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Heavy minerals in the Carboniferous sediments of the Intra-Sudetic Basin as palaeogeographic indicators

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Abstract The Intra-Sudetic Basin, a Variscan intramontane trough in the central Sudetes (NE part of the Bohemian Massif), is filled with Carboniferous, Permian, Triassic, Upper Cretaceous and Cenozoic deposits. The Carboniferous sediments display considerable lateral and vertical facies variation, which reflects intense synsedimentary, tectonic and volcanic activities. The sedimentary material was transported from various directions, and both the pebble lithology and the heavy minerals present are good palaeogeographic indicators of the alimentary areas.

This paper presents the results of heavy mineral analyses of the Carboniferous deposits of the Intra-Sudetic Basin and discusses the possible usage of the heavy mineral spectra as palaeogeographic and stratigraphic indicators. Samples representing all the Carboniferous formations were taken along two profiles: between Ciechanowice and Kamienna Góra (profile W), and between Sady Górne and Głuszyca (profile E).

The heavy mineral analyses show the variation of the heavy fraction, both in the stratigraphic column and laterally. The Upper Tournaisian sediments display a characteristic heavy mineral assemblage: epidote, biotite, and chlorite – pointing to the Kaczawa Mts as the source area. In the Visean sediments, a clear regional distinction can be seen: in profile W there are no significant differences compared to the older sediments; in profile E – garnet appears as a major component, pointing to possible transport from the Góry Sowie Block. In the Upper Visean, the regional differences disappear, probably as a result of redeposition of the older material. There is an important change in the mineralogy of the heavy fraction in the middle part of the Biały Kamień Formation. A considerable decrease in the garnet and ZRT (zircon+rutile+tourmaline) -mineral content is observed, and minerals formed during diagenesis (e.g. haematite) and/or hydrothermal processes (barite and siderite), become more abundant.

The chemical composition of some minerals (especially garnet and chlorite) appears to be very useful for establishing the alimentary areas. The garnets of the Ciechanowice and Lubomin Formations are rich in Grs and resemble the garnets from the contact-metamorphic basic rocks of the Rudawy Janowickie (garnets rich in Sps, typical of HP rocks of the eastern cover of the Karkonosze Pluton, were not found). In the Sady Górne Formation, garnets similar to those from the gneisses and migmatites of the Góry Sowie Block are the most common (a few grains rich in Sps, typical of low-grade metamorphic rocks are also found). The younger deposits display a wide variation of garnet formulae, which indicates various source areas and an important role of resedimentation.

The heavy mineral analyses confirm that the alimentary areas for the oldest sediments of the Intra-Sudetic Basin were the Kaczawa Mts and the eastern cover of the Karkonosze granite, whereas for the younger deposits, most probably, there was not a single source area; rather the materials derived from different sources and were redeposited. The distinct change in the heavy mineral spectra in the middle part of the Biały Kamień Formation suggests an important change in the factors controlling sedimentation in the basin. The heavy mineral analyses, in general, confirm previous interpretations based on sedimentological research; however, the direct transport from the Góry Sowie Block area is questionable (apart from garnets, other minerals typical of the rocks of that area do not occur).

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INTRODUCTION

The Intra-Sudetic Basin in the central Sudetes (NE part of the Bohemian Massif), is filled with a thick sequence of volcanic and sedimentary rocks mainly representing the Carboniferous and Permian (Fig. 1). In that sequence, a record of complicated and mutually connected tectonic, magmatic and sedimentary processes can be observed. The recognition of these processes is important for the reconstruction of the geological evolution of the Sudetes and, on a larger scale, of the eastern part of the Variscan orogen.

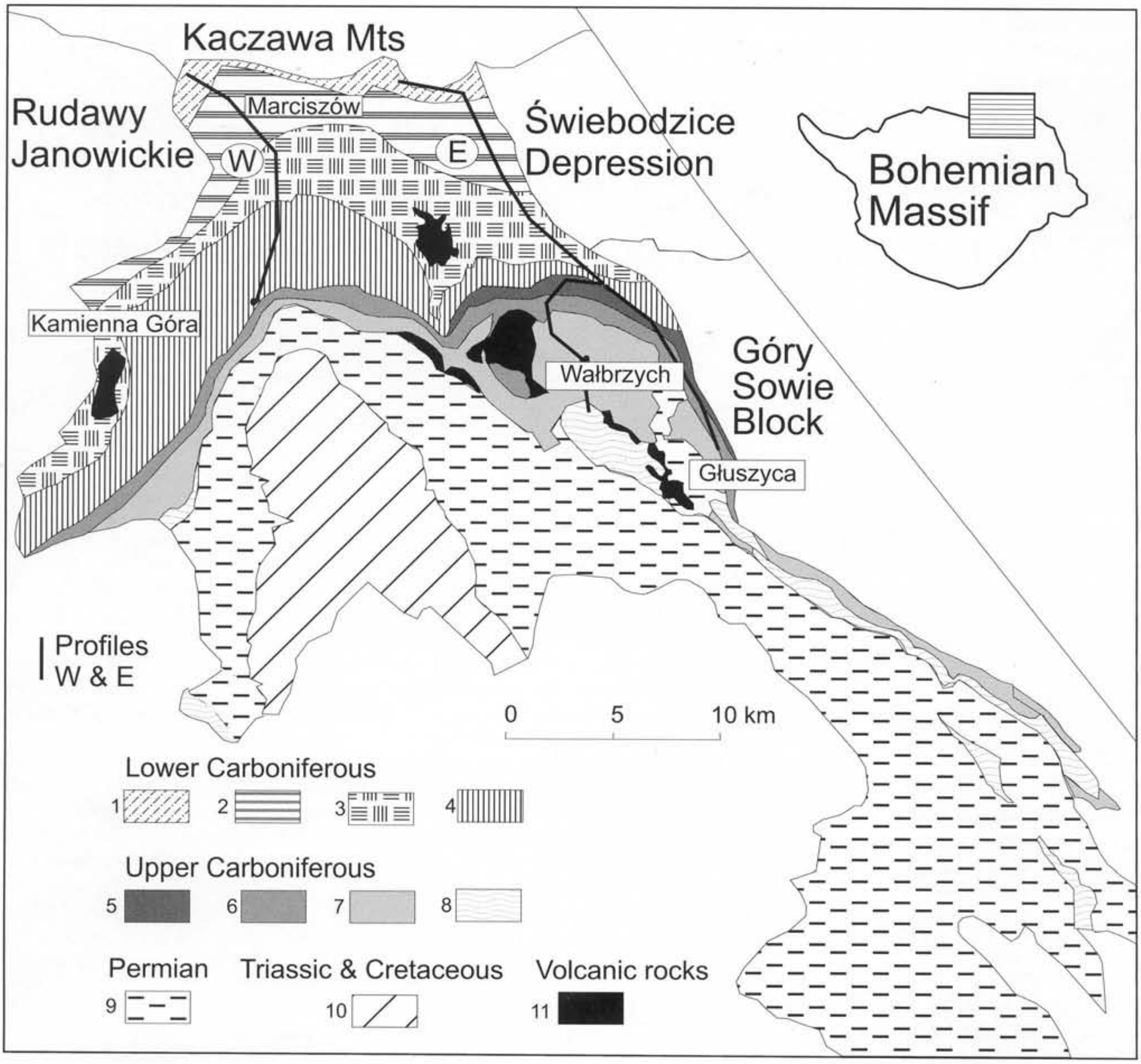

Fig. 1. Sketch map of the Polish part of the Intra-Sudetic Basin (based on Sawicki, 1967). Inset shows the position of the study area in the Bohemian Massif. Carboniferous formations: 1: - Ciechanowice, Nagórnik and Sady Górne; 2 - Stare Bogaczowice; 3 - Lubomin; 4 - Szczawno; 5 - Wałbrzych; 6 - Biały Kamień; 7 - Žacler; 8 - Glinik and Ludwikowice.

Teisseyre & Dziedzic (1990), based on the lithology of the pebbles and the sedimentary structures, determined the Kaczawa Mts, the Izera-Karkonosze Block, the Świebodzice Depression, the Góry Sowie Block, and the hypothetical "Southern Massif" (the metamorphic rocks of the Bystrzyckie and Orlickie Mts, and of the Kłodzko area, considered to be relics of this massif, Nemec *et al.*, 1982) as the alimentary areas for the Lower Carboniferous sediments.

The aim of this paper is:

- to recognise the variation of heavy mineral spectra, both laterally and in the stratigraphic column in the Carboniferous sediments of the Intra-Sudetic Basin,
- to define possible indicators of the alimentary areas for the Lower and Upper Carboniferous sediments in different parts of the basin,
- to attempt to find mineral indicators useful for stratigraphic correlation,
- to compare the transport directions inferred from the heavy mineral spectra with previous interpretations based on sedimentological criteria.

GEOLOGICAL SETTING

The borders of the Intra-Sudetic Basin are mainly tectonic, only along the western and northern edges, do sedimentary contacts also occur. The Carboniferous sediments are represented by 11 formations (Fig. 2): Ciechanowice, Nagórnik, Sady Górne (Upper Tournaisian), Stare Bogaczowice (Lower Visean), Lubomin (Middle Visean), Szczawno (Upper Visean), Wałbrzych

(Namurian A), Biały Kamień (Namurian B & C), Žacler (Westphalian AB), Glinik (Westphalian C & D and Lower Stephanian), and Ludwikowice (Upper Stephanian). Permian and Triassic rocks are found in the central parts of the basin whereas Cretaceous deposits cover its southernmost part, in the Czech Republic.

The Intra-Sudetic Basin was initiated as a narrow tectonic graben but the sedimentation area expanded and the depositional centres moved south-eastwards with time (Wojewoda & Mastalerz, 1989; Dziedzic & Teisseyre, 1990; Bossowski & Ihnatowicz, 1994; Mastalerz & Prouza, 1995, Awdankiewicz, 1999). The total thickness of the Carboniferous, Permian, Triassic and Upper Cretaceous deposits is about 12 km (Kurowski, 1995), of which the Lower Carboniferous sediments, represented mostly by fluvial conglomerates, attain 6.5 km, the Upper Carboniferous deltaic and marine deposits - 2 km, and the Permian - 1.5 km (Fig. 2). The basin provides a record of three successive stages of volcanic activity: Early Carboniferous, Late Carboniferous and Early Permian (Nemec *et al.*, 1982; Mastalerz & Prouza, 1995; Awdankiewicz, 1999).

In the northern part of the basin, the oldest Carboniferous deposits are represented in the east by the Sady Górne Formation, which is replaced westwards by the Figlów and Ciechanowice Formations, all considered to be of Upper Tournaisian age (Teisseyre, 1975; Nemec *et al.*, 1982). They are overlain by the Stare Bogaczowice Formation (Lower Visean) and the Lubomin Formation (Middle Visean). The Lubomin Formation is replaced upwards, and partly laterally, by the Szczawno Formation, which contains marine fossils of Late Visean age. The Szczawno Formation grades upwards into the Namurian continental deposits of the Wałbrzych Formation, except in the western part of the basin, where it is overlain by Westphalian deposits (Nemec *et al.*, 1982). The Wałbrzych Formation mainly consists of sandstones and mudstones with workable coal seams and is overlain by coarse conglomerates and sandstones of the Biały Kamień Formation. These sediments in turn are covered by the Žacler Formation, represented by sandstones and mudstones with workable coal seams. These rocks are overlain by Stephanian red coarse-clastic sediments.

SAMPLING AND METHODS

The samples for heavy mineral analysis were taken from the Carboniferous sediments of the Intra-Sudetic Basin from the area between Ciechanowice and Kamienna Góra (profile W), and between Sady Górne and Głuszyca (profile E). Altogether 29 samples representing all the Carboniferous formations in the study area were taken (Fig. 1). This allows the tracing the diversity of heavy mineral spectra in the stratigraphic column both in the eastern and western parts of the basin. Besides these samples, 2 specimens representing the Culm of the Góry Sowie Block and 4 from the molasse of the Świebodzice Depression were taken.

Heavy minerals were separated by a routine preparation procedure. All the samples were crushed in a jaw crusher. Pebbles were removed and the samples were sieved for calculation of grain size parameters. The heavy mineral separation was carried out on the 0.056 - 0.125 or 0.125-0.315 mm fractions of each sample by gravity-settling in sodium polytungstate aqueous solution (density 2.9 g/cm^3).

The heavy mineral separates were analysed under a petrographic microscope, counting 200 to 300 transparent grains per sample, using the ribbon method. The transparent minerals underwent detailed quantitative and qualitative analyses, while the opaques, only an estimation of the

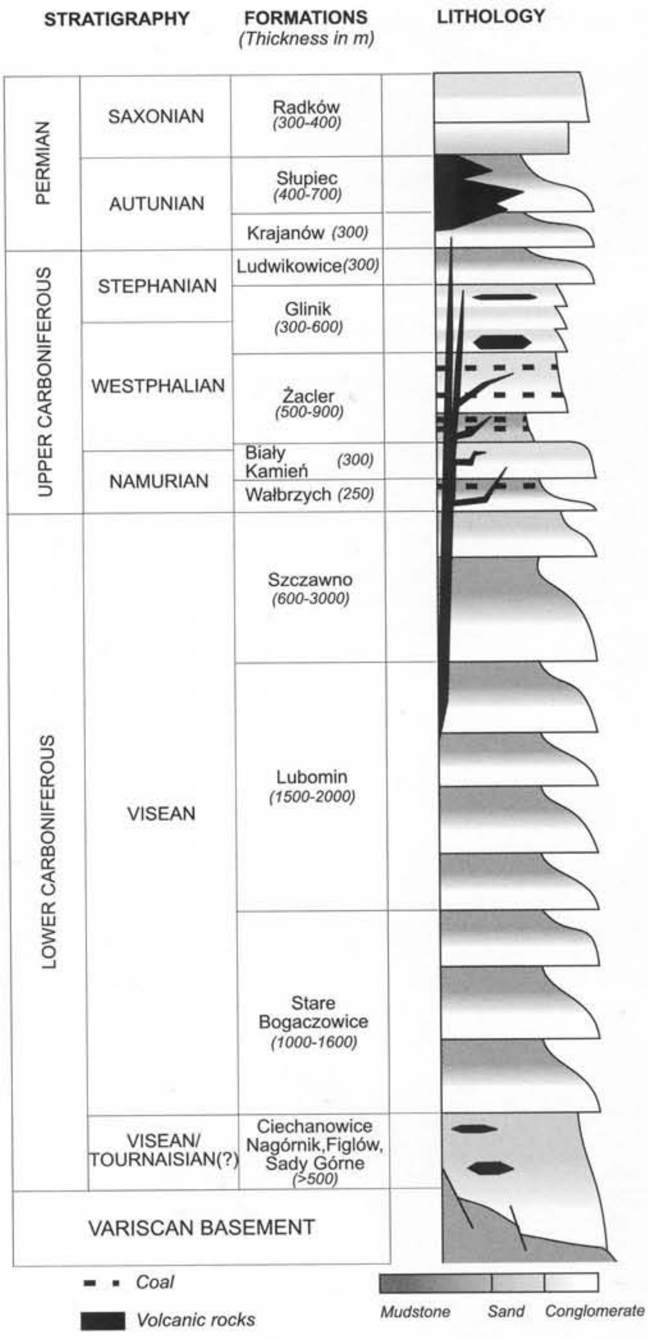

Fig. 2. Lithostratigraphy of the Carboniferous–Permian molasse succession of northern part of the Intra-Sudetic Basin (from Awdankiewicz, 1999, based on Mastalerz & Prouza, 1995).

amount was made.

Electron microprobe analyses (both WDS and EDS methods) were conducted on the Cambridge Microscan M9 in the Department of Mineralogy & Petrology, Institute of Geological Science of Wrocław University. The analytical conditions were: 15 kV accelerating potential, beam current of 50 nA and 15 s counting time. Natural and synthetic standards were used for calibration, and the ZAF procedure for correction. The microprobe analysis was performed on 16 samples representing eight formations (Ciechanowice, Nagórnik, Sady Górne, Stare Bogaczowice, Lubomin, Szczawno, Wałbrzych and Biały Kamień). Four samples rich in opaque minerals were analysed by X-ray diffraction using a Siemens D5005 Diffractometer in the same laboratory; the analyses were performed using the following conditions: 4–75° 2θ, step 0.04, time 2 s/step, 40 kV and 40 mA.

THE GENERAL VARIATION IN THE HEAVY MINERAL SPECTRA

Lower Carboniferous

The most frequent heavy minerals in the Lower Carboniferous sediments are opaques, the content of which is up to 90% of the heavy fraction. Among the transparent minerals, chlorite, epidote, garnet and apatite (Table 1) are the most abundant, whereas more resistant components (e.g. zircon) are rare.

Upper Carboniferous

The sediments of the Wałbrzych and Biały Kamień Formations are poorer in heavy fractions, than the younger sediments. The heavy minerals, as in the Lower Carboniferous rocks, are mainly represented by opaques (up to 99% of the heavy fraction in extreme cases). However, the transparent heavy mineral assemblages of the Upper Carboniferous sediments differ from the Lower Carboniferous ones. There are a lot more phases originated during weathering and/or hydrothermal processes, and the value of the ZRT (= zircon + rutile + tourmaline) index is considerably higher (Table 2). The authigenic minerals, such as haematite, chlorite, siderite and barite, are quite common, especially in the sediments of the uppermost Carboniferous.

Lateral diversity

Profile W

The heavy mineral assemblages of the Upper Tournaisian rocks mainly consist of clinozoisite and epidote (Fig. 3). The Stare Bogaczowice Formation sediments (except in their lowermost part) contain slightly less epidote and much more chlorite, accompanied by biotite, amphibole and apatite. In the upper part of that formation, Ti mineralisation is observed. The Ti minerals are represented by angular, euhedral brookite. Biotite, accompanied by chlorite and sphene, is the most common heavy mineral in the Lubomin and Szczawno Formations. The uppermost part of the latter formation is also rich in garnet.

There are only a few outcrops of the Upper Carboniferous sediments in the western part of the Intra-Sudetic Basin. The heavy mineral spectrum consists of mostly opaque minerals (more than 90%), the transparent minerals being represented by clinozoisite, apatite, rutile, chlo-

Table 1

The heavy mineral contents in the Lower Carboniferous sediments
(grain %; ZRT = zircon + rutile + tourmaline)

Formation	Ciechanowice, Nagórnik & Sady Górne				Stare Bogaczowice					Lubomin		Szczawno				
Sample	C1	C2	B1	A10	C6	A9	A7	M1	M2	A8	B2	A5	B5	A6	B3	B4
Muscovite	1.0	4.1	1.1	0.5	0.7	0.0	0.4	4.5	6.2	0.6	2.7	1.0	0.0	2.1	0.8	0.0
Biotite	1.6	1.6	9.0	9.2	2.7	0.9	1.3	14.3	2.1	10.1	4.7	1.0	14.0	12.1	9.9	0.0
Chlorite	17.0	25.2	27.0	19.8	25.5	0.9	23.6	42.9	1.2	18.5	30.5	20.8	26.4	33.3	29.0	12.7
Garnet	12.8	1.6	4.8	7.8	0.7	47.5	30.0	4.5	12.3	3.4	3.7	21.2	6.3	0.7	1.5	62.0
Epidote	21.6	45.9	27.0	13.0	20.1	2.5	1.3	2.6	9.1	7.3	0.0	3.1	5.1	13.5	20.6	6.0
Clinozoisite	10.8	9.0	9.2	18.1	12.1	0.9	3.4	0.8	3.7	1.7	2.0	2.3	0.7	4.3	3.8	5.0
Titanite	2.8	4.9	0.9	7.3	9.3	4.2	1.7	2.6	1.6	2.8	4.1	1.2	3.5	2.8	13.8	0.0
Brookite	0.1	0.0	0.6	0.0	0.7	3.0	6.3	0.0	57.6	11.2	2.7	15.1	0.7	0.0	0.8	0.0
Apatite	16.3	0.8	16.1	14.0	2.7	25.4	7.2	9.8	0.4	26.4	36.5	30.5	23.0	9.2	6.9	10.7
Amphibole	6.5	2.5	2.7	3.1	9.4	3.4	1.0	15.8	0.8	10.1	2.0	2.1	13.1	17.0	6.1	1.3
Pyroxene	0.8	1.0	0.7	0.5	3.3	0.0	14.8	0.0	0.0	0.0	1.4	0.3	0.7	0.0	0.8	0.0
Others	0.5	0.8	0.3	2.1	4.7	3.0	3.7	4.2	0.4	2.8	0.0	0.6	2.8	2.1	3.8	0.4
ZTR	9.1	2.5	1.5	4.7	5.4	7.17	6.4	0.8	6.2	3.5	10.9	2.5	2.8	2.8	2.3	5.6

Table 2

The heavy mineral contents in the Upper Carboniferous sediments
(grain %; ZRT = zircon + rutile + Tourmaline)

Formation	Wałbrzych		Biały Kamień					Żacler			Glinik & Ludwikowice		
Sample	AKL	W1u	J3u	W7	W8	K3	W9	J4	J5	W5	W11*	J6	W12
Muscovite	0.7	0.0	0.0	5.0	1.2	0.0	4.8	0.0	0.0	0.0	17.1	0.0	47.0
Biotite	0.0	4.4	2.5	0.0	5.6	0.0	2.4	0.0	0.0	3.0	2.0	0.5	1.6
Chlorite	17.6	23.4	12.3	0.0	8.3	14.0	7.2	5.2	0.6	32.1	12.9	1.0	1.6
Garnet	0.6	25.2	41.3	0.0	1.2	7.8	1.2	10.4	0.0	6.0	3.9	0.5	0.0
Epidote	13.7	12.9	6.4	1.2	4.8	0.0	2.4	6.5	0.0	0.0	2.0	3.3	7.3
Clinozoisite	22.2	6.9	7.4	4.4	11.9	29.0	6.0	2.6	2.4	9.7	0.0	11.4	1.6
Titanite	16.3	1.5	1.0	31.7	10.7	11.8	10.8	1.3	0.6	0.7	1.2	2.9	2.3
Brookite	0.0	1.2	0.5	0.0	1.2	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0
Apatite	16.3	13.7	16.9	0.0	27.4	15.7	26.5	31.2	4.2	29.9	5.9	7.6	2.4
Amphibole	1.4	7.5	1.0	0.0	3.6	2.0	1.2	1.3	0.0	2.2	2.0	0.5	0.0
Pyroxene	2.0	0.0	1.7	0.0	0.0	2.0	1.25	0.0	3.0	3.7	9.8	67.1	21.0
Others	5.9	0.7	1.0	0.6	1.2	3.9	20.5	1.3	89.2	0.0	>50	0.5	12.9
ZRT	4.0	3.2	8.9	58.4	19.0	14.0	14.4	39.0	0.0	12.7	2.0	4.8	3.3

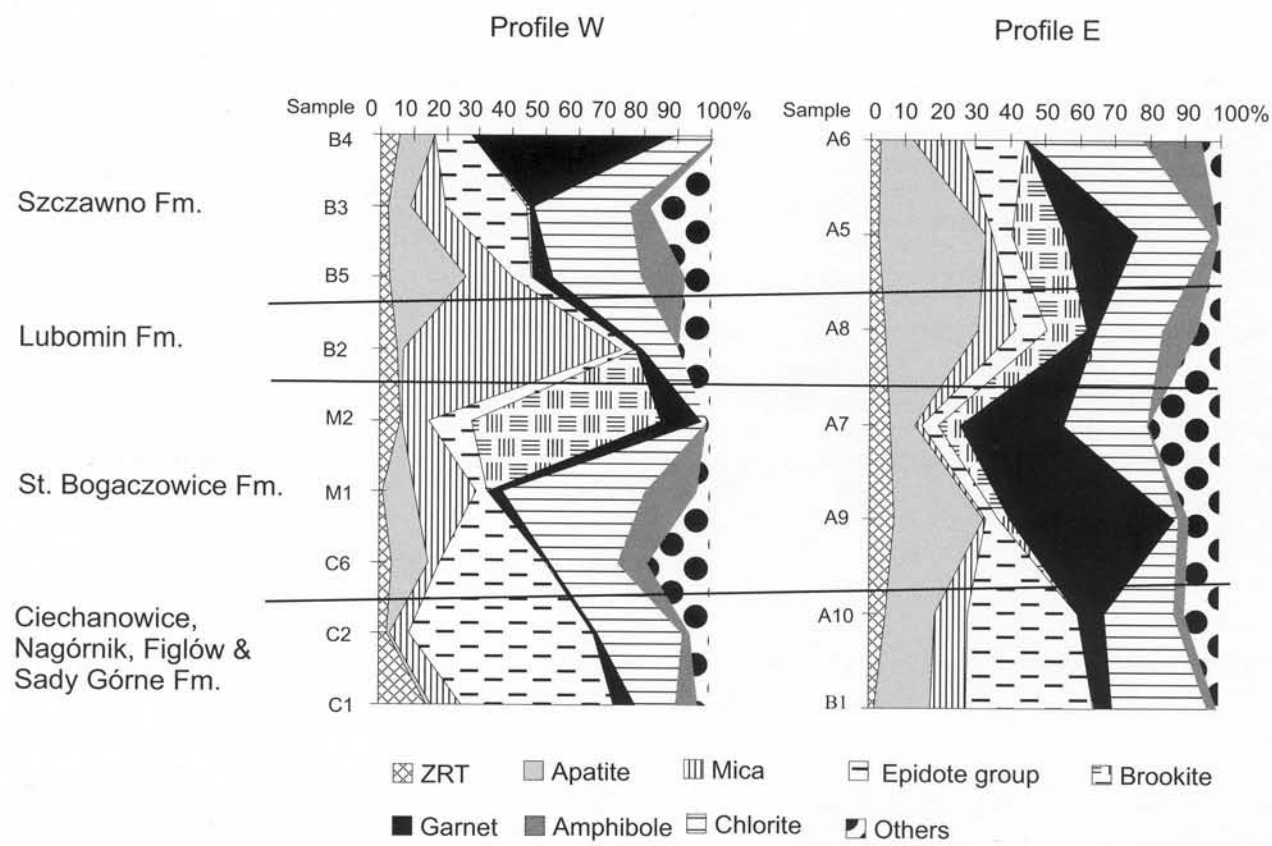

Fig. 3. The variation in the heavy fraction in the Lower Carboniferous sediments within the Intra-Sudetic Basin.

rite, sphene, garnet, amphibole and pyroxene (not shown in Fig. 4).

Profile E

The heavy mineral spectra in the Carboniferous sediments of the eastern part of the Intra-Sudetic Basin, as in the western part, depend on their position in the stratigraphic log. Epidotes are the most abundant minerals in the Upper Tournaisian, although they are not as abundant as in the western part. They are accompanied by chlorite and apatite, with minor biotite and garnet (Fig. 3).

The main heavy minerals of the Stare Bogaczowice Formation are garnet, apatite and chlorite whereas the epidote content is quite low. The Stare Bogaczowice Formation contains a small amount of epidote, and a higher

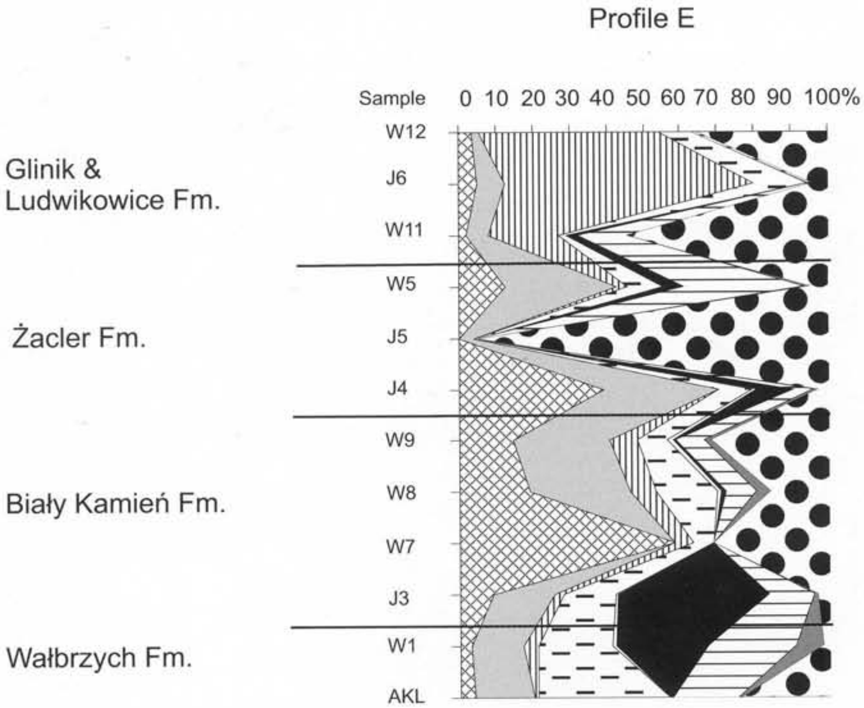

Fig. 4. The variation in the heavy fraction in the Upper Carboniferous sediments within the Intra-Sudetic Basin.

amount of garnet, apatite and chlorite. In the Lubomin Formation, garnet is less abundant, and apatite, accompanied by chlorite, biotite, epidote and authigenic brookite, is the dominant mineral. Again, the highest content of garnet occurs in the Upper Visean sediments.

Profile E is characterised by a more complete sedimentary column of the Upper Carboniferous than profile W. The lowermost parts of the Upper Carboniferous sediments comprise a great variety of the heavy fraction (Fig. 4), with clinozoisite, epidote, apatite, sphene and garnet as the dominant minerals. The rocks of the Biały Kamień Formation mainly contain rutile, apatite and sphene, accompanied by clinozoisite, epidote, chlorite and minor biotite and amphibole. The heavy fraction of the Žacler Formation is very similar to the one found in the Biały Kamień sediments. Sample J5 contains abundant barite and siderite, which are probably connected with volcanic activity in Early Permian times. Towards the top of the Permian sediments, the proportion of opaque minerals tends to increase, and the Stephanian rocks mainly comprise haematite. Among the transparent minerals, muscovite intergrown with haematite is abundant.

THE CHEMICAL COMPOSITIONS OF THE HEAVY MINERALS AS INDICATORS OF THE ALIMENTARY AREAS

In the determination of the alimentary areas, the chemical composition of heavy minerals can be very important, especially when the mineralogy is rather simple. In the Carboniferous of the Intra-Sudetic Basin, garnet and chlorite appear to be the most useful mineral indicators.

Garnet

Garnet is a widespread heavy mineral in most of the Carboniferous formations and its chemical composition varies considerably (Table 3). Among the Upper Tournaisian rocks, garnet is relatively common in the SE part of the Ciechanowice Formation. Its formulae ($Alm_{2-3}Prp_{2-3}Grs_{65-77}Adr_{18-31}$) resemble the garnets coming from metabasic rocks of the Czarnów Unit (Rudawy Janowicke Mts, Fig. 5). By contrast, the sediments of the Sady Górne Formation contain almandine-rich ($Alm_{68}Prp_{15}Grs_{3}Sps_{15}$) garnets which are similar to those occurring in gneisses and migmatities of the Góry Sowie Block. There are also a few other garnets, probably coming from HP rocks of the Niedamirów Unit in the SE part of the Izera–Karkonosze Massif (Fig. 5).

In the Stare Bogaczowice Formation, all the garnets are rich in almandine. There are species typical of garnets known from amphibolities of the Kłodzko Metamorphic Unit (Alm and Grs rich), and also from mica schists similar to those of the Kamieniec area and the Izera Mts (Alm rich; Fig. 6). The uppermost part of that formation con-

Table 3

Representative analyses and formulae of garnets from Carboniferous sediments of the Intra-Sudetic Basin (16 cations; if Si > 6 based on 6 atoms Si; if Si + Al + Ti + Cr > 10 based on 10 Si + Al + Ti + Cr)

Formations	Ciechanowice		Sady Górne						Stare Bogaczowice										
Sample	C2	C2	A10	A10	A10	A10	A10	A10	M2	M2	M2	M2	M2	M1	M1	M1	M1	M1	M1
Analyses	CGA	CGC	a	c	e	f	g	i-c	e	a	b	g	h	a	k	l	m	n	o
SiO_2	38.39	39.21	37.01	38.23	37.40	37.81	36.22	36.69	38.27	37.53	37.53	37.78	37.81	38.57	36.60	37.41	38.16	37.76	37.35
TiO_2	1.60	0.75	0.02	0.21	0.00	0.00	0.00	0.00	0.03	0.05	0.07	0.02	0.02	0.09	0.03	0.09	0.09	0.05	0.02
Al_2O_3	17.98	14.96	21.98	21.26	21.59	22.10	21.95	21.95	22.30	21.27	21.27	21.28	21.37	22.18	21.05	21.58	21.42	21.49	21.36
Fe_2O_3	6.29	10.56	0.00	0.36	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.01	0.00	0.00	0.00	0.17	0.00	0.00
FeO	1.09	1.24	29.74	11.82	31.20	30.11	33.56	29.92	30.63	32.09	31.80	34.30	34.50	27.17	33.15	31.74	31.06	29.49	31.99
MnO	0.11	0.22	5.82	18.28	0.54	6.55	2.67	6.49	2.44	6.59	6.22	3.14	3.26	1.53	1.13	0.75	0.81	0.38	4.52
MgO	0.62	0.26	3.20	0.28	0.75	3.71	2.80	3.03	5.09	2.30	2.37	2.46	2.61	7.31	3.00	4.04	4.05	2.05	3.16
CaO	34.87	34.12	2.75	11.25	9.43	0.93	1.89	1.69	1.93	1.52	1.49	2.02	1.88	2.81	3.45	4.18	4.35	9.10	1.87
Total	100.92	101.32	100.52	101.70	101.04	101.21	99.09	100.92	100.69	101.35	100.75	101.12	101.46	99.66	98.41	99.79	100.11	100.32	100.27
Si IV	5.86	6.00	5.88	6.00	5.94	5.92	5.83	5.80	5.93	5.99	5.99	6.00	6.00	5.95	5.96	5.95	6.00	5.98	5.97
Al IV	0.14	0.00	0.12	0.00	0.06	0.08	0.17	0.20	0.07	0.01	0.01	0.00	0.00	0.05	0.04	0.05	0.00	0.02	0.03
T site	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Al VI	3.10	2.70	4.00	3.93	3.98	4.00	4.00	4.00	4.00	3.99	3.99	3.98	4.00	3.99	4.00	3.99	3.97	3.99	4.00
Ti VI	0.18	0.09	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00
Fe^{+3}	0.72	1.22	0.00	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.00
O site	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Fe^{+2}	0.14	0.16	3.95	1.55	4.14	3.94	4.52	3.96	3.97	4.28	4.24	4.56	4.58	3.51	4.51	4.22	4.08	3.91	4.28
Mn^{+2}	0.01	0.03	0.78	2.43	0.07	0.87	0.36	0.87	0.32	0.89	0.84	0.42	0.44	0.20	0.16	0.10	0.11	0.05	0.61
Mg	0.14	0.06	0.76	0.07	0.18	0.87	0.67	0.86	1.18	0.55	0.56	0.58	0.62	1.68	0.73	0.96	0.95	0.48	0.75
Ca	5.70	5.59	0.47	1.89	1.61	0.16	0.33	0.29	0.32	0.26	0.25	0.34	0.32	0.46	0.60	0.71	0.73	1.54	0.32
A site	6.00	5.84	5.96	5.94	6.00	5.83	5.88	5.97	5.78	5.98	5.90	5.90	5.95	5.85	6.00	5.99	5.87	5.99	5.96
O	24.02	23.88	23.90	23.95	23.97	23.79	23.80	23.87	23.75	23.98	23.90	23.91	23.96	23.84	23.98	23.97	23.88	23.98	23.95
Prp	2	1	13	1	3	15	11	14	20	9	10	10	10	29	12	16	16	8	13
Alm	2	3	66	26	69	68	77	66	69	72	72	77	77	60	75	70	70	65	72
Sps	0	0	13	41	1	15	6	15	6	15	14	7	7	3	3	2	2	1	10
Grs	77	65	8	31	26	3	6	5	6	4	4	5	5	8	10	12	12	26	5
Adr	18	31	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

tains garnets ($Alm_{80}Sps_{15}Grs_{4\text{-}6}$) similar to those from the mica schists of the Kamieniec area.

Passing into the Lubomin Formation, the garnets display greater variation (Fig. 7). The predominant garnet species are those similar to garnets from HP rocks of the Niedamirów Unit ($Alm_{60}Prp_{3\text{-}6}Grs_{25\text{-}30}$ $Sps_{5\text{-}10}$) and also from mica schists (e.g. from the Śnieżnik Massif – $Alm_{70}Prp_{12}Sps_{14\text{-}18}$, or the Izera Mts – Alm_{70} Prp_5Grs_{25}) and gneisses and migmatites of the Góry Sowie Block (Alm_{70} $Prp_{12\text{-}14}$ $Sps_{12\text{-}14}Grs_4$).

Garnets also display great variation in the Szczawno Formation (Fig. 8). Some grains are similar to those from the gneisses and migmatites of the Góry Sowie Block, ($Alm_{72\text{-}73}Prp_{10\text{-}11}Sps_{13\text{-}15}Grs_{2\text{-}3}$) and some to those from HP schists of the Niedamirów Unit ($Alm_{50}Prp_6Sps_{24}Grs_{20}$). Garnets of composition typical of mica schists of the Izera Mts ($Alm_{53\text{-}64}$ $Prp_{2\text{-}10}Grs_{22}Sps_3Grs_{22\text{-}42}$) were found in the uppermost part of the Szczawno Formation.

Most garnets in the Upper Carboniferous sediments resemble those occurring in the gneisses and migmatites of the Góry Sowie Block; subordinate grains can have come from mica schists (e.g. from the Kamieniec area and/or the Izera Mts).

Chlorite

Chlorite also appears to be a useful indicator for determining the source areas. The Hay diagram (1954) shows a great variation of chlorite species, especially in terms of their X_{Fe} (=FeO/(FeO+MgO) index. Three chemically different groups are found in the Lower Carboniferous sediments: 1) high-Fe chlorites, probably coming from metapelitic rocks, 2) low-Fe chlorites, most likely derived from metabasic rocks, 3) low-Fe and high-Si chlorites typical of igneous basic rocks (products of am-

Table 3, continued

Representative analyses and formulae of garnets from Carboniferous sediments of the Intra-Sudetic Basin (16 cations; if Si > 6 based on 6 atoms Si; if Si + Al + Ti + Cr > 10 based on 10 Si + Al + Ti + Cr)

Formations	Lubomin						Szczawno					Wałbrzych							Biały Kamień
Sample	**B2**	**B2**	**B2**	**A8**	**A8**	**A8**	**B4**	**B3**	**B3**	**A5**	**A5**	**W1**	**W1**	**W1**	**W1**	**W1**	**W1**	**W1**	**J3**
Analyses	a	b	c	BGJ	BGK	BGN	e	AGB	AGC	h	i	FGA	FGB	FGC	FGD	FGF	HGB	HGD	GGA
SiO_2	37.61	37.19	36.52	37.38	38.47	37.94	37.81	36.32	37.42	38.28	37.43	39.29	37.84	36.80	36.03	35.55	37.29	37.05	36.84
TiO_2	0.02	0.02	0.10	0.17	0.19	0.19	0.03	0.02	0.02	0.02	0.03	0.07	0.05	0.11	0.02	0.90	0.02	0.00	0.02
Al_2O_3	21.38	21.10	20.81	21.75	21.85	21.69	22.35	22.18	22.18	21.75	21.90	22.64	22.07	21.97	21.70	21.61	21.61	21.69	22.10
Fe_2O_3	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.00	0.68	0.34	0.00	0.00
FeO	30.77	30.83	34.17	11.45	26.99	25.05	29.61	31.21	30.82	32.03	31.50	24.10	33.49	28.95	32.22	24.39	31.17	32.73	31.38
MnO	6.30	6.23	2.26	25.31	2.02	4.54	1.25	5.46	5.44	5.76	6.44	0.54	1.70	0.46	6.06	6.75	6.63	6.07	5.92
MgO	3.00	2.91	1.74	0.84	1.50	1.25	2.65	3.02	3.35	2.78	2.46	5.79	4.31	2.50	2.37	0.82	2.97	2.42	2.78
CaO	1.42	1.43	3.43	4.78	9.92	9.86	8.05	1.60	1.53	0.81	0.98	9.02	1.99	8.87	1.12	9.32	1.59	0.08	1.79
Total	100.50	99.71	99.22	101.68	100.94	100.52	101.75	99.81	100.76	101.43	100.74	101.45	101.45	100.03	99.52	100.02	101.62	100.04	100.83
Si IV	5.99	5.99	5.96	5.92	5.98	5.96	5.89	5.81	5.89	5.99	5.92	5.95	5.92	5.84	5.85	5.71	5.92	5.92	5.86
Al IV	0.01	0.01	0.04	0.08	0.02	0.04	0.11	0.19	0.11	0.01	0.08	0.05	0.08	0.16	0.15	0.29	0.08	0.08	0.14
T site	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Al VI	4.00	4.00	3.96	3.98	3.98	3.98	4.00	4.00	4.00	4.00	4.00	3.99	3.99	3.94	4.00	3.81	3.96	4.00	4.00
Ti VI	0.00	0.00	0.01	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.11	0.00	0.00	0.0
Fe^{+3}	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.08	0.04	0.00	0.00
O site	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Fe^{+2}	4.10	4.15	4.66	1.52	3.51	3.29	3.86	4.18	4.05	4.19	4.16	3.05	4.38	3.84	4.37	3.28	4.14	4.37	4.17
Mn^{+2}	0.85	0.85	0.31	3.40	0.27	0.60	0.16	0.74	0.72	0.76	0.86	0.07	0.23	0.06	0.83	0.92	0.89	0.82	0.80
Mg	0.71	0.70	0.42	0.20	0.35	0.29	0.62	0.72	0.79	0.65	0.58	1.31	1.01	0.59	0.57	0.20	0.70	0.58	0.66
Ca	0.24	0.25	0.60	0.81	1.65	1.66	1.34	0.27	0.26	0.14	0.17	1.46	0.33	1.51	0.19	1.61	0.27	0.01	0.30
A site	5.90	5.95	6.00	5.92	5.77	5.85	5.98	5.91	5.82	5.74	5.77	5.89	5.95	6.00	5.97	6.00	6.00	5.78	5.93
O	23.89	23.95	23.99	23.89	23.77	23.84	23.93	23.82	23.77	23.73	23.73	23.87	23.91	23.92	23.90	23.91	23.96	23.74	23.86
Prp	12	12	7	3	6	5	10	12	13	11	10	22	17	10	10	3	12	10	11
Alm	69	70	78	26	61	56	64	71	70	73	72	52	74	64	73	55	69	76	70
Sps	14	14	5	57	5	10	3	13	12	13	15	1	4	1	14	15	15	14	13
Grs	4	4	9	14	29	28	22	5	4	2	3	25	6	24	3	25	3	0	5
Adr	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	2	1	0	0

phibole and/or pyroxene alteration). However, some chlorites may have originated from unstable minerals, such as biotite, amphibole and epidote, during diagenetic processes.

Biotite

There are two types of biotite (brown and green) in the Carboniferous sediments of the Intra-Sudetic Basin. All the biotites contain about 0.5% Ti but they have different amounts of tetraedric and octaedric Al. Interestingly, biotite attains its highest quantities in samples which are rich in amphibole and poor in rutile and brookite. This suggests that biotite was partly replaced by chlorite in many samples.

Muscovite

Muscovite, very often intergrown with opaque minerals, occurs sporadically in the Lower Carboniferous rocks, whereas it is quite common in the Upper Carboniferous sediments, especially in the Stephanian formations. It usually forms intergrowths with haematite so it is difficult to estimate its exact amount. The microprobe analysis of the muscovite (high phengite and low Na contents) pointed to low-grade metamorphic and low-temperature rocks as the alimentary areas. The muscovites from the Sady Górne, Lubomin and Szczawno Formations are rich in Na and poor in Mg and Fe. Such a chemical composition suggests that higher-temperature metamorphic or igneous rocks may have been their source.

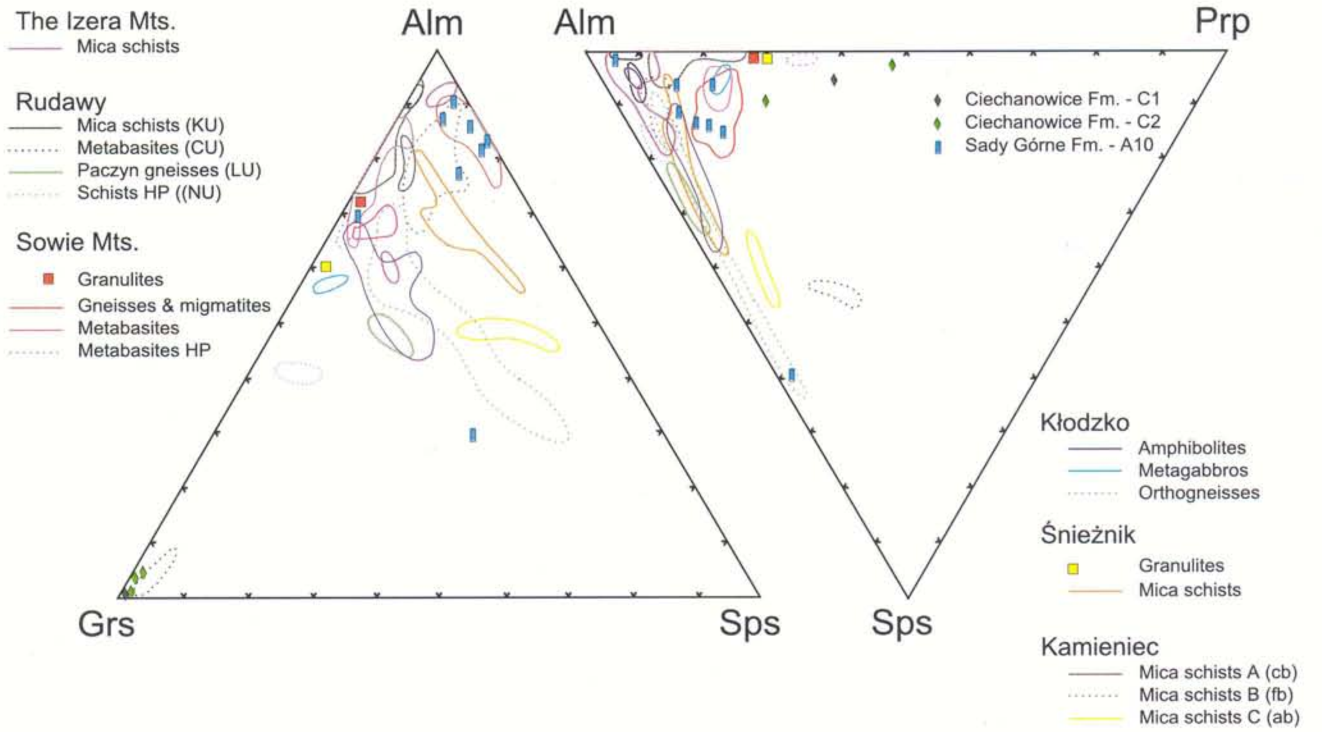

Fig. 5. The chemical composition of garnets from the Ciechanowice Fm., Nagórnik Fm., and Sady Górne Fm. compared with garnets of metamorphic rocks of the Sudetes (microprobe data of R. Kryza, 1999, unpublished; Kamieniec – data from Józefiak, 1998).

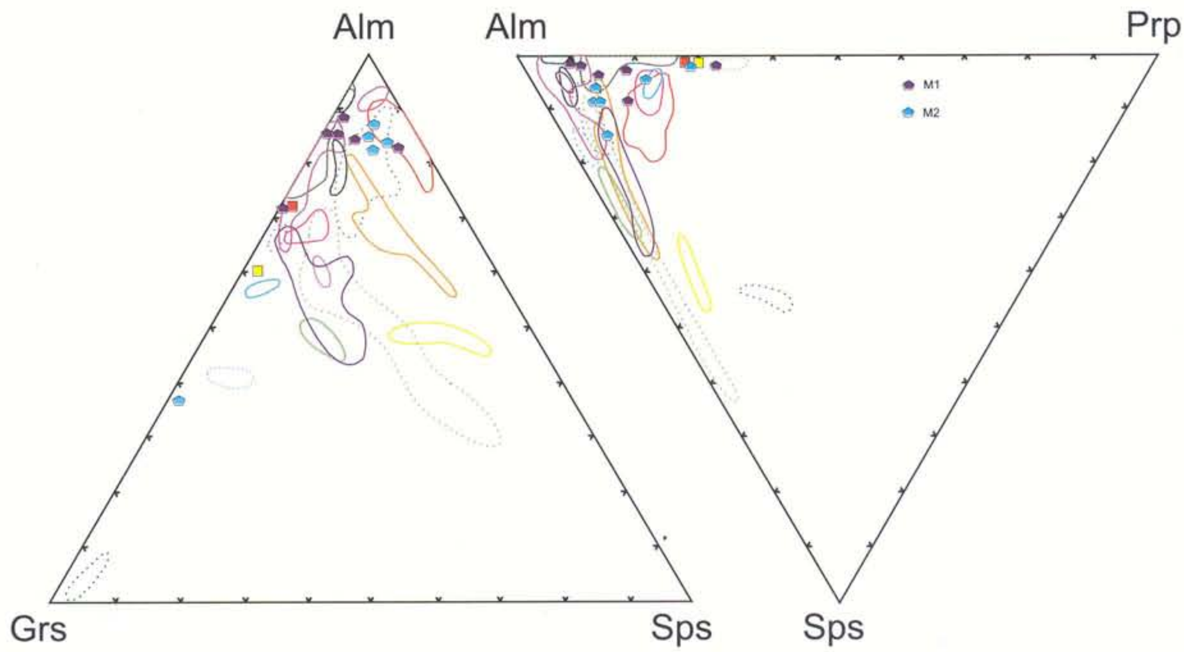

Fig. 6. The chemical composition of garnets from the Stare Bogaczowice Fm. compared with garnets of metamorphic rocks of the Sudetes (microprobe data of R. Kryza, 1999, unpublished; Kamieniec – data from Józefiak, 1998). Legend as in Fig. 5.

Amphibole

Amphibole is not a very common heavy mineral in the Carboniferous sediments. The reason may be its low resistance to chemical and physical weathering. Nevertheless, there are some formations where amphibole is widespread. The composition of the grains found in the Sady Górne Formation corresponds to actinolite which indicates relatively low-grade metamorphic rocks as their source. Such rocks are found in the Kaczawa Complex or the eastern cover of the Karkonosze Massif (Felicka, 1999). In the sediments of the Stare Bogaczowice Formation, single grains of blue amphibole (glaucophane?) were found, whereas in the Szczawno Formation, the amphi-

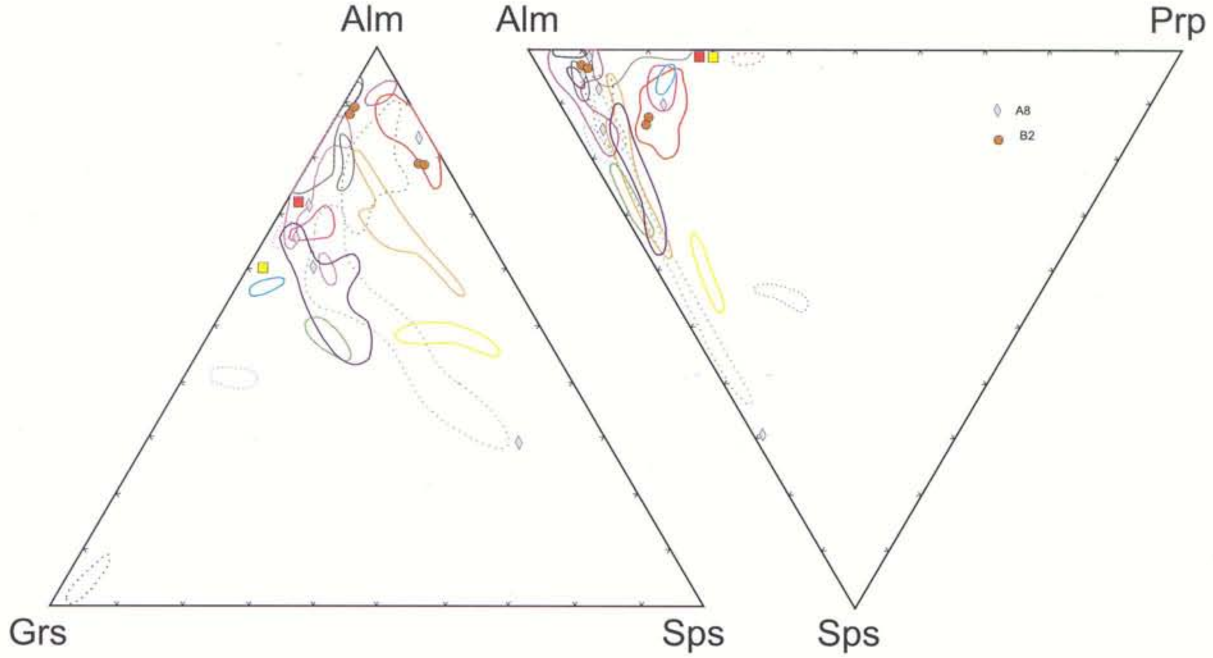

Fig. 7. The chemical composition of garnets from the Lubomin Fm. compared with garnets of metamorphic rocks of the Sudetes (microprobe data of R. Kryza, 1999, unpublished; Kamieniec – data from Józefiak, 1998). Legend as in Fig 5.

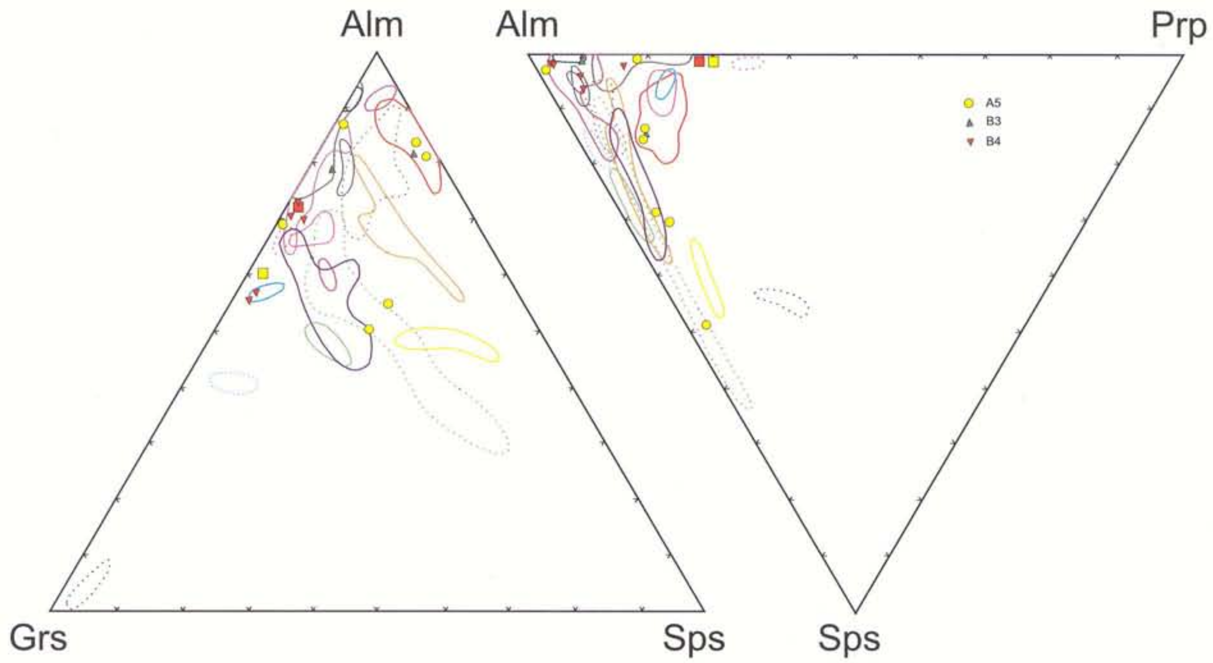

Fig. 8. The chemical composition of garnets from the Szczawno Fm. compared with garnets of metamorphic rocks of the Sudetes (microprobe data of R. Kryza, 1999, unpublished; Kamieniec – data from Józefiak, 1998). Legend as in Fig. 5.

boles display the composition of Mg-hornblende, typical of moderate and higher-grade metamorphism (e.g. the metabasic rocks of the eastern cover of the Karkonosze Pluton).

Pyroxene

Pyroxene, like amphibole, is characterised by low stability, hence it does not play important role in the heavy fractions of the studied sediments. The grains found in the Upper Tournaisian and Stare Bogaczowice Formations display diopside-hedenbergite composition, whereas in the Lubomin and Szczawno Formations, pyroxenes are represented by augite.

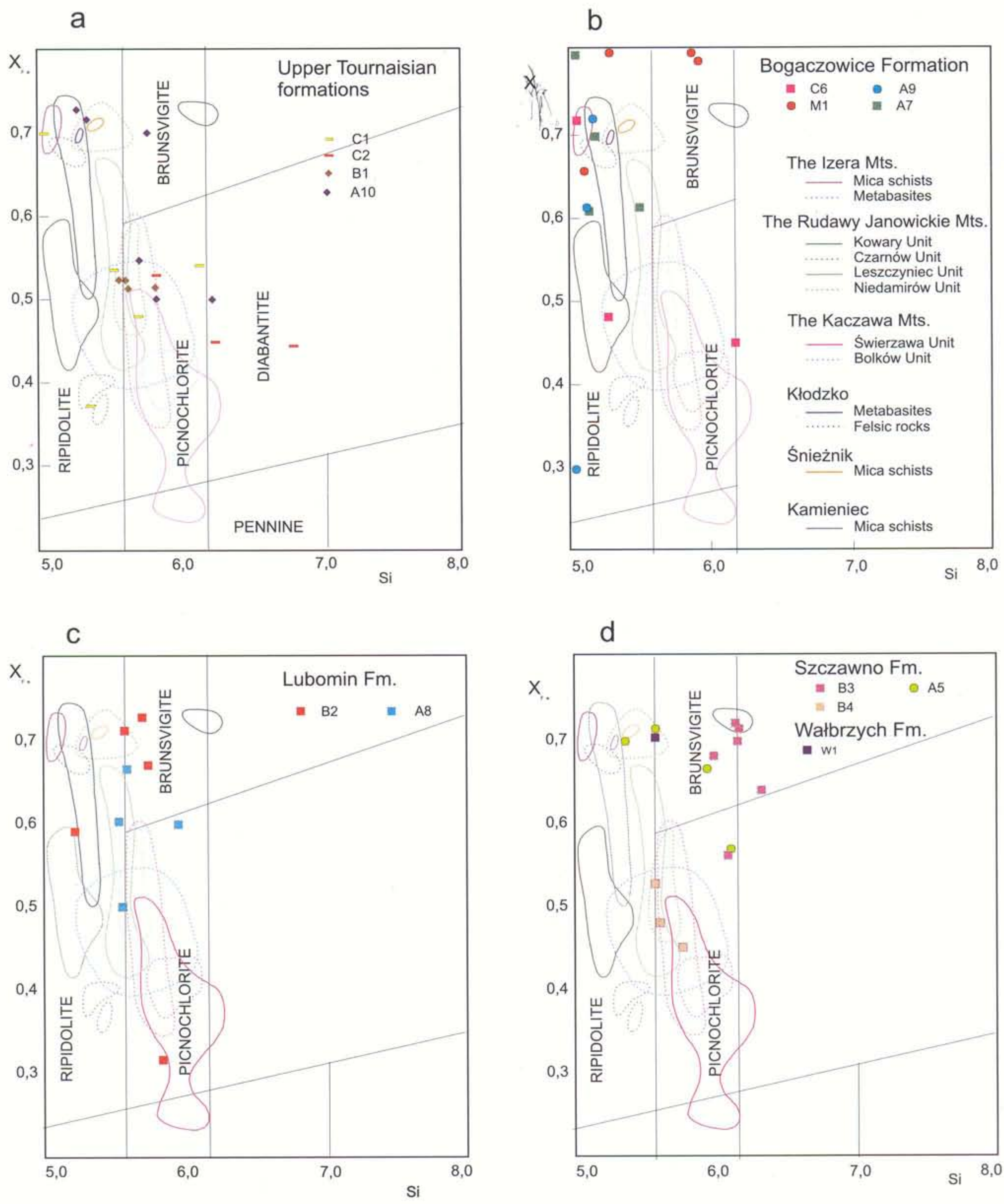

Fig. 9. The chemical composition of chlorites: **a** – Ciechanowice Fm., Nagórnik Fm., Sady Górne Fm.; **b** – Stare Bogaczowice Fm.; **c** – Lubomin Fm.; **d** – Szczawno Fm. and Wałbrzych Fm., compared with chlorites of metamorphic rocks of the Sudetes (microprobe data of R. Kryza, 1993 unpublished; Kamieniec – data from Józefiak, 1998).

Other minerals

Epidote group

The minerals of the clinozoisite-epidote group occur in all the Carboniferous formations, but their quantities vary greatly. All grains are characterised by rather similar chemical composition. The Ps = 100x $Fe^{3+}/(Fe^{3+} + Al)$ values range from 21 to 36, which resemble the epidotes from the Niedamirów Unit (the eastern cover of the Karkonosze Massif) or metabasites of the Kaczawa Mts

(Kryza & Mazur, 1995; Kryza, 1993).

Pumpellyite

Pumpellyite occurs in two samples (Nagórnik and Stare Bogaczowice Formations) and it is represented by both the Fe-rich and Fe-poor types. That mineral is quite common in metabasites of the Kaczawa Mts (Kryza 1993).

Apatite

Apatite is common in most samples, even thoughit is sometimes difficult to identify optically, having similar habit and, in specific orientation, optical features to white mica (*sic!*). "Typical" prismatic and oval apatite grains can seldom be found (~5% of all apatites) and are mainly in the Stare Bogaczowice and Szczawno Formations. Thin, platy or scaly forms resembling white mica are more abundant. They were confirmed as apatite using an electron microprobe. Such apatite occurs in all the Carboniferous formations, and all the studied grains are chemically rather pure.

OPAQUE AND Ti MINERALS AS INDICATORS OF SOURCE AND EPIGENETIC ALTERATION

Opaque minerals, especially Ti minerals and haematite, are often present in terrigenic sediments. Such minerals, especially TiO_2, haematite and ilmenite are widespread in the studied Carboniferous rocks. The Upper Tournaisian sediments contain a few TiO_2 grains, the habit of which (rounded, brown-red to black grains) suggests that they are rather of detrital than authigenic origin.

Authomorphic brookite occurs as either euhedral or irregular, dark yellow grains, showing strong pleochroism (yellow-dark grey) in the Stare Bogaczowice Formation. Surprisingly, it attains quantities of up to 57% in the heavy fraction of a sample representing the lower part of this formation. The titanium oxides are most abundant in rocks containing such minerals as ilmenite, biotite, amphibole and pyroxene. The chemical analysis of these minerals shows that they all contain considerable amounts of Ti, hence they could have been a source of Ti in the formation of secondary minerals.

As a consequence of the alteration of biotite, amphibole and ilmenite, both titanium and iron are released, creating, under oxidising conditions, haematite. This mineral is common in the Upper Carboniferous sediments, and it colours the rocks red. According to Teisseyre (1971), most of the haematite in the sediments was supplied long after sedimentation, and the process was connected with late Variscan tectonism, accompanied by volcanic activity.

SUMMARY AND DISCUSSION

Ciechanowice Formation (Late Tournaisian ?)

The heavy mineral analysis confirms the former interpretations of the alimentary areas and transport directions based on sedimentological research in this formation. The heavy fraction is mainly represented by angular and subangular minerals of the clinozoisite-epidote group, phyllosilicates (chlorite & green biotite) and actinolite (Fig. 3), which all point to the Kaczawa Mts and the eastern cover of the Karkonosze Pluton as the alimentary areas (Fig. 10a). This conclusion is also supported by the chemical analyses of chlorites and, partly, garnets (Figs. 5 & 9).

The Figlów and Nagórnik Formations (Late Tournaisian ?)

The clinozoisite-epidote group, chlorite (with many opaque inclusions), apatite, biotite, and minor amphibole are common heavy minerals in these formations. Such minerals are typical of the Kaczawa Mts rocks and the chemical composition of the studied minerals also points to that rock complex as the source area of the sediments (Fig. 9a).

The Sady Górne Formation (Late Tournaisian ?)

As in the other Upper Tournaisian formations, the Sady Górne sediments contain a lot of epidote group minerals, which strongly suggests that the Kaczawa Complex was the main source area. The composition of the garnets resembles that from migmatites of the Góry Sowie Block (Fig. 5), however, the lack of sillimanite and kyanite (minerals typical of the migmatites) suggests that the garnets might not have come directly from the crystalline rocks, but could have been redeposited, probably from sediments similar to those of the Świebodzice Depression. Moreover, the heavy fractions of the Intra-Sudetic Basin sediments are characterised by poorer heavy mineral assemblages than those from the Carboniferous sediments of the Świebodzice Depression or from the Culm of the Góry Sowie Block, which also suggests the likely redeposition of the sediments.

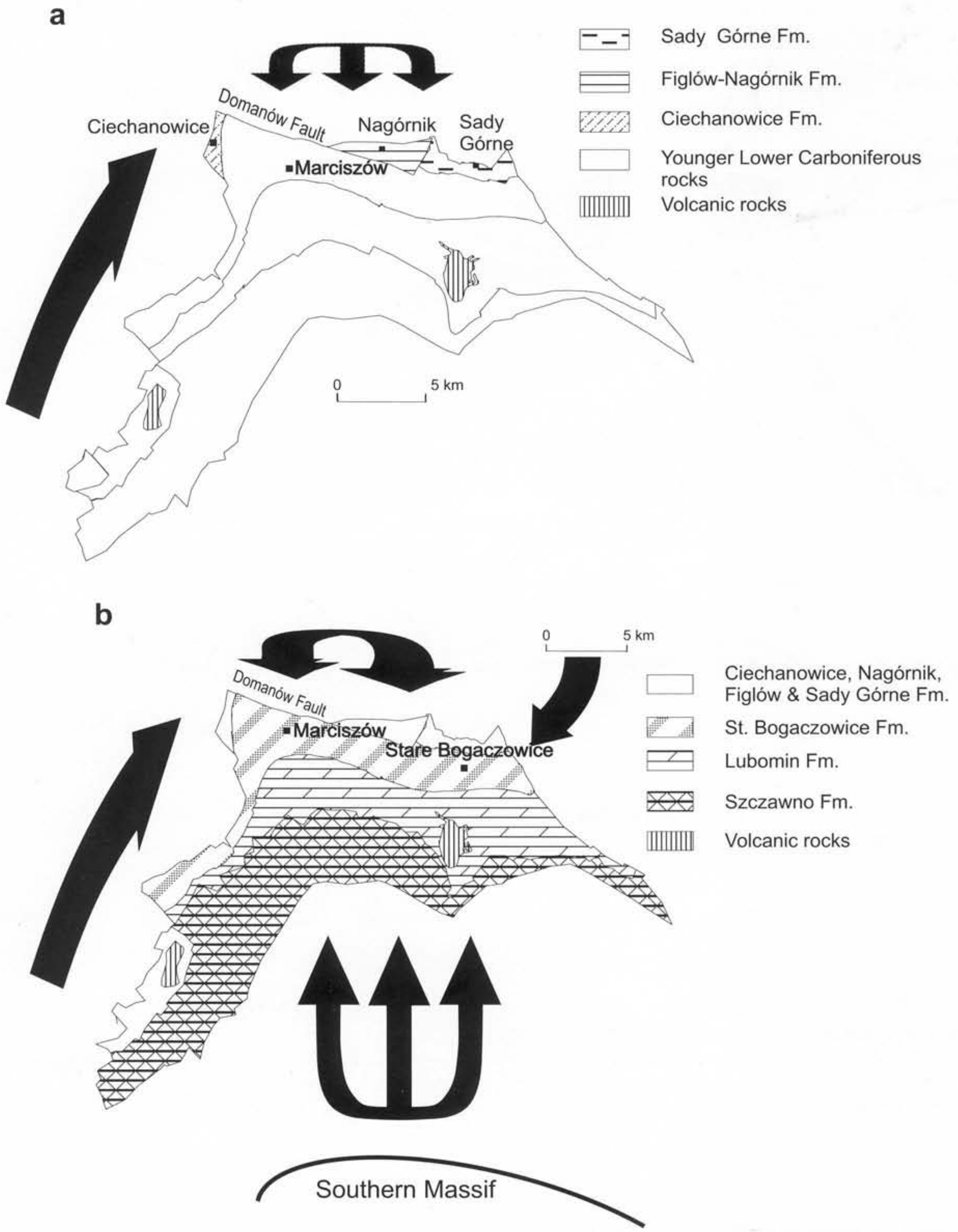

Fig. 10. **a)** The transport directions of the sedimentary material in the Upper Tournaisian. **b)** The main transport directions in the Visean.

The Stare Bogaczowice Formation (Early Visean)

Sedimentological studies pointed to the Kaczawa Mts, the Rudawy Janowickie and, partly, the Świebodzice Depression as the alimentary areas for this formation (Teisseyre, 1968; Dziedzic & Teisseyre, 1990). The heavy mineral analysis, in general, confirms this interpretation. The heavy mineral fraction in the eastern part of the formation is mainly represented by garnets (over 50%) which are similar to those from the rocks of the Kłodzko Metamorphic Unit, the Kamieniec area, the Izera Mts and, in part, granulites of the Góry Sowie Block (Fig. 5). The garnets are accompanied by epidote group minerals (~20%) and sphene, white mica, rutile, apatite, biotite and minor

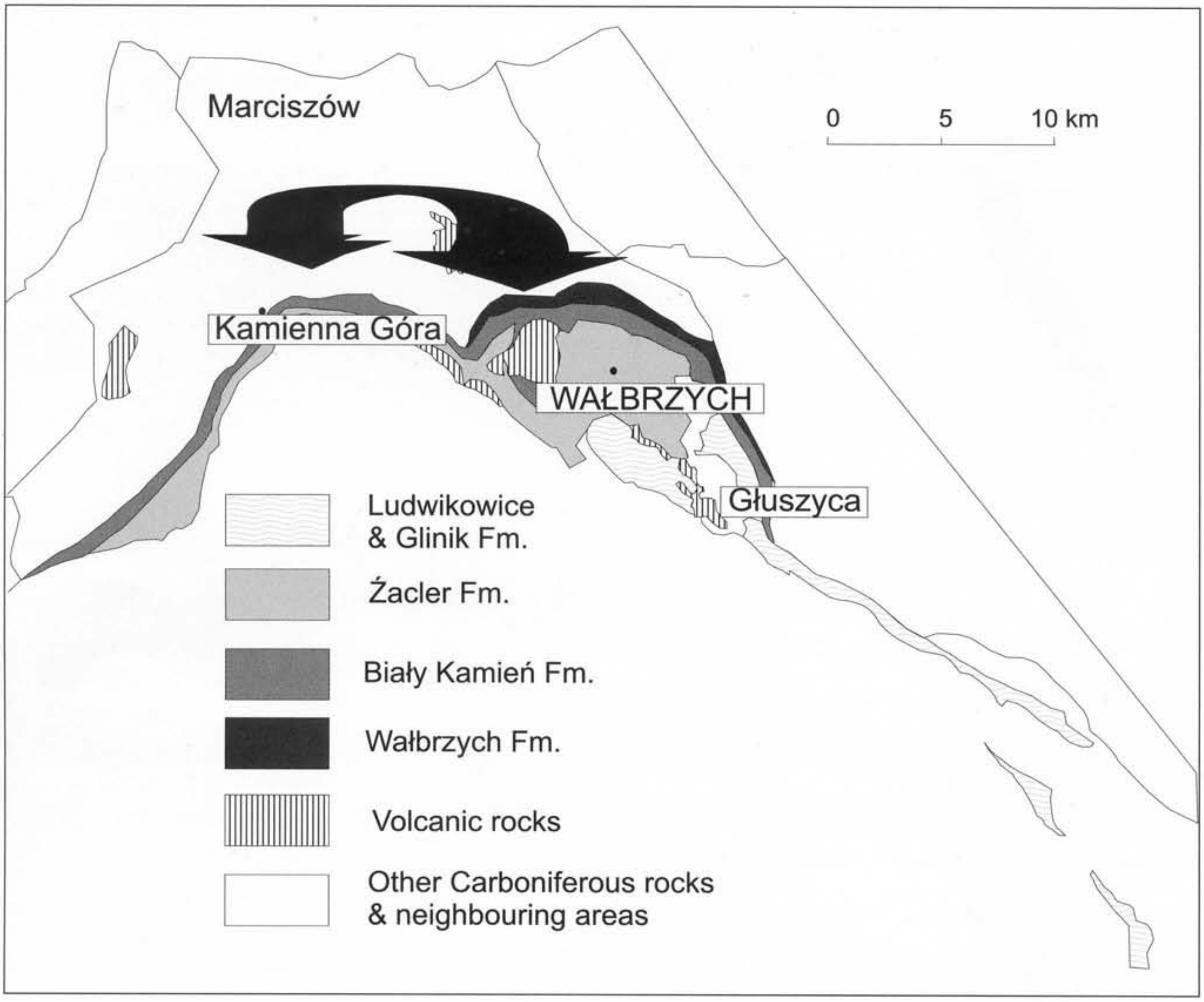

Fig. 11. The main transport directions in the Upper Carboniferous (redeposition plays an important role).

amphibole (Table 1). The varied heavy mineral assemblage indicates different alimentary areas (the eastern part of the Karkonosze cover, the Kaczawa Mts or the so called "Southern Massif") and the probable redeposition of the older sediments, e.g. those from the Świebodzice Depression (Fig. 10b).

The Lubomin Formation (Middle Visean)

The heavy fraction of the Lubomin Formation sediments is represented by chlorite (nearly 60%), biotite, apatite and minor clinozoisite, rutile and garnet. The chemical composition of the chlorite (brunsfigit and Fe rich ripidolite, Fig. 9c) resembles that from the Rudawy Janowickie rocks, and the garnets are similar to those from mica schists of the Śnieżnik Massif or the Izera Mts, and from gneisses and migmatites of the Góry Sowie Block. It suggests that the sediments were originally derived from various sources.

The Szczawno Formation (Late Visean)

The sediments of this formation are represented by alluvial and marine deposits. Sedimentological research pointed to the transport towards SE - ESE (Mastalerz, 1987). The heavy mineral analysis shows that the Izera-Karkonosze Massif, especially the metabasalts and the Paczyn gneisses of the Leszczyniec Unit, were the alimentary rock complexes. This is also confirmed by the abundant garnet, epidote, and green and brown chlorite. The chemical composition of the chlorite resembles that from the Rudawy Janowickie rocks, whereas the garnet displays a wide variation of chemical composition. The garnet might have been derived not only from the eastern cover of the Karkonosze Massif, but also from mica schists (e.g. in the Kamieniec area) or gneisses of the Góry Sowie Block (Fig. 8).

The Wałbrzych Formation (Namurian A)

The Wałbrzych Formation sediments are mainly represented by quartz conglomerates. In spite of such maturity of the coarse-grained sediments, a large variation in the heavy mineral spectra (similar to that from the Szczawno Culm) is observed in the eastern part of the Wałbrzych Formation. The dominant mineral there is garnet, the composition of which resembles that of garnets from the granulites of the Góry Sowie Block, or from the mica schists of the Kamieniec area and the Izera Mts (Fig. 8). Chlorite plays also an important role. Its chemical composition indicates that it was formed, at least in part, during the alteration of biotite and other mafic minerals. Beside chlorite, epidote, apatite and amphibole occur. The heavy fraction in the rocks of the western part of the Wałbrzych Formation is mostly represented by opaque minerals, especially haematite which is probably an authigenic mineral. Because of the high maturity of the material, it is very difficult to establish the alimentary areas.

The Biały Kamień Formation (Namurian B & C)

The sediments of this formation contain a small amount (~ 1%) of the heavy fraction, in which authigenic haematite is the main mineral. This fact makes establishing the source areas using heavy mineral analysis very difficult. The dominating transparent minerals are rutile, sphene, apatite and chlorite. Garnet is more abundant and displays a chemical composition similar to garnets from gneisses and migmatites of the Góry Sowie Block. It confirms that the material can have come from the Góry Sowie Block, although the direct transport from that area is questionable because of the high maturity of the sediments. Most probably, the Góry Sowie Block material got to the Intra-Sudetic Basin as a result of the redeposition of Lower Carboniferous sediments, which was already suggested by Dziedzic (1971).

The Žacler Formation (Westphalian A & B)

In the Žacler Formation, as in the older Upper Carboniferous sediments, haematite is the main heavy mineral. The transparent minerals are represented by apatite, rutile, chlorite and also barite and siderite, the latter two having originated during diagenesis or hydrothermal processes. Other minerals which could serve as indicators of the alimentary areas (e.g. amphibole, garnet) are very rare. Based on the heavy mineral analysis, it can be said that the sediments accumulated at that time mostly came from the redeposition of older molasse sediments (Fig. 11).

The Glinik and Ludwikowice Formations (Westphalian C & D and Stephanian)

The palaeogeographic reconstruction of these sediments is more difficult because of the lack of outcrops. However, in the analysed samples, the heavy mineral fraction is very poor in transparent minerals and, as in the older formations, haematite plays the main role. It is accompanied by chlorite and muscovite (often intergrown with haematite) and minor clinozoisite, epidote, apatite and also minerals formed during diagenesis (iron oxides, siderite). The heavy mineral analysis confirms the previous results of sedimentological studies, although direct transport form the Góry Sowie Block remains uncertain. The latter conclusion is supported by the fact that, apart from the garnet, there are no minerals typical of the Góry Sowie Block gneisses and migmatites present in the sediments.

CONCLUSIONS

1. The heavy mineral analysis in the Carboniferous sediments of the Intra-Sudetic Basin shows that the following opaque minerals are the most common: haematite, ilmenite and polymorphs of TiO_2. The transparent minerals are mostly represented by the clinozoisite-epidote group, garnet, chlorite, apatite and minor amphibole, pyroxene, zircon and several other accessories (Tables 1 & 2).

2. The heavy mineral assemblages display considerable variation, both laterally and in the stratigraphic column (Figs. 3 & 4).

– The Upper Tournaisian sediments contain a characteristic heavy mineral assemblage which is dominated by epidote, biotite and chlorite; such spectra are similar in both profiles W and E.

– In the upper part of the Lower Carboniferous, a clear regional distinction can be seen: in profile W, there are not many differences compared with the older sediments; in profile E – garnet, pointing to probable transport from the Góry Sowie Block, is much more abundant.

– Starting from the Szczawno Formation in the W profile, and from the Wałbrzych Formation in the E profile, garnet is a common mineral in the sediments. Most probably at that time, the basin became "uniform" and the deposits were "homogenised" by redeposition.

– There is an important change in the mineralogy of the heavy fraction in the middle part of the Biały Kamień Formation: a considerable decrease in the garnet and ZRT-mineral content, with a corresponding increase in the content of minerals formed during diagenesis and/or hydrothermal processes (haematite, barite and siderite).

– Haematite, often overgrown with muscovite, is the dominant heavy component in the Stephanian sediments. Other minerals occur subordinately.

3. The chemical analyses of the heavy minerals show that:

- The garnets of the Ciechanowice and Lubomin Formations are rich in Grs and resemble the garnets from the contact-metamorphic basic rocks of the Rudawy Janowickie (garnets rich in Sps, typical of HP rocks of the eastern cover of the Karkonosze Pluton were not found).

- In the Sady Górne Formation, garnets similar to those from the gneisses and migmatites of the Góry Sowie Block are most common (a few grains rich in Sps, typical of low-grade metamorphic rocks are also found).

- The younger deposits display a wide variation of garnet formulae, which indicates various source areas and an important role of resedimentation.

- The chlorites of the Nagórnik Formation are similar to those from the rocks of the Kaczawa Mts, whereas the chlorites of younger sediments resemble those from the eastern cover of the Karkonosze Massif; some chlorites might have formed through alteration of other mafic minerals;

- The chemical compositions of the examined amphiboles suggest their origin from low- (e.g. the Kaczawa Mts) to medium-grade metamorphic rocks (e.g. the eastern cover of the Karkonosze Pluton).

- Pyroxenes with diopside-augite formulae mostly resemble relic, igneous pyroxenes of the metabasites of the Kaczawa Mts.

4. The heavy mineral analyses confirm that the alimentary areas for the oldest sediments of the Intra-Sudetic Basin were the Kaczawa Mts and the eastern cover of the Karkonosze granite, whereas for the younger deposits, there was probably not a single source area but the materials derived from different sources and were redeposited.

5. The distinct change of the heavy mineral spectra in the middle part of the Biały Kamień Formation suggests an important change in the factors controlling sedimentation in the basin.

6. Comparing the composition and habit of grains from the Intra-Sudetic Basin with those from the Świebodzice Depression and the Góry Sowie Culm, it can be said that most of the sedimentary materials, including the sediments of the latter two areas, were redeposited.

7. In general, the heavy mineral analyses confirm previous interpretations based on sedimentological research; however, the direct transport from the Góry Sowie Block area is questionable (apart from garnets, other minerals typical of the rocks of that area do not occur).

8. The heavy minerals appear to be good indicators of the alimentary areas for the oldest Carboniferous sediments, whereas in case of the younger molasse deposits, which were probably redeposited several times, they are less useful.

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