0.26	0.48	0.38	0.25	0.24	0.37	0.37
Yb	1.53	3.78	2.84	2.47	1.7	3.28	2.66	1.76	1.55	2.87	2.42
Lu	0.26	0.51	0.35	0.34	0.28	0.48	0.4	0.23	0.27	0.37	0.4

&lt; value below the given detection limit

**Table 1. cont.** Chemical whole rock analyses of volcanic rocks from the Turku area (oxides and S in w%, other elements in ppm).

Sample	62- GJW-03	118- MAV-02	122- MAV-02	347.1- MJV-03	177-GJW- 03	253.1- GJW-03	253.2- GJW-03	302- GJW-03	121- MJV-03	321- MJV-03	328- MJV-03
Group	Turku	Turku	Turku	Turku	Vahto	Vahto	Vahto	Vahto	Vahto	Vahto	Vahto
Laboratory	Acme	Acme	Acme	Acme	GTK	GTK	GTK	GTK	GTK	GTK	GTK
SiO <sub>2</sub>	48.19	48.48	52.26	48.50	50.80	52.00	51.40	54.20	48.20	51.40	57.70
TiO <sub>2</sub>	0.83	0.74	1.45	1.36	1.43	1.05	1.18	1.05	0.81	0.97	0.96
Al <sub>2</sub> O <sub>3</sub>	16.63	16.30	14.81	13.75	17.00	15.70	16.70	16.00	12.00	14.60	17.10
FeO					9.67	10.35	7.66	8.79	10.45	9.16	8.35
Fe <sub>2</sub> O <sub>3</sub>	13.18	10.19	10.08	17.77							
MnO	0.17	0.15	0.09	0.22	0.18	0.36	0.11	0.16	0.16	0.16	0.17
MgO	8.04	8.59	7.15	6.52	6.50	6.53	5.66	5.80	11.40	7.53	2.68
CaO	9.29	12.77	10.03	10.42	7.53	8.16	10.02	7.41	9.99	10.62	5.78
Na <sub>2</sub> O	2.64	1.99	2.71	1.59	4.07	3.10	4.03	2.99	2.43	2.07	4.25
K <sub>2</sub> O	0.38	0.18	0.47	0.19	1.07	1.09	0.75	1.73	0.38	0.50	1.52
P <sub>2</sub> O <sub>5</sub>	0.09	0.07	0.13	0.15	0.25	0.17	0.29	0.21	0.15	0.19	0.19
S	0.01	0.02	0.04	0.04	0.009	0.006	<0.006	<0.006	<0.006	<0.006	0.011
Total	99.45	99.48	99.22	100.51	98.52	98.52	97.81	98.32	95.97	97.20	98.71
Cr	88.9	273.7	88.9	41.1	87	162	201	82	740	286	30
Ni	43	33.5	29	11.4	55	93	82	40	166	80	20
V	161	200	324	341	301	198	257	235	226	254	166
Zn	38	14	26	18	88	134	68	117	91	90	123
Cu	52.4	30.4	34.8	24.6	62	401	<20	62	75	142	41
As	4.1	1.9	12.9	< .5	<30	<30	<30	<30	<30	<30	<30
Ga	18	13.4	18.1	17.5	22	25	24	26	<20	27	28
Rb	11.3	4.1	8.8	2.6	38.5	24.7	8.35	102	5.17	11.9	37.9
Sr	314.8	189.9	193.6	185	582	381	727	478	531	380	425
Ba	81	37	76	22	165	424	179	455	148	173	391
Nb	3.3	1.4	4.6	5.5	4.94	5.65	7.94	5.5	3.19	4.45	7.09
Ta	0.2	< .1	0.3	0.3	0.32	0.31	0.61	0.36	0.21	0.31	0.48
Y	23.9	19.4	23.4	38.1	24.3	17.5	19.6	17.2	14.3	14.4	27
Zr	52.4	38.7	76.9	68.4	113	80.4	90.5	103	51.6	72.2	125
Hf	1.5	1.1	2.4	2	2.86	2.09	2.07	2.58	1.22	2.09	3.14
U	0.7	0.1	2	0.1	1.14	0.28	1.12	1.08	0.28	1.24	0.64
Th	0.9	0.6	0.4	< .1	1.85	<0.5	0.9	2.31	0.65	2.07	1.32
Pb	1.8	2	3.4	1.2	<30	<30	<30	<30	<30	<30	<30
Sn	< 1	< 1	< 1	< 1	<20	<20	<20	<20	<20	<20	<20
Sc	32	39	44	56	25.7	25.2	22.2	21.9	31	33.6	23.1
La	4.7	2.2	4.3	3.6	12.6	12.3	11.5	15.1	5.52	10.8	16
Ce	12.2	5.9	12.9	10.7	31.4	33	28.1	32.9	13.5	24.3	35.8
Pr	1.68	0.96	2.06	1.5	4.16	4.54	3.81	4.35	1.93	3.18	4.47
Nd	7.3	4.7	10.7	8.3	19.2	20.3	18.1	18.3	9.33	14.3	19.8
Sm	2.2	1.7	3.1	2.8	4.64	4.12	3.96	3.79	2.35	3.19	4.22
Eu	0.84	0.62	1.13	1.03	1.38	1.25	1.13	1.04	0.83	1	1.19
Gd	2.75	2.11	3.61	4.17	4.98	4.29	4.52	3.73	2.61	3.35	4.54
Tb	0.58	0.47	0.67	0.86	0.78	0.57	0.65	0.51	0.43	0.46	0.76
Dy	3.84	3.21	4.44	5.99	4.38	3.27	3.35	3.27	2.39	2.59	4.62
Ho	0.84	0.69	0.84	1.36	0.88	0.68	0.68	0.56	0.48	0.54	0.91
Er	2.45	1.8	2.3	4.04	2.22	1.67	1.78	1.46	1.33	1.27	2.76
Tm	0.36	0.29	0.34	0.61	0.31	0.24	0.26	0.22	0.2	0.22	0.38
Yb	2.45	2	2.37	4.21	2.18	1.43	1.76	1.44	1.32	1.29	2.65
Lu	0.4	0.27	0.29	0.65	0.3	0.21	0.24	0.21	0.2	0.19	0.39

&lt; value below the given detection limit

## 5. Major elements

The  $\text{SiO}_2$  contents of the samples vary between 45 and 61 %, which classify them to range from basalts to andesites. From the TAS diagram (Fig. 2) and from the major elements *vs* MgO plots (Fig. 3), it is evident that in average the Vahto group tends to show higher contents of alkalis and silica compared to the Pargas and Turku groups. The Pargas and Turku groups also show, excluding few differing samples, higher contents of CaO and  $\text{P}_2\text{O}_5$ . Other major elements show no clear grouping (Fig. 3). The analysed samples plot quite well within the igneous spectrum of Hughes (1973), indicating a rather low alkali alteration. The igneous spectrum diagram is shown in Westerlund (2005).

## 6. Trace elements

When the data are plotted on the Zr/Ti *vs* Nb/Y diagram (Fig. 4) it is evident that more data plot in the basalt field, including all the Pargas and Turku data, than using the TAS diagram in Fig. 2.

Other trace element data are presented in form of chondrite-normalised rare earth element (REE) diagrams and mid-ocean ridge basalt (MORB) normalised multielement diagrams that also include major elements K and Ti. The data are presented separately for each group below.

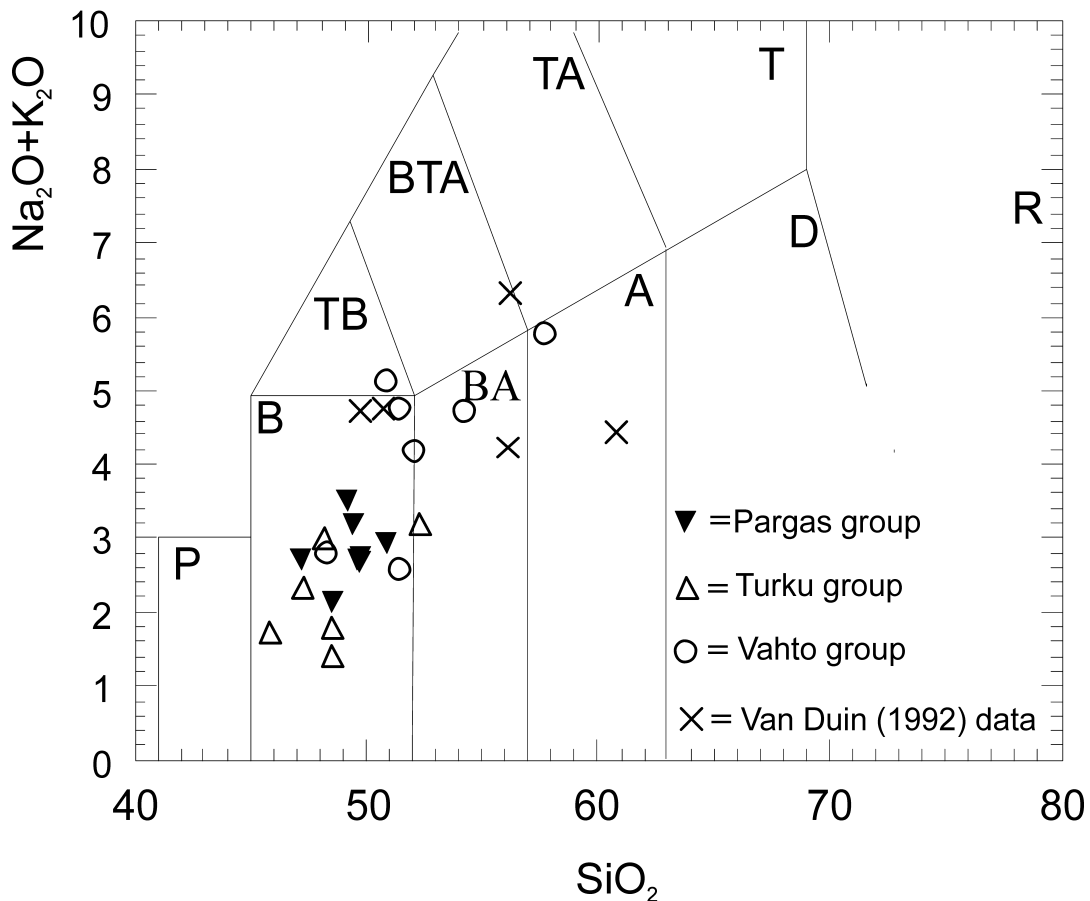


Fig. 2. Total alkali vs silica (TAS) diagram. Fields according to Le Maitre et al. (1989).

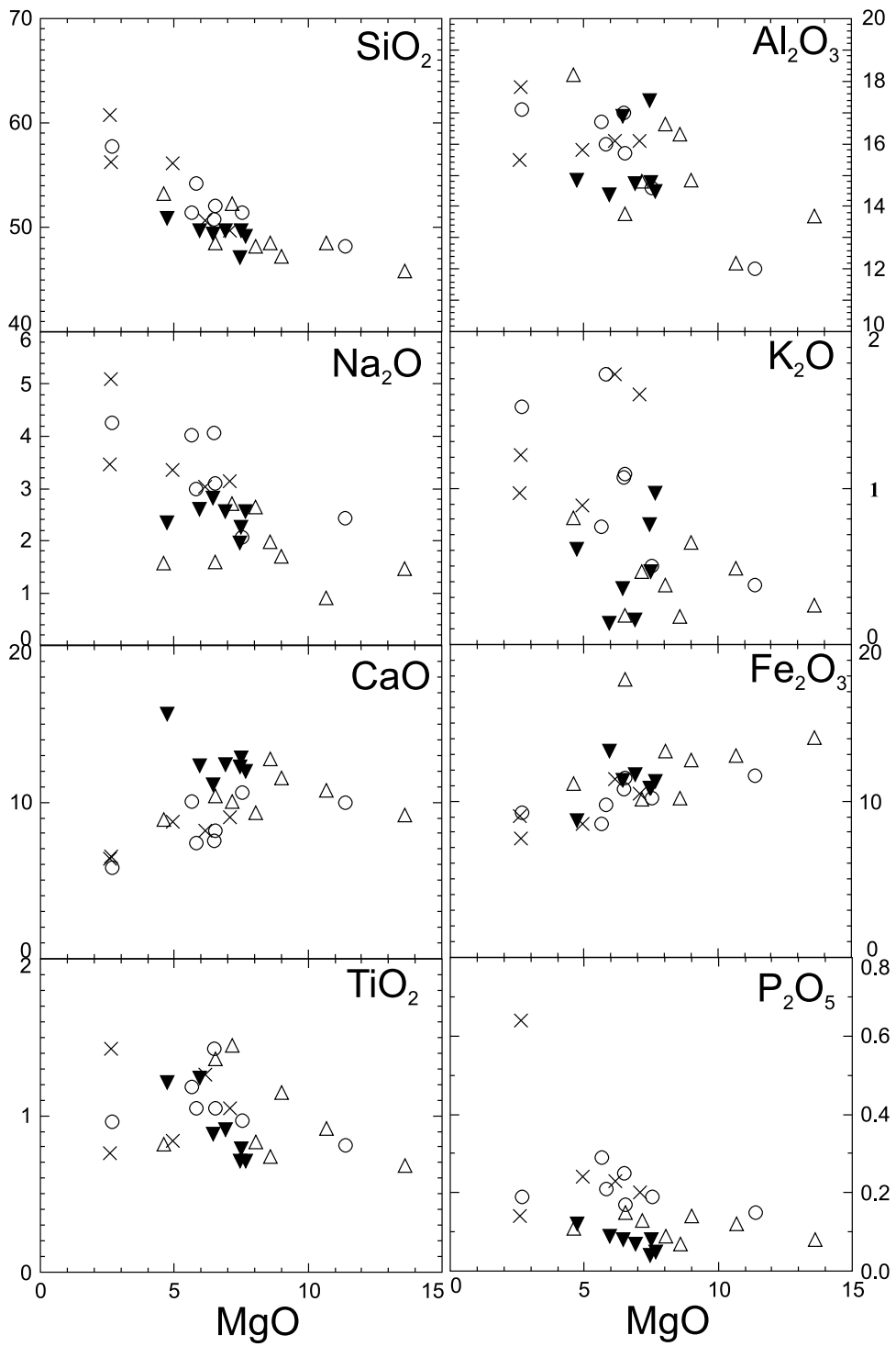


Fig. 3. Major element vs MgO diagrams. Symbols as in Fig. 2.

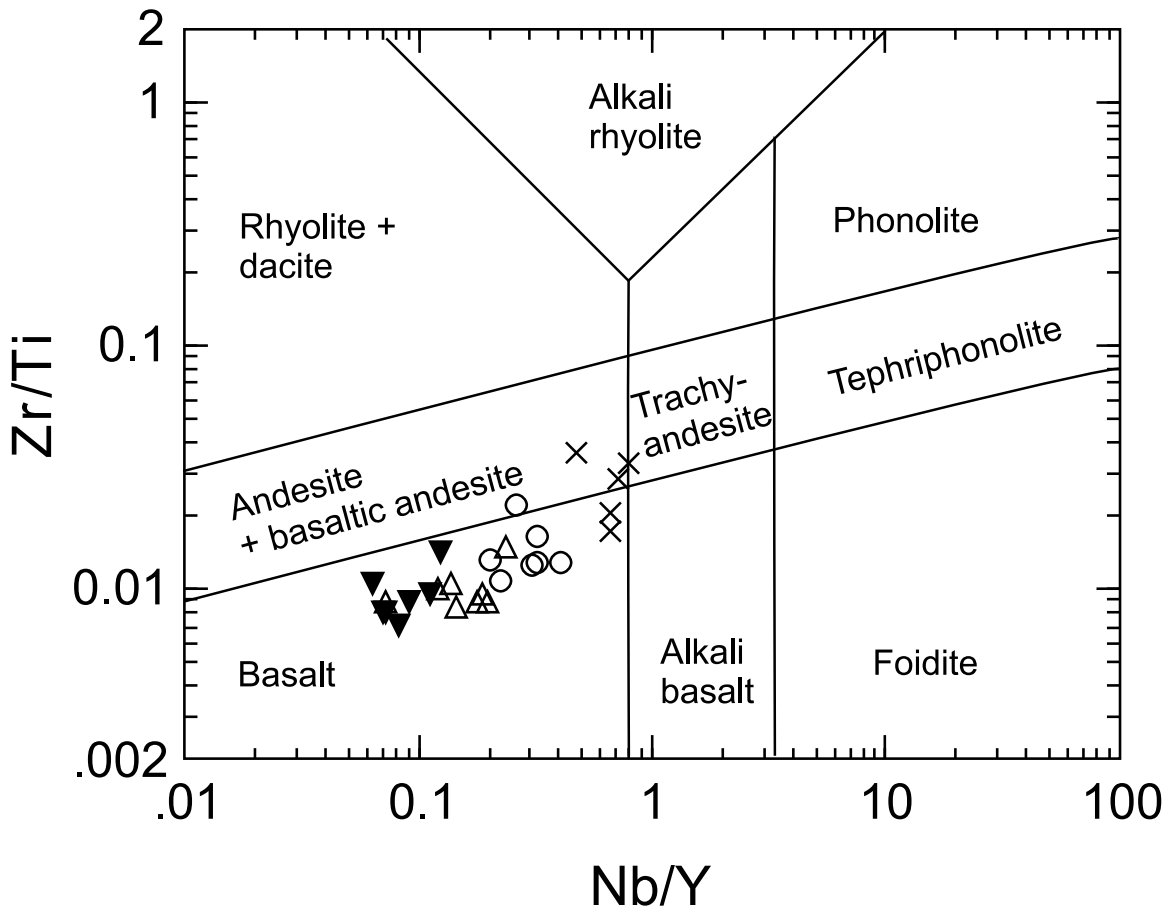


Fig. 4. Zr/Ti vs Nb/Y diagram after Pierce (1996). Symbols as in Fig. 2.

### 6.1. Pargas group

All the samples from this group come from the same volcanic unit underlying the marble horizon. Therefore, they are assumed to belong to the same magmatic phase.

The REE contents of the mafic rocks generally show quite a flat pattern, in average roughly twelve times enriched relative to chondrite (Fig. 5a). Eu shows both small negative and positive anomalies, possibly correlating with the amount of plagioclase in the samples. The sample ABO5-GJW-03 differs from other samples in showing more enriched REEs, LREEs in particular. We interpret that this is caused by secondary processes because the sample was tak-

en from highly strained and partly migmatized outcrop. Another sample (119-MAV-02) shows slightly depleted LREEs relative to other samples.

The multielement diagram (Fig. 5b) shows that, in general, the Pargas volcanic rocks are variably enriched in LIL-elements and slightly depleted in most HFS-elements compared to MORB. Rb, in particular, shows a wide scatter. Most Th and all Ce abundances are enriched compared to neighbouring elements which, consequently, causes small Ta-Nb troughs. As in the REE diagram, the sample ABO5-GJW-03 differs and is relatively rich in most elements.



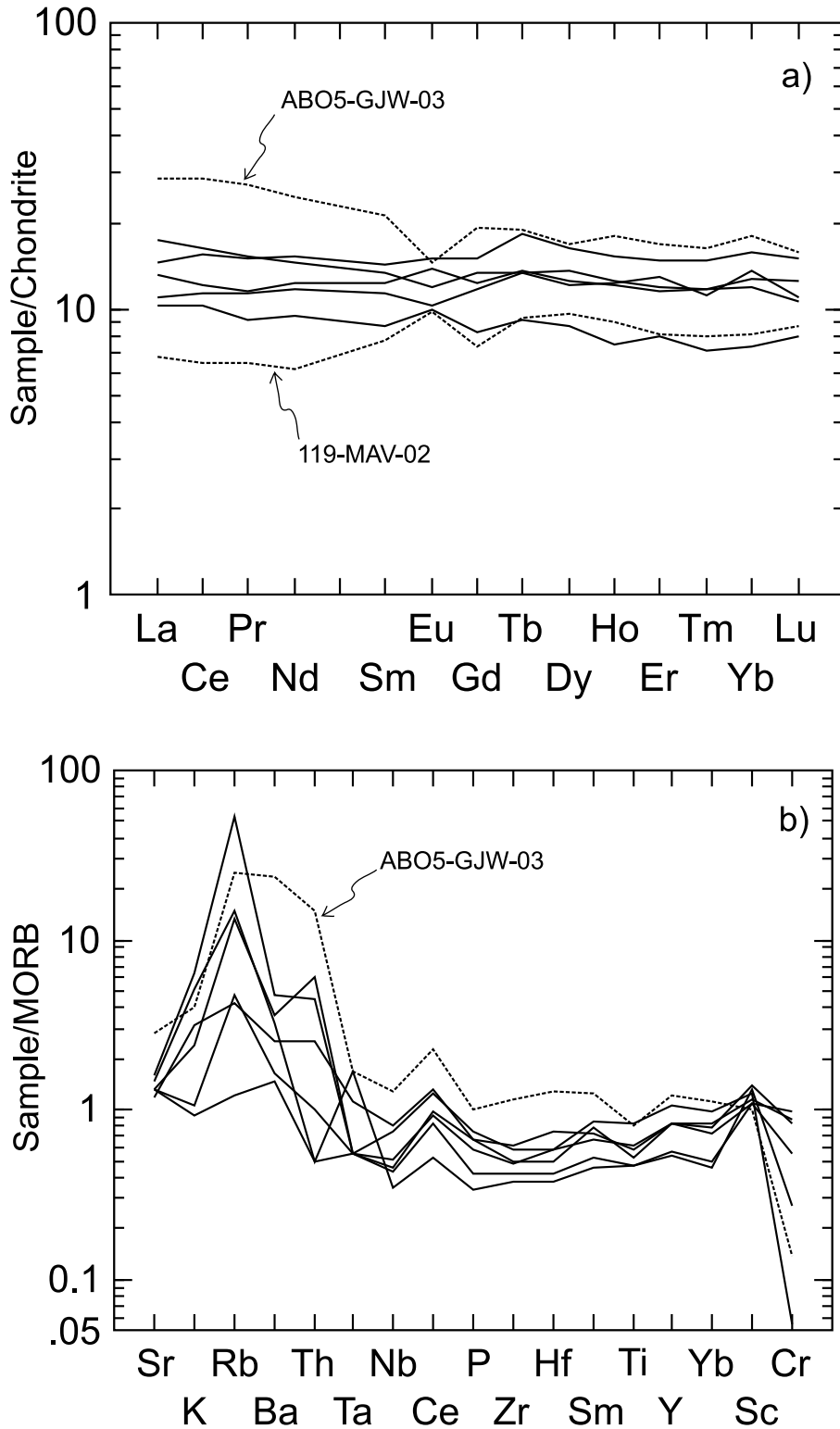


Fig. 5. Data from the Pargas group volcanic rocks. Samples referred to in the text are by dashed lines and indicated by arrows. a) Chondrite normalised REE diagram (normalisation after Boynton, 1984). b) N-MORB normalised multielement diagram (normalisation after Pearce, 1982).

### 6.2. Turku group

In this group the samples come from quite thin volcanic layers widely scattered across the study area (see Fig. 1 for sample locations). Therefore, their mutual field relations are not that clear. In spite of that, the data show good coherence.

The REE patterns of the samples (Fig. 6a) show a slight scatter with both gentle negative and gen-

tle positive slopes (samples 118-MAV-02 and 347.1-MJV-03). Sample ABO8-GJW-03 show clear LREE enrichment and sample 118-MAV-02 LREE depletion relative to other samples.

The multielement diagram (Fig. 6b) shows a slight LIL-element enrichment except sample ABO8-GJW-03 that shows a stronger enrichment, in accordance

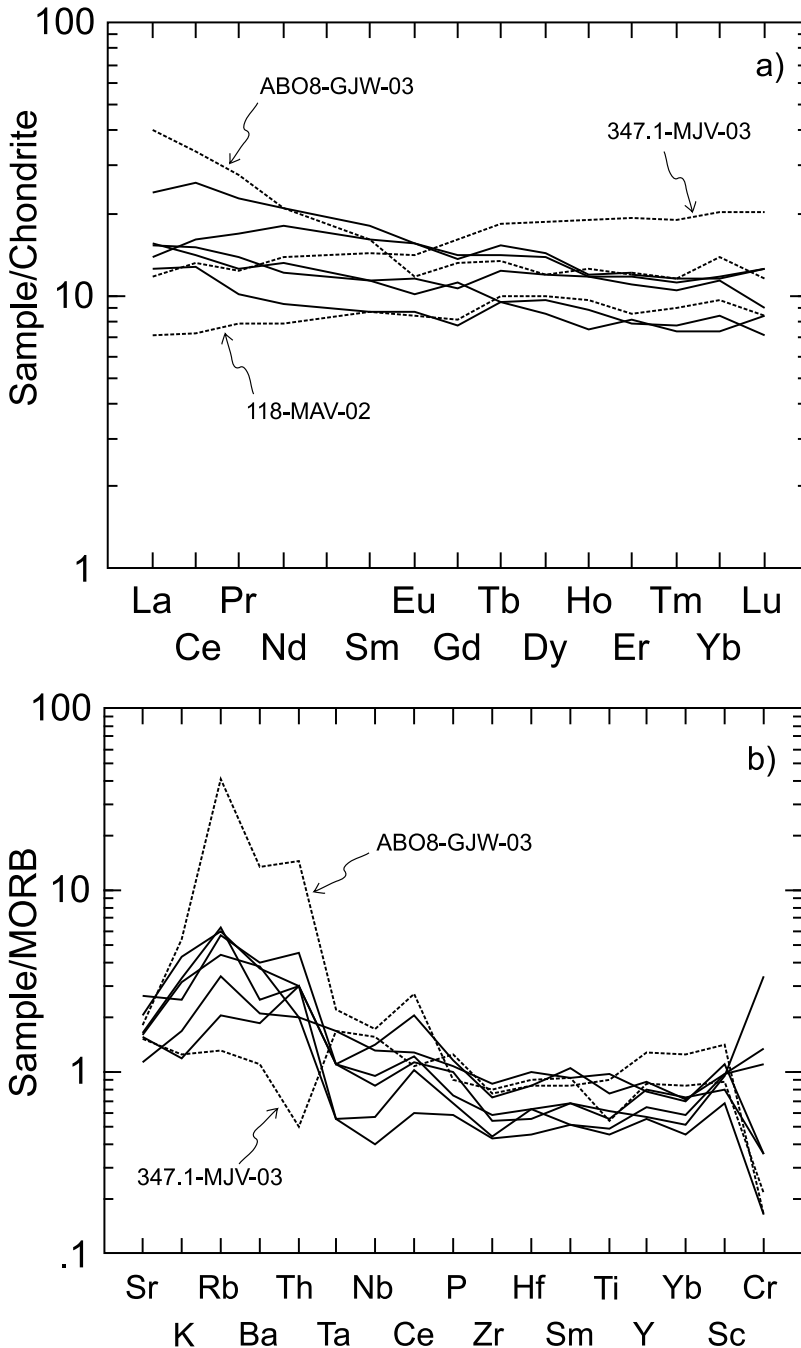


Fig. 6. Data from the Turku group volcanic rocks. Samples referred to in the text are by dashed lines and indicated by arrows. a) Chondrite normalised REE diagram (normalisation after Boynton, 1984). b) N-MORB normalised multielement diagram (normalisation after Pearce, 1982).

with the LREE enrichment of the same sample. HFS-element contents are, in average, slightly depleted relative to MORB but the patterns are very similar to it. Ce shows slight enrichments, and Ta-Nb shows weak negative anomalies. Sample 347.1-MJV-03 differs as it shows practically no LILE enrichment and a negative Th anomaly. Except for the Th trough, the pattern is close to that of MORB.

### 6.3. Vahto group

Samples from the Vahto group are characterised, compared to the samples from the other two groups, by higher LREE/HREE ratios. This is visible as negative slopes on REE patterns (Fig. 7a). Sample 121-MJV-03, which is the most mafic sample within the Vahto group, shows the least pronounced enrich-

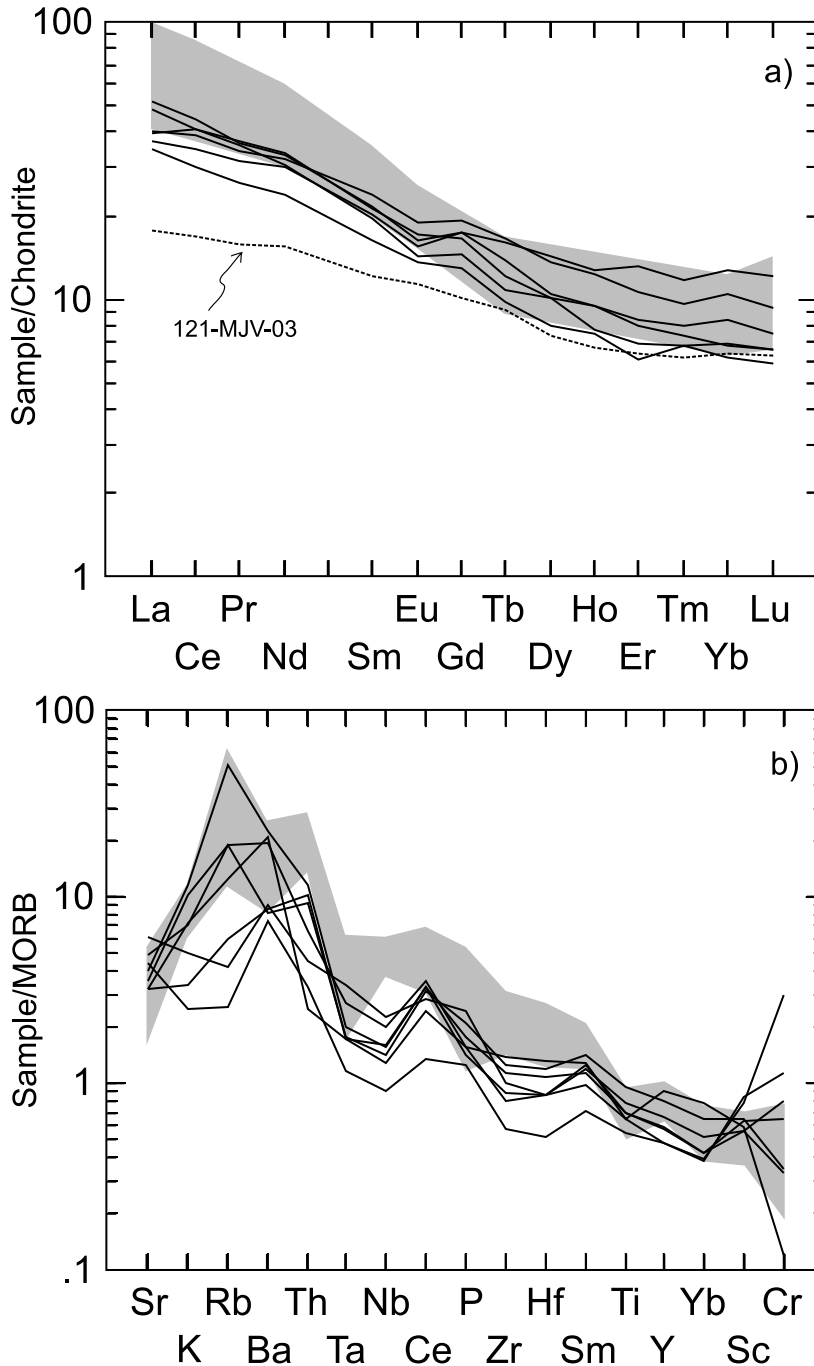


Fig. 7. Data from the Vahto group volcanic rocks. The grey shades in the figures show the compositional range of data from van Duin (1992). Sample referred to in the text are by dashed line and indicated by arrow. a) Chondrite normalised REE diagram. (normalisation after Boynton, 1984) b) N-MORB normalised multi-element diagram. (normalisation after Pearce, 1982).

ment. Van Duijn's (1992) data display higher LREE concentrations.

In the multielement diagram (Fig. 7b), samples are characterized by moderate LILE/HFSE ratios. This is shown as variable enrichment of K, Rb, Ba, Th, Ce and P while the Ta, Nb, Zr, Hf, Sm, Ti, Y and Yb values successively decrease in order of incompatibility. Rb shows the widest scatter. The most incompatible elements, Ti, Y and Yb are the most depleted ones, which plot below N-MORB compositions. Ta and Nb show negative anomalies. In average, the HFSE patterns form a negative slope.

## 7. Discussion and conclusions

The geochemical data of the Pargas and the Turku groups show many similarities. Both display quite flat REE patterns and more or less similar patterns in multielement diagrams (Figs 5 and 6), namely LILE enrichment and HFSE patterns slightly below

MORB but nearly parallel to it. Although many features resemble MORBs, slight enrichments in LILE, Ce and P and weak Ta-Nb troughs are more common among subduction-related arc rocks. Th abundances vary considerably causing high Th/Nb ratios in many samples. These features indicate either subduction signature or crustal contamination (Stern et al., 1995b; Pearce, 1996). Scatter in Th contents is also manifested in poor discrimination using Th-based diagrams and data plot in MORB and ARC fields (e.g. in Zr-Nb-Th diagram, not shown). The samples show increasing Ti with increasing Zr and plot in MORB field in the Ti vs Zr diagram (Fig. 8). In this respect the data resemble that of the Vestlax formation in Kemiö (Lindroos & Ehlers, 1994) and the Salittu formation in Orijärvi (Väisänen & Mänttari, 2002) as is also shown in the recent review and plots by Kähkönen (2005). Since the data show features both from MORBs and VABs (volcanic arc basalts), we call these groups as transitional between MORBs

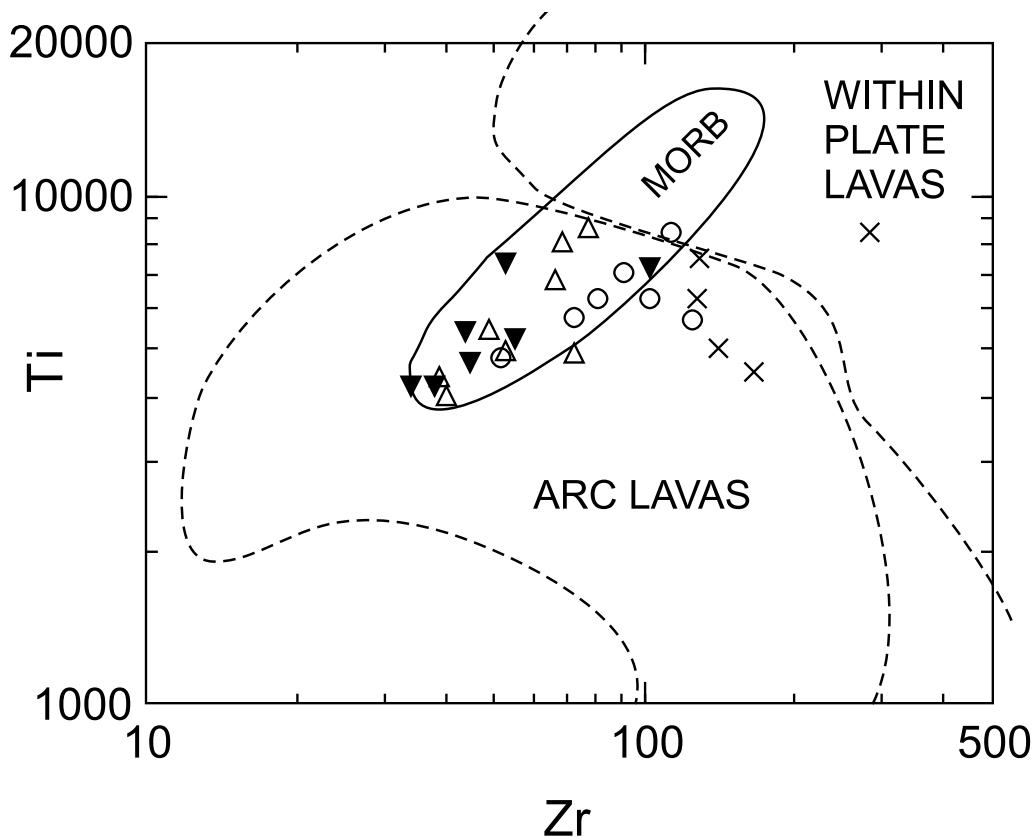


Fig. 8. Ti vs Zr diagram after Pearce (1982). Symbols as in Fig. 2.

and VABs as classified by Pearce (1996). Transitional data are common among marginal basins, but to infer the basin type requires other independent geological evidences (Pearce, 1996).

Three main alternatives are possible to explain the mafic volcanism erupted in sedimentary basin: 1) Mafic rocks were erupted in fore-arc setting. This scenario is not favoured as fore-arcs are supposed to contain boninitic magmas (e.g. Stern et al., 1995a) which are not found here. 2) Mafic rocks were erupted through an older rifted (attenuated) crust (Ehlers et al., 1986; Lahtinen et al., 2005). This is fully possible scenario, since the sediments contain both Archaean and older Palaeoproterozoic detrital zircons (Väisänen et al., 2002). 3) Mafic rocks were erupted in back-arc or intra-arc setting during rifting of arc of roughly the same age (Väisänen & Mänttari, 2002). This interpretation fits with existing age data of the crust in southern Finland and connects the Turku area to the Kemiö area and the Toija and Salittu formations in the Orijärvi area. We prefer this interpretation.

The geochemical data from the Vahto group differ from that of the Pargas and Turku groups. The enriched LREEs and LILEs, positive anomalies of Ce, P and Sm combined with Ta-Nb troughs all point to subduction signature. In the Ti *vs* Zr diagram (Fig. 8) the samples plot both in the MORB and in the ARC fields with no apparent Ti-Zr correlation. The data from the Häme belt (Hakkarainen (1994) and Lahtinen (1996), plotted in Kähkönen (2005), show a similar scatter. The REE and multielement diagrams in this study and from the Häme belt (op. cit) also show striking similarities. Therefore, as previously inferred from its geographically close position and especially from geological maps (e.g. Korsman et al., 1997), it is obvious also on geochemical grounds that the volcanic rocks within the Vahto group belong to the Häme belt.

Although the data of the Vahto group show an arc signature, the precise type of arc is less clear. Typical (oceanic) island arc basalts generally have normalised HFSE contents below the MORB-level which is

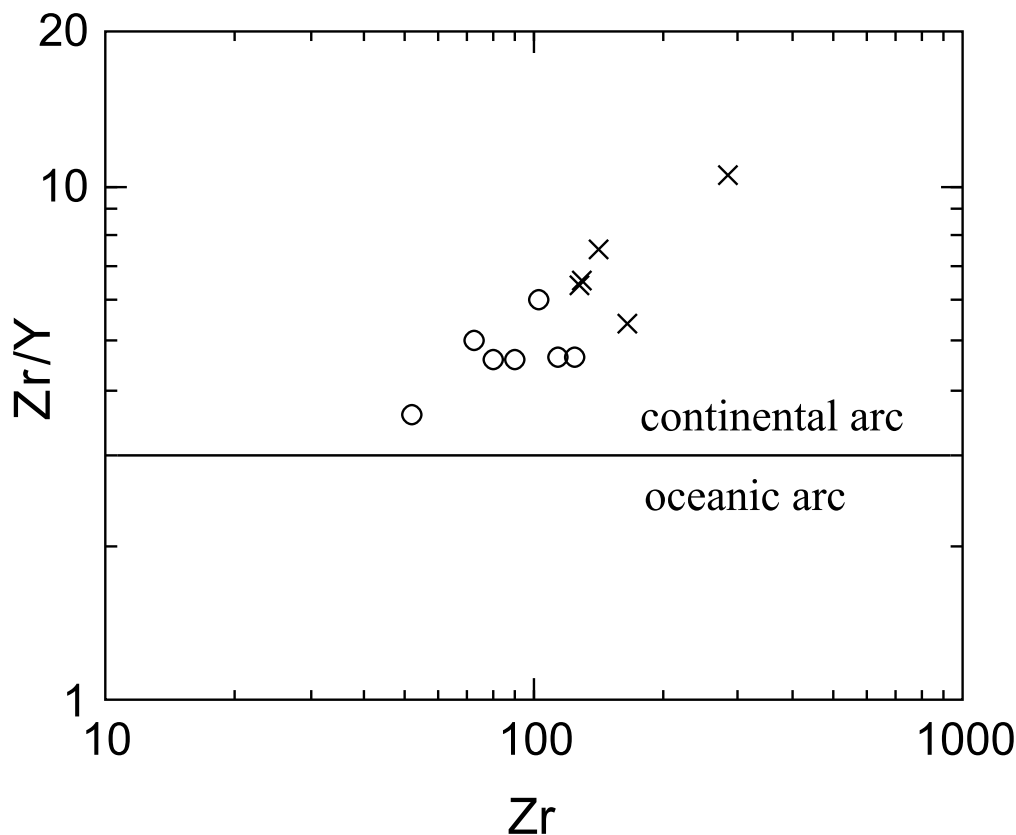


Fig. 9. Zr/Y vs Zr diagram, data from the Vahto group. Boundary line between continental and oceanic arcs after Pearce (1983). Symbols as in Fig. 2.

not the case in these samples. The multielement diagram in Fig. 7b further shows that the average normalized contents of Ta-Nb > Zr-Hf > Y-Yb are combined with positive anomalies of Ce, P and Sm. According to Pearce (1983), these features indicate both subduction and within plate components typically found among continental volcanic arcs (i.e. active continental margins). In the Zr/Y vs Zr diagram the data from the Vahto group plot within the continental arc field (Fig. 9).

Pursuing the idea of the continental volcanic arc, a problem arises about the nature of the continent because at the present erosion level no older continent is known to exist. Detrital zircon data (Claesson et al., 1993) and isotope data have, however, brought the ideas of a hidden older continent beneath the present crust (Lahtinen & Huhma, 1997). Recently, this enigmatic hidden crust was named as the Bergslagen microcontinent, but it is inferred to be situated below the Uusimaa belt, not the Häme belt (Lahtinen et al., 2005).

In conclusion, our geochemical data on the mafic and intermediate volcanic rocks from the Turku area show that compositions of the rocks fall in two main classes. The mafic volcanic units and intercalations within the sedimentary mica gneisses (the Pargas and Turku groups) show MORB and transitional MORB/VAB geochemical features. We interpret that they were formed in an extensional, preferably in back-arc or intra-arc setting. The rocks from the Vahto group are subduction-related and we interpret that they were formed at a continental volcanic arc.

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