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Petrology and geochemistry of rapakivi-type granites from the crystalline basement of NE Poland

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80 rock samples from drill-cores at 8 localities in the Mazury complex (Polish part of the crystalline East European Craton), representing rock types from monzodiorites to leucogranites, were studied for major, trace and REE elements by XRF and ICP-MS methods. The range in composition of the investigated rocks varies from 46 to 76% SiO_2 contents. All of them show similar REE distributions, which suggests that they are genetically linked. They also plot along a major trend with many similarities to the jotunitic liquid line of descent defined in AMCG rocks from Rogaland (Norway). Each group of rocks has however its own specific pattern of elements.

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INTRODUCTION

The Mazury complex, situated in NE Poland, is part of the East European Craton (EEC) that forms the northeastern part of Europe (Fig. 1). The western, Polish part of the EEC is covered by Phanerozoic platform sediments. The thickness of this cover varies from 400 m in the east, to 6500 m along the TTZ (Teisseyre-Tornquist Zone) (Fig. 2), as the crystalline basement dips to the SW.

The crystalline rocks of the Mazury complex have also been studied recently by Claesson *et al.* (1995*b*), Claesson and Ryka (1999), Lorenc and Wiszniewska (1999), Cymerman and Wiszniewska (1999), Bagiński *et al.* (1999, 2000) and Skridlaite *et al.* (2000). The main aim of the present study was to check new geochemical data on various rock types coming from different area (different massifs?) of the Mazury complex in respect of their evolution from cogenetic magma batches by similar processes though variable in degrees of pressure, temperature, contamination and level of emplacement.

GEOLOGICAL SETTING

The Polish part of the EEC consists of three large granitoid massifs (Mazovian, Dobrzyń and Pomeranian) separated by granulite-gneiss belts (Podlasie, Ciechanów, Kaszuby) with a complex Precambrian history (Fig. 2). The granitoids were thought by Kubicki and Ryka (1982) and by Znosko (1998) to be Archaean, based on sparse K-Ar age determinations of 2.65 Ga (Depciuch *et al.*, 1975). Recently, a new approach, based on combined geochronological and petrological studies (Claesson and Ryka, 1999), confines the Archaean domain to the northeastern part of the Baltic Shield (Karelia and Kola Peninsula) and to the eastern part of EEC (Ukraine), excluding Archaean rocks from Poland (Kubicki and Ryka, 1982). Indeed, new Nd model ages obtained at the Swedish Museum Isotopic Laboratory in Stockholm (Claesson and Ryka, 1999) on rocks from the main units of the crystalline basement of Poland were all Palaeoproterozoic. These rocks have been metamorphosed under amphibolite facies conditions and the main phase of deformation and metamorphism of the Polish part of the EEC is now

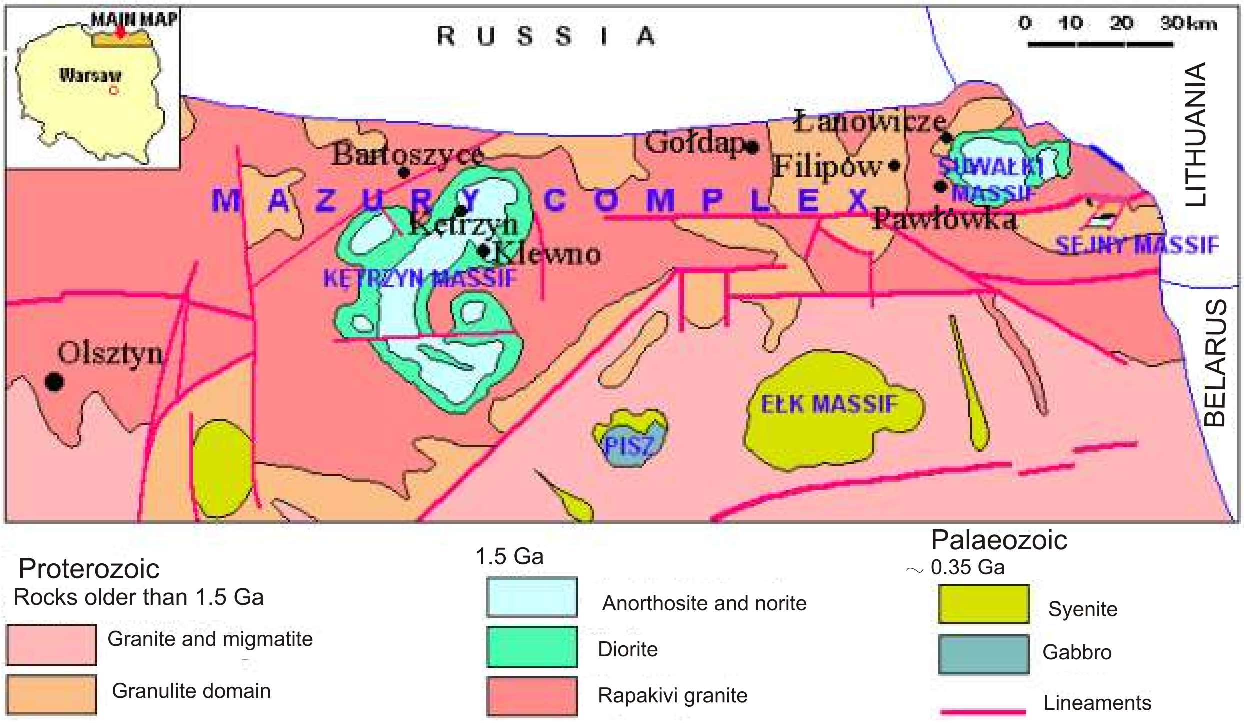


Fig. 1. Geological map of the Mazury complex, NE Poland (after Kubicki and Ryka, 1982, modified by Wiszniewska *et al*., 1999)

Location of the eight deep boreholes from which the samples studied have been collected

considered as Svecofennian in age (Claesson *et al.*, 1995*b*). Two zircon fractions extracted from the granites of Mazury complex gave an U-Pb age of about 1.5 Ga (Claesson *et al*., 1995*a*). Similar rapakivi-type intrusions from Lithuania, the Kabeliai complex (Skridlaite *et al*., 2000), yielded a zircon U-Pb age of 1505±11 Ma (Sundblad *et al.*, 1994). On another hand, Mazury acidic rocks gave depleted mantle Nd model ages $T(Nd)_{DM}$ of 2.1 to 2.2 Ga (Claesson *et al*., 1995*b*), while the Suwałki anorthosite-gabbronorite complex yielded Nd model ages of 1.7 to 2.3 Ga (Wiszniewska *et al.*, 1999). Titanomagnetite and sulphide ores from the Suwałki massif dated by the Re-Os method have given isochron ages of 1559±37 and 1556±94 Ma (Stein *et al.*, 1998; Morgan *et al*., 2000; Wiszniewska and Stein, 2000).

The tectonic setting of Mesoproterozoic magmatism in the Mazury complex has been considered (Kubicki and Ryka, 1982) as linked to a E–W trending zone of post-collisional origin or caused by rejuvenation of an older lineament. Several intrusions of anorogenic character and bimodal composition, mostly rapakivi-type granites and anorthosite-norite intrusions (Suwałki, Sejny, Kętrzyn), have been described within this area. Integrated geophysical approaches have been used to try to determine the shape, structure and extension of the magmatic belt (Wiszniewska *et al*., 2000). On the magnetic image map, the Mazury complex does not show any specific features, and generally comprises in a mosaic of positive anomalies. On a Bouguer map the anomaly is moderate in comparison to the gravity high on the northern rim of the Mazovian massif and the gravity low of the Dobrzyń domain in the west. The rapakivi-like granitoids show a variable densities, with values mostly higher than those of the anorthosite-norite massifs. In the vector image of the fractional vertical derivative, the gravity

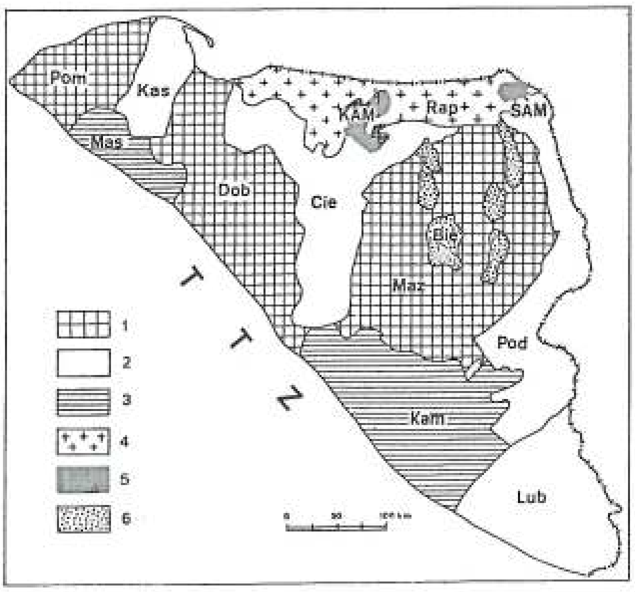


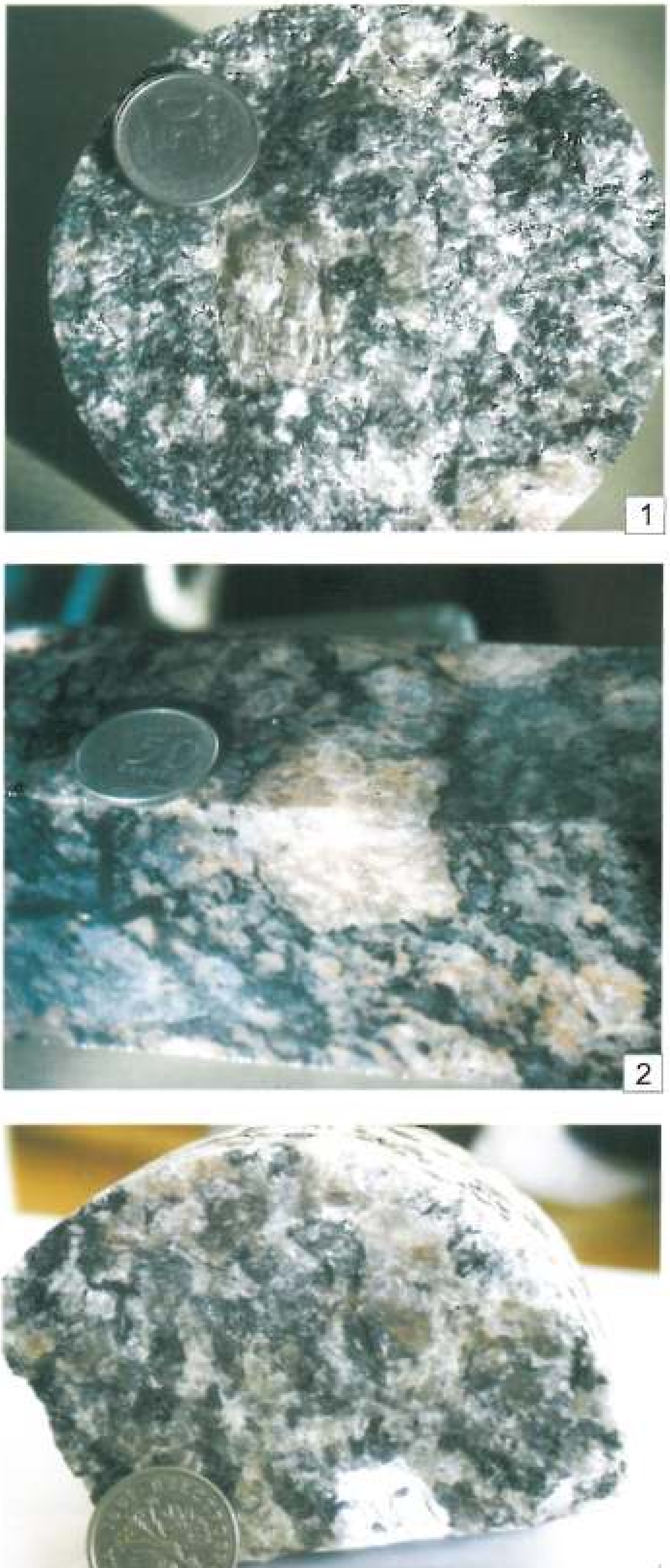
Fig. 2. Tectono-structural scheme of the crystalline basement in the Polish part of the Precambrian platform (after Kubicki and Ryka, 1982)

Palaeoproterozoic structures: 1 — granitoid massifs with substrate of older rock: Mazovian (Maz), Dobrzyń (Dob), Pomeranian (Pom), 2 — old metamorphic complexes: Lublin (Lub), Podlasie (Pod), Ciechanów (Cie), Kaszuby (Kas); **Mesoproterozoic structures**: 3 — metamorphic Kampinos complex (Kam), Mazury complex (Mas), 4 — rapakivi-like granitoids (Rap), 5 — anorthosite massifs: Suwałki (SAM) and Kętrzyn (KAM); **Neoproterozoic structures**: 6 — metamorphic *quasi*-platform cover: Biebrza complex (Bie); Teisseyre-Tornquist Zone (TTZ)

PLATE I

1. Charnockite; main rock components: hypersthene (right center), biotite, quartz, plagioclase; crossed polars, x 28, Łanowicze 10, depth 1162.5 m. ***2***. Charnockite; hypersthene with numerous inclusions of quartz, ilmenite, biotite and zircon (poikilitic texture); crossed polars, x 28, Łanowicze10, depth 1162.5 m. ***3***. Leucogranite; visible microcline and albite crystals, quartz and minute biotite; crossed polars, x 28, Olsztyn 1, depth 2764.0 m. ***4***. Advanced albitisation and sericitisation of plagioclase with small epidote crystals and xenomorphic quartz crystals; crossed polars, x 28, Olsztyn 4, depth 2780.5 m

PLATE II

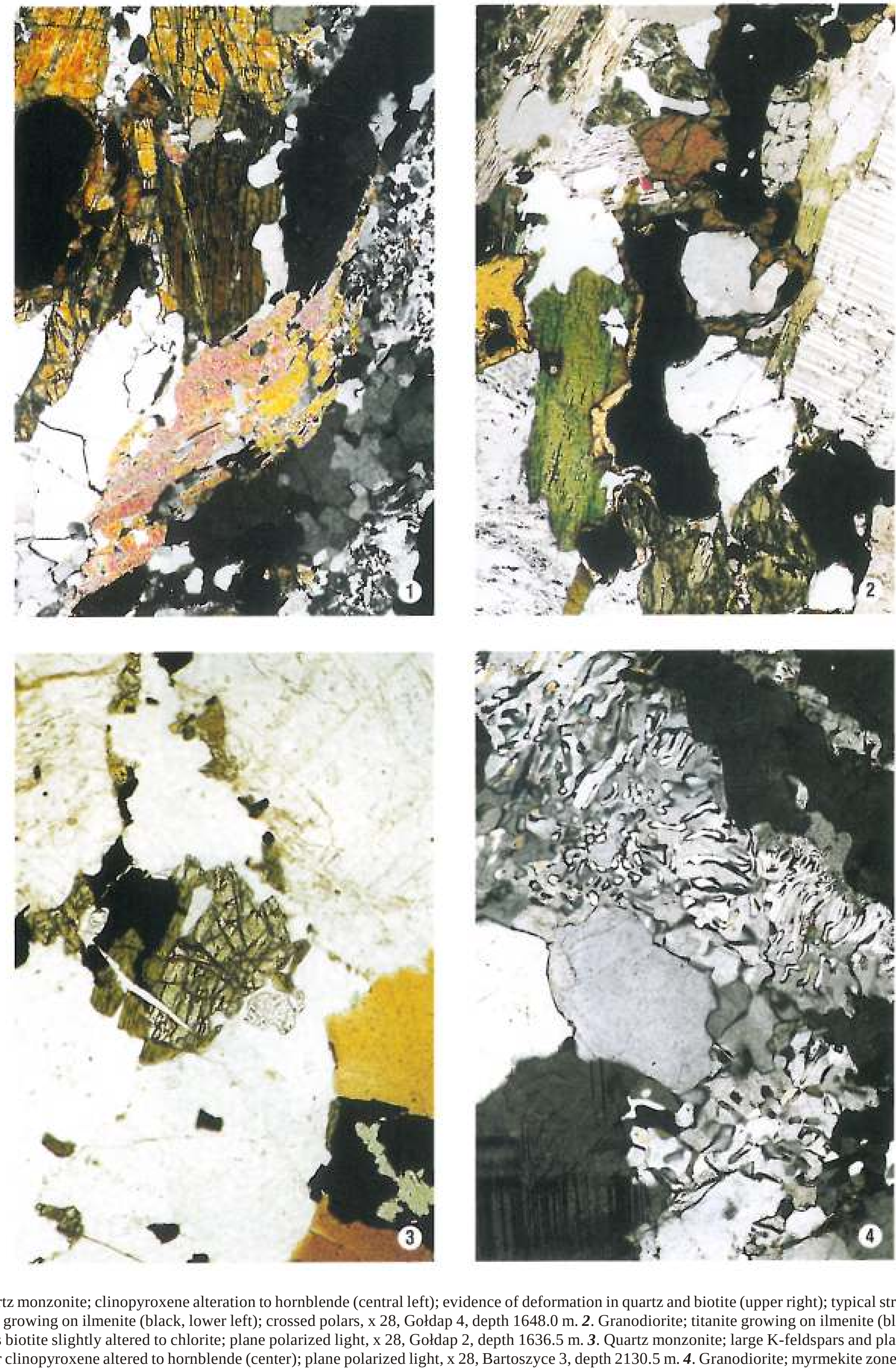


1. Porphyritic texture with large pink K-feldspar in charnockite from the Łanowicze drill-core; depth 1111.8 m. ***2.*** Large plagioclase in quartz monzodiorite from the Filipów drill-core; depth 1553.0 m. ***3.*** Porphyritic texture with large plagioclase crystals in quartz monzonite from the Kętrzyn drill-core; depth 1549.5 m; diameter of the coin is 1.5 cm on all photos

PLATE III

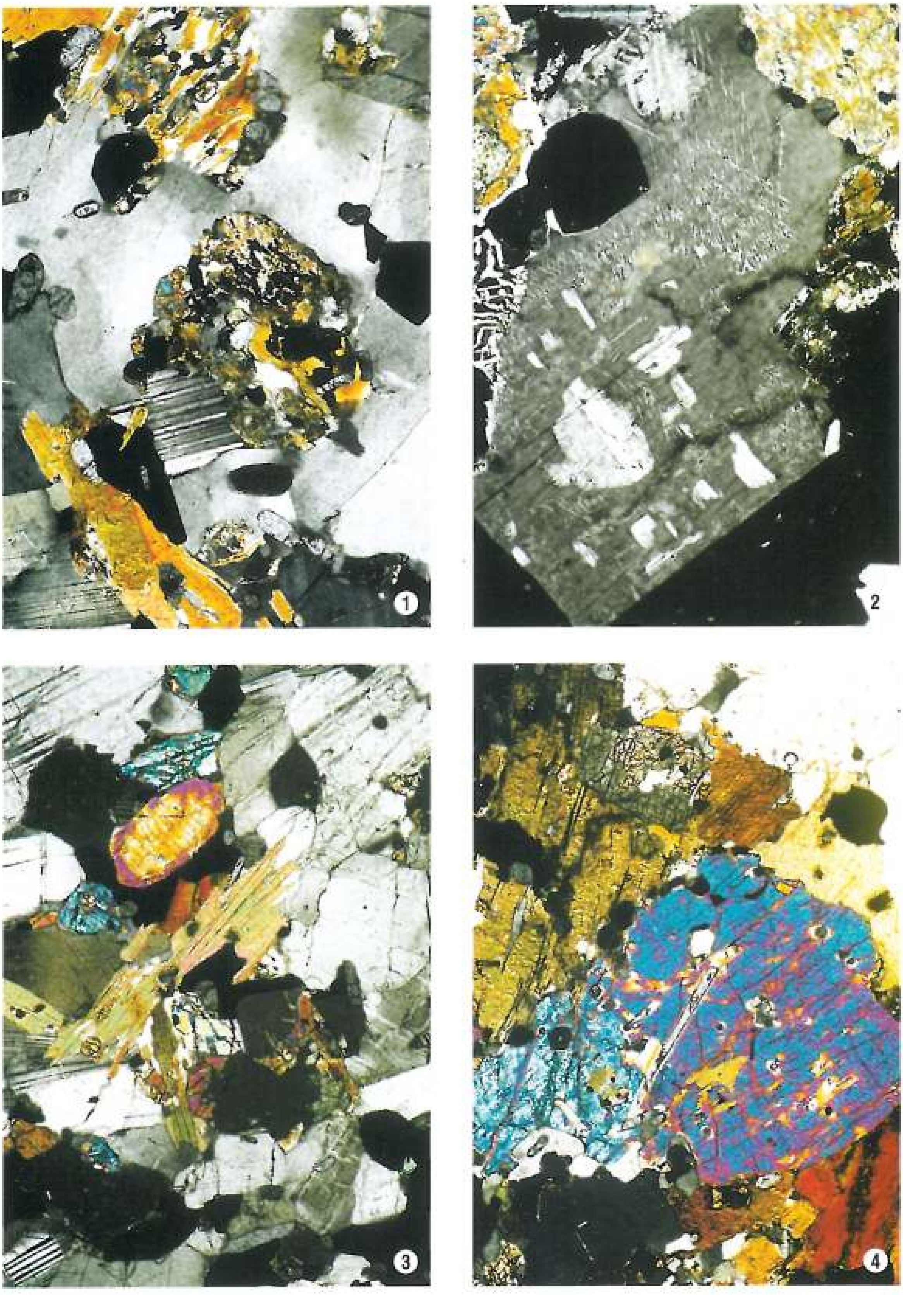
1. Porphyritic texture with large pink K-feldspar in the Gołdap granite; depth 1648.5 m. ***2***. Quartz monzodiorite from the Bartoszyce drill-core; depth 2141.5 m. ***3***. Porphyritic texture with large pink K-feldspar in the Pawłówka drill-core; depth 1907.0 m

PLATE IV



1. Quartz monzonite; clinopyroxene alteration to hornblende (central left); evidence of deformation in quartz and biotite (upper right); typical structure of titanite growing on ilmenite (black, lower left); crossed polars, x 28, Gołdap 4, depth 1648.0 m. ***2***. Granodiorite; titanite growing on ilmenite (black); numerous biotite slightly altered to chlorite; plane polarized light, x 28, Gołdap 2, depth 1636.5 m. ***3***. Quartz monzonite; large K-feldspars and plagioclase, smaller clinopyroxene altered to hornblende (center); plane polarized light, x 28, Bartoszyce 3, depth 2130.5 m. ***4***. Granodiorite; myrmekite zone; crossed polars, x 70, Bartoszyce 1A, depth 2141.5 m

PLATE V



1. Quartz monzodiorite; altered clinopyroxene crystals within quartz (in the middle); quartz/biotite/clinopyroxene symplectite (upper right); numerous small apatites; crossed polars, x 28, Klewno 1, depth 1782.0 m. ***2***. Quartz monzodiorite; relics of plagioclase within K-feldspar; alteration of clinopyroxene (upper left); crossed polars, x 28, Klewno 2, depth 1785.0 m. ***3***. Quartz monzonite; typical texture of the rock (not deformed); the main minerals visible: plagioclase, quartz, K-feldspar, biotite and amphibolitised pyroxene; crossed polars, x 28, Filipów 7, depth 1351.5 m. ***4***. Quartz monzonite; part of rock with clinopyroxene (central part), biotite and hornblende (right middle), long needle-like inclusion of apatite within cpx; crossed polars, x 28, Filipów 11, depth 1491.5 m

Major (%) and trace (ppm) element composition

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Ba	Ce
Olsztyn 1	71.88	0.39	14.53	1.94	0.03	0.76	2.20	3.53	4.16	0.08	753	51
Olsztyn 4	72.45	0.39	14.21	2.58	0.03	0.81	1.49	2.88	5.41	0.10	953	99
Olsztyn 5	74.71	0.33	14.15	2.16	0.03	0.65	1.55	3.07	4.86	0.08	652	95
Olsztyn 7	73.51	0.27	13.71	2.37	0.02	0.56	0.48	3.06	5.41	0.06	707	71
Łanowicze 1	63.78	0.91	16.28	6.81	0.08	1.78	3.88	3.19	2.86	0.19	1009	109
Łanowicze 2	71.69	0.37	13.26	3.04	0.07	0.97	1.34	2.35	4.85	0.06	717	58
Łanowicze 9	63.71	1.01	15.85	7.57	0.11	2.02	3.97	2.86	2.94	0.23	1231	124
Łanowicze 11	61.37	1.03	16.03	7.67	0.12	1.92	4.05	2.96	2.94	0.23	1371	116
Łanowicze 15	62.02	0.99	16.40	7.66	0.13	1.95	3.92	3.03	3.45	0.32	1292	117
Łanowicze 17	69.24	0.67	14.85	4.70	0.07	1.27	2.53	2.72	4.25	0.14	871	100
Łanowicze 19	67.91	0.60	14.75	4.18	0.07	1.10	2.73	2.83	4.14	0.19	1080	93
Łanowicze 22	67.00	0.79	15.36	5.47	0.08	1.38	3.22	2.93	3.66	0.23	995	103
Łanowicze 24	69.86	0.46	13.94	4.14	0.10	0.46	2.30	2.57	4.26	0.08	1720	141
Łanowicze 25	70.71	0.43	13.35	4.06	0.10	0.39	1.94	2.37	4.85	0.09	1802	122
Łanowicze 26	70.36	0.43	14.29	3.79	0.08	0.42	2.40	2.76	4.16	0.09	1287	133
Łanowicze 27	68.66	0.68	14.74	5.10	0.07	1.23	2.72	2.69	4.27	0.18	1244	100
Gołdap 2	65.36	0.75	15.92	3.62	0.06	0.99	2.28	2.75	7.45	0.39	2344	236
Gołdap 3	63.96	1.38	14.37	6.59	0.12	1.50	3.88	3.11	4.65	0.70	1394	388
Gołdap 4	63.94	1.21	15.51	5.45	0.11	1.34	3.61	3.26	5.29	0.54	1701	358
Gołdap 5	65.89	0.86	15.40	4.65	0.08	1.04	3.21	3.27	5.20	0.48	1606	262
Gołdap 6	66.75	0.81	15.26	4.10	0.06	0.98	2.66	3.03	6.27	0.44	1883	269
Gołdap 7	64.98	1.04	14.96	5.09	0.09	1.17	3.08	2.97	5.84	0.55	1874	307
Bartoszyce 4	60.66	1.37	16.05	7.31	0.14	1.63	4.87	3.72	3.74	0.73	1679	347
Bartoszyce 5	60.91	1.21	16.01	7.12	0.13	1.48	4.35	3.37	4.82	0.71	2164	300
Bartoszyce 6	51.29	2.22	14.65	14.82	0.23	2.42	6.01	3.19	3.83	1.29	1673	467
Bartoszyce 7	62.06	0.99	16.97	5.55	0.10	1.15	4.18	3.82	4.98	0.55	2193	265
Pawłówka 17	61.09	1.53	14.00	8.84	0.13	2.02	4.12	2.60	4.08	0.53	1322	192
Pawłówka 144	60.75	1.68	13.94	10.02	0.17	2.29	4.51	2.80	3.47	0.62	1083	225
Pawłówka 85	58.00	1.39	14.91	8.01	0.13	1.87	4.10	2.73	3.52	0.50	1467	180
Filipów 1	58.64	1.49	15.17	8.60	0.13	2.34	4.09	2.72	4.02	0.52	1968	129
Filipów 5	59.74	1.48	14.83	8.64	0.13	2.14	4.40	2.82	3.69	0.53	1795	181
Filipów 8	58.57	1.53	15.14	8.71	0.15	2.16	4.59	2.83	3.99	0.54	2121	183
Filipów 13	57.29	1.84	14.71	10.25	0.17	2.52	5.47	2.97	2.89	0.64	1560	198
Klewno 2	46.30	2.87	14.74	14.86	0.22	3.93	7.63	2.90	3.68	2.15	2110	497
Klewno 3	47.87	2.57	16.34	13.53	0.13	3.75	6.63	3.24	2.60	1.79	1567	444
Kętrzyn 1	58.80	1.03	17.56	5.59	0.10	1.64	4.00	3.16	6.52	0.68	3509	214
Kętrzyn 3	55.35	1.91	17.60	9.50	0.15	1.97	6.69	3.87	4.07	1.39	2235	419
Kętrzyn 4	57.86	1.48	17.47	8.42	0.13	1.90	5.92	3.78	4.10	1.10	2228	276
Kętrzyn 5	53.17	1.75	16.72	9.24	0.15	2.07	6.31	3.69	3.57	1.21	2042	311
Kętrzyn 6	53.78	1.81	16.56	9.89	0.15	1.92	6.42	3.56	4.11	1.38	2431	350

lineaments, marking density contrasts, are enhanced (Wiszniewska *et al.*, 1998, 2000). We suppose that rapakivi-like granite plutons are probably multiple intrusions, emplaced at relatively shallow levels.

PETROLOGY

Eight drill-cores from Olsztyn, Łanowicze, Gołdap, Bartoszyce, Pawłówka, Filipów, Kętrzyn, and Klewno, were investigated geochemically (Fig. 1). Their composition ranges from diorites and monzodiorites (Klewno) to leucogranites (Olsztyn, Łanowicze). Eighty samples were chosen for geochemical and petrological investigation.

The Olsztyn leucogranite is a medium-grained rock characterized by abundant, oriented xenomorphic quartz crystals. The ground-mass is composed of quartz, microcline, plagioclase (An_{21} — normative), minor biotite, and accessory minerals (apatite, zircon, rutile and opaques) (Pl. I, Fig. 3). The rock is commonly albitised (Pl. I, Fig. 4) and partly chloritised and shows various degrees of chloritisation and sericitisation. Some myrmekites are also present.

The Łanowicze drill-core has yielded more than 500 m of crystalline rocks. It consists of several rock types:

1. **Charnockite**. This is a medium-grained rock, in which biotite can locally define a linear fabric. Its modal composition consists of quartz, plagioclase (An_{38} — normative), K-feldspar, biotite, hypersthene and accessory minerals (apatite, zircon, magnetite, ilmenite and monazite) (Pl. I, Fig. 1). Garnet appears in meta-charnockite rocks as well as hypersthene, which breaks down to bowlingite-like material. Rocks display a porphyritic texture with cm-sized K-feldspar and plagioclase crystals (Pl. II, Fig. 1). A poikilitic texture is also present with hypersthene, quartz, biotite and opaques (Pl. I, Fig. 2).

Table 1

of representative samples from the Mazury complex

Co	Cr	Cu	Mo	Nb	Ni	Pb	Rb	Sr	Th	U	V	Y	Zn	Zr
9	18	10	2	9	6	28	159	199	3	3	48	9	38	134
4	19	5	2	6	7	24	185	194	7	3	39	21	50	173
5	23	5	2	7	5	26	166	151	9	3	23	17	34	147
6	12	6	2	6	5	21	181	134	8	3	25	16	27	123
20	37	33	<2	13	25	23	115	223	23	<3	99	40	82	290
11	24	13	<2	9	10	31	145	111	10	<3	35	15	46	141
21	39	25	<2	13	27	21	109	194	24	<3	118	34	101	314
19	47	27	<2	13	27	24	97	245	22	<3	112	35	109	310
21	38	54	<2	17	29	23	138	193	22	<3	115	49	109	336
15	32	21	<2	12	16	25	149	145	21	<3	65	31	64	230
12	22	22	2	11	15	26	146	165	18	<3	59	31	61	220
12	26	25	<2	14	18	24	145	169	21	<3	78	34	79	286
<3	15	91	<2	9	5	27	136	193	22	<3	17	30	91	436
5	21	40	<2	6	5	34	151	174	15	<3	14	32	97	400
9	14	32	<2	5	7	29	137	177	22	<3	15	33	57	396
12	21	19	<2	12	17	26	154	169	21	<3	72	27	76	252
6	3	10	3	11	3	39	233	383	15	3	37	38	74	336
7	3	10	4	33	3	34	170	320	25	3	93	97	130	671
3	3	10	3	31	3	33	180	351	22	3	61	76	111	578
3	3	10	3	15	3	36	173	348	15	3	47	44	93	457
5	3	10	4	20	3	35	205	359	14	5	50	33	74	439
5	3	10	3	26	3	36	196	353	19	3	57	56	96	578
3	3	10	3	20	3	29	108	409	5	6	87	52	147	632
3	3	10	3	15	3	33	129	433	5	5	78	51	140	763
7	3	10	3	33	3	24	117	370	8	7	168	102	240	1316
6	3	10	3	15	3	35	130	457	4	6	66	35	113	552
17	3	22	2	22	18	30	157	274	23	4	134	52	122	504
17	12	21	2	24	15	31	146	262	16	3	155	62	173	572
17	6	19	2	19	17	30	143	359	12	3	115	50	136	444
23	8	29	<2	19	21	12	177	356	9	3	138	37	149	497
18	10	28	<2	17	20	25	121	359	13	<3	142	45	139	500
21	10	23	<2	19	22	27	114	369	9	<3	147	47	142	444
20	< 3	30	<2	22	19	22	108	367	17	3	164	56	169	525
33	6	68	2	45	22	19	82	745	6	3	244	102	299	462
27	3	27	2	33	17	20	94	712	6	3	254	76	256	1171
10	9	5	2	16	4	26	175	561	9	3	66	52	128	659
15	12	11	2	26	8	20	102	546	27	4	122	96	172	1017
13	10	7	2	18	8	20	109	530	11	3	111	69	170	902
14	11	14	2	24	7	20	97	528	12	3	120	85	184	1010
14	13	13	2	26	9	18	105	529	15	3	132	95	182	1181

2. **Granodiorites and granites**. These are less abundant than charnockites from which they differ only by a lack of hypersthene and differences in plagioclase and K-feldspar abundances.

3. **Leucogranites**. These are similar to granodiorite, but are usually albitised with biotite, altered to chlorite.

Metamorphosed rocks with a granitic composition have been also found in the Łanowicze drill-core. They form layers several metres thick within charnockites, granodiorites and granites. The relationships between these rock types suggest that they could have been generated in two magmatic episodes, the first one linked to the last metamorphic event, dated in the Belarussian part of the BBG (Baltic-Belarussian Granulite) zone at 1.76 Ga (Bogdanova *et al.*, 1996), and the second one connected with rapakivi magmatism at *ca.* 1.5 Ga (Claesson *et al.*, 1995*b*). This view is supported by the different textures of the charnockites: the "older" display metamorphic textures with linear biotite and deformed quartz and feldspars, while the "younger" ones display a texture similar to granodiorites. More isotope data are needed to better detail their evolution.

The Gołdap porphyritic granodiorites and quartz monzodiorites are medium- and coarse-grained massive rocks with 3–5 cm-sized plagioclase (An_{29} — normative) and K-feldspar megacrysts (Pl. III, Fig. 1). The groundmass of the rock is made up of plagioclase, K-feldspar, quartz, biotite, minor hornblende, numerous titanite crystals, apatite, zircon and opaques (Pl. IV, Fig. 2). Myrmekites and quartz-biotite symplectites are also present. Changes in the plagioclase/K-feldspar ratio resulted in a magmatic suite from granodiorite (samples 1–3) to quartz monzonite and granite (samples 4–7). The rocks were slightly altered by sericitisation (plagioclases) and amphibolitisation (clinopyroxenes) pro-

Table 2

Rare Earth element (ppm) composition of representative samples from the Mazury complex

Sample	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Olsztyn 1	28.26	47.25	4.84	15.24	2.65	1.43	2.07	0.30	1.64	0.40	0.91	0.13	0.87	0.13
Olsztyn 4	44.67	82.23	9.22	30.79	5.54	1.39	4.53	0.72	3.91	0.81	1.88	0.28	1.57	0.17
Olsztyn 5	48.07	88.98	9.47	29.91	4.90	1.19	3.90	0.61	3.22	0.64	1.58	0.19	1.27	0.18
Olsztyn 7	32.21	58.93	6.35	21.23	3.59	0.96	3.17	N/D	2.69	0.50	1.42	0.19	1.04	0.14
Łanowicze 1	82.71	175.63	19.93	69.96	11.35	2.22	11.51	N/D	7.95	1.73	4.07	0.59	4.15	0.55
Łanowicze 2	33.48	63.99	7.33	24.80	4.17	1.30	3.16	0.44	2.58	0.57	1.71	0.30	2.32	0.39
Łanowicze 9	80.37	171.21	19.39	71.38	12.05	2.44	11.41	N/D	7.22	1.53	3.55	0.48	3.56	0.48
Łanowicze 11	71.16	141.85	16.60	61.19	10.70	2.58	8.87	1.25	7.03	1.42	3.47	0.49	3.08	0.45
Łanowicze 15	72.46	153.21	17.24	62.59	11.02	2.12	11.64	N/D	8.97	1.99	5.02	0.69	4.80	0.60
Łanowicze 17	53.60	119.43	13.49	50.17	9.36	1.52	9.47	0.79	6.36	1.39	3.38	0.50	3.85	0.49
Łanowicze 19	48.40	100.32	11.90	42.27	7.93	1.58	6.88	1.04	5.87	1.16	2.81	0.38	2.08	0.30
Łanowicze 22	58.07	126.64	14.30	52.23	9.91	1.75	10.32	0.96	7.47	1.64	3.57	0.45	3.12	0.39
Łanowicze 24	78.19	160.41	18.80	69.59	12.40	2.52	9.54	1.36	7.70	1.50	4.11	0.57	3.91	0.54
Łanowicze 25	68.13	135.18	16.50	58.89	10.50	3.13	7.61	1.08	5.88	1.17	2.88	0.37	2.49	0.36
Łanowicze 26	49.77	99.08	11.70	42.53	7.71	2.19	6.28	0.96	5.41	1.10	2.90	0.41	2.73	0.39
Łanowicze 27	52.05	114.30	13.14	49.81	8.89	1.80	9.82	N/D	5.95	1.38	2.86	0.38	3.04	0.34
Gołdap 2	104.50	224.50	25.30	98.90	16.60	3.08	11.80	1.90	10.25	2.20	5.55	0.80	5.03	0.76
Gołdap 3	163.00	390.00	44.60	174.00	31.10	5.17	21.20	3.01	18.45	3.85	9,86	1.45	9.40	1.55
Gołdap 4	152.76	336.06	41.36	140.78	27.99	5.40	20.20	2.92	16.79	3.50	9.07	1.31	8.50	1.31
Gołdap 5	116.00	238.00	27.80	102.00	18.10	3.27	12.10	1.92	10.75	2.29	5.75	0.82	5.66	0.83
Gołdap 6	114.00	234.00	26.50	101.00	17.20	2.76	10.40	1.54	8.51	1.91	4.70	0.74	4.56	0.72
Gołdap 7	144.00	301.00	35.90	130.00	22.60	3.97	14.10	2.11	12.35	2.58	6.74	1.04	6.66	1.07
Bartoszyce 4	142.00	291.00	35.60	137.00	23.80	4.67	15.00	2.38	12.30	2.45	5.84	0.76	4.85	0.73
Bartoszyce 5	134.00	271.00	33.00	154.00	22.30	4.51	15.40	2.16	11.70	2.34	5.56	0.71	4.60	0.71
Bartoszyce 6	198.00	432.00	55.90	219.00	40.50	5.78	27.80	4.06	20.90	4.24	10.20	1.39	8.15	1.17
Bartoszyce 7	110.43	227.14	26.58	104.82	17.41	4.61	13.12	1.81	9.41	1.93	4.47	0.66	3.83	0.53
Pawłówka 17	114.01	214.47	24.47	96.17	16.79	3.62	13.05	1.80	10.09	2.02	5.29	0.69	4.45	0.63
Pawłówka 144	92.89	186.96	21.65	84.04	16.10	3.51	12.64	1.84	10.38	2.06	4.99	0.58	3.58	0.48
Pawłówka 85	118.15	241.43	28.01	110.57	19.17	3.38	14.78	2.04	11.72	2.34	6.46	0.85	5.27	0.76
Filipów 1	55.60	125.26	16.11	71.02	12.50	3.49	9.96	1.36	7.79	1.55	3.71	0.46	3.00	0.44
Filipów 5	94.08	187.71	21.69	86.32	14.98	3.71	11.39	1.48	8.68	1.75	4.54	0.60	3.58	0.47
Filipów 8	88.85	177.62	20.75	83.24	14.56	3.71	11.35	1.57	8.79	1.79	4.59	0.60	3.52	0.50
Filipów 13	100.65	205.91	24.24	96.22	16.67	3.84	13.34	1.81	10.50	2.11	5.35	0.71	4.41	0.64
Klewno 2	265.47	573.51	69.32	282.45	45.57	8.08	31.14	3.96	20.86	3.83	9.37	1.22	6.89	0.95
Klewno 3	243.29	517.09	61.25	237.57	37.08	6.99	25.35	3.14	15.98	3.03	7.28	0.92	5.19	0.71
Kętrzyn 1	102.05	224.96	N/D	111.28	20.84	5.00	15.73	2.38	11.44	N/D	5.29	N/D	4.53	0.55
Kętrzyn 3	235.22	517.85	N/D	242.27	39.66	8.29	28.39	3.98	20.19	N/D	9.31	N/D	8.39	1.03
Kętrzyn 4	132.66	293.27	N/D	143.75	25.12	5.78	20.30	2.94	15.03	N/D	6.95	N/D	5.49	0.75
Kętrzyn 5	155.35	351.50	N/D	177.61	31.79	6.50	24.80	3.41	17.62	N/D	8.63	N/D	6.70	0.86
Kętrzyn 6	190.36	424.54	N/D	204.60	35.68	7.78	26.28	3.70	19.21	N/D	9.10	N/D	7.51	1.10

ND — no detected

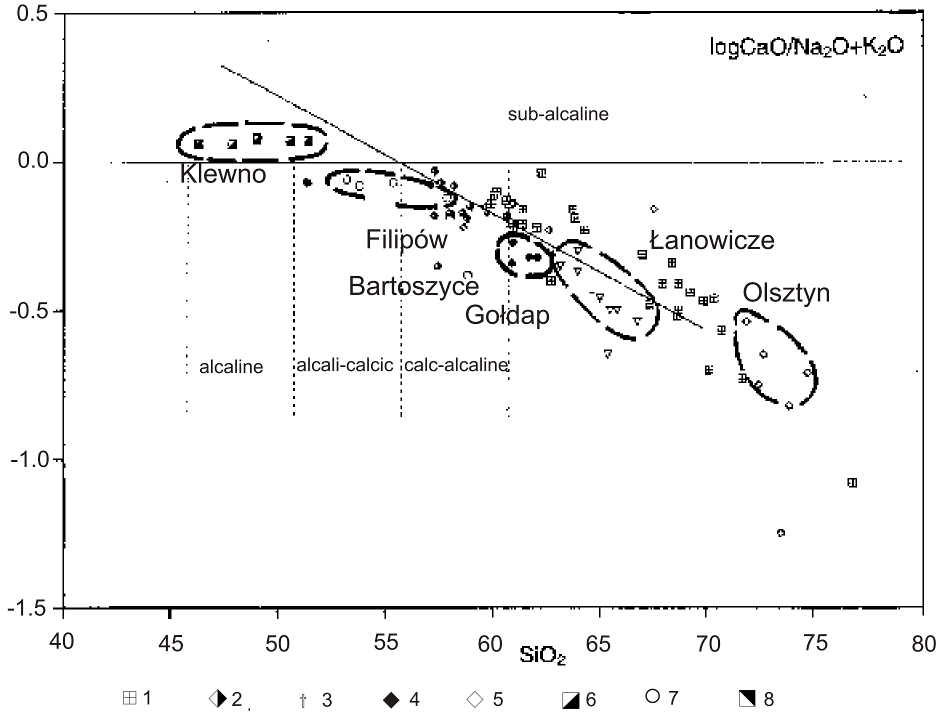


Fig. 3. Peacock index ($CaO/Na_2O + K_2O$) *vs* SiO_2 after Brown (1981)

1 — Łanowicze, 2 — Filipów, 3 — Gołdap, 4 — Bartoszyce, 5 — Olsztyn, 6 — Klewno, 7 — Kętrzyn, 8 — Pawłówka

cesses (Pl. IV, Fig. 1). Minor prehnite and calcite result from late alteration (samples 4 and 5).

Quartz monzonites and granodiorites with subordinate quartz syenites and quartz monzodiorites occur in the Bartoszyce core. They are composed of K-feldspar, plagioclase (An_{33} — normative), quartz, biotite, hornblende, clinopyroxene, apatite, zircon and opaques. The rock is characterised by a porphyritic texture (Pl. III, Fig. 2), with large plagioclase and K-feldspar phenocrysts (Pl. IV, Fig. 3). Myrmekites are widespread (Pl. IV, Fig. 4).

Pawłówka rocks consist in granodiorites made of quartz, plagioclase (An_{41} — normative), K-feldspar, biotite, minor hornblende and clinopyroxene, apatite, zircon and opaques, and rare titanite (usually associated with hornblende). A porphyritic texture (Pl. III, Fig. 3), with 5 cm-sized plagioclases and K-feldspar phenocrysts, is typical. Sericitisation and chloritisation are conspicuous.

Quartz monzonite and minor quartz monzodiorite have been described from the Filipów drill-core. They are made up of plagioclase (An_{42} — normative), quartz, K-feldspar, biotite, clinopyroxene, hornblende, titanite, apatite, minor zircon and opaques (Pl. V, Figs. 3 and 4). They display a porphyritic texture (Pl. II, Fig. 2) with plagioclase and K-feldspar crystals up to 5 cm. The rock is commonly deformed and partly mylonitised.

Quartz monzodiorites to mafic diorites occur in Klewno. The rocks are medium- to coarse-grained and have a massive, ophitic texture. Plagioclase (up to 40 vol% — An_{43} — normative) and biotite are the main component of the rocks. Large euhedral plagioclase crystals, biotite, clinopyroxene or hornblende resulting from clinopyroxene alteration (Pl. V, Fig. 1) were distinguished. The porphyritic texture is present in samples from Klewno where megacrysts (up to 3 cm) of plagioclases are visible. Large K-feldspar (Pl. V, Fig. 2) and quartz are also basic constituents. The accessories are titanite,

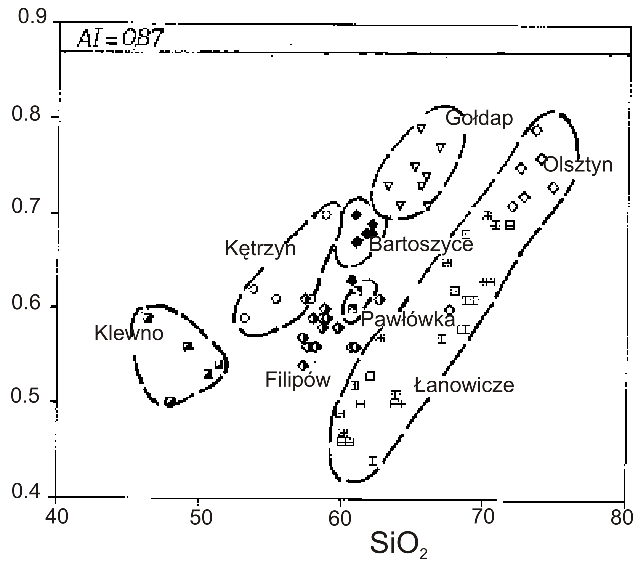


Fig. 4. Agpaitic index (Na +K/Al (atom %) *vs* SiO_2; the limit at AI = 0.87 (minimum value for alkaline meta-aluminous granitoids) is after Liégeois and Black (1987)

For explanations see Fig. 3

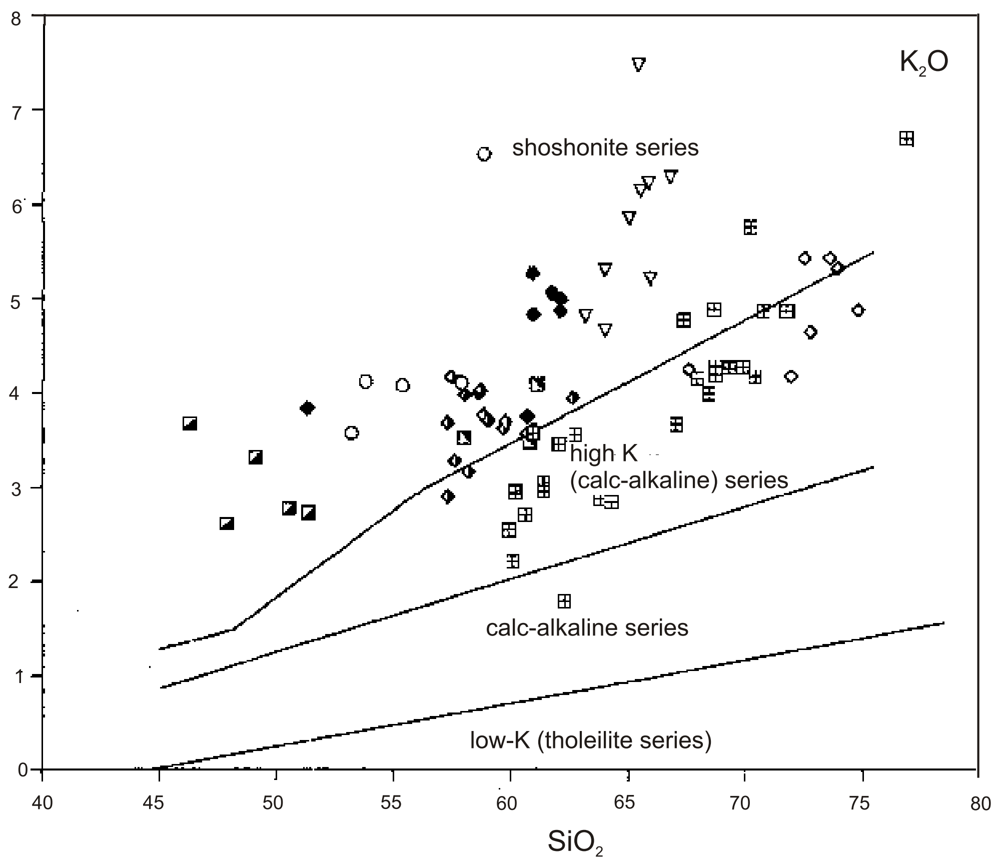


Fig. 5. K_2O *vs* SiO_2 (the dividers are after Rickwood, 1989)

For explanations see Fig. 3

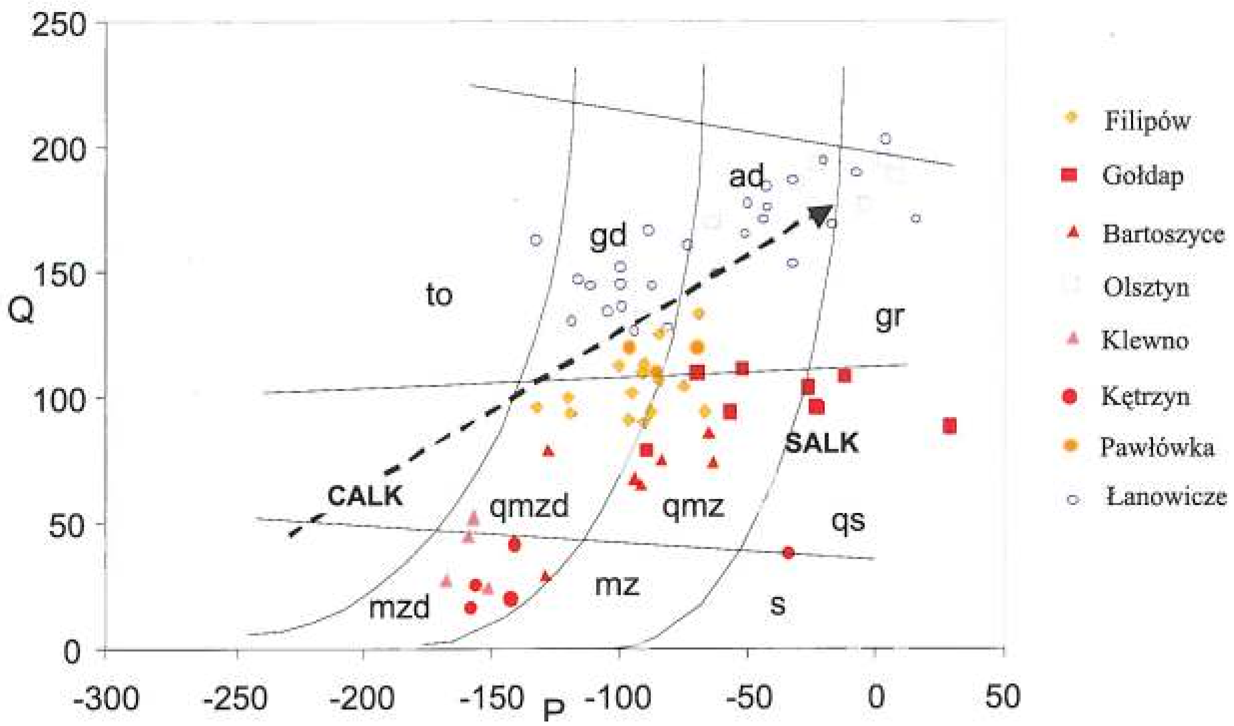


Fig. 6. Q = (Si/3)–[K+Na+(2Ca/3)] against P=K–(Na+Ca) diagram of Debon and Le Fort (1988)

Symbols have following meanings: to — tonalite, gd — granodiorite, ad — adamellite, gr — granite, qmzd — quartz monzodiorite, qmz — quartz monzonite; CALK — line, shown trends of calk-alkaline rocks, SALK — trend lines are also shown

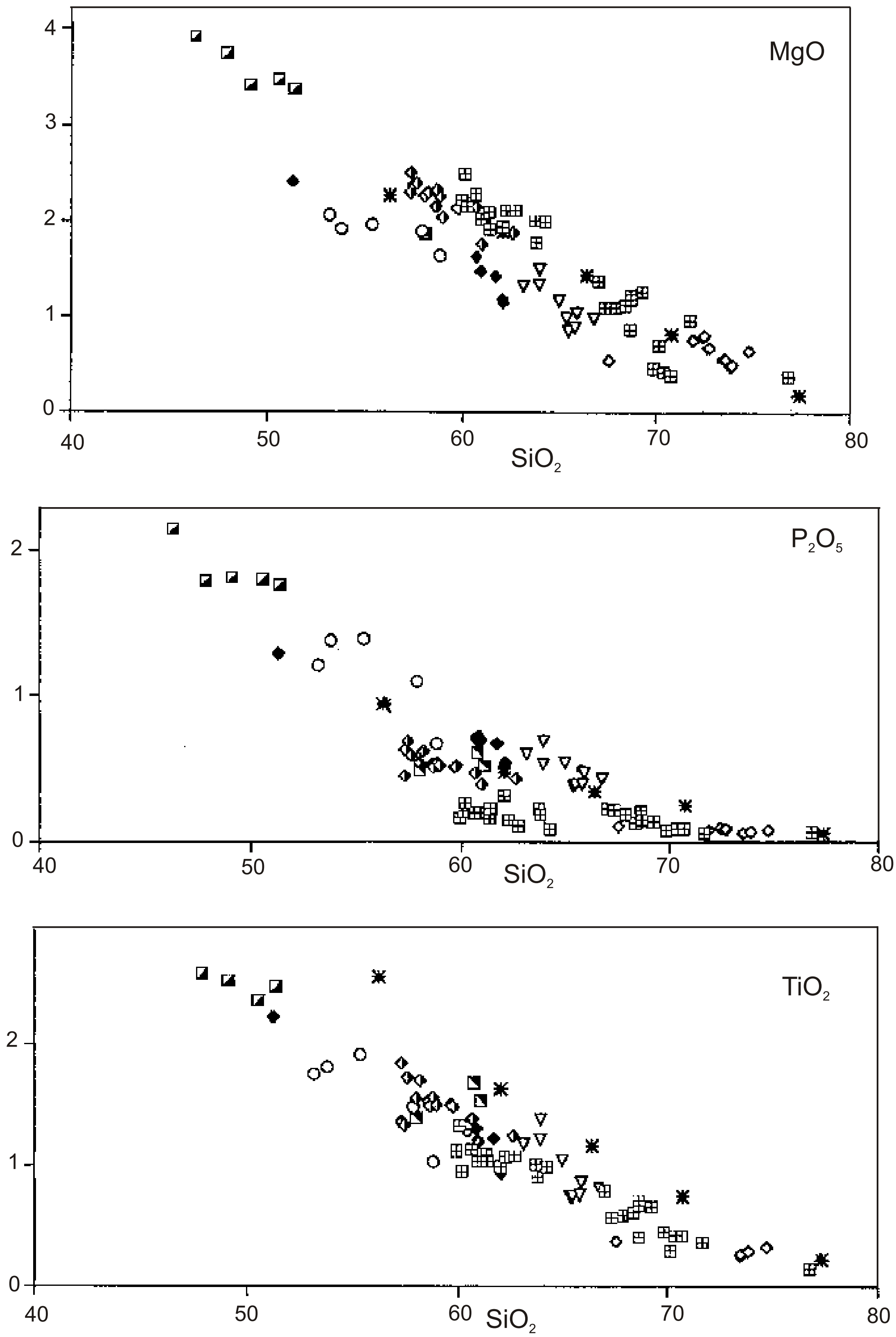


Fig. 7. Major elements content (%) *vs* SiO_2 (Harker diagrams), additional samples from Ardery (C-type granite trend) (Kilpatrick and Ellis, 1992) are included

For explanations see Fig. 3

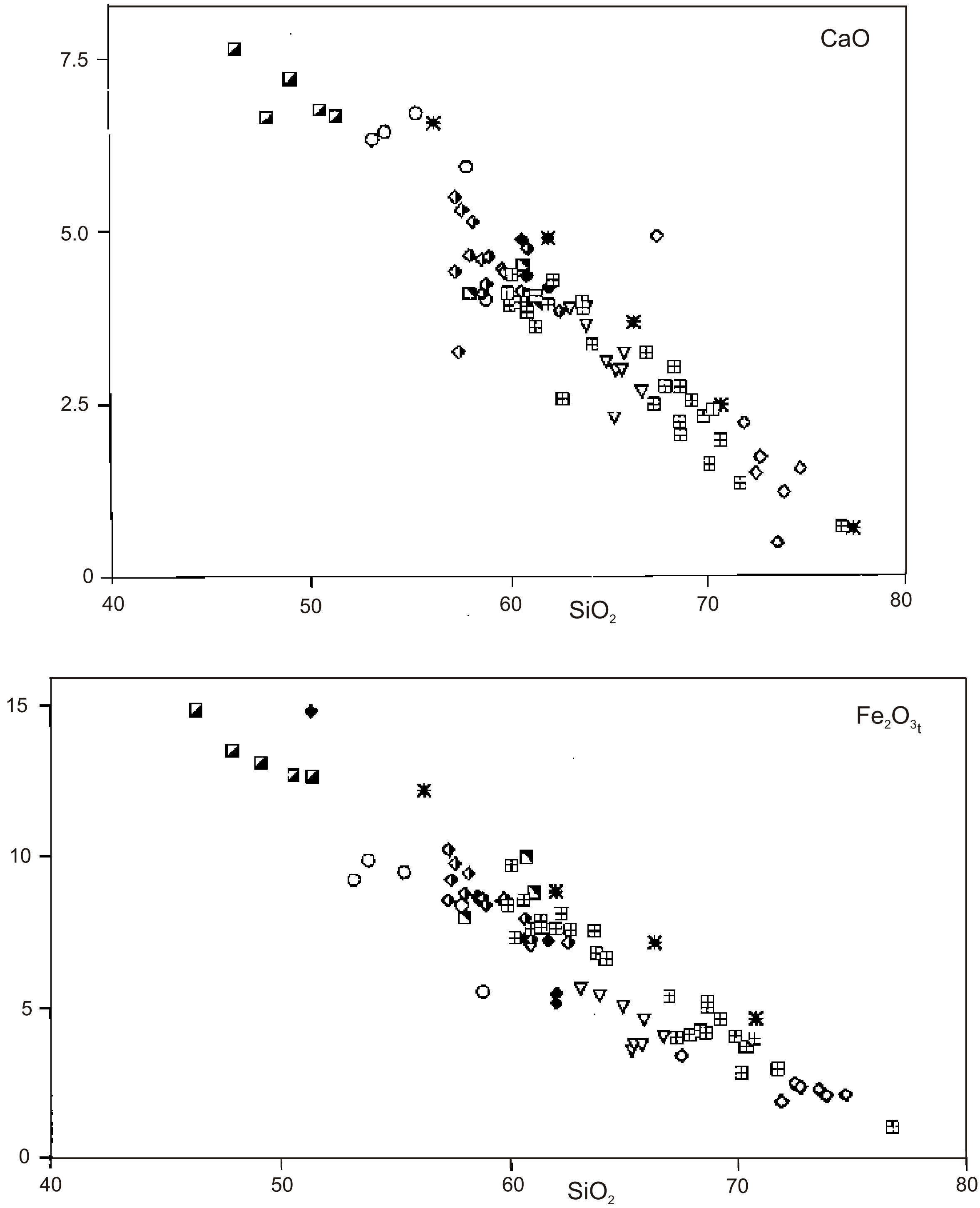


Fig. 7 continued

apatite, zircon and opaques. Myrmekites and biotite-quartz symplectites are also abundant.

The Kętrzyn samples are quartz monzodiorites composed of plagioclase (An_{36} — normative), K-feldspar, quartz, biotite, hornblende, titanite, apatite, zircon and opaques. They display coarse, porphyritic textures with large plagioclase and K-feldspar crystals (Pl. II, Fig. 3).

Most rocks display clear porphyritic textures similar to those observed in rapakivi granite (the only exception are the samples from the Olsztyn drill-core). Typical K-feldspars rimmed by plagioclase have, however, not been observed.

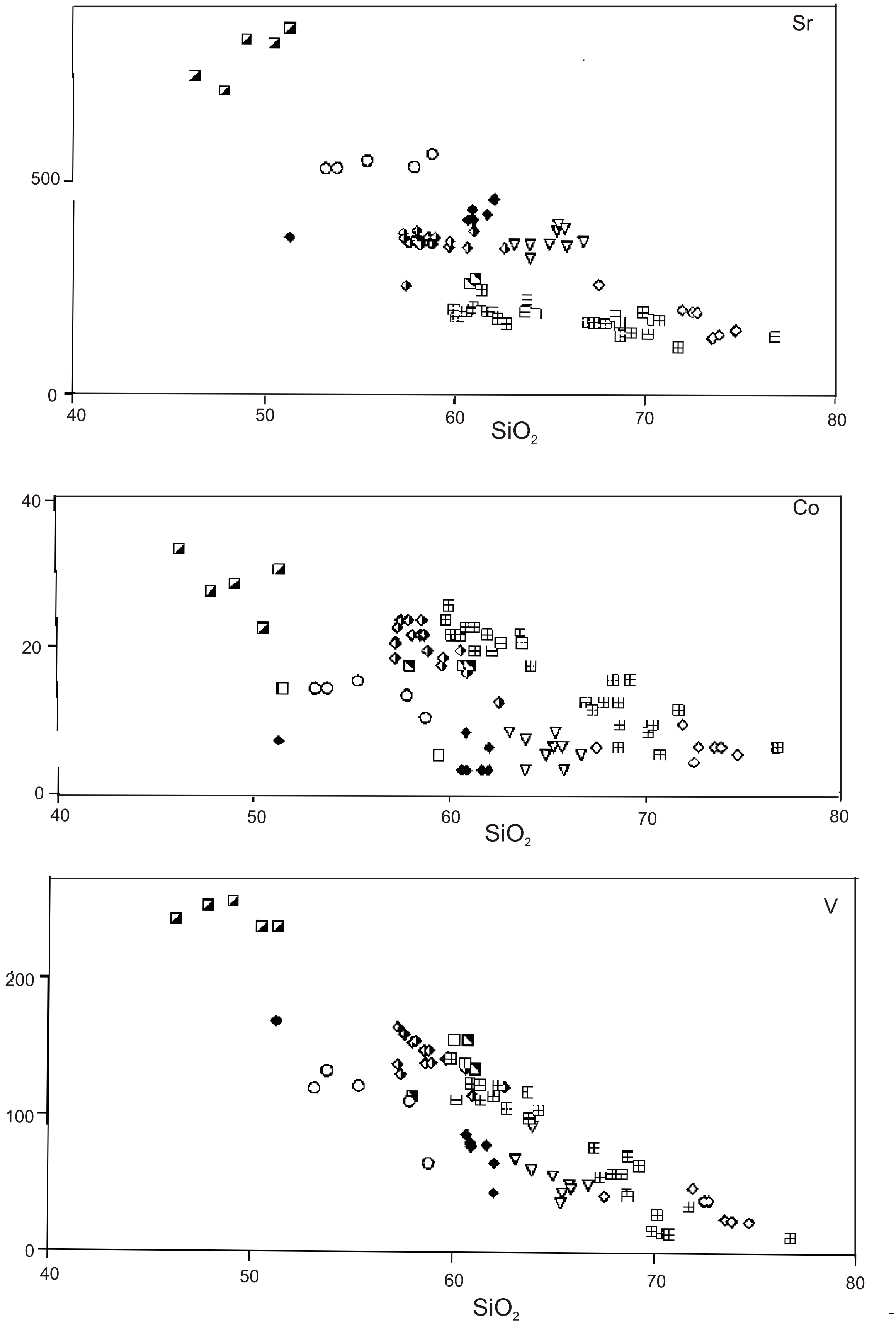


Fig. 8. Sr, Co and V content (ppm) *vs* SiO_2

For explanations see Fig. 3

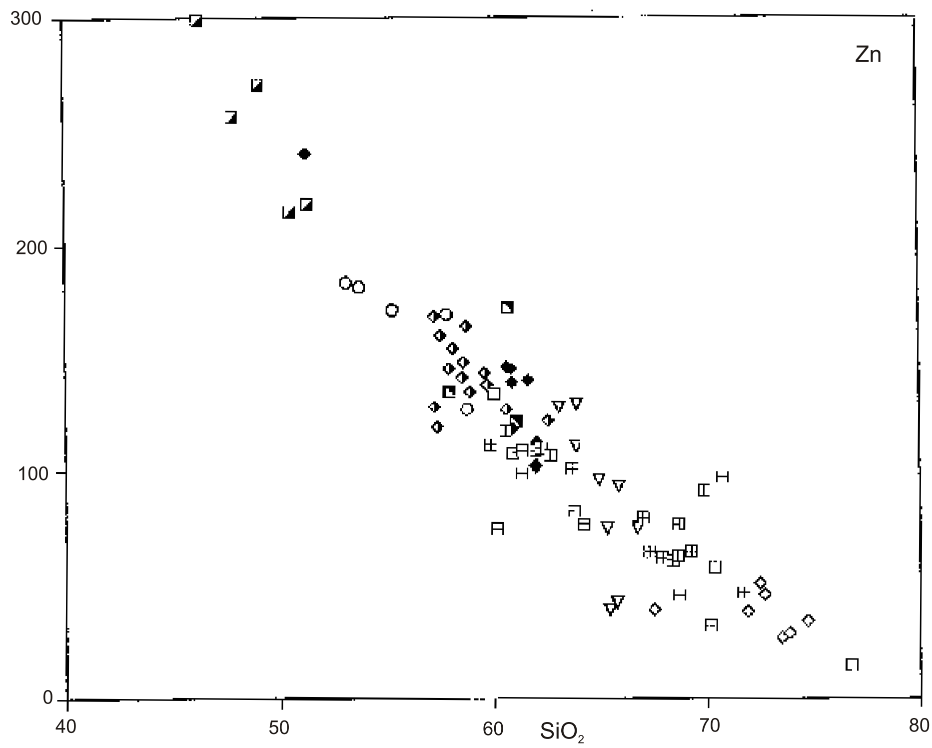


Fig. 9. Zn content (ppm) *vs* SiO_2

For explanations see Fig. 3

GEOCHEMISTRY

Major and trace elements on 80 samples have been analysed by XRF with a *Philips PW 2400 Rtg* spectrometer at the Polish Geological Institute following the standard borate melting method, while REE and some ultratrace elements were analysed in 40 samples by the ICP-MS method with a VG elemental *PQ 2 Plus* spectrometer at the University of Liége (Belgium) following the method described by Vander Auwera *et al.* (1998*a*)> The results are presented in Tables 1 and 2.

The SiO_2 contents range from 46 to 76%. Rock types vary from diorite (Klewno) to leucogranite (Olsztyn) comprising also quartz monzodiorite, quartz monzonite and granodiorite. The more differentiated rock suite is the Łanowicze massif in which SiO_2 ranges from 60 to 76%, other drill-cores giving less differentiated suites.

MAGMA TYPES

In the Peacock diagram (Fig. 3), Łanowicze and Olsztyn are calc-alkaline, and the other massifs lie ambiguously close to the limit between alkali-calcic and alkaline series. None of the rocks has an agpaitic index > 0.8 (except one albitised sample from Łanowicze — Fig. 4), and thus they are not alkaline. The K_2O–SiO_2 diagram (Fig. 5) shows that rocks from Łanowicze are high K calc-alkaline, whereas the rest of the rocks plot into the very high K domain. Since their calc-alkaline character is absent, they cannot be considered as shoshonites. They rather belong to the subalkaline potassic suite (*sensu* Debon and Le Fort, 1988) (Fig. 6).

MAJOR ELEMENTS

Harker diagrams for major elements show that the rocks plot along a grossly defined jotunitic line of descent (Duchesne and Wilmart, 1997; Vander Auwera *et al.*, 1998*b*), which is close to the C-type granite trend (Fig. 7) (Kilpatrick and Ellis, 1992) and is typical of the AMCG suite (anorthosite, mangerite, charnockite [rapakivi] granite). The mafic terms of the suite are TiO_2-, FeO_t- and P_2O_5-rich (4, 18 and 3% respectively), which is a typical feature of jotunites (Fe-Ti-P-rich hypersthene monzodiorites). FeO_{3_t}, MgO and CaO are positively correlated with SiO_2. The Fe/Mg ratio for the Mazury complex is intermediate in most massifs compared to the higher values in the evolved jotunites from Norway (Duchesne and Wilmart, 1997; Vander Auwera *et al.*, 1998*b*).

TRACE ELEMENTS

Harker diagrams for trace elements do not display unique differentiation trends as regards major elements, each group

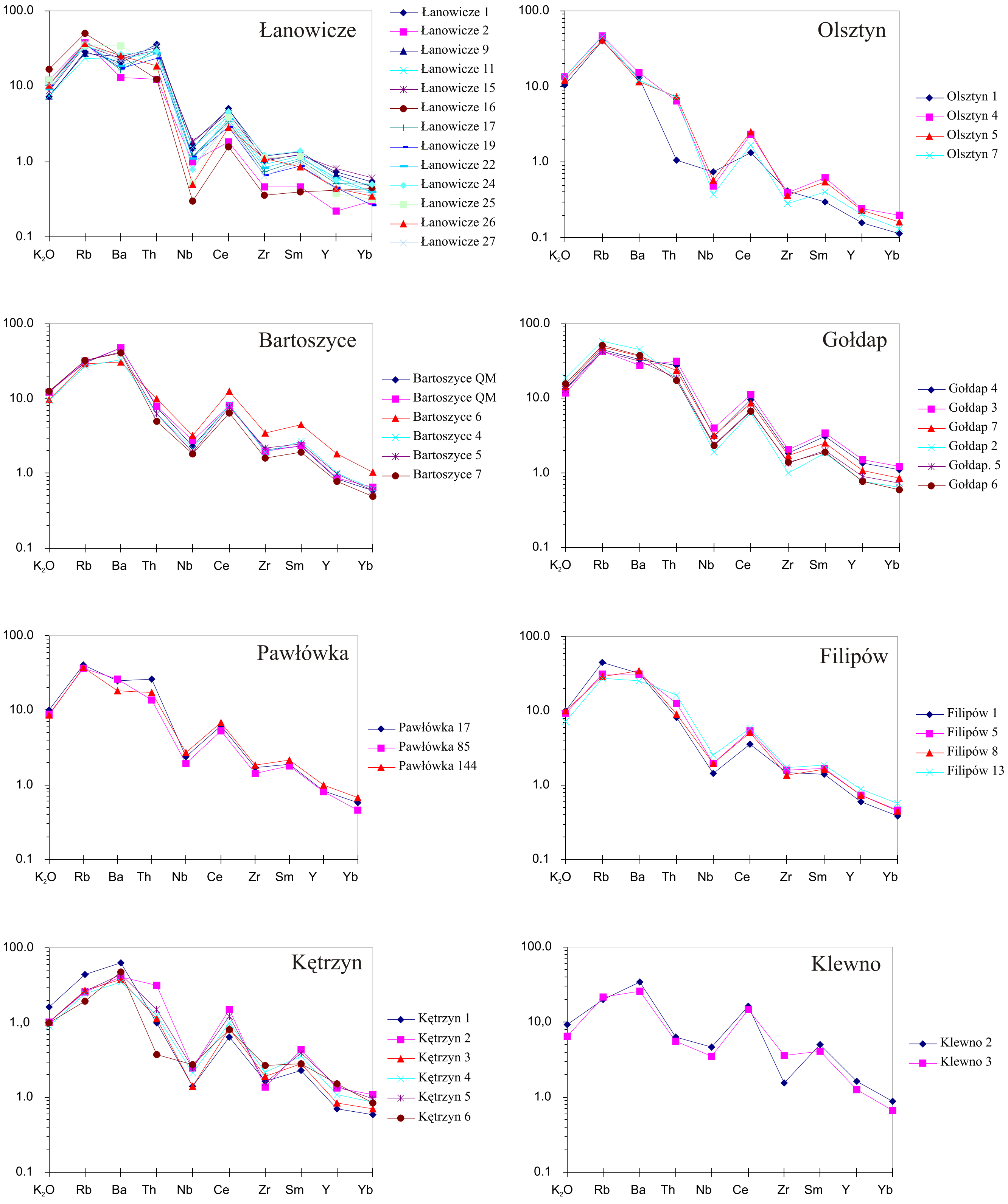


Fig. 10. Spidergrams for rocks from the Mazury complex normalized to ORG (ocean ridge granite)

having its own specificity. The most striking variation is observed in the Sr *vs* SiO_2 diagram (Fig. 8). Each group of rocks has distinct Sr contents which remain nearly constant with differentiation (slightly positive or negative slopes). This horizontal evolution is probably due to a partition coefficient of Sr between plagioclase and melt close to 2 and a liquids mineral assemblage containing *ca.* 50% plagioclase (the main bearer of Sr), thus giving a bulk partition coefficient close to 1. Zn, V and Co show a systematic decrease with SiO_2 (Figs. 8, 9) at the scale of the various drill-cores and within each core. This is

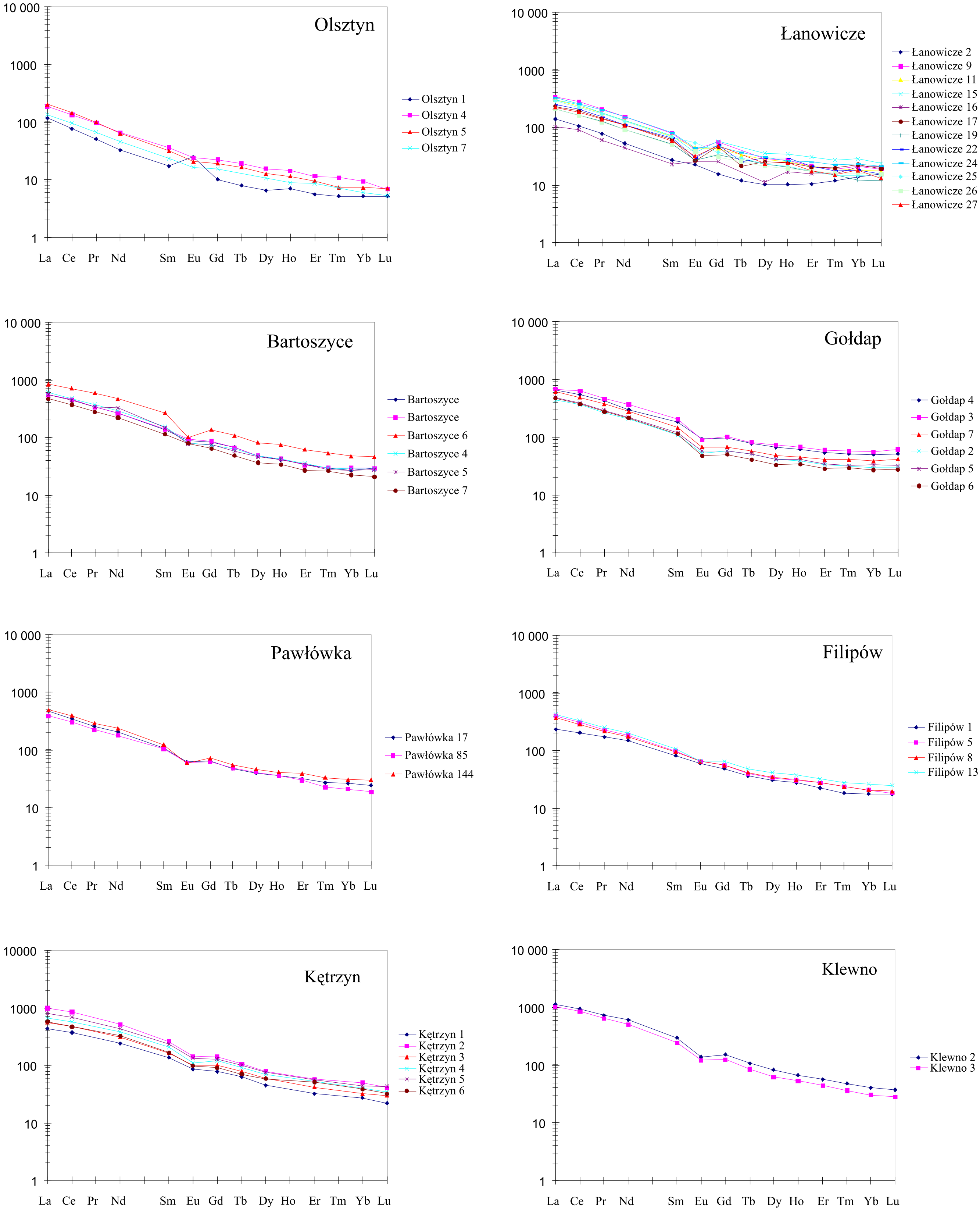


Fig. 11. Chondrite normalized REE distribution in the studied rocks from the Mazury complex

mostly due to a constant subtraction of mafic minerals in the fractional crystallization process or to mixing with a leucogranitic melt.

REE EARTH ELEMENTS

Each group of rocks show similar REE distributions and ORG-normalized spidergrams (Fig. 10), which corroborates their consanguinity, as inferred by Lorenc and Wiszniewska (1999). Each group of rocks has, however, its own signature when considering REE amounts and spidergrams (Fig. 11). Moreover, the small range of variation in REE and other incompatible elements in each massif confirms that fractional crystallisation has only played a subordinate role in internal differentiation (except for Łanowicze). More or less pronounced Nb and Zr anomalies can be observed in all the massifs. The Nb anomaly is classically interpreted as reflecting a crustal input or influence, but this can also result from Nb-rich mineral fractionation. The Zr negative anomaly is probably due to zircon fractionation.

SUGGESTIONS FOR FURTHER RESEARCH

These new data support our working hypothesis which proposes that the different massifs represent different cogenetic magma batches, each of them having slightly evolved by differentiation in magma chambers at the level of final emplacement. As the parental magmas grossly define a liquid line of descent and because most of their geochemical characteristics are similar (for instance parallel REE patterns and spidergrams), we also put forward the working hypothesis that they were generated by different degrees of partial melting of a unique source. If it is accepted that the liquid line of descent reproduces the position of a cotectic line in a phase diagram at the P,T, fO_2 conditions of melting, it would be interesting to investigate whether the variation from batch to batch results from variation of position of the cotectic line with pressure and other intensive variables (fO_2, *etc*.). Mixing with anatectic liquids must also be taken into consideration. The source rocks should have a relatively homogeneous modal composition resulting in a monotonous REE distribution. Similarities with the Rogaland jotunites (Norway) point to a source made up of a series of deep crustal rocks of basic composition, either gabbronoritic or amphibolitic.

The problems that we have just outlined here require further investigation. Isotope geochemistry, modelling of partial melting process and calculation of mineral assemblages responsible for the fractionation in each batch should help in deciphering the genetic processes and the nature of the source.

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