

Supplementary Material for: Major-Element Geochemistry, Redox Systematics, and Petrogenesis of the Estonian Rapakivi Intrusions, Finnish Wiborg Batholith, and Onas intrusion: A Revised Analysis of Fennoscandian AMCG Magmatism

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Table 1. Data completeness, sample distribution, and non-positive-value diagnostics for the compositional analysis. All 186 samples contained complete and strictly positive values for the 10 selected major-element variables; consequently, no samples were excluded and no zero replacement was required. The potential replacement value corresponds to one-half of the minimum positive value for each oxide.

Oxide or group	Missing values	Non-positive values	Minimum positive value	Potential replacement value
<i>Major-element data diagnostics</i>				
<i>SiO₂</i>	0	0	64.439044	32.219522
<i>TiO₂</i>	0	0	0.006075	0.003038
<i>Al₂O₃</i>	0	0	10.965795	5.482897
<i>FeO</i> *	0	0	0.849495	0.424748
<i>MnO</i>	0	0	0.009012	0.004506
<i>MgO</i>	0	0	0.090217	0.045108
<i>CaO</i>	0	0	0.657030	0.328515
<i>Na₂O</i>	0	0	1.375683	0.687841
<i>K₂O</i>	0	0	2.939686	1.469843
<i>P₂O₅</i>	0	0	0.009052	0.004526
<i>Sample distribution by rapakivi body or phase</i>				
Wiborg			Number of samples	81
Taebila			Number of samples	5
Ereda			Number of samples	3
Neeme Phase Ia			Number of samples	10
Neeme Phase Ib			Number of samples	10
Neeme Phase II			Number of samples	17
Onas			Number of samples	3
Märjamaa Phase I			Number of samples	22
Märjamaa Phase II			Number of samples	15
Kloostri Phase III			Number of samples	10
Naissaare Phase I			Number of samples	5
Naissaare Phase II			Number of samples	2
Riga			Number of samples	3
Initial number of rows				186
Rows retained				186
Rows removed				0
Number of oxide variables				10
Number of replaced values				0

Table 2. Quality-control diagnostics and descriptive statistics for the centred log-ratio-transformed major-element dataset. Compositions were closed to 100% before CLR transformation. The near-zero maximum CLR row sum confirms the numerical consistency of the transformation.

Variable or diagnostic	Mean	SD	Minimum	25th percentile	Median	75th percentile	Maximum
<i>Compositional sums before closure</i>							
Oxide sum (wt.%)	99.8705	0.0734	99.4759	99.8516	99.8873	99.9169	99.9802
<i>Compositional sums after closure</i>							
Closed oxide sum (wt.%)	100.0000	0.0000	100.0000	100.0000	100.0000	100.0000	100.0000
<i>Descriptive statistics of CLR-transformed variables</i>							
<i>SiO₂</i>	3.8188	0.3291	3.0705	3.6553	3.7815	4.0250	4.8554
<i>TiO₂</i>	-1.3771	0.4057	-4.5606	-1.5526	-1.2922	-1.1293	-0.7900
<i>Al₂O₃</i>	2.1527	0.2711	1.5482	2.0068	2.1322	2.3155	3.2568
<i>FeO*</i>	0.7484	0.1746	0.1928	0.6379	0.7828	0.8512	1.3025
<i>MnO</i>	-3.4033	0.4462	-5.3730	-3.4410	-3.3264	-3.2101	-2.3638
<i>MgO</i>	-1.2624	0.5359	-2.3198	-1.7142	-1.1866	-0.8313	-0.1943
<i>CaO</i>	0.2039	0.2122	-0.7011	0.1049	0.1947	0.3082	0.7849
<i>Na₂O</i>	0.5857	0.3130	-0.1746	0.4049	0.5678	0.7566	1.8866
<i>K₂O</i>	1.2588	0.3625	0.2606	1.0876	1.2501	1.5189	2.0944
<i>P₂O₅</i>	-2.7255	0.5982	-4.3969	-3.1795	-2.5528	-2.3905	-1.5451
<i>Numerical validation</i>							
Maximum deviation from 100 after closure							4.263×10^{-14}
Maximum absolute CLR row sum							2.887×10^{-15}
CLR matrix dimensions							186×10
All CLR values finite							Yes

Table 3. Summary of the compositional principal-component analysis and major-element loadings for the five retained components. The PCA was performed on centred log-ratio-transformed major-element compositions from 186 samples and 10 oxide variables. PC1 and PC2 together explain 74.01% of the total compositional variance.

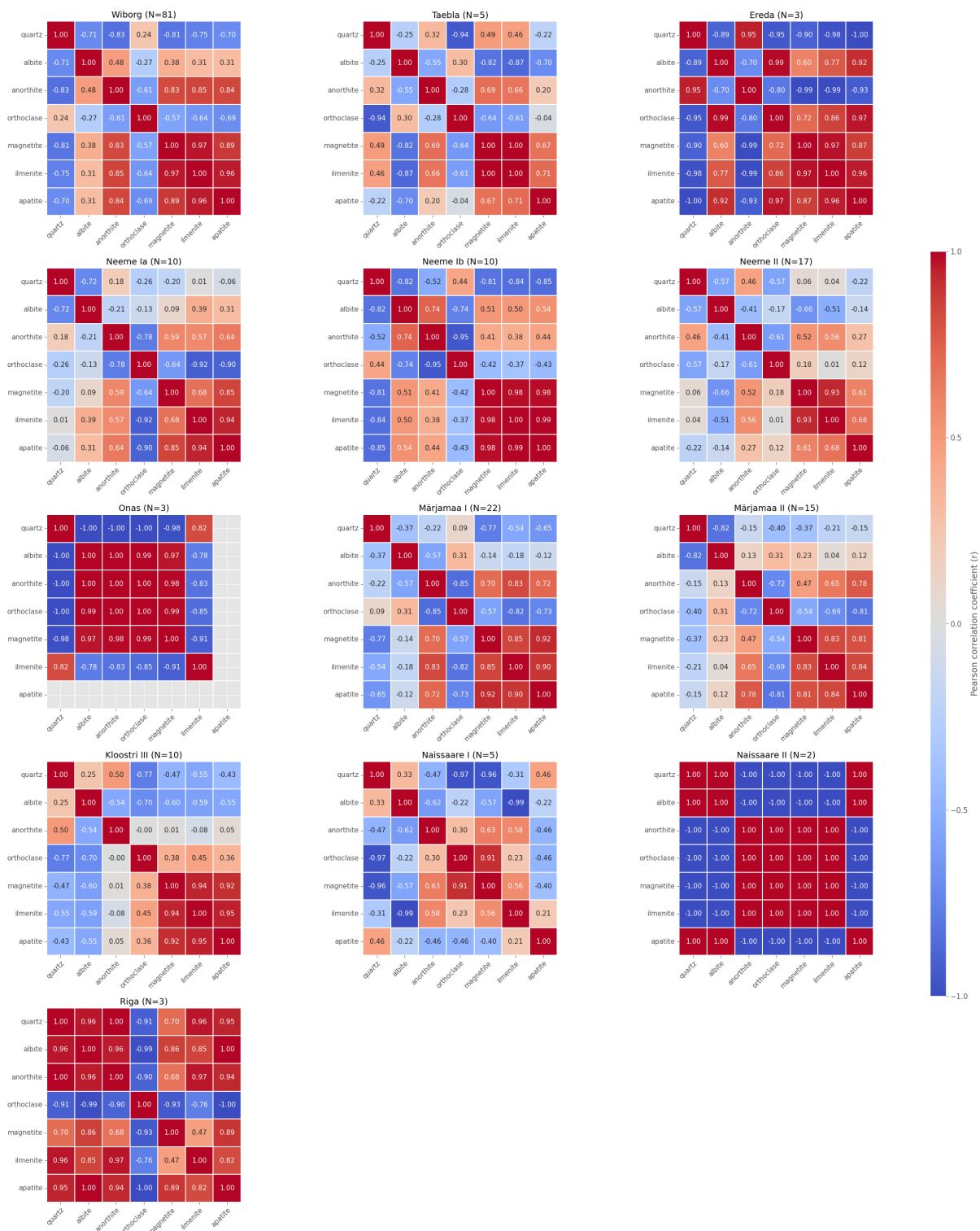
Variable or statistic	PC1	PC2	PC3	PC4	PC5
<i>Major-element loadings</i>					
<i>SiO₂</i>	-0.353	0.039	-0.114	-0.057	-0.143
<i>TiO₂</i>	0.314	-0.271	-0.168	0.758	0.134
<i>Al₂O₃</i>	-0.290	0.024	-0.115	-0.086	-0.055
<i>FeO</i> *	0.077	-0.104	-0.126	0.170	-0.097
<i>MnO</i>	0.032	-0.464	0.801	-0.126	-0.151
<i>MgO</i>	0.299	0.801	0.300	0.108	-0.205
<i>CaO</i>	0.015	0.144	0.093	-0.167	0.814
<i>Na₂O</i>	-0.316	-0.031	-0.131	-0.124	0.242
<i>K₂O</i>	-0.374	0.041	-0.159	0.078	-0.362
<i>P₂O₅</i>	0.597	-0.180	-0.383	-0.556	-0.178
<i>PCA statistics</i>					
Eigenvalue	0.8057	0.3009	0.2038	0.0946	0.0470
Explained variance (%)	53.88	20.12	13.63	6.33	3.14
Cumulative variance (%)	53.88	74.01	87.63	93.96	97.10
Score minimum	-2.856	-0.877	-1.639	-2.592	-0.981
Score maximum	1.822	1.630	1.161	0.866	0.700
Score mean	0.000	0.000	0.000	0.000	0.000
Score standard deviation	0.898	0.549	0.451	0.308	0.217

Table 4. Sample numbers and centroid coordinates of the analysed rapakivi bodies and magmatic phases in the PC1–PC2 compositional space. Centroids represent the mean scores of the samples assigned to each group.

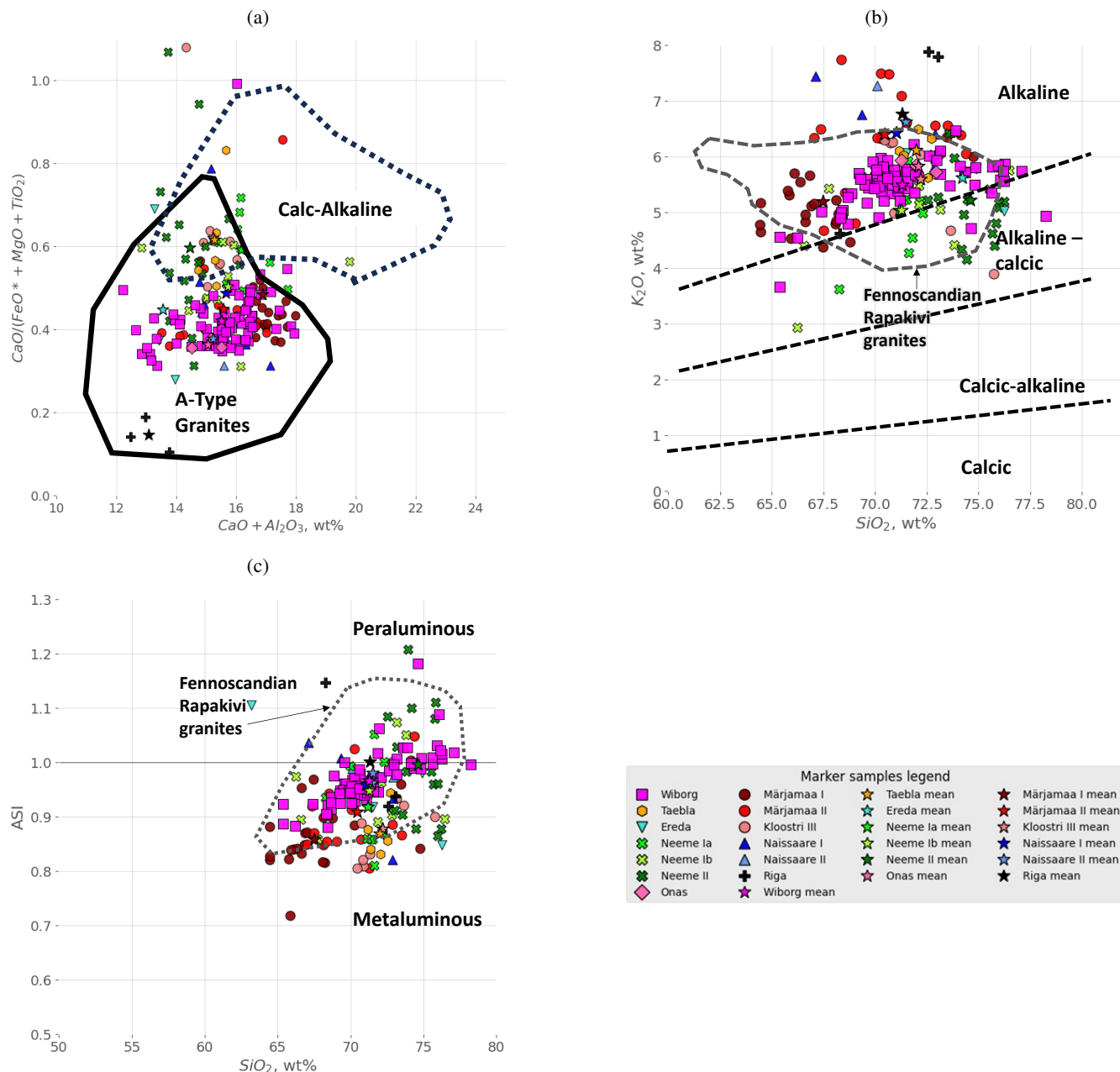
Rapakivi body or phase	<i>N</i>	PC1	PC2
Wiborg	81	-0.089	-0.479
Taebila	5	-0.511	0.105
Ereda	3	-0.186	0.908
Neeme Phase Ia	10	0.394	0.454
Neeme Phase Ib	10	0.443	0.336
Neeme Phase II	17	-0.584	0.352
Onas	3	-1.099	-0.535
Märjamaa Phase I	22	1.117	0.463
Märjamaa Phase II	15	-0.155	0.259
Kloostri Phase III	10	-0.762	0.485
Naissaare Phase I	5	0.012	0.657
Naissaare Phase II	2	-0.269	0.440
Riga	3	0.337	0.053
Total	186	–	–

Table 5. Centred log-ratio (CLR) centroids used for hierarchical clustering of the 13 rapakivi bodies and magmatic phases. The analysis includes 10 major-element variables, and all centroid values are finite.

Rapakivi body or phase	<i>SiO</i> ₂	<i>TiO</i> ₂	<i>Al</i> ₂ <i>O</i> ₃	<i>FeO</i> *	<i>MnO</i>	<i>MgO</i>	<i>CaO</i>	<i>Na</i> ₂ <i>O</i>	<i>K</i> ₂ <i>O</i>	<i>P</i> ₂ <i>O</i> ₅
Wiborg	3.848	-1.232	2.195	0.809	-3.342	-1.731	0.125	0.671	1.284	-2.626
Taebila	3.930	-1.735	2.215	0.778	-3.212	-1.307	0.476	0.568	1.463	-3.176
Ereda	4.076	-1.525	2.233	0.968	-4.434	-0.823	0.319	0.536	1.493	-2.843
Neeme Phase Ia	3.729	-1.451	2.068	0.670	-3.642	-0.847	0.436	0.461	1.072	-2.495
Neeme Phase Ib	3.698	-1.478	2.027	0.609	-3.278	-0.765	0.225	0.447	1.032	-2.517
Neeme Phase II	4.088	-1.854	2.323	0.573	-3.315	-1.080	0.268	0.698	1.422	-3.124
Onas	4.043	-1.470	2.384	0.912	-2.857	-1.830	0.049	0.925	1.529	-3.685
Märjamaa Phase I	3.428	-1.144	1.835	0.739	-3.609	-0.577	0.336	0.256	0.858	-2.122
Märjamaa Phase II	3.790	-1.491	2.138	0.754	-3.216	-0.954	0.188	0.494	1.382	-3.086
Kloostri Phase III	3.963	-1.552	2.269	0.514	-3.231	-0.893	0.336	0.888	1.396	-3.689
Naissaare Phase I	3.854	-1.577	2.201	0.781	-3.799	-0.782	0.281	0.370	1.448	-2.777
Naissaare Phase II	4.001	-1.587	2.361	0.811	-4.225	-1.205	0.025	0.740	1.617	-2.538
Riga	3.887	-1.251	2.127	1.128	-3.812	-1.105	-0.625	0.384	1.504	-2.237



Supplementary Figure 1. Comparative analysis of mineral correlation matrices across studied magmatic Rapakivi plutons and their respective phases.



Supplementary Figure 2. Supplementary petrogenetic plots: (a) $\text{CaO}/(\text{FeO}^* + \text{MgO} + \text{TiO}_2)$ vs. $\text{CaO} + \text{Al}_2\text{O}_3$, and (b) K_2O vs. SiO_2 magma-series discrimination diagram after Kosunen, 1999 and references therein; (c) ASI vs. SiO_2 after Kosunen, 1999. Sources of Fennoscandian rapakivi plutons are based on the work of Dall'Agnol and de Oliveira, 2007 and Grabarczyk et al., 2023, utilising results from Rämö and Haapala, 1995, 2005 for the Wiborg area, Kosunen, 1999 for the Bodom and Obbnäs rapakivi plutons, Heinonen et al., 2010b for the Ahvenisto body, and Sharkov, 2010 for the Salmi granitoids.