Sr ISOTOPIC COMPOSITION OF FINNISH RAPAKIVI GRANITES: THE SUOMENNIEMI BATHOLITH

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INTRODUCTION

The Proterozoic rapakivi granites and related rocks have recently been the subject of active research that has employed petrological, mineralogical, geochemical, and geophysical methods (see Rämö & Haapala 1995 and Haapala & Rämö 1999 and references in these articles). Isotope geochemical studies, in particular, have turned out to be powerful in assessing the origin and protolith history of the rapakivi granites and the mafic rocks associated with them (e.g., Rämö 1991, Haapala & Rämö 1992, Fröjdö et al. 1996, Rämö et al. 1996, Andersson 1997). The classic rapakivi granites of southeastern Fennoscandia are believed to have crystallized from anatectic melts derived from deep, yet crustal, sources (e.g., Haapala & Rämö 1992). The contemporaneous mafic rocks (gabbroids, anorthosites, diabase dikes) presumably represent derivatives of the mantle-originated thermal perturbations that caused anatexis of deep parts of the crust and subsequent emplacement of rapakivi granite batholiths in an extensional tectonic setting.

Differences in the initial Nd and Pb isotopic composition between the silicic and mafic rocks of the rapakivi occurrences of the Fennoscandian Shield have been found to be quite small, regardless of whether they are associated with Paleoproterozoic (Rämö 1991, Fröjdö et al. 1996, Lindh & Johansson 1996) or Archean (Neymark et al. 1994, Andersson 1997, Persson 1997) lithosphere. A comagmatic relationship for the contrasting rock types has, however, been considered unlikely on combined isotopic-petrological reasoning (e.g., Rämö 1991, Salonsaari 1995, Andersson 1997). The purpose of this communication is to present Sr isotopic data on one of the southeastern Finnish rapakivi granite plutons and to make a note on the petrogenetic relationship of the silicic and mafic rocks of the classic rapakivi association of Finland from that perspective.

GEOLOGICAL SETTING AND SAMPLES

The Sr isotopic data presented here come from the Suomenniemi rapakivi batholith situated on the northern flank of the Wiborg batholith in southeastern Finland (Fig. 1). The lithology, geochemistry (including Nd and Pb isotopes), and geochronology of the Suomenniemi batholith have been studied in considerable detail (Rämö 1991, Vaasjoki et al. 1991). The batholith includes four main granite rock types (Fig. 1): hornblende granite, biotite-hornblende granite, biotite granite, and topaz-bearing alkali-feldspar granite. One sample of hornblende granite and two biotite granites have yielded U-Pb zircon ages that cluster tightly at 1640 Ma (1641±2, 1641±1, and 1639±6 Ma; Vaasjoki et al. 1991). Rämö (1991) concluded that the four main granite types of the batholith probably form a fractionation series that can be related to a common, relatively silicic parental magma; the latter was presumably generated by partial melting of an intermediate to silicic deep crustal source. The most highly fractionated topaz-bearing alkali-feldspar granites in the nothern parts

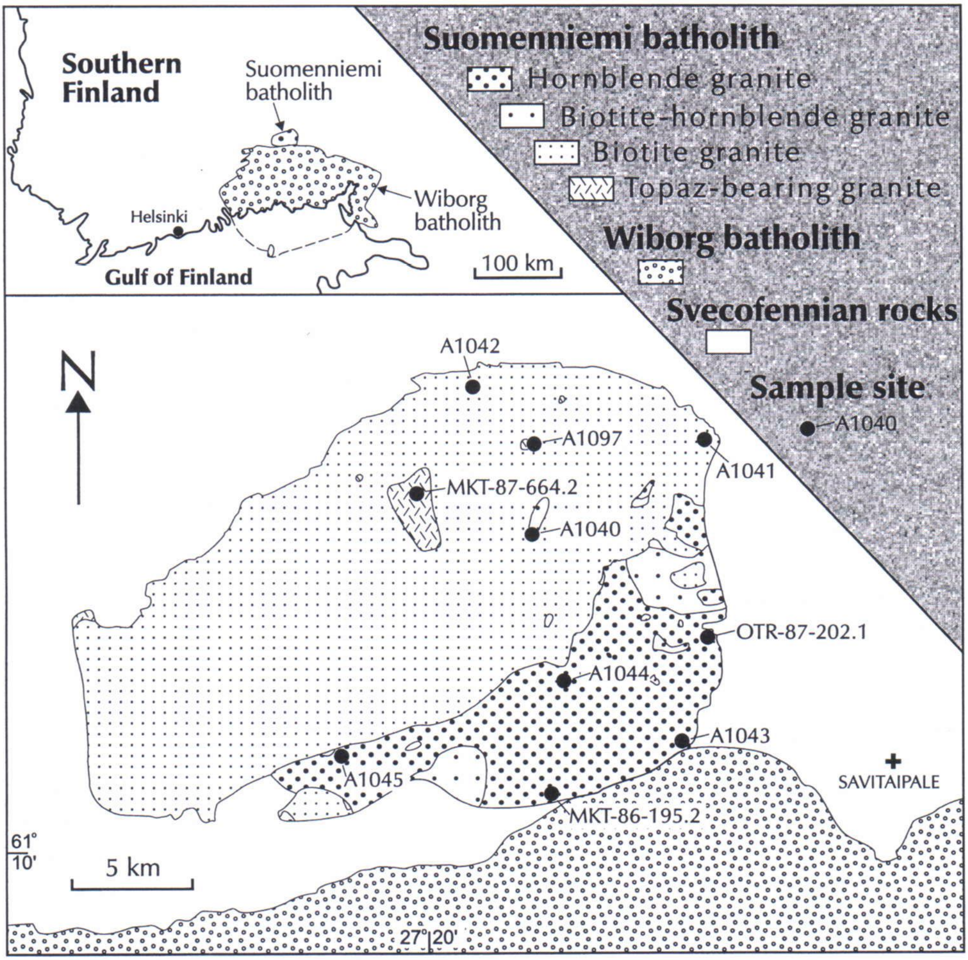

Fig. 1. Geologic sketch map showing the location of the Wiborg and Suomenniemi rapakivi granite batholiths, distribution of the main granite types in the latter, and sample sites for Rb-Sr isotope analysis. Simplified from Appendix 4 in Rämö (1991).

of the batholith also show evidence for subsolidus compositional changes, e.g., anomalously high Rb and low Sr concentrations (Rämö 1991).

In total ten samples were chosen for Rb-Sr isotope analysis from the main granite types of the Suomenniemi batholith (Fig. 1, Table 1). Five of them (OTR-87-202.1, MKT-86-195.2, A1043, A1044, A1045) are from the hornblende granite in the southern and southeastern part of the batholith, and five (A1040, A1041, A1042, MKT-87-664.2, A1097) are from the biotite-hornblende, biotite, and topaz-bearing granites in the central and northern parts of the batholith. Sampling was focused on the hornblende granites as they were known to have much lower Rb-Sr ratios than the other, more evolved, granite types and thus were likely to have experienced less dramatic subsolidus changes that might have affected the Rb-Sr isotopic system.

RESULTS

The Sr isotopic data for the ten samples are listed in Table 1 and shown in a Rb-Sr isochron diagram in Fig. 2. The samples show an overall increase in the Rb-Sr ratio from the hornblende granites (Rb/Sr ~1) to the topaz-bearing granites (Rb/Sr ~77 in sample A1097). Likewise, the measured ^{87}Sr-^{86}Sr ratios range from relatively low (~0.76 in hornblende granite sample OTR-87-202.1) to extremely high (~10.8 in topaz-bearing granite A1097). The Rb-Sr and ^{87}Sr-^{86}Sr ratios in the Proterozoic rapakivi granites are higher than in granitic rocks in general and reflect their low overall Sr content (cf. Rämö & Haapala 1995, Rämö et al. 1996). Calculated back to the U-Pb (presumable crystallization) age of the batholith, the ^{87}Sr-^{86}Sr ratios of the individual granite samples vary widely (from 0.4316 to 0.7082; Table 1) and fail to register an initial Sr isotopic composition for the batholith. In the Rb-Sr isochron diagram (Fig. 2), the samples fall on a trend with a slope corresponding to an age of 1600 ± 7 Ma, initial ^{87}Sr-^{86}Sr ratio of 0.7066 ± 0.0023, and M.S.W.D. (Mean Square of Weighted Deviates) of 28.9. Using this age, the time-corrected ^{87}Sr-^{86}Sr ratios (Table 1) correspond rather well to the initial ratio of the Rb-Sr errorchron (Fig. 2), save for the four samples with the highest Rb-Sr ratios (biotite granites and topaz-bearing granites).

DISCUSSION AND CONCLUSIONS

The age registered by the Rb-Sr system of the granites of the Suomenniemi batholith, 1600 ± 7 Ma, is measurably lower than the 1640 Ma U-Pb age (Vaasjoki et al. 1991) and probably represents a cooling age by which subsolidus migration of Rb and Sr between mineral grains had ceased in the batholith. Rb-Sr whole rock ages have often been reported to be substantially younger than U-Pb ages in granitic plutons, and have been ascribed to slow cooling of the plutons and/or subsequent thermal events (see Welin et al. 1983, Kähkönen et al. 1989, Haudenschild 1995 and references in these articles) or to heterogeneous initial Sr isotopic composition (Romer 1994). The age difference in the Suomeniemi batholith – at minimum, ~30 Ma – is small and may reflect the relatively small size of the intrusion, the overall H_2O-poor nature of the rapakivi granite magma, and the fact that the batholith presumably crystallized from a single batch of granite magma that probably was relatively homogeneous in terms of its initial ^{87}Sr-^{86}Sr ratio.

The four samples with the highest Rb-Sr ratios show the largest deviations from the calculated errorchron (i.e., their initial ratios at 1600 Ma are clearly different from that of the errorchron) which suggests that their igneous Rb-Sr ratios were substantially changed at the subsolidus stage. This could have happened by way of exhange reactions between the granites and autometasomatic fluids that leached Sr out of the granites (e.g., deanorthization of plagioclase) and added Rb to altered feldspars and micas (see Haapala 1997).

As a result of the apparent low Rb-Sr age of the batholith, the calculated initial ^{87}Sr-^{86}Sr ratio, 0.7066 ± 0.0023, is somewhat higher than the ^{87}Sr-^{86}Sr ratio of the magma from which the granites of the batholith probably crystallized 1640 Ma ago. A rough estimate of this difference can be

Table 1. Whole-rock Rb-Sr isotopic data for the Suomenniemi rapakivi granite batholith, southeastern Finland

Sample	Location (Map; Northing; Easting)	Rb (p.p.m.)	Sr (p.p.m.)	Rb/Sr *	$^{87}Rb/^{86}Sr$ †	$^{87}Sr/^{86}Sr$ ‡ (at present)	$^{87}Sr/^{86}Sr$ (1640 Ma ago)	$^{87}Sr/^{86}Sr$ (1600 Ma ago)
Hornblende granite								
OTR-87-202.1	313209C; 6793.32; 3529.85	144.9	190.1	0.762	2.217	0.760419 ± 27	0.70819	0.70948
MKT-86-195.2	313208B; 6786.85; 3523.68	182.0	156.2	1.17	3.398	0.786347 ± 24	0.70628	0.70826
A1043	313208D; 6788.76; 3528.02	177.2	169.1	1.05	3.052	0.777363 ± 16	0.70546	0.70723
A1044	313209A; 6791.44; 3523.57	238.6	78.75	3.03	8.942	0.913227 ± 15	0.70256	0.70776
A1045	313205B; 6788.64; 3513.94	255.1	151.1	1.69	4.935	0.818894 ± 15	0.70261	0.70548
Biotite-hornblende granite								
A1040	313209B; 6797.71; 3521.92	229.0	98.35	2.33	6.837	0.862640 ± 10	0.70155	0.70552
Biotite granite								
A1041	314107C; 6801.70; 3529.38	351.0	58.35	6.02	18.10	1.119189 ± 18	0.69276	0.70328
A1042	314104C; 6803.94; 3519.30	321.6	65.93	4.88	14.57	1.039237 ± 15	0.69595	0.70442
Topaz-bearing granite								
MKT-87-664.2	313206D; 6799.43; 3517.25	683.0	19.10	35.8	134.9	3.82024 ± 6	0.64166	0.72010
A1097	314107A; 6801.54; 3521.84	695.9	9.064	76.8	442.4	10.84869 ± 24	0.43157	0.68873

Note: The isotopic analyses were carried out at the Unit for Isotope Geology, Geological Survey of Finland. For details of the analytical procedure, see Rämö et al. (1996).

* Weight ratio.

† Atomic ratio; estimated error is better than 0.5 %.

‡ Normalized to $^{86}Sr/^{88}Sr = 0.1194$. Within-run precision expressed as $2\sigma_m$ in the last significant digits; external error is 0.009% (2σ).

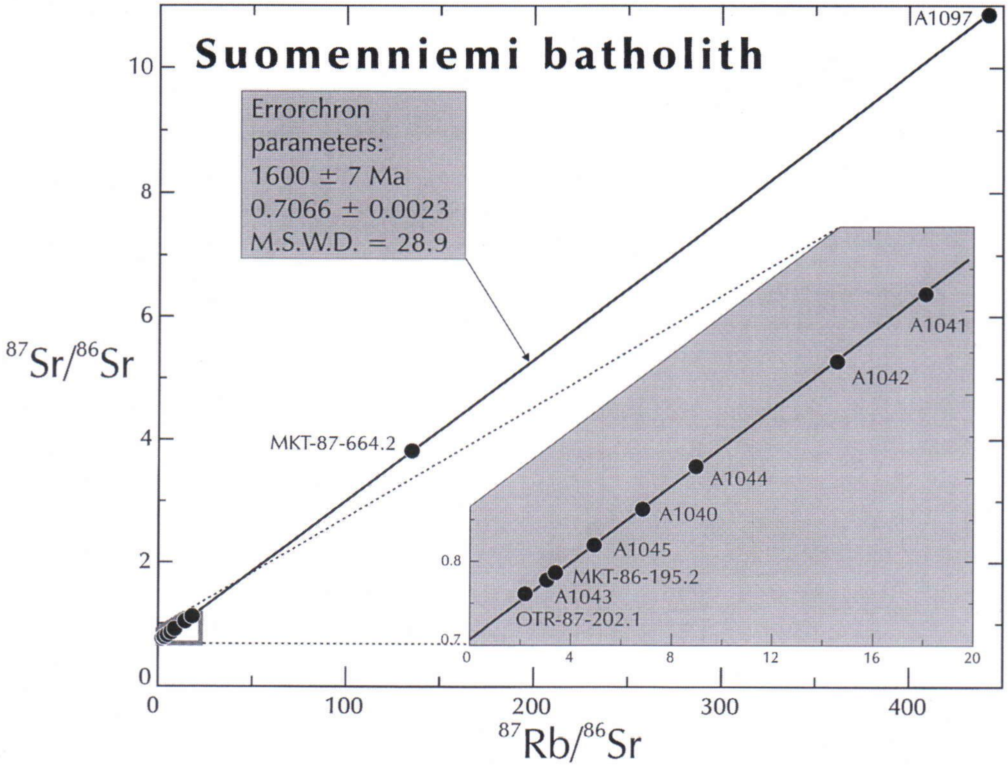

Fig. 2. $^{87}Rb/^{86}Sr$ vs. $^{87}Sr/^{86}Sr$ diagram for the main granite types of the Suomenniemi rapakivi granite batholith of southeastern Finland.

obtained by choosing a lower Rb-Sr ratio for the highest-Rb/Sr topaz-bearing granite sample so that a fictious 1640 Ma Rb-Sr isochron is obtained. To do this, I used the lowest-Rb/Sr hornblende granite sample OTR-87-202.1 and the highest-Rb/Sr topaz-bearing granite sample A1097 and lowered the Rb-Sr ratio of the latter to get a 1640 Ma slope for the line through the two points; for this, a 2.7 % decrease in the ^{87}Rb-^{86}Sr ratio (from 442.4 to 430.5) was required. The corresponding decrease in the initial ^{87}Sr-^{86}Sr ratio was 0.2 %, that is from 0.7066 to 0.7052, which is well within the 2σ error of ±0.33 % (±0.0023) calculated from the actual data. Thus the initial ratio of 0.7066 ± 0.0023 can be considered a fair estimate of the initial ratio of the Suomenniemi batholith.

The initial ratio of 0.7066 ± 0.0023 is comparable to the initial ratio presented for five whole rocks from the southwest Finnish Åland rapakivi granite batholith by Suominen (1991). The Åland samples fall on a trend with an age of approximately 1520 Ma and initial ratio of 0.706 ± 0.003 (see Table 16 in Suominen 1991). As the difference between the U-Pb age (~1575 Ma) and the Rb-Sr age of the Åland batholith is somewhat greater than that of the Suomenniemi batholith, the initial ratio for Åland is less well-defined, yet of the same order.

Initial Sr isotopic compositions for three Subjotnian diabase dikes associated with the Finnish rapakivi granites have been published by Suominen (1991). Two dikes (Föglö, Kumlinge) from the Åland area and one dike (Ansio) from the Häme dike swarm west-northwest of the Wiborg batholith (Laitakari 1987) all have initial ratios on the order of 0.7035–0.7036 and thus plot on the evolution curve of average subcontinental mantle (see Fig. 8 in Rämö et al. 1996). Similar initial ratios have recently also been measured for the gabbroic and anorthositic rocks of the 1640 Ma

Ahvenisto rapakivi granite – massif-type anorthosite complex just west of the Suomenniemi batholith (Rämö et al. 1999; see also Alviola et al. 1999). These figures are, at face value and presumably also if the experimental errors are considered, distinctly lower than the initial ratio of the Suomenniemi batholith and suggest that the mafic and silicic rocks were derived from different protoliths, the former from a mantle source and the latter probably from a relatively Rb-poor lower crustal domain.

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