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Strontium isotope ratios and REE geochemistry in the Suwałki anorthosites, NE Poland

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Strontium isotope ratios for 14 samples of anorthositic rocks in the Suwałki Anorthosite Massif (SAM) range from 0.704875 to 0.705772. The same isotopic ratios calculated for 1.5 Ga (the U-Pb zircon age of the rapakivi-like granites from adjacent Mazury Complex) range from 0.704583 to 0.705483. The corresponding $\varepsilon_{Sr_{1500}}$ values for the same rocks range from 25.5 to 39.0. The pronounced Eu anomaly which characterises the REE distribution in the anorthosite plagioclase is consistent with early crystallization from basic magma.

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Key words: Suwałki Anorthosite Massif, strontium ratio, REE geochemistry.

INTRODUCTION

Initial $^{87}Sr/^{86}Sr$ ratios in igneous rocks are important in the recognition of magma sources. Data from basaltic achondrites with low Rb/Sr ratios show that the primordial value of $^{87}Sr/^{86}Sr$, about 4.6 bilion years ago was 0.699 (BABI — basaltic achondrite best initial) — a value of the primary strontium ratio for the whole solar system. With passing time, that initial $^{87}Sr/^{86}Sr$ has changed due to the release of radiogenic ^{87}Sr from Rb-bearing minerals (e.g., biotite, feldspars). The earth's crust has a higher Rb/Sr ratio then the upper mantle. If a magma source lay in the upper mantle or lower crust, and on its way upwards, was not contaminated by foreign strontium, the $^{87}Sr/^{86}Sr$ ratio would remain low; the value would be close to that of mantle derived basalts. For a crustal source or in cases where crustal assimilation had occurred, the value of $^{87}Sr/^{86}Sr$ would be higher (Faure and Powell, 1972).

The 14 samples of the anorthositic rocks selected for rubidium and strontium determination were taken from several deep drill holes sited on magnetic anomalies in the Suwałki Anorthosite Massif (SAM) 20 km north from Suwałki town (Fig. 1). SAM is representative of a wide range of massif-type Anorthosite-Mangerite-Charnockite-Granite (AMCG) igneous complexes and is situated within the crystalline complex known as the Mazury Complex.

The earliest geochronological studies of the SAM were performed by Depciuch *et al.* (1975) using the K-Ar method. Later Jarmołowicz-Szulc (1990) calculated a K-Ar age of 1347±93 Ma. This is probably a reset age. Late granitoids in veins cutting the anorthosite complex may be responsible. U-Pb zircon studies on granites (quartz monzonites from the Gołdap core) of the Mazury Complex (Claesson *et al.*, 1995) and of the Kabeliai pluton in Lithuania (Sundblad *et al.*, 1994) have yieled *ca.* 1500 Ma age. It is assumed that the granites surrounding the anorthosite massif are genetically related to the anorthosites — as is observed to be the case with AMCG complexes worldwide and including rapakivi granites, considered as anorogenic, related to active or reactivated deep crustal structures.

The Re-Os studies on magnetite and sulphide mineralization dispersed in the Suwałki anorthosites and norites (Stein *et al.*, 1998; Morgan *et al.*, in press) have yielded a similar age of 1559±37 Ma for the Jezioro Okrągłe and Krzemianka deposits and 1556±94 Ma for Udryń deposit. Initial values of ε_{Sr} were therefore calculated for 1.5 Ga (Table 1).

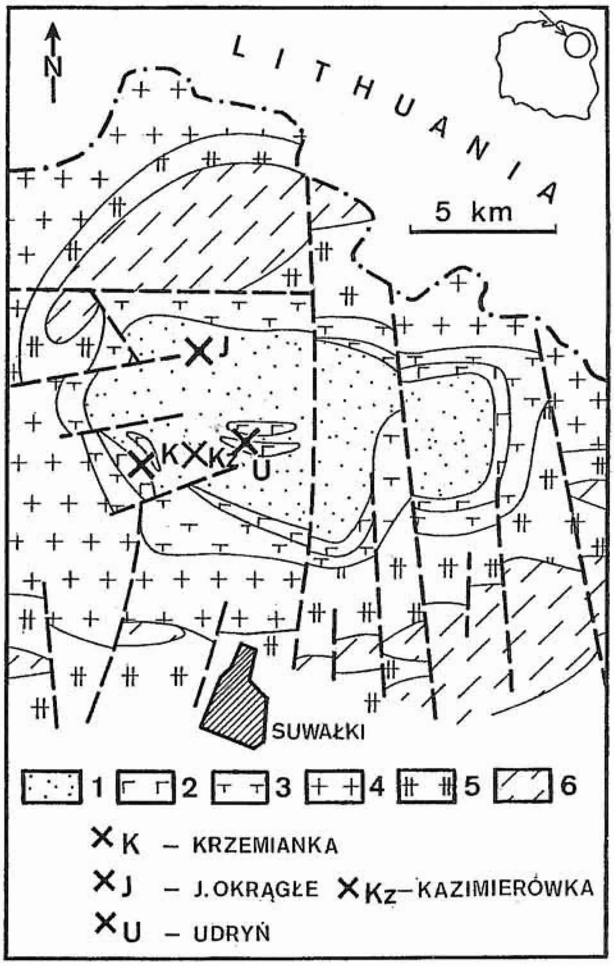

Fig. 1. Geological map of the Suwałki Anorthosite Massif (after Kubicki and Ryka, 1982)

1 — anorthosites, 2 — norites, 3 — gabbronorites and diorites, 4 — granitoids, 5 — granitogneisses, 6 — gneisses; K, J, U, Kz — drill holes

METHODS

The anorthosites were initially examined under the optical microscope to confirm that they had not been altered by secondary processes. Major and trace element compositions were determined by Atomic Absorbtion Spectrometry using the PU 9100 X spectrometer (UNICAM) at the Polish Geological Institute (Warsaw) and REE were determined by Inductively Coupled Plasma Mass Spectrometry at the University of Liége (Belgium). The strontium isotope determinations were carried out at the Isotope Laboratory of the Polish Academy of Sciences in Warsaw. Samples (100 mg) were dissolved in hydrofluoric and nitric acides and the Rb and Sr separated by chromatographic methods. The isotopic ratios were measured on a VG Sector 54 mass spectrometer using five collectors in dynamic mode. Errors in Rb and Sr concentrations (determined by flame AAS) are ±1 ppm. This errors may be ignored in the case of high (800–900 ppm) Sr samples. In the case of low Rb (2–7 ppm) samples, the error is of considerable significance. The measured Sr and Rb values were compared with measurements of various international reference material, e.g. BM, TS, TB, and BE-N. All $^{87}Sr/^{86}Sr$ ratios were normalised relative to a value of $^{86}Sr/^{88}Sr = 0.1194$, to correct for machine fractionation. Replicate analyses of the NBS SRM 987 standard gave an average $^{87}Sr/^{86}Sr$ ratio of 0.710255±0.000011 over the period of this study.

RESULTS

The analysed anorthosite samples come from four sites in the Suwałki Massif — Krzemianka, Kazimierówka, Jezioro Okrągłe and Udryń. All are only a few kilometres distance from one another. The anorthosites comprise relatively pure, medium- to coarse-grained feldspar (80–95% normative plagioclase) with anorthite content of 45–55% on average, small amounts of quartz and K-feldspar and accessory pyroxene, amphibole, carbonate and biotite.

The rocks are geochemically similar to other Proterozoic massif-type anorthosites elsewhere in the world, e.g., those in the Grenville and Nain Provinces, Michicamau (Labrador), Morin (Quebec) and Egersund-Ogna, Rogaland Province (Norway). The anorthosites of Suwałki are enriched in Al_2O_3 (18.5–29.9%), CaO (8.29–10.6%) and Na_2O and depleted in all other oxides except SiO_2 (~50%) and K_2O. The normative ratio of An/An+Ab is 0.50–0.64. The rocks have relatively high concentrations of Sr (800–900 ppm), Ba (300–530 ppm), Fe (0.5–1.0% Fe_2O_{3t}), Ti (0.04–0.1% TiO_2) and of other compatible

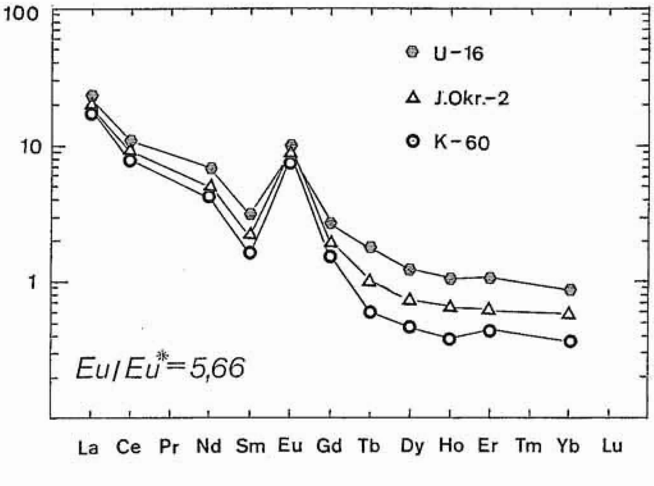

Fig. 2. Chondrite-normalized REE patterns of plagioclases separated from anorthosites in drillcores Udryń 16 (U-16), Krzemianka 60 (K-60), and Jezioro Okrągle IG 2 (J. Okr.-2) (Table 2)

Table 1

Isotopic data for the Suwałki anorthosites*

Number of sample	Locality	Depth [m]	$^{87}Sr/^{86}SR$	Error [%]	Sr [ppm]	Rb [ppm]	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr_{1500}$	$\varepsilon_{Sr_{1500}}$
12	Krzemianka 60	1570.6	0.705136	0.0014	817	5	0.017268	0.704764	28.76
13	Kazimierówka 1	2160.6	0.705354	0.0016	873	5	0.014500	0.705042	32.71
15	Jez. Okrągłe IG 2	1386.0	0.705772	0.0017	842	4	0.013405	0.705483	39.00
16	Jez. Okrągłe IG 2	1913.2	0.705093	0.0015	812	3	0.010424	0.704869	30.24
17	Jez. Okrągłe IG 2	2245.2	0.705014	0.0016	831	2	0.006791	0.704868	30.23
18	Udryń 18	923.0	0.705133	0.0015	896	4	0.012596	0.704862	30.15
19	Udryń 7	1559.6	0.705338	0.0014	847	7	0.023319	0.704836	29.78
20	Udryń 7	1867.7	0.705101	0.0012	832	3	0.010174	0.704882	30.43
21	Udryń 4	1560.4	0.705436	0.0012	834	4	0.013533	0.705145	34.17
22	Udryń 7	1866.7	0.705429	0.0015	827	3	0.010236	0.705209	35.08
23	Udryń 16	1127.0	0.704875	0.0016	833	4	0.013548	0.704583	26.18
24	Udryń 16	1134.0	0.704920	0.0016	876	4	0.014359	0.704611	26.58
25	Udryń 16	1779.5	0.705071	0.0015	800	7	0.024688	0.704540	25.56
26	Udryń 18	2214.6	0.704995	0.0016	732	2	0.007709	0.704829	29.68

*Analyses by R. Bachliński ING PAN

elements as Cr, Ni, Co, Cu (e.g. Ni and Cr ranging from 38–148 and 32–268 ppm, respectively). The total REE contents in the anorthosites are rather high, ranging from 11 to 58. Pure plagioclase feldspar from Udryń, Krzemianka and Jezioro Okrągłe, analysed by ICP MS at the University in Liegé (Table 2) show classical, pronounced, positive Europium anomalies (Fig. 2) and LREE/HREE of 21/2, 43/7 and 32/4, respectively. The REE are highly fractionated ($La/Yb_N = 25.1$). The data lie within the range typical of plagioclase in massif-type anorthosites (Griffin *et al.*, 1974).

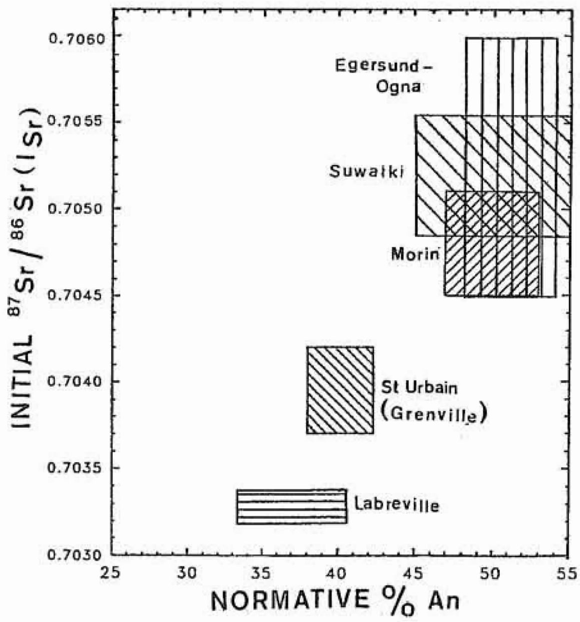

Fig. 3. A plot of I_{Sr} ratio vs. normative %An for the Suwałki anorthosites; ratios for Labreville, Morin, St. Urbain and Egersund-Sogndal anorthosites (after Owens *et al.*, 1994 and Demaiffe *et al.*, 1986) are also shown

The low initial strontium ratios in the Suwałki anorthosites range from 0.704583 to 0.705483 (Table 1). They have been calculated from the measured ratios accounting for *in situ* decay of ^{87}Rb since 1500 Ma — the age of the rapakivi granites from the Mazury Complex (Claesson *et al.*, 1995). As in most samples, the Rb/Sr ratio is very low, this correction is not very significant. The corresponding ε_{Sr} values range from 25.5–39.0

Table 2

REE and some trace element compositions of plagioclases from anorthosites from three different areas of the Suwałki Anorthosite Massif*

Constituents	Udryń 16	Krzemianka 60	Jez. Okrągłe IG 2
Sr ppm	884	840	797
CaO	10.99	10.80	11.31
K_2O	0.54	0.51	0.56
Fe_2O_3	0.47	0.78	1.03
TiO_2 ppm	412	543	972
Ba	278	285	292
Ba (ICP)	268	265	302
Rb	4.89	4.78	5.19
Y			
La	7.17	6.23	6.10
Ce	9.54	7.05	8.01
Nd	4.39	2.75	3.14
Sm	0.65	0.33	0.44
Eu	0.63	0.69	0.76
Gd	0.76	0.43	0.54
Tb	0.09	0.03	0.05
Dy	0.42	0.16	0.25
Ho	0.08	0.03	0.05
Er	0.24	0.10	0.14
Yb	0.19	0.08	0.13
Pb	2.21	2.19	3.28
Th	0.48	0.13	0.25
U	0.08	0.05	0.09

*Analyses by J.-C. Duchesne (University of Liegé)

Table 3

Isotope measured $^{87}Sr/^{86}Sr$ ratio for massif-type anorthosites from Poland and some other places worldwide

Localisation	Sr [ppm]	Rb [ppm]	$^{Sr}87/^{86}Sr$ measured
SUWAŁKI Poland	833	4	0.7049
	842	4	0.7058
MICHIKAMAU Labrador	860	9	0.7026
	570	7	0.7039
	280	N.D.	0.7050
MORIN Quebec	750	N.D	0.7054
	620	N.D.	0.7050
ROSELAND Virginia	1250	17	0.7019
	730	11.4	0.7058
	1240	23	0.7056
	1330	10.6	0.7054
EGERSUND-OGNA Norway	425	0.9	0.7045
	677	0.4	0.7051
	797	1.8	0.7059

(Table 1). An I_{Sr} vs. normative %An plot (Fig. 3.) shows the large variation in I_{Sr} (initial ratios) that exists between anorthosites from different massifs, e.g. Labreville, Morin, St. Urbain (Grenville Province) and Egersund–Ogna (Norway). The Suwałki data partly overlap those of the Morin and Egersund anorthosites. The low isotopic strontium ratios for the Suwałki anorthosites compare with those of many other massif-type igneous anorthosites in large AMCG complexes (Table 3).

CONCLUDING REMARKS

As the plagioclase-rich Suwałki anorthosites usually have very low Rb/Sr ratios ranging from 0.008–0.02 approximately, it is impossible to obtain Rb-Sr isochrons. However, initial $^{87}Sr/^{86}Sr$ value can place some constraints on the genesis of the anorthosite parental magma.

The present $^{87}Sr/^{86}Sr$ data fall into a narrow and low range. Whether the parental magma originated directly from the mantle at around 1500 Ma, or from the lower crust, is not open to resolution using only strontium initial ratios and REE patterns. New Nd and Os isotope results obtained for the Suwałki anorthosites, norites, diorites and ore minerals may be of some help (Wiszniewska *et al.*, 1999). According to Demaiffe *et al.* (1986), strontium isotope data may indicate an upper mantle origin for the parental magma of the anorthosites and related norites and jotunites of the Rogaland anorthositic suite in Norway. Alternatively, an origin in the lower crust by melting of juvenile basic components is possible.The new Sr-isotope data for the Suwałki Anorthosite Massif rare consistent with a fractional crystallization from a basic parental magma that originated by melting in the upper mantle or lower crust.

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