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PETROGRAPHICAL AND PETROCHEMICAL FEATURES OF THE ESTONIAN PRECAMBRIAN PORPHYRACEOUS POTASSIUM GRANITES

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Project 275
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Abstract. Estonian porphyraceous potassium granites of rapakivi age are coarse- to medium-grained, pinkish-grey rocks with microcline porphyroblasts. Five small plutons of these granites — Märjamaa, Neeme, Ereda, Naissaare, and Taebla — sharply transect the surrounding rocks. These granites as well as the veins of aplites cutting them contain microcline, quartz, plagioclase, and biotite as principal minerals and apatite, fluorite, zircon, sphene, orthite, muscovite, and rutile as accessory minerals; hornblende is common in melanocratic granites; the main opaque minerals are magnetite and ilmenite. By their chemical composition, Estonian porphyraceous granites can be assigned to the rapakivi granite formation. Estonian porphyraceous granites have relatively low Niggli *mg*-indices (0.1—0.35) and negative *t* value; the value of *alk* is systematically lower than that of the rapakivi granites. On the basis of different Mg/Mg+Fe and Ca/Ca+Na ratios, three separate trends, possibly corresponding to different phases, can be distinguished. The age of these granites varies from 1.62—1.69 Ga (K—Ar, biotite), U—Pb age show 1.66 Ga and Rb—Sr — 1.71 Ga. On the basis of the mineralogical and chemical composition, different subtypes (possible phases) of granites are described.

Introduction

The present paper gives a descriptive review of the general petrographical (M. Niin) and petrochemical (A. Soesoo) features of the Estonian porphyraceous granites, being an introduction to subsequent detailed investigations.

In Estonia, five small plutons of porphyraceous granites — Märjamaa, Neeme, Ereda, Naissaare, and Taebla — are known (Fig. 1). Possibly, the oval-shaped northwestern part of the Märjamaa pluton can be considered as an individual pluton. According to the geophysical data, these plutons occur as intrusions sharply transecting the surrounding rocks. This is also confirmed by two drill cores through the Märjamaa and Taebla plutons. In the regional geophysical fields, the porphyraceous granites can be distinguished by negative gravity and magnetic fields (Побул, 1962).

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Fig. 1. Location of plutons of the porphyraceous potassium granites and zonation of the Estonian basement. *1* — Taebla, *2* — Märjamaa, *3* — Naissaare, *4* — Neeme, *5* — Ereda, *6* — Riga pluton of rapakivi granites. I — Tallinn, II — Alutaguse, III — Jõhvi zones; IV — Tapa, V — West-Estonian, and VI — South-Estonian blocks.

The density of the above-mentioned rocks ranges from 2.57 to 2.81 g/cm^3, averaging 2.63 g/cm^3 (Побул et al., 1968).

Kuuspalu (Кууспалу, 1975) compared the porphyraceous granites of North Estonia with the granites of South Finland, describing their similarities to the third-group granites by Sederholm (Эскола, 1967) and showing that these granites belong to the rapakivi granite formation.

The age of the Estonian porphyraceous granites ranges from 1.62 to 1.69 Ga (K—Ar, biotite), or 1.66 Ga by U—Pb and 1.71 Ga by Rb—Sr estimations (Пуура, 1974; Пуура et al., 1974; Пуура et al., 1983). Three zircon fractions from the first phase of the Märjamaa pluton provide an upper intercept age of 1.626 Ga (Kirs et al., 1991). By the isotopic age, the Estonian porphyraceous granites are comparable with some Finnish intrusions such as Wiborg, Suomenniemi, Ahvenisto, Onas, Bodom, Obbnäs of 1.62—1.65 Ga age (Rämö, 1991; Vaasjoki, 1977) and Dala granites — 1.67 Ga old (Lundqvist, 1968; Welin and Lundqvist, 1970).

Materials and Methods

Altogether, 61 drill holes of five Estonian small plutons — Neeme (35 cores), Naissaare (7), Märjamaa (15), Taebla (2), and Ereda (2) — have been studied. Petrographical descriptions of the Estonian porphyraceous granites are based on the earlier field works and thin section studies. Ninety-eight wet chemical analyses of these rocks and their aplites (made in the laboratory of the Geological Survey of Estonia; Table 1) were used for general petrochemical description. K—Na—Ca—Si ratio, Ca/Ca+Na, Mg/Mg+Fe ratios and Niggli main values were used as characteristics reflecting the general petrochemical features of the porphyraceous granites and for their comparison with typical rapakivi granites.

Petrography

The Märjamaa pluton (40×25 km) is composed of coarse-grained, pinkish-grey porphyraceous granite. According to the geophysical data, the contacts between the granites and the surrounding gneisses are sharp. In drill core No. 314, contact alteration was absent but some apophyses of porphyraceous granites within the surrounding gneisses were observed. The rocks of the central part of the pluton contain gneiss xenoliths with the diameter up to 20 cm.

Data on the mineralogical composition of 25 analysed thin sections of Märjamaa porphyraceous granites are presented in Table 2.

The quartz of the porphyraceous granites of the Estonian small plutons shows often weak undulatory extinction. Two generations of quartz have been distinguished. The first generation occurs partly between the potash feldspar individuals as anhedral crystals and partly as euhedral inclusions within the potash feldspar (microcline). The second generation occurs as anhedral crystals in the groundmass. Potash feldspar (microcline) is present as phenocryst (diameter 2—3 cm) and in the groundmass. The mineral is often perthitic. The phenocryst contains inclusions of quartz, biotite, and rare sphene. The plagioclase forming euhedral tabular or prismatic crystals is represented by oligoclase-andesine. In places, the observed plagioclase shows a zone of andesine in the central part of the crystal and a zone of oligoclase at the margins. Twinning according to the albite law is common. Biotite is pleochroic in light yellow to brown colours. Its anhedral crystals are often clustered together as swarms of small or large flakes.

Among the accessory minerals, apatite, fluorite, zircon, sphene, and orthite are present, with the content of sphene and zircon reaching 5% and 3%, respectively. Hornblende occurs sporadically, being common in drill cores 314 and 302. The content of main opaque minerals, magnetite and ilmenite, may reach 3%.

The central part, the most melanocratic and basic type of porphyraceous granites within the Märjamaa pluton, is interpreted as the first intrusive phase. The second intrusive phase is represented by muscovite-bearing granites containing biotite. The granites of the third phase are of more leucocratic composition and in places of trachytoid texture.

The density groups of Märjamaa granites correspond to the phases distinguished on the basis of petrographical data. The density of the rocks forming the first phase is 2.71 g/cm^3, that of the second phase — 2.66 g/cm^3 (similar to the Ereda granites), the third phase — 2.63 g/cm^3, and the fourth phase — 2.59 g/cm^3; the density of aplites is 2.60 g/cm^3.

The Neeme pluton with the diameter of about 25 km and with its northern part under the Gulf of Finland, is composed of coarse- and medium-grained, pinkish-gray porphyraceous granites. In places, e. g. drill cores 507, 513, 521, 524, the rocks are very leucocratic with a pegmatitic structure (location of drill holes see Klein et al., in prep.). By the chemical and mineralogical composition, the rocks form two groups,

Table 1

Chemical composition of the Estonian porphyraceous potassium granites

Sample number	Drill core	Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	S	H_2O^-	l.o.i.	Sum
								MARJAMAA PLUTON									
1	12	123295	62.86	1.08	14.77	2.64	5.59	0.18	1.31	2.33	1.30	6.70	0.43	0.12	0.52	2.07	101.38
2	302	3023320	63.52	1.08	13.67	3.02	3.66	0.04	1.83	3.78	2.93	4.58	0.46	0.09	0.12	0.78	99.44
3	302	3023700	65.48	0.73	14.26	2.01	2.99		1.35	2.98	3.30	5.65	0.32	0.07	0.12	0.51	99.65
4	302	3024051	66.12	0.78	13.83	2.07	0.87		1.40	3.05	2.85	5.60	0.34	0.09	0.13	0.67	97.67
5	302	3024384	65.86	0.76	13.81	2.04	3.48		1.42	3.04	3.00	5.50	0.32	0.08	0.14	0.49	99.80
6	302	3024784	66.06	0.93	13.51	2.21	3.18	0.02	1.60	2.93	2.88	5.05	0.39	0.08	0.13	0.64	99.48
7	302	3024805	66.21	0.90	14.29	2.24	3.56	0.14	1.24	2.88	2.77	4.80	0.33			0.54	99.90
8	302	3024850	66.58	0.80	13.83	2.31	2.87	0.14	1.40	2.95	3.01	5.12	0.30			0.54	99.85
9	302	3024874	65.44	0.88	13.06	2.98	2.79	0.11	1.65	3.24	2.75	4.88	0.43	0.20	0.24	0.73	99.14
10	303	3032833	69.36	0.53	13.30	0.96	3.16	0.06	0.67	2.07	2.44	6.28	0.14		0.14	0.52	99.49
11	303	3033190	67.62	0.66	13.82	1.11	3.92	0.08	0.84	2.65	2.50	5.28	0.19		0.12	0.78	99.45
12	303	3033338	69.54	0.17	15.74	0.29	1.08	0.03	0.38	1.62	2.66	7.42	0.03		0.24	0.44	99.40
13	304	3042790	70.10	0.26	13.18	0.69	2.66	0.06	0.50	1.62	2.66	7.42	0.04		0.12	0.56	99.75
14	304	3043035	70.96	0.19	13.61	0.72	2.26	0.07	0.54	1.67	2.58	6.56	0.05		0.19	0.22	99.43
15	304	3043288	68.04	0.25	14.27	0.95	2.80	0.08	0.50	2.08	2.79	7.70	0.06		0.10	0.36	99.88
16	305	3052780	69.80	0.37	13.28	0.84	3.12	0.09	0.67	2.19	2.58	6.28	0.12		0.15	0.35	99.69
17	305	3052972	61.66	1.25	12.06	3.16	8.48	0.19	1.43	4.62	2.37	3.00	0.31		0.20	0.98	99.51
18	306	3063064	67.54	1.11	13.59	1.93	2.66	0.10	1.38	3.12	2.58	4.81	0.32		0.15	0.55	99.69
19	306	3063430	67.56	0.65	13.61	1.89	2.62	0.09	1.26	3.12	2.89	5.18	0.30		0.13	0.43	99.60
20	314	3142442	72.66	0.34	11.48	0.92	2.16	0.05	0.50	1.50	2.38	6.48	0.03	0.10	0.26	0.64	99.24
21	314	3142558	73.72	0.17	13.10	0.81	1.29	0.03	0.42	1.01	2.53	6.00	0.03	0.10	0.23	0.38	99.59
22	314	3142676	72.04	0.34	12.09	1.10	2.37	0.06	0.46	1.50	2.38	6.48	0.02	0.10	0.28	0.60	99.54
23	314	3142906	73.34	0.22	12.94	0.73	1.29	0.03	0.46	1.01	2.56	6.32	0.03	0.10	0.38	0.46	99.49
24	315	3152675	67.94	0.88	13.30	2.03	2.73	0.10	1.34	3.17	2.60	4.42	0.27	0.12	0.18	0.66	99.56
25	315	3152813	66.58	0.90	14.00	2.25	3.05	0.12	1.55	3.29	2.30	4.32	0.34	0.11	0.28	0.79	99.60
26	315	3153087	64.96	0.94	13.97	2.12	3.02	0.13	1.51	3.46	3.00	5.33	0.32	0.12	0.24	0.68	99.56
27	319	3192560	66.12	0.60	14.38	1.05	3.09	0.07	1.26	2.31	2.76	6.38	0.13		0.12	0.69	98.84
28	319	3193090	70.68	0.43	12.66	0.75	2.16	0.07	0.63	2.13	2.57	7.04	0.05		0.19	0.46	99.63
29	322	3222408	69.74	0.63	12.12	2.45	1.90	0.13	0.80	2.62	2.98	4.90	0.08		0.06	0.68	99.03
30	322	3222707	70.92	0.37	14.04	1.12	1.36	0.07	0.80	2.01	3.26	6.26	0.04		0.07	0.46	100.71
31	323	3232892	72.54	0.14	12.97	1.78	0.61	0.03	0.45	1.71	3.64	4.60	0.02		0.12	0.69	99.18

Sample number	Drill core	Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	S	H_2O-	l.o.i.	Sum
32	323	3233042	72.46	0.25	13.27	0.79	1.19	0.04	0.53	1.71	2.80	6.00	0.03		0.18	0.54	99.61
33	323	3233330	71.72	0.33	13.27	0.89	1.33	0.07	0.62	1.89	3.20	6.00	0.03		0.07	0.53	99.88
34	324	3242760	66.40	0.73	13.17	1.46	4.56	0.13	1.11	3.23	2.60	4.60	0.37	0.10	0.02	0.53	98.99
35	324	3243312	68.36	0.56	12.76	1.67	3.99	0.11	0.89	3.11	2.51	4.76	0.30		0.14	0.36	99.38
36	324	3243510	78.18	0.16	9.82	0.79	1.11	0.02	0.89	1.10	1.45	6.00	0.07		0.19	0.69	100.28
37	238	3282580	70.84	0.40	13.38	1.15	1.65	0.06	0.62	2.07	3.50	6.26	0.05		0.06	0.34	100.32
38	328	3282810	70.00	0.44	13.36	1.36	1.54	0.07	0.58	2.32	3.40	6.26	0.05		0.05	0.46	99.84
39	328	3283100	70.62	0.42	12.62	1.53	1.62	0.10	1.07	2.26	2.93	5.78	0.04	0.00	0.11	0.43	99.42
40	5	52497	64.46	0.92	14.90	3.19	3.70	0.24	1.23	3.40	2.60	5.60	0.44	0.17	0.33	1.24	102.09
41	9	93270	64.16	0.89	14.00	3.81	3.10	0.28	1.78	3.40	2.50	5.15	0.48	0.18	0.33	1.29	101.02
NAISSAARE PLUTON																	
42	115	1151955	72.41	0.22	13.42	0.43	2.10	0.04	0.28	1.32	3.02	5.93	0.15	0.10		0.93	100.35
43	120	1201382	69.42	0.32	14.10	1.65	1.94		0.54	1.34	2.45	7.20	0.07	0.02	0.19	0.79	99.84
44	296	2962280	71.88	0.32	12.87	1.40	1.65	0.05	0.75	1.84	2.11	5.66	0.07		0.16	0.91	99.51
45	296	2962725	71.92	0.26	12.87	0.92	1.72	0.03	0.48	1.69	2.35	6.32	0.08		0.16	0.90	99.54
46	296	2962815	71.82	0.32	12.14	0.99	1.80	0.03	0.56	2.81	2.10	5.74	0.25		0.16	1.20	99.76
47	327	3272342	66.26	0.35	15.09	2.23	2.73	0.03	0.76	1.83	2.00	7.34	0.08		0.21	0.82	99.52
48	327	3272518	68.40	0.29	14.26	1.78	2.19	0.03	0.94	1.83	2.20	6.66	0.06		0.18	0.83	99.47
NEEME PLUTON																	
49	106	1061400	70.24	0.46	12.45	1.36	2.27	0.06	0.79	2.32	2.20	5.50			0.14	1.31	98.96
50	106	1061535	68.92	0.64	13.38	1.31	2.75	0.08	1.12	2.52	2.85	5.10			0.34	1.02	99.69
51	106	1061630	70.40	0.43	13.28	1.51	2.73	0.05	0.91	2.68	1.95	4.20	0.16	0.14	0.32	0.49	98.93
52	106	1061985	68.78	0.30	14.37	1.37	2.01	0.03	0.84	2.46	2.35	5.65	0.12	0.13	0.28	0.72	99.13
53	115	1151332	71.04	0.39	13.26	1.31	1.92	0.04	0.37	2.77	2.90	5.20	0.14	0.14	0.21	0.97	100.45
54	115	1151335	68.98	0.41	13.78	1.51	2.15	0.04	0.04	3.25	2.45	6.75	0.13	0.18	0.21	0.96	100.63
55	115	1151420	74.04	0.39	13.26	1.31	1.92	0.04	0.57	2.77	2.90	5.20	0.14	0.14	0.21	1.18	103.86
56	115	1151509	71.30	0.38	12.64	1.39	1.89	0.03	0.60	2.53	2.80	5.90	0.13	0.05	0.16	0.83	100.47
57	115	1151754	71.98	0.37	12.88	1.35	1.91	0.04	0.61	2.50	2.80	5.20	0.13	0.10	0.17	0.87	100.74
58	115	1151920	70.54	0.23	13.09	1.03	1.88	0.02	0.70	2.14	4.40	5.30	0.10	0.17	0.34	0.16	99.76
59	115	1151993	70.74	0.35	13.26	1.07	2.12	0.04	0.71	2.66	2.75	5.60	0.12	0.14	0.14	0.76	100.22
60	119	1191755	72.60	0.28	13.43	1.40	0.72	0.06	1.13	1.92	2.85	5.40	0.00	0.19	0.20	0.45	100.43
61	119	1191855	70.90	0.10	13.95	0.84	1.57	0.02	0.40	1.90	5.00	4.50	0.06	0.11	0.30	0.14	99.49
62	501	5011165	72.28	0.22	13.08	1.42	0.90	0.03	0.50	1.70	1.18	7.64	0.05		0.17	0.96	99.96

Sample number	Drill core	Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	S	H_2O^-	l.o.i.	Sum
63	501	5011950	72.07	0.32	12.81	1.51	1.65	0.05	0.54	1.47	2.00	6.00	0.09		0.18	1.08	99.59
64	501	5012065	74.70	0.24	12.27	1.25	1.29	0.05	0.41	1.29	2.18	4.73	0.08		0.11	0.80	99.29
65	502	5022027	72.98	0.24	13.50	1.16	1.29	0.05	0.41	1.99	2.45	4.27	0.04		0.09	1.25	99.63
66	503	5032560	72.88	0.28	13.23	1.16	1.51	0.06	0.62	2.11	2.45	4.36	0.08		0.10	0.57	99.31
67	503	5033655	72.46	0.22	13.77	1.08	1.36	0.05	0.75	1.99	2.30	5.00	0.08		0.09	0.51	99.57
68	504	5041600	73.10	0.24	13.35	1.48	1.15	0.05	0.66	1.06	1.36	6.36	0.05		0.18	0.85	99.71
69	504	5041800	72.22	0.24	14.16	1.40	1.22	0.05	0.66	1.88	2.44	5.20	0.07		0.12	0.74	100.28
70	505	5052015	75.64	0.20	12.40	1.22	1.54	0.05	0.46	1.88	2.00	4.40	0.04		0.10	0.53	100.36
71	507	5072330	75.86	0.22	12.01	1.16	1.51	0.05	0.46	2.11	2.22	4.64	0.02		0.08	0.54	100.80
72	508	5082220	76.04	0.05	12.09	1.03	0.43	0.03		1.60	3.19	5.18	0.03	0.10	0.08	0.20	99.97
73	513	5131638	73.40	0.19	12.84	0.93	1.33	0.04	0.31	1.38	2.90	6.40	0.05	0.10	0.12	0.51	100.38
74	513	5131786	72.96	0.23	12.74	0.65	1.72	0.06	0.62	1.49	2.35	5.90	0.10	0.10	0.15	0.65	99.57
75	515	5152120	73.34	0.30	12.61	0.61	2.16	0.06	0.54	2.13	2.60	4.10	0.10	0.10	0.13	0.38	99.03
76	523	5232252	75.70	0.17	11.70	0.28	1.51	0.04	0.39	1.70	2.95	5.15	0.04	0.10	0.14	0.54	100.27
77	526	5261865	72.70	0.31	12.87	0.46	2.16	0.06	0.70	1.92	3.00	5.25	0.11	0.10	0.13	0.62	100.26
78	527	5271973	71.60	0.36	13.39	0.50	2.33	0.06	0.81	1.86	2.80	5.45	0.14	0.13	0.17	0.68	100.11
79	529	5291990	67.14	0.11	16.51	0.48	0.79	0.03	0.46	1.17	2.85	9.52	0.04	0.10	0.18	0.73	99.93
80	530	5301787	67.32	0.79	13.54	1.12	3.74	0.11	1.32	2.88	2.85	5.40	0.31	0.17	0.15	0.81	100.36
81	530	5301830	66.24	0.90	13.20	1.77	5.32	0.12	1.43	2.88	2.90	4.38	0.38	0.14	0.14	0.70	100.36
82	530	5302347	71.48	0.39	13.39	0.61	2.44	0.06	0.74	2.18	2.60	5.10	0.14	0.16	0.15	0.65	99.94
83	530	5302389	71.28	0.41	12.87	0.92	2.16	0.06	0.85	2.02	2.80	5.70	0.14	0.10	0.21	1.08	100.39
84	531	5311770	65.34	0.58	16.01	1.13	3.59	0.10	1.04	3.51	4.20	2.90	0.25	0.10	0.19	0.93	99.68
85	535	5351795	73.44	0.12	12.74	0.70	0.86	0.03	0.31	1.81	3.43	5.16	0.02	0.13	0.06	0.73	99.48
86	535	5352302	75.18	0.12	12.22	0.85	0.86	0.03	0.31	1.28	3.00	5.04	0.05	0.14	0.08	0.62	99.70
87	537	5371672	72.28	0.33	12.61	0.69	2.16	0.06	0.70	1.70	2.65	6.00	0.10	0.11	0.18	0.97	100.36
88	537	5372160	72.84	0.28	12.41	2.89	0.93	0.03	0.42	0.80	7.75	1.00	0.12	0.10	0.20	0.66	100.23
89	538	5381705	69.24	0.60	13.01	1.18	2.87	0.09	1.08	2.29	2.60	5.00	0.21	0.60	0.12	0.64	99.41
90	539	5391739	75.44	0.21	11.18	0.75	1.22	0.03	0.39	1.49	2.20	5.68	0.06	0.12	0.09	0.70	99.47
91	540	5402300	74.70	0.15	12.22	0.66	1.44	0.03	0.39	1.38	2.50	5.36	0.07	0.13	0.09	0.70	99.73
EREDA PLUTON																	
92	319	3193425	73.92	0.25	11.92	0.24	2.44		0.63	1.32	2.18	5.70	0.08	0.02	0.15	0.87	99.57
93	319	3192768	70.78	0.40	12.12	0.19	4.60			0.84	1.68	2.22	6.00	0.12	0.01	0.92	99.87

Sample number	Drill core	Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	S	H_2O^-	l.o.i.	Sum
								TAEBLA PLUTON									
94	348	3483550	71.76	0.10	13.49	0.83	1.62	0.07	0.12	1.64	2.77	6.24	0.03	0.10	0.14	0.97	99.74
95	349	3492942	69.94	0.45	12.68	1.99	1.98	0.05	0.51	2.39	2.20	6.00	0.07	0.15	0.13	1.10	99.51
96	349	3493013	71.44	0.33	12.18	1.84	1.72	0.05	0.57	2.32	2.44	5.54	0.05	0.12	0.12	0.84	99.44
97	349	3493516	71.06	0.38	12.70	2.05	1.66	0.08	0.55	2.51	2.47	6.00	0.08	0.13	0.15	0.65	100.32
98	349	3493610	71.06	0.16	12.93	1.13	1.44	0.04	0.40	2.51	2.47	6.40	0.06	0.13	0.19	0.79	99.52

Table 2

Mineralogical composition of the porphyraceous potassium granites of Estonia. Range limits, vol. %, of the principal minerals

Mineral	Plutons			
	Märjamaa	Neeme	Naissaare	Ereda
Quartz	15—40	15—30	20—40	20—45
Microcline	15—50	35—45	30—50	35—45
Plagioclase	15—50	10—30	10—35	15—33
Biotite	1—15	2—10	3—10	5—10
Hornblende	>10	>5	>5	
Muscovite			>5	

possibly two phases. Two small bodies in the central and northeastern parts of the pluton studied with drill cores 503, 527, 530, 531, 532, 533, 538 and 512, 106, 115, respectively, are more melanocratic, being chemically similar to granodiorite. Also, in some drill cores (106, 512, 537, 538), partly assimilated xenoliths of surrounding gneisses with the diameter of about 20—30 cm have been observed. In thin sections, the granites display granitic texture, in places trachytoidic. The structure of these rocks is massive. The inclusions of quartz are rare. Quartz is euhedral (diameter of crystals up to 5 mm) and anhedral (diameter smaller). Plagioclase occurs generally as euhedral crystals, of oligoclase-andesine composition. Sericitization and pelitization are common. The plagioclase is twinned according to the albite and Carlsbad laws. The additional and accessory minerals are muscovite, apatite, fluorite, sphene, orthite, zircon, and opaques.

The first phase of the Neeme granites has a density of 2.64 g/cm³, the second phase — 2.62 g/cm³.

The Naissaare pluton, ca 35×25 km, with its northern part under the Gulf of Finland, is composed of porphyraceous granites cut by aplites. By its chemical and mineralogical composition this pluton can be divided into two phases. The central part of the pluton is composed of leucocratic granites (second phase), having some similarities with the second and third phases of the Märjamaa pluton. Muscovite and fluorite are common additional minerals for this granite type. In places trachytoidic texture has been observed. The more melanocratic granites (first phase) form the periphery of the pluton.

Two generations of quartz have been observed: euhedral crystals within potash feldspar phenocryst and anhedral crystals in the groundmass. Microcline is present as tabular crystals, sometimes containing the inclusions of plagioclase; the twinning is usually according to the Carlsbad law. Plagioclase appears as euhedral to subhedral zoned crystals, partly altered to sericite. Biotite forms small flakes containing euhedral crystals of zircon and apatite as inclusions. The mineral is partly altered into chlorite. Muscovite and fluorite of postmagmatic origin replace plagioclase.

The additional and accessory minerals are epidote, fluorite, apatite, sphene, zircon, and opaques represented by magnetite and ilmenite.

The average density of the Naissaare granites is the same for the first and second phases — 2.64 g/cm³.

The Ereda pluton, ca 5×15 km, oval in form, is composed of homogeneous, pinkish-grey, coarse-grained porphyraceous granites. With only two drill cores available, it is difficult to correlate the rocks of the Ereda pluton and the others. Some similarities have been observed in the mineralogical composition and structure of the Ereda granites and the Märjamaa and Neeme leucocratic type of granites.

Quartz is present as euhedral bipyramidal crystals (first generation) and as anhedral crystals (second generation). In places, the zonation of bipyramidal quartz caused by zonal division of fine-grained needle-like crystals of rutile can be observed (Кууспалу, 1971). Microcline is twinned according to the Carlsbad law; great phenocrysts are zoned. In places, the inclusions of bipyramidal quartz have been traced. Plagioclase is observed as euhedral, tabular, and prismatic crystals of various size. The twinning is according to the albite or Carlsbad law. Fresh plagioclase is represented by andesine (An: 30—42%). Biotite has partly altered into chlorite.

The additional and accessory minerals are fluorite, apatite, zircon, orthite, rutile, and opaques.

Table 3

Mineralogical composition of aplites of the porphyraceous potassium granites of Estonia. Range limits, vol%, of the principal minerals are provided

Pluton	Q	Mi	Pl	Bt	Others
Märjamaa	25—35	20—40	25—50	1—10	Hbl, Ms, Ap, Fl, Sph, Zr, opaque
Naissaare	20—30	30—40	30—40	5—15	Ap, Sph, Zr, opaque
Neeme	30—35	35—40	25—30	3—10	Ms$<$1, Ap, Fl, Zr, Sph, Orth, opaque

Ap — apatite, Fl — fluorite, Sph — sphene, Ms — muscovite, Orth — orthite, Zr — zircon, Hbl — hornblende

The Taebla pluton, which is the smallest with the diameter of about 6—7 km, is composed of homogeneous leucocratic porphyraceous granites. The petrographic description of the Taebla granites is based on the material of two drill cores. By their mineralogical and partly by their chemical composition, Taebla granites are similar to the rocks of the third phase of the Märjamaa pluton and to the second phase of the Neeme and Naissaare plutons.

The aplites related to porphyraceous granites are pink or reddish-pink, fine-grained, homogeneous rocks. They have predominantly a massive texture. Sometimes the homogeneous groundmass contains phenocryst of feldspar. The aplites cutting porphyraceous granites form veins with various width and shape. The mineral composition of aplites is given in Table 3.

A different type of aplites — aplite-like unakitic microsyenite — is observed in drill core 120, the Naissaare pluton. By their chemical composition, they are close to syenite. The mineralogical composition is: albite — 40—50 vol%, potash feldspar — 30—40 vol%, epidote — 10—15 vol%, quartz — 2—3 vol%, and chlorite — 2—3 vol%. The additional minerals are apatite, sphene, zircon, and opaque minerals.

General Petrochemistry

Estonian porphyraceous potassium granites differ from other granitic rocks in several compositional features, such as peraluminous chemistry, high SiO_2, TiO_2, K_2O, and total iron content, high K/Na ratio, and relatively low CaO and MgO contents. On the AFM diagram, the plot corresponding to the samples of Estonian porphyraceous granites occupies the field along the transition boundary from tholeiitic rock to subalkaline and calcalkaline types (Кирс et al., 1990). Also, the silica content of the Estonian porphyraceous granites is close to the Si-range of rocks of the rapakivi formation (Великославинский et al., 1978), but they have a slightly higher content of Ti and somewhat lower content of Al and Fe.

Petrographically distinguishable subdivisions of the two best studied plutons, displaying differences in the silica content, are here interpreted as different intrusive phases. Thus, Märjamaa samples form two equally represented SiO_2-groups: one with the SiO_2 content below 68%, the other with that ranging from 70% to 73%. Similarly, the samples of Neeme granites form three SiO_2-groups with SiO_2 content below 67%, 69—73%, and above 75%, respectively.

Table 4

The average of the Niggli mean values of Estonian porphyraceous potassium granites and the Niggli average rapakivi magma (Vorma, 1976)

Pluton	*al*	*fm*	*c*	*alk*	*si*	
Taebla	38.7	16.7	12.5	32.1	364	
Neeme	40.2	17.0	11.1	31.7	376	
Naissaare	39.7	18.9	10.2	31.2	350	
Märjamaa	36.6	22.1	12.0	29.4	322	
Ereda	41.7	20.5	8.5	29.3	415	
Average of plutons	39.4	19.0	10.9	30.7	366	
Rapakivi magma type						
	40	18	9	33	380	After Niggli, 1923
	41	18	9	32	350	After Niggli, 1936 (cited in Vorma, 1976)

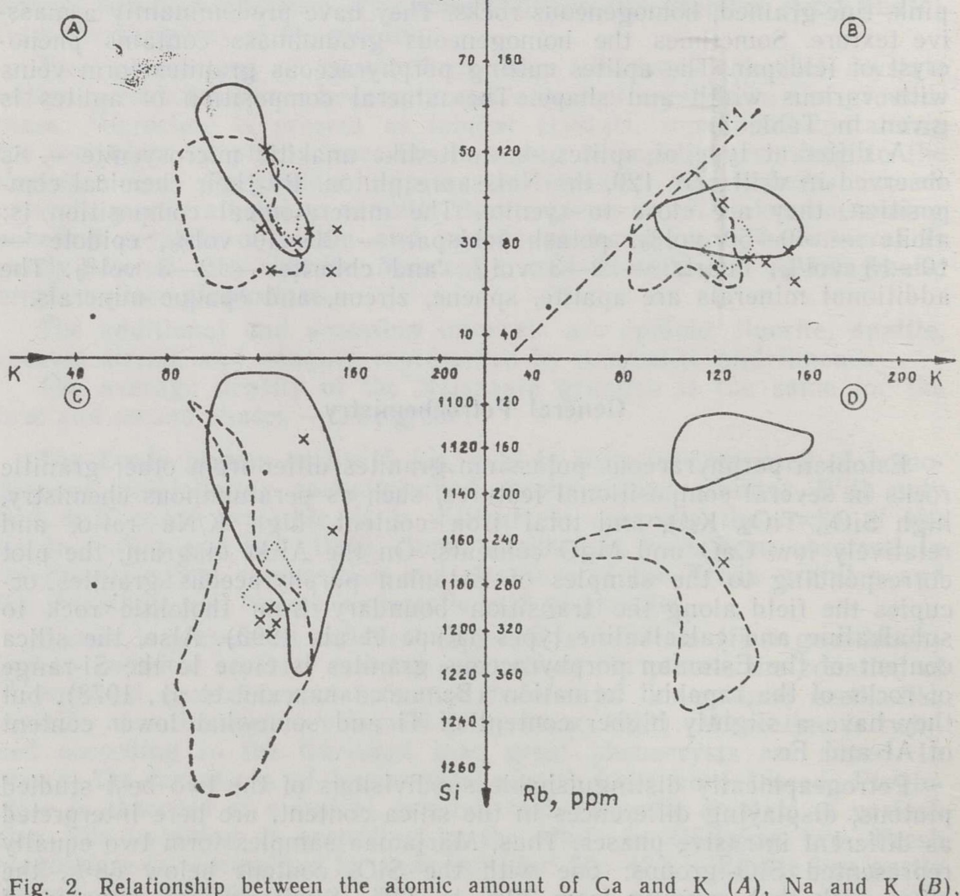

Fig. 2. Relationship between the atomic amount of Ca and K (*A*), Na and K (*B*), K and Si (*C*), and K and Rb (*D*) of the porphyraceous granites of Estonia. Solid line surrounds Märjamaa, broken line Neeme, and dotted line Taebla granites; dots and inclined crosses correspond to the Ereda and Naissaare granites, respectively.

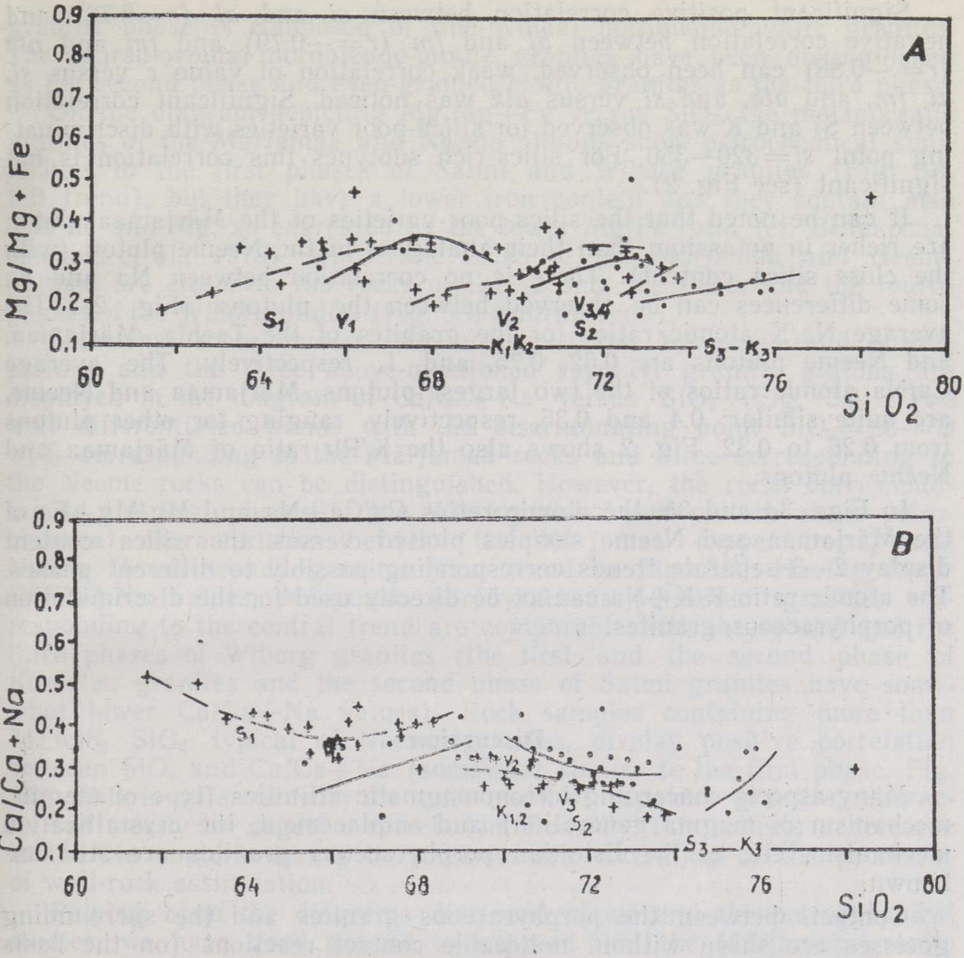

Fig. 3. Plots of the atomic ratios Mg/Mg+Fe versus wt% SiO_2 (*A*) and Ca/Ca+Na versus SiO_2 (*B*) of the porphyraceous granites of Märjamaa (crosses) and Neeme (dots) plutons. Broken and solid lines display the main trends of Märjamaa and Neeme granites, respectively. S_1—S_3, V_1—V_4, and K_1—K_3 correspond to the averages of the different phases of the Salmi, Wiborg, and Korosten rapakivi granite plutons, respectively.

The mean Na_2O/K_2O ratio is different: Naissaare granites have the lowest ratio — 0.37, while the highest Na_2O/K_2O ratio, 0.7, characterizes the granites of the Neeme pluton. Na_2O content varies from 2.5% to 3%, being close to the rapakivi granites.

For all the five plutons studied, the correlation between Si and Ti is weakly negative both for the silica-poor varieties (SiO_2<69—70%) and the silica-rich granites. With a strong negative correlation between Si and Ti, two separate trends have been observed in the Si range 71.0—72.5%. Silica-poor (up to 70%) Neeme granites have ca 0.6% TiO_2, whereas the Märjamaa granites contain 0.7—0.9% TiO_2; the mean TiO_2 content of the silica-rich subtypes of both plutons is 0.2—0.3%.

The Estonian porphyraceous granites are characterized by relatively low Niggli *mg* indices varying from 0.1 to 0.35, and negative value *t* ($t = al - (c + alk)$) ranging from —1 to —8. The Niggli main values suggest that the composition of the Estonian granites is close to typical rapakivi granites (Table 4), but value *alk* of the Estonian granites is systematically lower.

Significant positive correlation between *si* and *al* ($r=0.76$) and negative correlation between *al* and *fm* ($r=-0.79$) and *fm* and *alk* ($r=-0.88$) can been observed, weak correlation of value *c* versus *si*, *al*, *fm*, and *alk*, and *si* versus *alk* was noticed. Significant correlation between Si and K was observed for silica-poor varieties with discriminating point $si=320—350$. For silica-rich subtypes this correlation is not significant (see Fig. 2).

It can be noted that the silica-poor varieties of the Märjamaa pluton are richer in potassium than their analogues of the Neeme pluton (with the close silica content). There is no correlation between Na and K; some differences can be observed between the plutons (Fig. 2). The average Na/K atomic ratios for the granites of the Taebla, Märjamaa, and Neeme plutons are 0.62, 0.75, and 1, respectively. The average Ca/Na atomic ratios of the two largest plutons, Märjamaa and Neeme, are quite similar: 0.4 and 0.35, respectively, ranging for other plutons from 0.26 to 0.32. Fig. 2 shows also the K/Rb ratio of Märjamaa and Neeme plutons.

In Figs. 3*a* and 3*b*, the atomic ratios Ca/Ca+Na and Mg/Mg+Fe of the Märjamaa and Neeme samples plotted versus the silica content display 2—3 separate trends corresponding possibly to different phases. The atomic ratio K/K+Na cannot be directly used for the discrimination of porphyraceous granites.

Discussion

Many aspects concerning tectonomagmatic affinities (type of magma, mechanism of magma generation) and emplacement, the crystallization mechanism, etc. of the Estonian porphyraceous granites are still unknown.

Contacts between the porphyraceous granites and the surrounding gneisses are sharp without noticeable contact reactions (on the basis of two contact drill cores). However, in drill core 348 (Taebla pluton), a fresh K-feldspar generation in the surrounding gneisses can be traced.

On the basis of several petrogenetic components and their ratios (Mg, Ca, Fe, Ti, Mg/Mg+Fe, Ca/Ca+Na), the differences between the two best studied plutons, Neeme and Märjamaa, can be observed (see Figs. 3*A* and 3*B*). The present data suggest that Neeme granites are richer in silica and their Mg/Ma+Fe ratio is mostly lower than that of Märjamaa granites.

The Estonian porphyraceous granites show similarities to typical rapakivi granites of the Salmi, Wiborg, and Korosten plutons. The acid rocks of the Salmi pluton, Karelia, form four intrusive phases (see also Figs. 3*A* and 3*B*; Великославинский et al., 1978). The first and the second phase are represented by olivine-pyroxene-hornblende adamellites and ovoidal hornblende-biotite granites, respectively. Even-grained biotite granites as the third phase and porphyraceous biotite as the fourth phase are known. The Wiborg pluton consists of four main intrusive phases (Великославинский et al., 1978; Vorma, 1976). The rocks of the first intrusive phase are represented by pyroxene-hornblende granites (Lappee-granite) corresponding to adamellites. Ovoidal granites containing biotite and hornblende are interpreted as the second phase and trachytoidic varieties as the third phase. The fourth phase is represented by porphyraceous granites with fine-grained groundmass. Granitic rocks of the Korosten rapakivi granite pluton in the Ukrainian Shield form three intrusive phases (Великославинский et al., 1978). The earliest granitic phase is composed of fine-ovoidal hornblende-biotite granites. The coarse-ovoidal hornblende-biotite granites have been distinguished as the second phase and even-grained biotite granites as the third phase.

On the diagram depicting $Mg/Mg+Fe$ versus SiO_2, the melanocratic granites of the Märjamaa and Neeme plutons show petrochemical similarities to the first phases of Salmi and Wiborg granites (Fig. 3*A*, left trend), but they have a lower iron content and they contain also less Fe and Mg, as expressed by the lower Mg/Fe ratio (cf. Великославинский et al., 1978), leucocratic rocks of the Märjamaa and Neeme plutons are closer to the rocks of the second, the third, and the fourth phases of the Wiborg pluton (Fig. 3*A*, central trend).

Somewhat more obvious similarities of the Märjamaa and Neeme plutons and the three above-mentioned rapakivi granitic plutons are displayed in the diagram of $Ca/Ca+Na$ versus SiO_2 (Fig. 3*B*). Two well differentiated trends with the discriminating point $SiO_2=68$—69 wt% corresponding to the Märjamaa rocks and three corresponding to the Neeme rocks can be distinguished. However, the rocks corresponding to the first phases of the Wiborg and Salmi plutons show petrochemical characteristics between the Märjamaa (upper trend) and Neeme (lower trend) granites (first trend in Fig. 3*B*). Having lower $Ca/Ca+Na$ values, Märjamaa porphyraceous potassium granites corresponding to the central trend are comparable with the second and the third phases of Wiborg granites (the first and the second phase of Korosten granites and the second phase of Salmi granites have somewhat lower $Ca/Ca+Na$ values). Rock samples containing more than 74 wt% SiO_2, typical of Neeme granites, display positive correlation between SiO_2 and $Ca/Ca+Na$ (somewhat similar to the first phase, Fig. 3*B*). This is different from the main trend of rapakivi granites, characterized mostly by negative correlation. Possibly, this reflects a decrease in the Na content during the metasomatic alteration or the processes of wall-rock assimilation.

Relying upon the diagrams discussed above and the petrographical studies, we have good ground to suppose that the Märjamaa granite pluton consists of at least two phases, possibly originating from two different primary magmas or one which has evolved in different ways. Analogous acidic-basic differentiation of Neeme granites is not as clearly expressed. In comparison with their Märjamaa analogues, the Neeme granites exhibit smaller chemical fluctuation of petrogenic components and display three variation trends of the interrelations of Ca, Fe, Mg, and Na, possibly corresponding to their three phases.

Conclusions

The porphyraceous potassium granites of the Estonian small plutons differ from typical rapakivi granites in their smaller size that reaches only a few dozens of kilometres and the lack of the bodies of gabbroic and anorthositic rocks inside the plutons. Mineralogically, these granites are biotite granites with porphyraceous texture, whereas the melanocratic varieties contain hornblende. The typical rapakivi texture (plagioclase-mantled K-feldspar) is very rare. Bipyramidal quartz in groundmass is grey or blueish-grey, not black as is common for the rapakivi granites. The close chemical composition, expressed especially by Niggli main values, geological settings, and similar crystallization age of the Estonian porphyraceous granites and those of the rapakivi formation allow us to consider them as belonging to this formation.

Within the plutons, two to three petrographically and chemically distinguishable phases have been characterized. Similar behaviour of some petrogenic components, such as Mg, Fe, and especially Ca and Na of the Estonian porphyraceous granites and the rapakivi granites of Wiborg, Salmi, and Korosteni, CIS, rapakivi granite plutons can be observed.

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EESTI EELKAMBRIUMI PORFÜÜRILAADSETE KAALIUMGRANIITIDE PETROGRAAFIAST JA PETROKEEMIAST

Eesti aluskorras on teada viis intrusiivse iseloomuga varaplatvormset porfüürilaadset kaaliumgraniidi (PKG) massiivi: Märjamaa, Neeme, Naissaare, Ereda ja Taebla. Peamised kivimit moodustavad mineraalid on mikrokliin, kvarts, plagioklass ja biotiit, melanokraatsetel erimitel ka küünekivi. Lisandmineraalidena on teada apatiit, fluoriit, tsirkoon, sfeen, muskoviit jt. Eesti PKG keemiline koostis on üsna lähedane tüüpilisele rapakivi graniidile, erinedes viimasest mõneti suurema titaani ja väiksema summaarse raua ja alumiiniumi sisalduse poolest. Ka mitmed geoloogilis-struktuursed iseärasused (kuju, varaplatvormsed tingimused jt.) lubavad nimetatud massiivide kivimeid võrrelda rapakivi graniitidega. Petrograafiliselt, samuti keemilise koostise põhjal on eristatavad 2—3 intrusiivset faasi. Mg/Mg+Fe—SiO_2 ja Ca/Ca+Na—SiO_2 diagrammidel moodustavad Märjamaa ja Neeme massiivide PKG-d kolm eraldi trendi, mis on võrreldavad mitmete rapakivi graniitide vastavate suurustega eraldi faaside kaupa.

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ПЕТРОГРАФИЧЕСКИЕ И ПЕТРОХИМИЧЕСКИЕ ЧЕРТЫ ДОКЕМБРИЙСКИХ ПОРФИРОВИДНЫХ КАЛИЕВЫХ ГРАНИТОВ ЭСТОНИИ

Описаны пять раннеплатформенных интрузивных массивов порфировидных калиевых гранитов фундамента Эстонии: Мярьямааский, Неэмеский, Таэблаский, Найссаареский и Эредаский. Основные минералы названных гранитов: микроклин, кварц, плагиоклаз, биотит, для меланократовых разновидностей характерна и роговая обманка. Второстепенные минералы представлены апатитом, флюоритом, цирконом, сфеном, мусковитом и др. По химическому составу порфировидные калиевые граниты Эстонии довольно близки к типичным гранитам рапакиви, хотя отличаются от них повышенным содержанием титана и пониженным содержанием железа и глинозема. Состав, а также некоторые геолого-структурные черты позволяют сравнивать описанные граниты с типичными гранитами рапакиви. Петрографически и петрохимически выделяются 2—3 фазы. На диаграммах Mg/Mg+Fe—SiO_2 и Ca/Ca+Na—SiO_2 образуются 2—3 отдельных тренда, которые, вероятно, отвечают разным фазам интрузии некоторых гранитов рапакиви.