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DETRITAL GARNETS FROM THE UPPER CRETACEOUS–PALAEOCENE SANDSTONES OF THE POLISH PART OF THE MAGURA NAPPE AND THE PIENINY KLIPPEN BELT: CHEMICAL CONSTRAINTS

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Abstract: Heavy mineral assemblages of the Upper Cretaceous–Palaeocene sandstones of the Polish part of the Magura Nappe and the Pieniny Klippen Belt (PKB) were studied. They consist mainly of stable minerals, such as zircon, tourmaline and rutile, but in many assemblages significant amounts of garnets are also present. To describe the provenance of the main heavy mineral groups their chemical composition was analysed. This article deals with the garnets group. Heavy minerals, including garnets, were derived to the Magura Basin from two opposite source areas: the north-west (northern) and the south-east. In the chemical composition of the analysed garnets, FeO and the almandine molecule are definitely dominant, but garnets with a raised MgO and pyrope molecule content were also found. Proportions among the main elements occurring in garnets indicate that they were formed under low- to medium grade metamorphic conditions in the southeastern source area, and medium- to high-grade conditions in the northern one.

Key words: heavy minerals, garnets, source rocks, Magura Nappe, Polish Carpathians.

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INTRODUCTION

The problem of location and character of source areas supplying the Magura Basin with clastic material was touched upon many times in the literature. Attempts at such a characterisation were undertaken on the basis of investigations of exotic rocks (Birkenmajer, 1979, 1986, 1988; Sikora & Wieser, 1979; Oszczypko, 1975; Krawczyk & Słomka, 1985, 1987; Wieser, 1985; Krawczyk *et al.*, 1987; Birkenmajer & Skupiński, 1989; Birkenmajer & Wieser, 1990), and heavy mineral analyses (Łoziński, 1956, 1966; Krystek, 1965; Krysowska-Iwaszkiewicz & Unrug, 1967; Szczurowska, 1985; Marek, 1988; Fediuk & Kozłowski, 1989; Winkler & Ślączka, 1992, 1994; Cieszkowski *et al.*, 1999; Salata & Oszczypko, 2000; Salata, 2001, 2002 a, b, 2003).

Investigations of heavy mineral assemblages from the Upper Cretaceous–Palaeocene sandstones of the Magura Nappe, and especially analyses of their chemical composition, have revealed the petrographic nature of their source rocks (Salata & Oszczypko, 2000; Salata, 2001, 2002 a, b; Salata, 2003). The results were established on the basis of analyses of the chemical composition of main mineral groups occurring in the investigated assemblages. In heavy mineral assemblages a mixture of different groups of minerals were present and each of them could have crystallized in different type of rocks. Therefore, in order to be accurate about the petrographic type of rocks building source areas, a separate description of each mineral group is needed.

The aim of this paper is to present the results of the chemical analyses of garnets occurring in the Upper Cretaceous–Palaeocene sandstones of the Magura Nappe and, on that basis, to characterise the types of their source rocks.

SOURCE AREAS OF THE MAGURA BASIN DURING UPPER CRETACEOUS–PALAEOGENE TIME

During the Late Cretaceous and Palaeogene, the Magura Basin was supplied with clastic material from the, non-existing today, source areas situated at the northern and southern margins of this Basin. The Silesian Ridge is commonly considered to be the northern source area (Książkiewicz, 1962; Pescatore & Ślączka, 1984), while the position of the southern one is still a topic for discussion (see Birkenmajer, 1986, 1988; Oszczypko, 1975, 1992, 1999; Oszczypko *et al.*, 2003 a, b; Sikora, 1976; Marschalko, 1975,

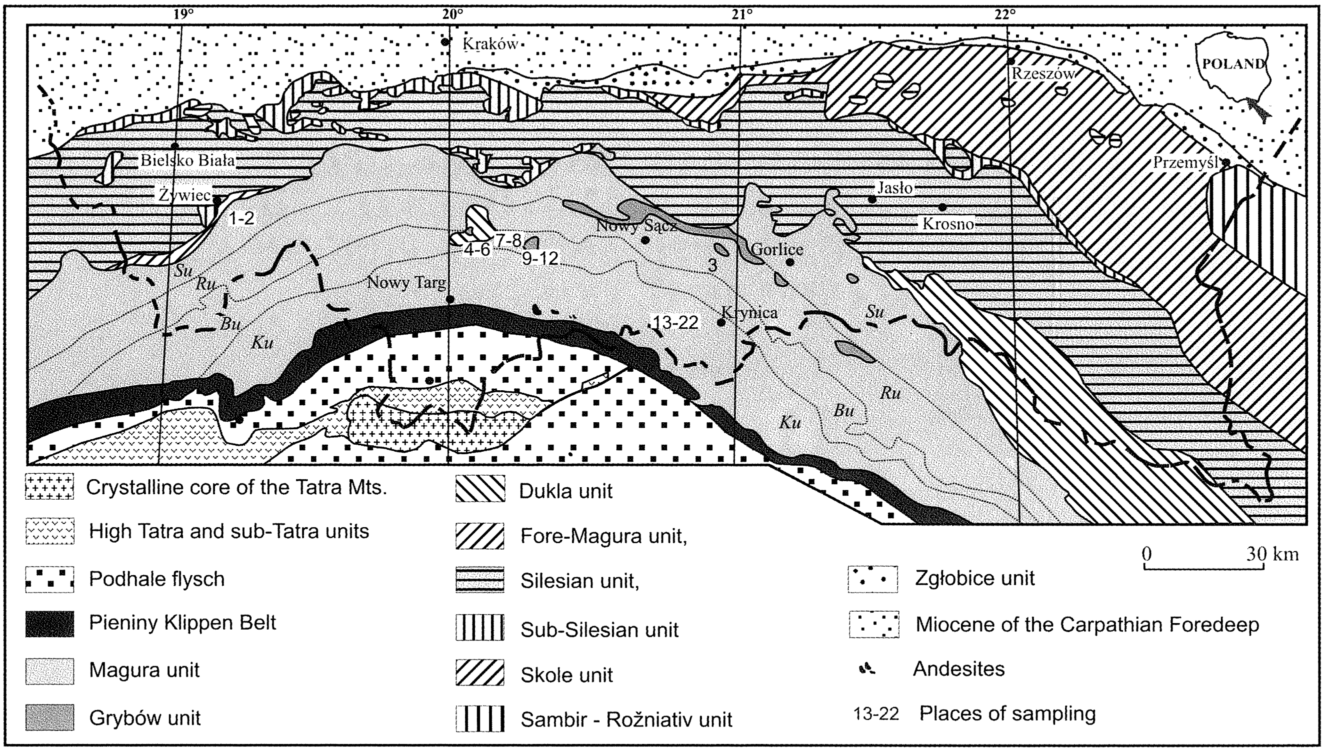

Fig. 1. Geological map of the Carpathians and location of the studied sections (after Żytko *et al.*, 1989, and Lexa *et al.*, 2000; supplemented and modified): 1 – Mutne (M), 2 – Stryszawa (ST), 3 – Grybów (G), 4 – Konina (KO), 5 – Koninki (KN), 6 – Poręba Wielka (PW), 7 – Półrzeczki (PŁ), 8 – Lubomierz (L), 9 – Przysłop (PRZ), 10 – Białe (B), 11 – Szczawa (SC), 12 – Zasadne (Z), 13 – Krościenko Łąkcica (KŁ), 14 – Krościenko Zawiasy (KZ), 15 – Sielski Stream (PS), 16 – Stary Stream (D), 17 – Szczawnica Zabaniszcze (SZ), 18 – Czarna Woda stream (CW), 19 – Życzanów (Ż), 20 – Wierchomla (W), 21 – Muszyna Złockie (SL), 22 – Jastrzębik (J) (symbols of locations are used in Tables 1–8), Su – Siary, Ru – Rača, Bu – Bystrica, and Ku – Krynica subunits

1980; Rakus *et al.*, 1988; Mišik *et al.*, 1991 a, b; Winkler & Ślączka, 1994; Ellouz & Roca, 1994; Golonka *et al.*, 2000, 2003; Nemčok *et al.*, 2000; Poprawa *et al.*, 2002).

According to Birkenmajer and Wieser (1990) as well as Birkenmajer and Skupiński (1989), the clastic material (among which andesite pebbles were found) of the Pieniny Klippen Belt (PKB) was derived from the Andrusov Ridge. The ridge is considered to be an accretionary prism located on the southern margin of the PKB, which was formed as result of the subduction of the ocean floor with its sedimentary cover under the continental block.

In the Late Cretaceous through Palaeocene, the northwest source area supplied the clastic material to the Magura Basin for Jaworzynka Beds, Mutne Sandstone, and Ropianka Beds in the Beskid Żywiecki range (Sikora & Żytko, 1959; Książkiewicz, 1962), and for Jaworzynka Beds of the Magura and Grybów units on the southern rim of the Mszana Dolna tectonic window (Salata & Oszczypko, 2000).

The clastic material for Szczawina Sandstone in the Beskid Żywiecki range (Sikora & Żytko, 1959), Szczawina Sandstone and Ropianka Beds in the Grybów area (Sikora, 1970), Szczawina Sandstone and Ropianka Beds in the area of Szczawa, Młyńczyska and the southern rim of the Mszana Dolna tectonic window (Cieszkowski *et al.*, 1989; Malata *et al.*, 1996; Oszczypko, 1999), as well as Jarmuta and Szczawnica formations (Książkiewicz, 1962) was derived from the opposite directions.

GEOLOGICAL SETTING

The investigations were concentrated in the middle and southern part of the Magura Nappe, where the best exposures of Upper Cretaceous and Palaeocene sediments could be found.

The samples were collected in the Siary, Rača, Bystrica, and Krynica subunits of the Magura Nappe as well as in the Grybów Unit, in the Grajcarek Unit, and in the Branisko-type succession of the PKB (Fig. 1).

Sandstone samples for heavy mineral investigations were collected from the following lithostratigraphic units:

(1) Sromowce Fm./Jarmuta Fm. (Coniacian–Campanian) in the Branisko-type succession of the PKB (Birkenmajer, 1977; Kulka *et al.*, 1985),

(2) Malinowa Fm. (Turonian–Santonian) in the Krynica and Bystrica subunits (Birkenmajer & Oszczypko, 1989; Cieszkowski *et al.*, 1989; Oszczypko *et al.*, 1990),

(3) Kanina Beds (Campanian–Maastrichtian) in the Rača (Cieszkowski *et al.*, 1989; Oszczypko, 1992; Bąk & Oszczypko, 2000) and Bystrica subunits (Sikora & Żytko, 1959; Sikora, 1970; Cieszkowski *et al.*, 1989; Malata & Oszczypko, 1990; Oszczypko *et al.*, 1991; Oszczypko, 1992; Malata *et al.*, 1996),

(4) Jaworzynka Beds (Senonian–Palaeocene) in the Grybów Unit (Burtan & Łydka, 1978) and Rača Subunit (Sikora & Żytko, 1959; Bąk & Oszczypko, 2000),

(5) Szczawina Sandstone (Campanian–Maastrichtian;

Table 1

Representative compositions of heavy mineral assemblages in the studied Upper Cretaceous-Palaeocene sandstones

Lithostratigraphic unit	Sample No.	Zr, Mnz, Xe	Tur	Rt	Grt	Cr-Spl	Ap	Ep	St	Brk	Cld
Jaworzynka Beds	KN12	30.8	29.5	17.5	17.0	0.3	2.9	0.2	1.5	0.3	-
Mutne Sandstone	M1	20.0	5.7	13.8	60.3	0.1	-	-	0.1	-	-
	M2	31.9	6.4	18.9	42.5	0.2	-	-	0.1	-	-
	M3	24.2	14.5	29.1	31.2	0.1	0.9	-	-	-	-
	ST1	17.8	11.9	24.9	45.0	0.2	0.2	-	-	-	-
	ST2	16.2	11.6	12.4	59.0	-	0.8	-	-	-	-
Szczawina-like sandstone	KN 1	29.6	41.1	15.9	2.5	-	10.5	-	0.1	0.3	-
	KN2	19.9	53.2	11.9	9.3	-	2.9	0.2	0.2	2.2	0.2
Ropianka Beds	KN7	26.1	60.9	8.3	2.6	0.6	0.6	-	0.9	-	-
Szczawina Sandstone	PW1	17.5	35.7	20.5	23.8	-	0.9	0.1	0.3	1.2	-
	PW2	28.9	38.0	18.6	2.5	-	9.8	-	-	2.2	-
Ropianka Beds	PŁ2	32.7	44.4	17.0	3.7	0.2	0.0	1.8	-	0.2	-
Jaworzynka Beds	PŁ4	21.3	18.5	21.1	2.4	-	26.6	2.6	-	7.5	-
	PŁ5	26.0	31.8	23.9	9.9	0.8	6.3	0.9	-	0.4	-
	PŁ6	58.3	11.5	7.2	10.4	0.2	6.2	2.2	0.8	2.8	0.4
Szczawina-like sandstone	G1	19.2	52.3	12.5	7.7	-	7.7	-	-	0.6	-
Kanina Beds	G3	4.2	72.2	1.9	15.6	3.3	2.8	-	-	-	-
Ropianka Beds	G4	31.6	10.8	8.3	45.8	0.7	2.8	-	-	-	-
	G5	12.5	51.7	11.8	14.7	6.1	3.2	-	-	-	-
Kanina Beds	G6	4.6	55.0	32.8	3.8	2.9	0.9	-	-	-	-
Szczawina Sandstone	PW4	11.7	58.9	20.5	4.4	0.1	1.7	0.3	0.5	1.6	0.3
	KN9	22.4	40.3	17.4	15.3	1.0	2.7	0.1	-	0.6	0.2
Ropianka Beds	KN10	18.3	47.3	28.5	3.4	-	0.8	-	-	1.7	-
	KN11	19.2	49.6	26.5	2.2	-	0.8	-	-	1.7	-
Szczawina Sandstone	KO1	18.4	30.6	24.1	0.5	-	17.0	-	-	9.4	-
	KO4	18.1	35.5	9.9	28.1	-	6.2	0.2	0.3	1.7	-
Ropianka Beds	KO5	31.7	28.3	15.3	20.1	-	4.3	-	-	0.3	-
Szczawina Sandstone	L4	14.2	37.0	24.0	22.0	0.3	2.2	-	-	0.3	-
Kanina Beds	B1	65.0	18.2	7.8	0.7	8.0	0.1	-	0.2	-	-
Szczawina Sandstone	B2	40.9	30.3	25.7	1.2	-	1.9	-	-	-	-
	Z2	10.1	67.7	8.0	7.4	-	4.2	1.7	-	0.9	-
Malinowa Fm.	SC1	23.2	42.2	17.2	12.2	-	4.5	-	-	0.7	-
	SC2	15.8	53.3	23.4	3.0	-	2.8	-	-	1.7	-
Życzanów Mb.	Ż1	21.1	21.2	20.8	36.0	0.3	0.6	-	-	-	-
	Ż2	25.3	41.8	15.9	14.4	0.4	2.2	-	-	-	-
	Ż3	39.1	25.9	18.5	13.1	0.9	0.3	-	-	2.2	-
Szczawnica Fm.	Ż4	17.6	56.3	10.4	12.2	3.5	-	-	-	-	-
	W1	17.5	31.1	27.3	12.7	11.4	-	-	-	-	-
	W2	21.8	18.3	23.3	36.0	0.6	-	-	-	-	-
	KŁ2	43.4	32.2	16.6	0.2	5.9	0.1	1.4	-	0.2	-
Malinowa Fm.	J2	30.8	31.1	16.9	17.3	0.3	3.6	-	-	-	-
	SL3 132-133	31.9	29.8	14.3	19.2	-	4.5	-	-	0.3	-
	SL3 136-136.10	33.8	21.0	15.2	24.8	0.2	5.0	-	-	-	-
Jarmuta Fm. (Magura Nappe)	PS1	45.7	25.7	13.6	10.5	1.6	2.4	-	-	0.5	-
	D2	16.3	48.6	13.2	17.3	3.7	0.7	-	0.2	-	-
	CW	44.2	18.0	13.8	14.8	8.2	0.5	-	0.2	-	0.3
	SZ1	48.4	25.1	14.8	0.9	9.1	1.7	-	-	-	-
	SZ2	20.6	41.6	6.8	23.5	1.5	5.6	-	-	0.1	0.3
Sromowce Fm./ Jarmuta Fm. (PKB)	KZ 1	35.3	36.3	17.4	3.7	2.3	0.9	4.1	-	-	-
	KZ3	38.0	47.2	10.0	2.2	1.8	0.6	0.2	-	-	-

Zr – zircon, Mnz – monazite, Xe – xenotime, Tur – tourmaline, Rt – rutile, Grt – garnet, Cr-Spl – chromian spinel, Ap – apatite, Ep – epidote, St – staurolite, Brk – brookite, Cld – chloritoid (Salata, 2003)

Maastrichtian–Palaeocene) in the Rača and Bystrica subunits (Sikora & Żytko, 1959; Sikora, 1970; Cieszkowski *et al.*, 1989; Malata & Oszczypko, 1990; Oszczypko *et al.*, 1991; Oszczypko, 1992; Malata *et al.*, 1996),

(6) Jarmuta Fm. (Maastrichtian–Palaeocene) in the Grajcarek Unit (Birkenmajer & Oszczypko, 1989),

(7) Ropianka Beds (Palaeocene) in Rača and Bystrica subunits (Cieszkowski & Oszczypko, 1986; Cieszkowski *et al.*, 1989; Oszczypko *et al.*, 1990; Oszczypko, 1992; Malata *et al.*, 1996; Bąk & Oszczypko, 2000); in case of Ropianka Beds samples from sandstones displaying palaeotransport from the northern source area were chosen for chemical analyses of garnets.

(8) Mutne Sandstone (Palaeocene) in the Siary Subunit (Sikora & Żytko, 1959; Chodyń, 2002)

(9) Szczawnica Fm. (Palaeocene–Lower Eocene) in the Krynica Subunit (Birkenmajer, 1965; Birkenmajer *et al.*, 1979; Birkenmajer & Dudziak, 1981; Birkenmajer & Oszczypko, 1989; Oszczypko *et al.*, 1990),

(10) Życzanów Mb. of the Szczawnica Fm. (Palaeocene) in the Krynica Subunit (Oszczypko, 1973, 1979; Oszczypko & Porębski, 1985; Birkenmajer & Oszczypko, 1989; Oszczypko *et al.*, 1990).

MATERIALS AND METHODS

The studied samples were taken from medium-grained sandstones. To avoid error caused by the hydraulic factor, all samples were of similar grain sizes. The samples were crushed, cleaned of clay material, and sieved. For separation of heavy minerals and further analyses, the fraction 0.063–0.13 mm was chosen as it comprised the best spectrum of heavy minerals. Heavy fractions were separated using magnetohydrostatic method (Kusiak & Paszkowski, 1998) in the aqueous solution of manganese chloride ($MnCl_2 \cdot 4H_2O$) with the concentration 1240 kg/m^3 at 24–30A. The amounts of heavy minerals were established during standard microscopic observations by counting 200–300 transparent grains in each sample. In heavy mineral assemblages (especially in Mutne Sandstone), grains of monazite and xenotime were found. Nevertheless, due to the high degree of roundness and corrosion of grains their distinction from zircon grains and their exact amount was difficult to establish. Consequently, these minerals were counted and summed together with the zircon population (Table 1).

The chemical composition of garnets was estimated in polished grain mounts using scanning electron microscopy (SEM) JEOL 5410 equipped with an energy dispersive spectrometer (EDS) Voyager 3100 (Noran). The calculations of the chemical formulae of garnets were carried out according to standards from the software library supplied by the manufacturer. All calculations were based on 24 oxygen atoms. In analytical procedures, the total amount of Fe was expressed as FeO and the amount of Fe^{+3} was established according to the ideal stoichiometric formula of garnets.

The total numbers of analyses are given in explanations to Tables 3, 4, and 5.

Table 2

Contents of garnets in sandstones from the investigated lithostratigraphic units

	[%] of garnets		
Lithostratigraphic unit	minimum	maximum	average amounts
Jaworzynka Beds	1	17	8
Ropianka Beds	0	46	46
Mutne Sandstone	31	60	48
Malinowa Fm.	3	25	13
Kanina Beds	1	16	6
Szczawina Sandstone	0	28	8
Jarmuta Fm.	1	23	13
Szczawnica Fm.	0	36	10
Życzanów Mb.	13	36	21

RESULTS

CONTENTS OF GARNETS IN THE INVESTIGATED SEDIMENTS

Heavy mineral assemblages occurring in the investigated sediments are dominated by stable and ultrastable minerals, such as zircon, tourmaline and rutile, which occur in all the studied samples in variable amounts. Garnets are present in almost all of the sampled lithostratigraphic units. Nevertheless, the highest amounts of garnets are connected with sediments displaying NW palaeocurrents, especially with Mutne Sandstone (Table 1). Garnet is the main component there reaching an amount of 60% of the heavy fractions. In sediments derived from the SE direction the minerals of garnet group usually did not exceed 20% of all transparent minerals, and only in exceptional cases they reached the amount of 36% (in two samples of the Szczawnica Fm. and the Życzanów Mb.) (Tables 1, 2).

MICROSCOPIC FEATURES OF GARNETS

In the investigated sediments garnets occur in the forms of non rounded, irregular fragments and splinters; rounded grains may be found sporadically. They are macroscopically mostly pink, sometimes orange-brownish. The observed grains did not display anomalous anisotropy. Fractured grains are usually filled with carbonates. Solid inclusions of quartz were also found inside garnets. The faceted surfaces of grains in the analysed garnets are common, which indicates their dissolution during diagenesis (Morton, 1985).

CHEMICAL COMPOSITION OF GARNETS

The chemical composition of the analysed garnets from the sampled lithostratigraphic units is very similar (the representative data for each sampled lithostratigraphic unit are presented in Tables 3–8). In all of the garnets studied, the dominating component is FeO – its content usually exceeds 30 wt %. This is accompanied by much smaller amounts (up to 5 wt %) of MgO, MnO and CaO. Higher contents of

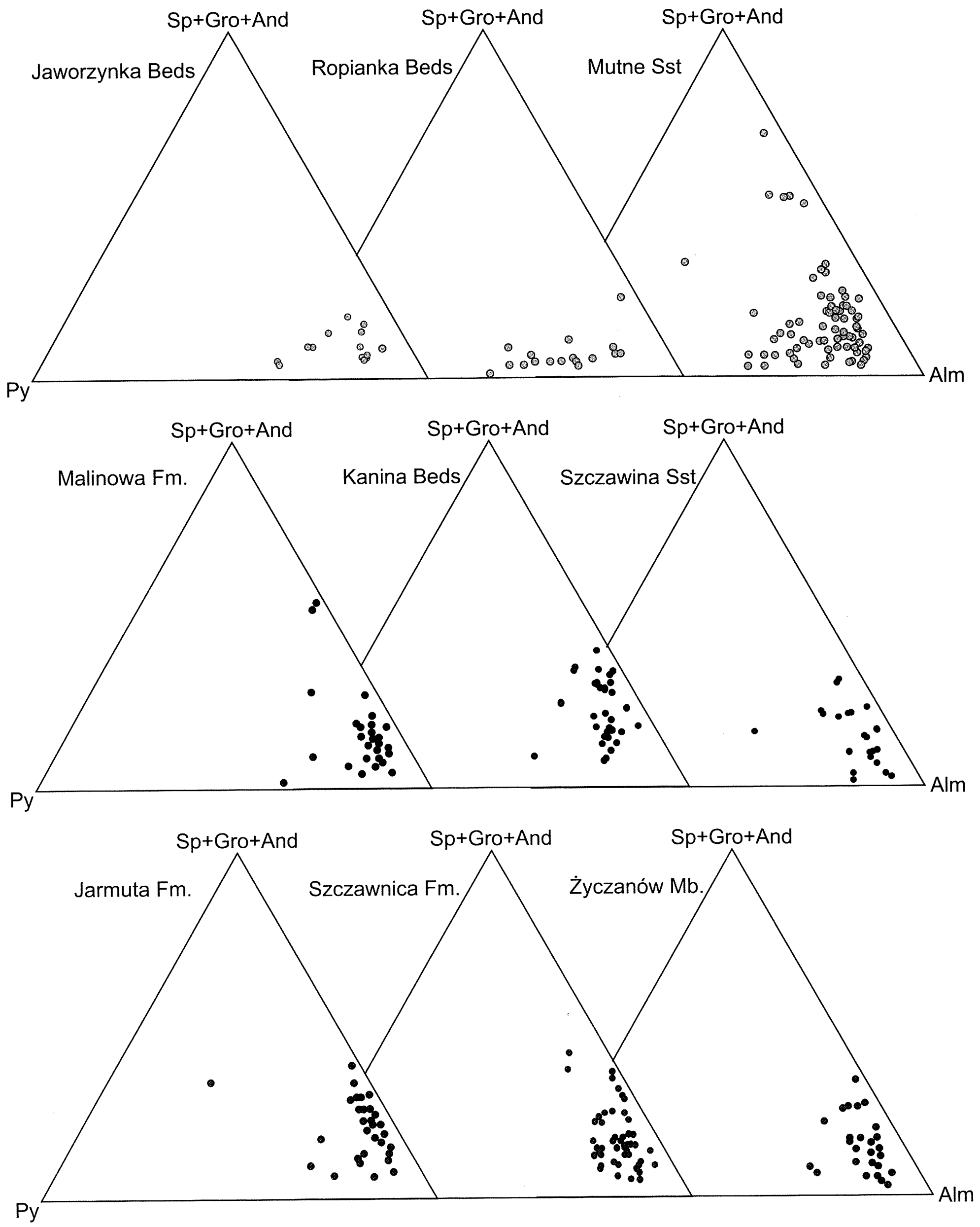

Fig. 2. Ternary diagrams of end-members in the studied garnets (abbreviations as in Table 4)

MgO, reaching about 11 wt %, were in most cases reported for garnets occurring in Ropianka Beds and in Mutne Sandstone (Table 3), whereas in garnets from other lithostratigraphic units such a content of MgO is sporadic (Tables 4, 5). The amounts of MnO and CaO only sporadically exceed 10 wt %. In some garnets the traces of TiO_2 (up to 0.4 wt %) were also present.

In terms of percentages of the end-members, pyrope, almandine, and spessartine belonging to the pyralspite series, as well as andradite and grossular representing ugrandite series were distinguished in the analysed garnets (Tables 6–8; Fig. 2). The dominating molecule among the listed ones is almandine, the amount of which in most garnets exceeds 60 mol %, while the content of other molecules is lower (Tables 6, 7, 8; Fig. 2). The spessartine molecule usually does not exceed 6 mol %, but there were found garnets with the amount of it comprising over 20 mol %. Such garnets occur in Mutne Sandstone (northern source area), as well as in the Malinowa Fm., Jarmuta Fm., and Życzanów Mb. (south-eastern source area). Among the end-members of the ugrandite series, the andradite molecule is usually up to 5 mol %, while the grossular molecule, because of the small amounts of CaO, is rather low in the analysed garnets. Garnets containing higher amounts of grossular molecule (reaching up to 20 mol %) are more frequent in populations transported from the SE source region.

Although the chemical composition of the analysed garnets is similar, those transported from the NW direction (from the Silesian Ridge) occurring in Ropianka Beds and Mutne Sandstone display a high amount of pyrope, ranging from 20 to 42 mol %. Such garnets represent about 12% of the garnet populations in these sediments. In sandstones of Jaworzynka Beds the amount of such garnets is not so high, the almandine molecule being definitely dominating.

Table 3

Chemical composition of representative samples of garnets from Jaworzynka Beds (total number of analyses: 30), Ropianka Beds (total number of analyses: 34), and Mutne Sandstone (total number of analyses: 75)

		Oxides [wt%]							Elements							
	Sample No.	SiO_2	Al_2O_3	TiO_2	MgO	FeO	MnO	CaO	Si^{+4}	Al^{+3}	Fe^{+3}	Ti^{+4}	Mg^{+2}	Fe^{+2}	Mn^{+2}	Ca^{+2}
Jaworzynka Beds	KN12-16a	39.44	21.83		9.39	27.6	0.48	1.25	6.06	3.95	0.05		2.15	3.49	0.06	0.21
	KN12-11	36.97	20.26		3.59	37.00	0.88	1.3	5.99	3.87	0.13		0.87	4.88	0.12	0.23
	KN12-4	36.81	20.42		3.39	36.09	1.16	2.12	5.96	3.90	0.19		0.82	4.69	0.16	0.37
	KN12-9	36.70	20.03		3.15	38.06	0.90	1.13	5.98	3.85	0.15		0.76	5.03	0.12	0.20
	KN12s5e	38.61	21.03		6.76	30.23	0.44	2.94	6.05	3.88	0.12		1.58	3.96	0.06	0.49
	KN12-32	35.90	19.99		3.23	39.98	0.33	0.58	5.89	3.87	0.24		0.79	5.24	0.05	0.10
	KN12-14	36.41	20.19	0.05	2.92	33.31	5.94	1.17	5.94	3.88	0.11	0.01	0.71	4.44	0.82	0.21
	PŁ4-7	35.63	20.15		2.22	35.83	4.54	0.87	5.87	3.91	0.24		0.55	4.70	0.63	0.15
	PŁ4-5	36.44	20.28		3.49	38.45	0.77	0.57	5.94	3.89	0.15		0.85	5.09	0.11	0.10
Ropianka Beds	1197s3a	37.2	22.37		11.55	26.64	0.33	1.41	5.94	3.91	0.16		2.56	3.29	0.03	0.23
	G4-17a	37.70	21.48		4.49	0.58	30.74	1.00	5.90	3.96	0.14		1.98	3.89	0.08	0.17
	G4-15a	21.58	38.61	0.05	10.10	27.86	0.57	1.24	5.96	3.88	0.12	0.01	2.33	3.48	0.07	0.20
	G4-20a	21.61	38.92		10.77	25.28	0.45	2.97	5.96	3.85	0.15		2.46	3.09	0.06	0.49
	G4-3a	38.49	21.84		9.15	28.73	0.51	1.28	5.96	3.98	0.06		2.11	3.66	0.07	0.21
	G4-7a	37.45	21.20		6.43	32.75	1.26	0.92	5.91	3.92	0.17		0.33	4.40	0.16	1.25
	G4-12a	36.41	20.83		3.40	36.62	1.48	1.26	5.89	4.00	0.11		0.87	4.82	0.26	0.15
	G4-11a	39.75	22.12	0.11	12.79	24.36	0.21	0.67	6.00	3.93	0.06	0.01	2.88	3.01	0.03	0.11
	G4-16a	37.56	21.31		6.56	32.48	0.65	1.41	5.88	3.93	0.19		1.56	4.21	0.09	0.29
	G4-23a	38.61	21.58	0.05	10.10	27.86	0.57	1.24	5.95	3.99	0.07		1.73	4.05	0.09	0.19
Mutne Sandstone	M2-45A	37.89	21.35		8.95	28.97	1.61	1.23	5.91	3.93	0.16		2.08	3.62	0.21	0.21
	M2-84A	40.00	22.61	0.15	11.55	12.57	0.22	12.90	5.93	3.95	0.12	0.02	2.55	1.44	0.03	2.05
	M2-101B	36.21	20.86		1.13	21.16	12.78	7.85	5.88	3.99	0.14		0.27	2.74	1.76	1.36
	M2-74A	37.68	21.42		7.43	31.19	1.07	1.21	5.93	3.97	0.10		1.74	4.00	0.14	0.20
	M2-50B	36.51	20.75		1.92	31.24	5.07	4.51	5.93	3.97	0.10		0.47	4.14	0.70	0.79
	M2-49A	35.87	20.40		2.89	17.68	19.12	4.04	5.84	3.91	0.25		0.70	2.16	2.64	0.70
	ST2-28B	36.45	20.92		5.37	33.61	2.82	0.83	5.86	3.96	0.18		1.29	4.34	0.38	0.14
	ST2-18A	36.25	20.68		3.41	38.79	0.35	0.52	5.90	3.97	0.13		0.83	5.15	0.05	0.09
	ST2-28A	36.74	20.82		5.13	33.58	2.9	0.82	5.90	3.94	0.15		1.23	4.36	0.40	0.14
	ST2-39A	36.81	20.77		2.92	31.89	4.88	2.72	5.95	3.96	0.09		0.70	4.23	0.67	0.47

Table 4

Chemical composition of representative samples of garnets from the Malinowa Fm. (total number of analyses: 82), Kanina Beds (total number of analyses: 50), and Szczawina Sandstone (total number of analyses: 50)

		Oxides [wt%]							Elements							
	Sample No.	SiO_2	Al_2O_3	TiO_2	MgO	FeO	MnO	CaO	Si^{+4}	Al^{+3}	Fe^{+3}	Ti^{+4}	Mg^{+2}	Fe^{+2}	Mn^{+2}	Ca^{+2}
Malinowa Fm	sl3-15b	36.53	20.52	0.16	1.76	30.30	1.88	3.84	5.95	3.94	0.12	0.02	0.43	4.69	0.26	0.67
	sl3-20a	36.32	20.65	0.39	0.35	20.13	15.94	6.21	5.92	3.97	0.11	0.05	0.09	2.63	2.2	1.08
	sl3-4a	36.52	20.58	0.11	2.51	33.86	4.65	1.77	5.94	3.95	0.11	0.01	0.61	4.5	0.64	0.31
	sl3-14b	36.48	20.44	0.10	1.4	34.69	2.19	4.7	5.95	3.92	0.13	0.01	0.34	4.6	0.3	0.82
	sl3-12b	37.60	21.43		6.86	30.48	1.5	2.13	5.92	3.98	0.10		1.61	3.92	0.2	0.36
	sl3-58a	36.49	21.00	0.11	4.45	34.78	2.01	1.17	5.88	3.99	0.12	0.01	1.07	4.57	0.27	0.2
	sl3-7a	35.93	20.28	0.07	1.87	40.54	0.61	0.69	5.92	3.93	0.15	0.01	0.46	5.43	0.09	0.12
	SC2-32B	35.53	20.23	0.15	2.36	38.48	2.13	1.12	5.85	3.93	0.21	0.02	0.58	5.10	0.30	0.20
	SC2-13B	36.46	20.71	0.62	1.52	34.22	1.34	5.14	5.91	3.96	0.05	0.08	0.37	4.59	0.18	0.89
	SC2-22B	35.49	20.35	0.66	1.67	35.15	3.07	3.63	5.82	3.94	0.16	0.08	0.41	4.66	0.43	0.64
Kanina Beds	G3-13na	37.10	21.02		3.19	32.03	5.81	0.84	5.99	4.00	0.00		0.77	4.32	0.80	0.15
	G3-1a	35.70	20.62		1.48	30.94	10.73	0.52	5.89	4.01			0.36	4.27	1.50	0.09
	G3-11b	37.63	21.48	0.05	3.56	29.89	1.55	5.85	5.97	4.02		0.01	0.84	3.97	0.21	0.99
	G3-18nb	37.14	21.11		3.02	33.83	2.69	2.20	5.98	4.01			0.73	4.56	0.37	0.38
	G3-11na	37.00	20.92		0.98	29.47	1.63	9.98	5.95	3.97	0.03		0.23	3.93	0.22	1.72

Table 4 continued

Chemical composition of representative samples of garnets from the Malinowa Fm. (total number of analyses: 82), Kanina Beds (total number of analyses: 50), and Szczawina Sandstone (total number of analyses: 50)

		Oxides [wt%]							Elements							
	Sample No.	SiO_2	Al_2O_3	TiO_2	MgO	FeO	MnO	CaO	Si^{+4}	Al^{+3}	Fe^{+3}	Ti^{+4}	Mg^{+2}	Fe^{+2}	Mn^{+2}	Ca^{+2}
Kanina Beds	G3-10nb	37.55	20.93		2.54	32.19	0.53	6.26	6.01	3.95	0.05		0.61	4.26	0.07	1.07
	G3-24na	37.33	21.10		2.22	27.48	7.51	4.34	6.00	4.00			0.53	3.69	1.02	0.75
	G3-36a	36.51	20.44		1.79	30.67	2.92	7.68	5.91	3.90	0.10		0.43	4.06	0.40	1.33
	G3-7na	37.38	21.20		3.35	32.31	4.28	1.48	6.00	4.01			0.80	4.34	0.58	0.25
	G3-3nb	38.29	21.63		5.27	26.04	0.91	7.86	5.98	3.98	0.02		1.23	3.38	0.12	1.32
Szczawina Sandstone	PW1-4	36.60	19.75		2.26	41.01	0.61	0.77	5.89	3.85	0.26		0.56	5.41	0.09	0.14
	PW1-12	35.87	20.19		2.68	38.46	0.45	2.36	5.88	3.90	0.23		0.65	5.04	0.41	0.06
	KN9-6a	35.63	20.25		2.10	36.78	4.40	0.83	5.87	3.94	0.19		0.52	4.88	0.62	0.15
	G1-25a	36.94	20.83	0.41	1.60	28.90	2.31	9.01	5.93	3.94	0.08	0.05	0.38	3.80	0.31	1.55
	G1-38a	36.69	20.85	0.08	2.17	36.52	1.60	2.08	5.96	3.99	0.04	0.01	0.53	4.93	0.22	0.36
	G1-29a	36.60	20.40	0.07	0.72	33.36	3.65	5.20	5.98	3.93	0.09	0.01	0.17	4.46	0.51	0.91
	G1-17b	37.28	20.91	0.22	3.45	34.20	1.55	2.39	5.99	3.95	0.03	0.03	0.83	4.56	0.21	0.41
	G1-11a	37.07	21.05		4.11	36.36	0.66	0.75	5.96	3.99	0.05		0.98	4.84	0.09	0.13
	G1-12a	36.78	20.64		3.82	29.62	8.04	1.09	5.94	3.93	0.13		0.92	3.88	1.10	0.19
	G1-5a	36.68	20.74	0.42	1.63	39.42	0.31	0.81	5.98	3.99		0.05	0.40	5.38	0.04	0.14

Table 5

Chemical composition of representative samples of garnets from the Jarmuta Fm. (total number of analyses: 99), Szczawnica Fm. (total number of analyses: 84), and Życzanów Mb. (total number of analyses: 68)

		Oxides [wt%]							Elements							
	Sample No.	SiO_2	Al_2O_3	TiO_2	MgO	FeO	MnO	CaO	Si^{+4}	Al^{+3}	Fe^{+3}	Ti^{+4}	Mg^{+2}	Fe^{+2}	Mn^{+2}	Ca^{+2}
Jarmuta Fm.	CW47	36.41	20.01		2.96	35.28	3.50	1.85	5.94	3.85	0.21		0.72	4.61	0.48	0.32
	CW38	36.45	19.95		0.90	31.91	5.45	5.33	5.97	3.85	0.18		0.22	4.19	0.76	0.94
	CW39	36.29	19.80	0.11	0.83	32.44	5.50	5.06	5.96	3.83	0.20	0.01	0.20	4.26	0.77	0.89
	CW57	37.03	19.72		3.63	35.74	0.71	3.16	6.00	3.76	0.24		0.88	4.60	0.10	0.55
	CW105	37.38	20.12		3.44	34.55	2.11	2.40	6.03	3.83	0.17		0.83	4.49	0.29	0.42
	D3-54B	36.37	20.63		1.59	36.81	0.27	4.33	5.93	3.96	0.11		0.39	4.91	0.04	0.76
	D3-50A	36.33	20.99		0.41	27.54	9.60	5.14	5.93	4.04	0.03		0.10	3.73	1.33	0.90
	D3-27B	36.53	20.90		0.92	30.09	5.84	5.71	5.94	4.01	0.05		0.22	4.04	0.80	1.00
	D3-51C	35.86	20.13	0.06	0.83	34.22	4.83	4.07	5.91	3.91	0.17	0.01	0.20	4.54	0.67	0.72
	D3-6B	37.88	20.73		5.82	32.34	1.17	2.04	6.01	3.88	0.12		1.38	4.17	0.16	0.35
Szczawnica Fm.	W2-73b	36.14	20.29	0.11	2.22	34.32	4.96	1.96	5.92	3.92	0.16	0.01	0.54	4.54	0.69	0.34
	W2-75b	36.48	20.44	0.07	2.54	37.03	0.16	3.29	5.93	3.92	0.14	0.01	0.62	4.89	0.02	0.57
	W2-83a	36.32	20.19	0.05	2.36	22.98	15.55	2.55	5.93	3.88	0.18	0.01	0.58	2.95	2.15	0.45
	W2-86a	36.53	20.58	0.12	2.44	34.44	0.85	5.04	5.92	3.93	0.14	0.01	0.59	4.53	0.12	0.88
	W2-90b	37.36	21.10		4.93	33.14	2.68	0.78	5.97	3.97	0.06		1.18	4.37	0.36	0.13
	W2-77b	36.25	20.84	0.13	0.76	31.44	1.89	8.68	5.88	3.97	0.13	0.02	0.18	4.14	0.26	1.51
	W2-52a	36.68	20.66		3.25	37.62	0.4	1.4	5.95	3.95	0.11		0.79	5	0.06	0.24
	W2-47b	36.79	20.51		4.33	33.25	1.67	3.44	5.92	3.89	0.19		1.04	4.28	0.23	0.59
	W2-50a	36.43	20.65		4.09	36.9	0.68	1.25	5.9	3.94	0.16		0.99	4.84	0.09	0.22
	W2-71a	36.12	20.31	0.19	0.75	28.92	8.5	5.21	5.92	3.92	0.14	0.02	0.18	3.82	1.18	0.92
	W2-44b	36.66	20.88	0.08	3.18	31.43	1.26	6.51	5.89	3.95	0.15	0.01	0.76	4.07	0.17	1.12
Życzanów Mb.	z1-28b	36.15	20.41	0.13	1.12	35.07	1.48	5.64	5.91	3.93	0.14	0.02	0.27	4.65	0.21	0.99
	z1-33b	36.18	20.23	0.12	0.58	29.44	7.51	5.93	5.93	3.91	0.15	0.02	0.14	3.88	1.04	1.04
	z1-25b	37.70	21.38	0.08	6.67	30.65	1.14	2.38	5.94	3.97	0.09	0.01	1.57	3.95	0.15	0.40
	z1-22b	36.99	20.61		4.37	28.94	6.59	2.5	5.94	3.90	0.16		1.05	3.73	0.90	0.43
	z1-6b	36.52	20.44		2.49	39.36	0.48	0.67	5.96	3.93	0.10		0.61	5.27	0.07	0.12
	z1-7a	35.63	20.45		1.59	31.76	10.10	0.48	5.88	3.98	0.14		0.39	4.24	1.41	0.09
	z1-2a	36.41	20.53	0.08	2.01	35.13	1.37	4.46	5.92	3.94	0.13	0.01	0.49	4.65	0.19	0.78
	z1-8b	36.33	21.11		2.63	33.37	3.14	3.43	5.89	4.03	0.08		0.64	4.44	0.43	0.60
	z1-11a	36.67	20.70		3.37	32.65	3.94	2.66	5.93	3.94	0.13		0.81	4.29	0.54	0.46
	z1-3a	36.17	20.48		1.46	35.58	1.84	4.47	5.91	3.95	0.14		0.36	4.72	0.26	0.78

Table 6

End-member composition of the analysed garnets from Jaworzynka Beds, Ropianka Beds, and Mutne Sandstone

		End-members [mol %]				
	Sample No.	**Py**	**Alm**	**Sp**	**And**	**Gro**
Jaworzynka Beds	KN12-16a	36.4	59.6	1.0	1.0	2.0
	KN12-11	14.0	80.0	2.0	4.0	-
	KN12-4	13.0	78.0	3.0	4.0	2.0
	KN12-9	12.4	81.2	2.0	4.4	-
	KN12s5e	26.3	64.6	1.0	3.0	5.1
	KN12-14	11.5	70.8	13.3	4.3	-
	KN12-32	12.2	81.2	0.8	5.8	-
	PŁ4-7	8.8	76.5	9.8	4.9	-
	PŁ4-5	13.6	80.6	1.9	3.9	-
Ropianka Beds	1197s3a	41.9	53.7	0.5	3.9	-
	G4-17a	32.2	63.2	1.3	3.4	-
	G4-15a	38.5	57.4	1.2	2.9	-
	G4-20a	40.3	50.7	1.0	3.6	4.4
	G4-3a	35.4	60.6	1.0	1.0	2.0
	G4-7a	5.0	72.0	3.0	4.0	16.0
	G4-12a	14.0	79.0	4.0	3.0	-
	G4-11a	48.0	50.0	0.0	1.0	1.0
	G4-16a	25.3	68.7	1.0	5.0	-
	G4-23a	28.7	66.3	1.0	2.0	2.0
Mutne Sandstone	M2-45A	33.8	58.8	3.4	4.0	-
	M2-84A	42.0	24.0	0.0	3.0	31.0
	M2-101B	4.0	45.0	29.0	3.0	19.0
	M2-74A	28.7	65.3	2.0	3.0	1.0
	M2-50B	8.0	68.0	11.0	3.0	10.0
	M2-49A	11.0	35.0	43.0	6.0	5.0
	ST2-28B	16.9	73.8	5.4	3.8	-
	ST2-18A	13.7	82.4	1.0	2.9	-
	ST2-28A	20.6	69.6	5.9	3.9	-
	ST2-39A	11.9	69.3	10.9	2.0	5.9

(Py – pyrope, Alm – almandine, Sp – spessartine, And – andradite, Gro – grossular)

Table 7

End-member composition of the analysed garnets from the Malinowa Fm., Kanina Beds, and Szczawina Sandstone

		End-members [mol %]				
	Sample No.	**Py**	**Alm**	**Sp**	**And**	**Gro**
Malinowa Fm.	sl3-15b	7.0	77.6	4.3	2.9	8.2
	sl3-20a	1.0	44.0	37.0	3.0	15.0
	sl3-4a	10.0	74.0	11.0	3.0	2.0
	sl3-14b	5.1	75.8	5.1	2.0	12.0
	sl3-12b	26.5	65.3	3.1	2.0	3.1
	sl3-58a	18.0	75.0	4.0	3.0	-
	sl3-7a	7.8	87.3	1.0	3.9	-
	SC2-32B	9.2	81.0	4.7	5.1	-
	SC2-13B	6.1	76.8	3.0	1.0	13.1
	SC2-22B	8.8	81.4	4.9	4.9	-
Kanina Beds	G3-13na	12.9	71.9	13.3	-	2.0
	G3-1a	5.9	67.2	24.2	2.7	-
	G3-11b	14.0	66.0	3.0	-	17.0
	G3-18nb	12.0	76.0	6.0	-	6.0
	G3-11na	4.0	64.0	4.0	2.0	26.0
	G3-10nb	10.0	71.0	1.0	1.0	17.0
	G3-24na	9.0	62.0	17.0	-	12.0
	G3-36a	6.9	64.4	6.9	5.0	16.8
	G3-7na	13.0	73.0	10.0	-	4.0
	G3-3nb	20.0	56.0	2.0	1.0	21.0
Szczawina Sandstone	PW1-4	11.5	68.3	13.5	6.7	-
	PW1-12	10.6	81.8	1.0	5.6	1.0
	KN9-6a	7.8	77.5	9.8	4.9	-
	G1-25a	6.3	62.9	5.2	1.9	23.7
	G1-38a	8.8	81.2	4.0	1.0	5.0
	G1-29a	3.0	74.0	8.0	2.0	13.0
	G1-17b	14.0	76.0	3.0	1.0	6.0
	G1-11a	16.2	80.8	1.0	1.0	1.0
	G1-12a	15.0	64.0	18.0	3.0	-
	G1-5a	7.0	90.0	1.0	0.0	2.0

(Py – pyrope, Alm – almandine, Sp – spessartine, And – andradite, Gro – grossular)

A comparison of the chemical composition of garnets from the mentioned lithostratigraphic units shows an increase in MgO and in the pyrope contents towards younger deposits, according to the scheme: Jaworzynka Beds→Ropianka Beds and Mutne Sandstone (Fig. 2; Tables 3, 6).

On the contrary, the garnets showing a high pyrope content are almost lacking in sediments derived from the opposite SE transport direction (Kanina Beds, Szczawina Sandstone, Jarmuta Fm., Szczawnica Fm., Życzanów Mb.). In these garnets pyrope and other end-members only accompany the prevailing almandine and no important change in the chemical composition of garnets with time is visible (Fig. 2; Tables 4, 5 and 7, 8).

PROVENANCE OF GARNETS

Almandine is the most common end-member of the pyralspite series. Unfortunately, it can be found in many types of rocks, including both igneous and metamorphic ones. Since there are no data on coexisting minerals, it is impossible to determine the detailed conditions of metamorphism. Therefore, the exact description of P-T conditions during garnet growth cannot be known and the interpretation of provenance of almandine garnets is difficult. Nevertheless, the most important parent rocks for them are metamorphic rocks (mainly garnet schists, but also gneisses, amphibolites, granulites) forming under medium- (epidote-amphibolite, amphibolite facies) and high grade metamorphic conditions (granulite facies), whereas igneous rocks, like granites and associated pegmatites, are less important (Miyashiro, 1975; Deer *et al.*, 1962; Yardley, 1989).

Almandine usually contains significant amounts of pyrope and spessartine, as well as admixtures of andradite and grossular molecules (Deer *et al.*, 1962). According to the theory of decreasing amount of CaO and MnO and increasing content of FeO and MgO with progressing metamorphism (Miyashiro, 1953, 1975; Sturt, 1962; Nandi, 1967; Miyashiro & Shido, 1973), almandines containing raised spessartine and andradite molecules are more likely to form under conditions of low to medium grade metamorphic fa-

Table 8

End-member composition of the analysed garnets from the Jarmuta Fm., Szczawnica Fm., and Życzanów Mb.

		End-members [mol %]				
	Sample No.	**Py**	**Alm**	**Sp**	**And**	**Gro**
Jarmuta Fm.	CW47	12.0	75.0	8.0	5.0	-
	CW38	4.0	69.0	12.0	4.0	11.0
	CW39	3.0	70.0	13.0	5.0	9.0
	CW57	14.0	75.0	2.0	6.0	3.0
	CW105	13.8	74.2	5.0	4.0	3.0
	D3-54B	5.9	80.2	1.0	3.0	9.9
	D3-50A	2.0	61.4	21.8	1.0	13.8
	D3-27B	4.0	67.0	13.0	1.0	15.0
	D3-51C	3.0	74.7	11.2	4.0	7.1
	D3-6B	22.7	68.3	3.0	3.0	3.0
Szczawnica Fm.	W2-73b	9.0	74.0	11.0	4.0	2.0
	W2-75b	9.4	48.2	35.1	4.6	2.7
	W2-83a	10.0	80.2	0.4	3.6	5.8
	W2-86a	9.9	73.3	2.0	4.0	10.9
	W2-90b	19.2	72.7	6.1	1.0	1.0
	W2-77b	3.0	68.7	4.0	3.0	21.2
	W2-52a	13.0	82.0	1.0	3.0	1.0
	W2-47b	16.8	69.3	4.0	5.0	5.0
	W2-50a	15.8	78.2	2.0	4.0	-
	W2-71a	3.0	63.0	19.0	3.0	12.0
	W2-44b	12.0	66.0	3.0	4.0	15.0
Życzanów Mb.	z1-28b	4.0	76.0	3.0	4.0	13.0
	z1-33b	2.0	64.0	17.0	4.0	13.0
	z1-25b	26.0	65.0	3.0	2.0	4.0
	z1-22b	17.0	61.0	15.0	4.0	3.0
	z1-6b	9.9	86.1	1.0	3.0	-
	z1-7a	5.9	67.6	22.5	4.0	-
	z1-2a	8.0	76.2	3.1	3.3	9.4
	z1-8b	10.4	72.7	7.1	2.1	7.7
	z1-11a	13.1	70.7	9.2	3.0	4.0
	z1-3a	6.0	77.0	4.0	4.0	9.0

(Py – pyrope, Alm – almandine, Sp – spessartine, And – andradite, Gro – grossular)

cies, while almandine and pyrope in medium and high grade facies. Typical rocks forming under conditions of the above mentioned facies are amphibolites, amphibolite schists, mica schists, gneisses, and granulites. Almandine containing significant amounts of spessartine molecule can also form in metamorphic rocks within contact aureoles (Deer *et al.*, 1962).

The analysed garnets occur in fragments of different shapes. Consequently it is impossible to establish whether the fragments differing in chemical composition represent parts of zonal grains or pieces of unzoned ones. Almandine rarely forms zonal crystals. Therefore, the obtained data were interpreted as for non zonal ones. Since garnets with a prevailing almandine molecule form – in most cases – under metamorphic conditions, such origin was assumed in the interpretation of provenance of the studied garnets.

In the diagrams showing the dependence of amounts of main cations on the metamorphic facies, the projection points of garnets from Jaworzynka Beds plot mainly in the fields of medium grade metamorphic facies, whereas only a few points plotted in fields of high grade facies. In Ropianka Beds and Mutne Sandstone more garnets deriving from high grade metamorphic facies are present (Fig. 3). The location of the projection points for Jaworzynka Beds in the fields of epidote-amphibolite, garnet-amphibolite and amphibolite zones suggests their provenance from amphibolites, gneisses and/or garnet-mica schists. The chemical composition of garnets from Ropianka Beds and Mutne Sandstone indicates that they could have derived from the listed rocks, as well as from granulites.

The content of (FeO+MgO) versus (CaO+MnO) suggests that garnets of Jaworzynka Beds formed mainly under conditions of sillimanite (and to lesser extent kyanite) zones (Fig. 4A), those from Ropianka Beds represent mainly the sillimanite zone (Fig. 4B), while garnets from Mutne Sandstone crystallized in the sillimanite, kyanite, and less frequently, in the garnet zone (Fig. 4C).

The change in the chemical composition of garnets with age reflects a gradual erosion and exposition of different parts of the crystalline complex of the Silesian Ridge, built up of medium grade metamorphic rocks (schists, gneisses, and amphibolites) in the upper part and of high grade rocks (granulites) in the deeper zones. The idea of garnet origin is supported by the fact that pebbles of such rocks were found in exotic-bearing conglomerates (e.g. Wieser, 1985).

Garnets showing similar almandine-pyrope compositions were reported from the Flysch Carpathians in southern Moravia (Otava *et al.*, 197, 1998) and interpreted as deriving from the Moldanubicum of the Bohemian Massif. The data obtained from the analyses of garnets suggest that the petrographic character of the Silesian Ridge could be similar to the mentioned zone.

Contrary to above described conclusion, garnets deriving from the south-eastern source area (occurring in the Malinowa Fm., Kanina Beds, Szczawina Sandstone, Jarmuta and Szczawnica formations, and the Życzanów Mb.) do not display compositional change with age (Fig. 3). The projection points reflecting their chemical composition locate mainly in the fields of low and medium grade metamorphic facies. Only individual points did plot in the field of granulite facies.

Garnets rich in pyrope molecule were found in the Jurassic sediments of the PKB (Aubrecht & Méres, 2000) what indicates their source in high-grade metamorphic rocks (e.g. granulites) which, according to these authors, could be a part of the Moldanubian zone. The chemical composition of garnets described in this article, as well as the SE palaeocurrent directions of the host Upper Cretaceous and Palaeocene sediments indicate their origin from a different area located in the Inner Carpathians, where under metamorphic processes gneisses, mica schists, and amphibolites were formed.

The location of projection points in the (FeO+MgO) versus (CaO+MnO) diagrams suggests that garnets of the Malinowa Fm., Kanina Beds, Szczawina Sandstone, Jarmuta and Szczawnica formations, and the Życzanów Mb. crystallised under conditions of sillimanite, kyanite, and garnet zones (Fig. 4 D–I). The chemical composition of the studied garnets indicates that low and medium grade schists,

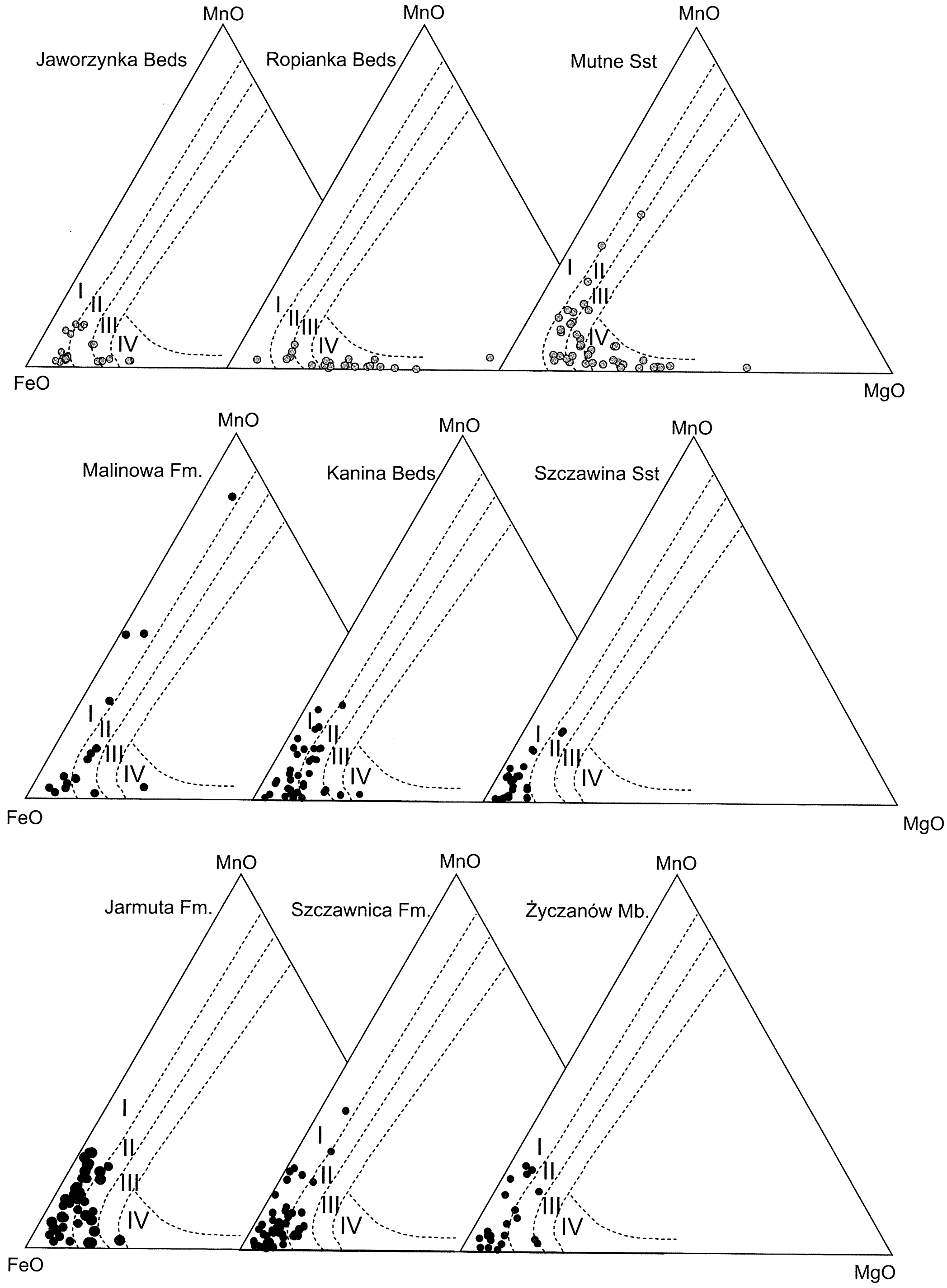

Fig. 3. Chemical composition of the detrital garnets from the investigated lithostratigraphic units. The individual fields represent various metamorphic zones (Salata, 2003; according to Miyashiro and Kuculu in Antipin, 1977). I – garnets from greenschists and epidote-amphibolite facies, II – garnets from epidote-amphibolite facies and low-temperature subfacies of garnet-amphibolite facies, III – garnets from amphibolite facies, IV – garnets from granulite facies

gneisses and/or amphibolites probably occurred among metamorphic rocks building the south-eastern source area.

CONCLUSIONS

A large amount of garnets within clastic material transported from the northern direction suggests that the source massif was composed of rocks rich in garnets. The chemical composition of garnets derived from the northern source area (Silesian Ridge) indicates that they were formed in rocks of a medium to high degree metamorphic conditions, such as garnet-mica schists, gneisses, amphibolites, and granulites. On the contrary, in heavy mineral assemblages deriving from the south-east direction garnet is not the dominating mineral. This suggests that in the source area lo-

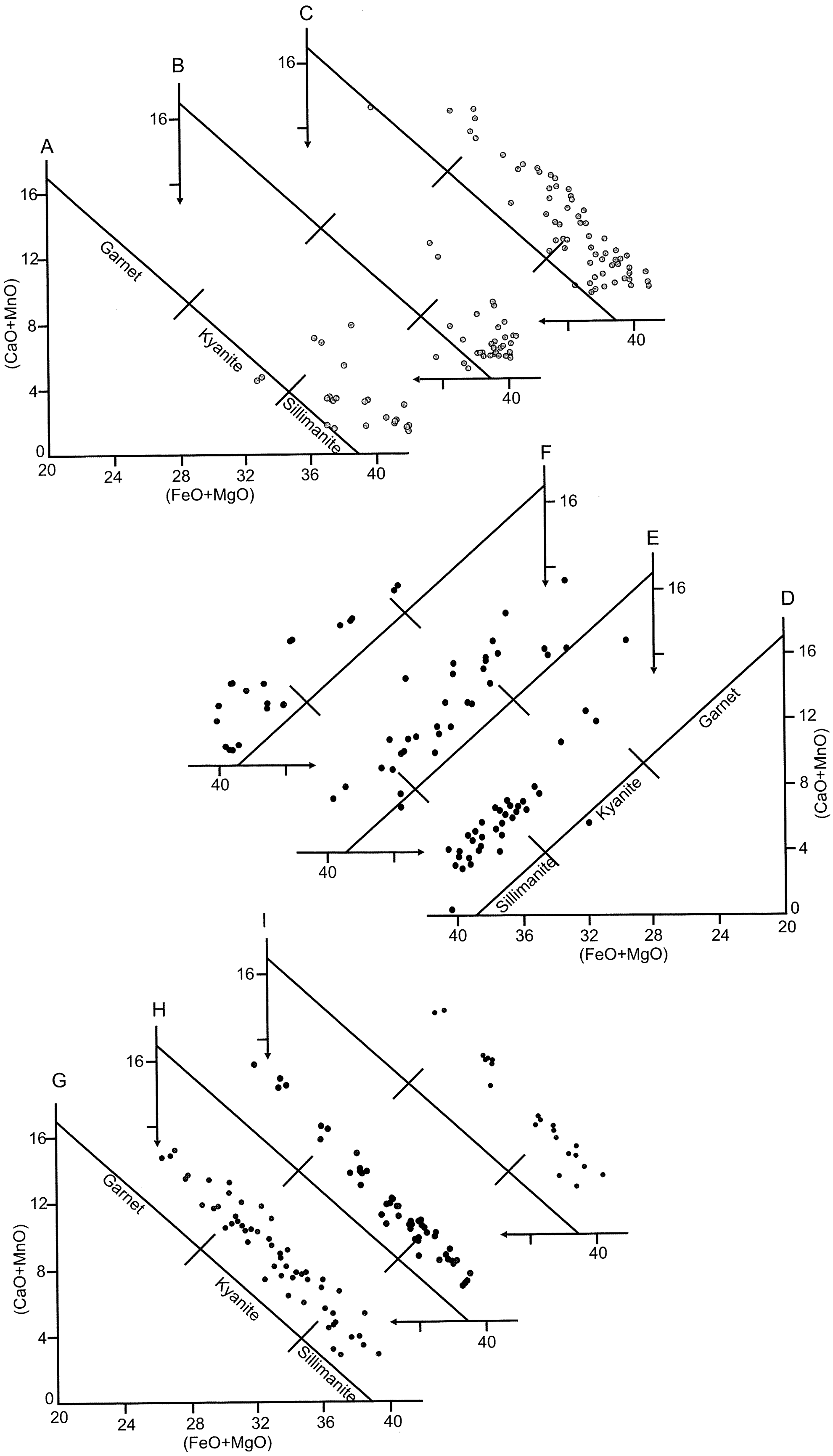

Fig. 4. Points reflecting chemical composition of the analysed garnets on the diagrams showing the dependence of (CaO+MnO) versus (FeO+MgO) from the metamorphic zone [wt %] (Salata, 2003; according to Nandi, 1967): A – Jaworzynka Beds, B – Ropianka Beds, C – Mutne Sandstone, D – Malinowa Fm., E – Kanina Beds, F – Szczawina Sandstone, G – Jarmuta Fm., H – Szczawnica Fm., I – Życzanów Mb.

cated south of the Magura Basin there existed rocks in which garnets could have been subordinate minerals. Their chemistry indicates that the parent rocks were formed under low- to medium grade metamorphic conditions, as, e.g. mica schists, gneisses, and/or amphibolites.

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Streszczenie

DETRYTYCZNE GRANATY Z GÓRNOKREDOWO-PALEOCEŃSKICH PIASKOWCÓW POLSKIEJ CZĘŚCI PŁASZCZOWINY MAGURSKIEJ I PIENIŃSKIEGO PASA SKAŁKOWEGO: WNIOSKI UZYSKANE NA PODSTAWIE ICH SKŁADU CHEMICZNEGO

Dorota Salata

Artykuł ten dotyczy interpretacji składu chemicznego granatów występujących w górnokredowo-paleoceńskich piaskowcach polskiej części płaszczowiny magurskiej.

Opróbowaniu poddane zostały piaskowce występujące w obrębie utworów formacji sromowieckiej (koniak–kampan), z Malinowej (turon), warstw z Kaniny (kampan–mastrycht), warstw z Jaworzynki (kampan–mastrycht), piaskowców ze Szczawiny (kampan–mastrycht, mastrycht–paleocen), formacji jarmuckiej (paleocen), warstw ropianieckich (paleocen), a także piaskowców z Mutnego (paleocen), formacji szczawnickiej (paleocen–dolny eocen) oraz ogniwa piaskowców z Życzanowa (paleocen) (Tabela 1).

Głównym składnikiem w analizowanych granatach (we wszystkich opróbowanych jednostkach litostratygraficznych) jest FeO, którego ilość zwykle przekracza 30% wag. Poza tym w granatach obecne są MgO, CaO, MnO w ilościach nieprzekraczających 5% wag. oraz – w niektórych ziarnach – śladowe ilości TiO_2 (do 0,4% wag). Jedynie w granatach warstw ropianieckich i piaskowców z Mutnego ilość FeO w ok. 12% analiz dochodzi do 11% wag., co wyróżnia dane granaty spośród wszystkich analizowanych (Tabele 3, 5, 7). Spośród członów krańcowych występujących w granatach zdecydowanie przeważa człon almandynowy, którego ilości przekraczają 60% mol. Pozostałe człony, tj. pirop, spessartyn andradyt i grossular, w większości ziaren stanowią domieszki standardowo występujące w granatach o przewadze almandynu (Tabele 4, 6, 8; Fig. 2). Nieco większe ilości piropu (dochodzące do 42% mol) zaobserwowano we wspomnianych granatach z warstw ropianieckich i piaskowców z Mutnego, dla których materiał klastyczny dostarczany był z kierunku NW. Ilość piropu zwiększa się ponadto w kierunku osadów młodszych, tj. od warstw z Jaworzynki do piaskowców z Mutnego.

W granatach transportowanych z kierunku południowo-wschodniego obecnych w piaskowcach ze Szczawiny (kampan–mastrycht, mastrycht–paleocen), formacji jarmuckiej (paleocen), formacji szczawnickiej (paleocen–dolny eocen) oraz ogniwie piaskowców z Życzanowa (paleocen) zdecydowanie dominuje człon almandynowy. W granatach tych nie zaobserwowano podwyższonej ilości członu piropowego, część ziaren wykazuje jednak podwyższone (do 20%) udziały członu grossularowego.

Proporcje głównych składników występujących w granatach pozwalają na stwierdzenie, że granaty pochodzące ze źródła północno-zachodniego (Kordyliery Śląskiej) powstawały głównie w warunkach metamorfizmu średniego i – w mniejszych ilościach – wysokiego stopnia. Sugeruje to pochodzenie granatów głównie ze skał typu łupków łyszczykowych, gnejsów i/lub amfibolitów oraz w mniejszym stopniu z granulitów. Zwiększenie udziału członu piropowego w granatach może wskazywać na stopniowe wynurzanie się skał powstałych w wyższym zakresie warunków metamorficznych (Fig. 3).

Skład granatów pochodzących ze źródła południowo-wschodniego wskazuje na ich krystalizację w warunkach głównie średniego stopnia metamorfizmu regionalnego (Fig. 3), co sugeruje, że ich skałami źródłowymi były głównie łupki łyszczykowe, gnejsy i/lub amfibolity.