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Wojciech NARĘBSKI *

PALEOTECTONIC SETTING OF THE CIRCUM-KARKONOSZE LOWER PALAEOZOIC SPLILITE-KERATOPHYRE SUITES BASED ON GEOCHEMISTRY OF IRON GROUP ELEMENTS

(8 Figs.)

Pozycja paleotektoniczna wokółkarkonoskich dolnopaleozoicznych serii spilitowo-keratofirowych w świetle geochemii pierwiastków grupy żelaza

(8 fig.)

Abstract: Distinct differences in statistical parameters of distributions of Ti, Cr and Ni, as well as in total FeO and TiO_2 versus FeO/MgO trends in metabasic rocks of Lower Palaeozoic spilite-keratophyre suites of the Góry Kaczawskie Mts. and of the Rudawy Janowickie-Lasocki Grzbiet range are interpreted on the basis of recent data on geochemical diversity of basalts originated under different tectonic setting.

It is concluded that spilitic and associated volcanics of the Góry Kaczawskie Mts. are geochemically corresponding to the present Hawaiitic within-plate ocean-island basalts, whilst those of the Rudawy Janowickie-Lasocki Grzbiet range (representing E part of the SE metamorphic mantle of the Karkonosze granite) — to island-arc tholeiites, genetically connected with Benioff zones.

This conclusion is supported by various geological data and by the occurrence of traces of glaucophane schist belt at the outer boundary of the SE part of metamorphic mantle of the Karkonosze granite.

Lack of typical ocean ridge basaltic series in this part of the Variscan geosyncline suggests the possibility of only local and small-scale oceanization preceding the formation of active arc-trench system in question.

INTRODUCTION

Rapid development of investigatoins of basic volcanic rocks occurring and formed in different tectonic environments resulted in establishing their, formerly not appreciated, but rather distinct geochemical peculi-

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* Polish Academy of Sciences, Museum of the Earth, Warsaw. Mailing address: Collegium Geologicum UJ, ul. Oleandry 2a, 30-063 Kraków (Poland).

arities (Chayes and Velde, 1965; Floyd and Winchester, 1975; Garcia, 1978; Green, 1973; Herrmann et al. 1974, Jakeŝ and White, 1972; Kushiro, 1973; Kutolin, 1972; Miyashiro, 1974; Pearce and Cann, 1973; Pearce, 1976; Kuźmin and Popolitov, 1978).

When accepting plate-tectonic approach to this problem, which considerably stimulated very rapid progress in this branch of petrology, we may distinguish the following types of basaltic rock series (Pearce and Cann, 1973; Pearce, 1976):

1. Ocean-floor basalts (OFB) or, more precisely, ocean-ridge tholeiites (ORT) erupted at diverging plate margins within mid-oceanic ridges or within small basins formed behind island arcs.
2. Ocean-island basalts (OIB) formed within oceanic plates and ranging from tholeiitic to alkalic types (Hawaiitic within-plate basalts).
   It should be emphasized that these two geochemically slightly differing basalt series (1 and 2) are by some authors (Miyashiro, 1974) treated together as so called abyssal tholeiites (AT).
3. Island-arc tholeiites (IAT), also called low-K tholeiites (LKT) erupted at converging plate margins close to deep-ocean trenches during the initial stage of formation of island arc-trench systems (eg. Tonga islands).
4. Calc-alkali basalts (CAB) erupted at converging plate margins above Benioff zones but on continental crust, rather distant from the trench and in more mature stage of development of island arc (eg. Java, Kamchatka, Kurile islands).
5. Shoshonites (SHO) — K-rich trachybasalts erupted in senile stage of evolution of island arc-trench systems, usually far behind the trench (eg. Papua, N. Guinea, Stromboli and Vulcano in Eolian isl.)
6. Continental basalts (CON), ranging from tholeiitic to alkalic in composition, erupted in within-plate setting, mainly at continental rifts.

When dealing with the problem of tectonic setting of Lower Silesian spilite-keratophyre suites we are, obviously, interested in the series originated in oceanic and circum-oceanic environments i.e. in the first four types of basaltic rocks distinguished. Their most important geochemical characteristics, selected by the present author from recent data summarized by Kutolin (1972), Condie (1976) and Pearce (1976), are presented in table 1.

As far as transitional elements of the iron group (3d) are concerned, inspection of these data clearly indicates that the most important differences consist in statistical parameters of distribution of Ti, Cr and Ni, as well as of FeO/MgO ratio. Among other elements, island-arc basalts distinguish by higher Si and Al and lower Mg contents. Besides, alkali and calc-alkali basalts are distinctly enriched in potassium and phosphorus. Petrogenetically very important differences in abundances of other immobile trace elements called „incompatible”, as Zr, Y, Nb and TR are not presented and discussed in this paper since they have not yet been determined in the rocks under consideration.

As already mentioned, all these geochemical features reflect different tectonic conditions of the above mentioned basaltic magma types. The proposed models are based not only on plate-tectonic assumptions but also on experimental studies on partial melting of mantle material (pyrolite) under different p-t conditions both in anhydrous and water-bearing systems (Kushiro, 1973; Green, 1973). Summarizing very briefly the actually available data, it is supposed that during large-scale mantle diapirism within ocean ridges, rather high-degree ($>$ 20%) partial melting at relatively shallow depths (40—60 km) under anhydrous conditions produces the common tholeiitic magmas. Because of rather short migration before eruption they are subjected to moderate fractionation and thus abound in trace elements of the iron group (Cr and Ni, to lesser extent Ti). Ridge magmatism is predominantly non-violent, effusive in character.

In oceanic island chains, situated within oceanic plate (e.g. the Hawaiians), there occur individual eruptive centres consisting mainly of tholeiitic and, partly, alkali basalts which, following recent data, slightly differ geochemically from those of ocean ridges. Magmatic activity in such environments is supposed to be due to local thermal disturbances in the low-velocity zone of the mantle (hot spots) probably caused by tensional failure of the overlying lithosphere which also allows the upraisal of produced lavas, accompanied by more pronounced differentiation. Alkali basalts of ocean islands are, most probably, the products of low-degree partial melting ($<$ 20%) at higher depths ($>$ 50 km). Consequently these magmas are most abundant in Ti and P, as well as in Cr and Ni, amongst all the basalts in question. According to available observations, ocean-island volcanism is mainly effusive in character.

Completely different and much more diversified conditions of basaltic magma generation are those governing in arc-trench systems, connected with complex processes taking place at the convergent plate contacts along Benioff zones. Because of very diversified t and p distributions in these systems and the presence of water-bearing sedimentary envelope of subducted slab, the partial melting phenomena may take place either in peridotite of lithospheric wedge overlying the Benioff zone or within basaltic layer of the upper part of descending plate. In the former case this process is caused mainly by upward migration of released water and the basaltic magma, formed by 20—30% partial melting, leaving residual olivine, orthopyroxene and ore minerals during fractionation, is tholeiitic in character. Specific conditions of its origin is reflected in different geochemistry of these rocks when compared with those of ocean ridge and ocean island tholeiites e.g. considerably lower contents of trace elements of the iron group (Ti, Cr, Ni).

In later stage of island-arc evolution, partial melting of basic source material in the slab at higher depths may produce calc-alkali magmas, ranging from basaltic to andesitic and dacitic in composition. According to Ringwood's model (1974), the liquids formed in dehydrated slab at 100—150 km, being of rhyolitic composition, only rarely reach directly the surface. They are predominantly reacting with overlying pyrolite to produce wet pyroxenite diapirs which by partial melting during uprise yield a wide range of calc-alkali magmas showing high K/Na ratios, fractionated RE patterns and abounding in incompatible elements. When uprising, these magmas are subjected to fractionation.

Besides, upward migration of volatiles from dehydrating subducted slab into the overlying thickened continental crust may cause mobilization of low-melting fractions, resulting in the formation of acid volcanics, migmatites, gneissic domes and granitoids.

Another possible setting of basaltic magma generation is related with small basins with bottom consisting of intermediate oceanic-continental crust, formed behind arc-trench systems above the deepest parts of Benioff zone (eg. Japan Sea in the Pacific or Thyrrenian Sea in the Mediterranean). Within central parts of such basins small-scale mantle diapirism may take place producing, as already mentioned, tholeiites, showing geochemistry close to that of ocean-ridge basalts.

No matter of recent progresses in our knowledge of submarine and circum-oceanic volcanic phenomena, there are still very controversial opinions concerning one of the topics of modern petrology — possible geological settings and origin of ophiolitic associations in general and of its specific partial equivalents — spilite-kerytophyre suites in particular (Coleman, 1977). Actually, the majority of petrologists, following plate-tectonical viewpoint, indicates ocean-ridge environment as the most probable place of origin of all the three members of Steinmann trinity: metamorphic persidotites, ultrabasic-basic cumulates and basaltic volcanics, usually showing mutual tectotnic contacts. Nevertheless, even such „classical" ophiolitic complex as the well known Troodos in Cyprus is recently interpreted by several authors, on the ground of geochemical data, to be formed in island-arc system (Miyashiro 1973) or within back-arc basin (Pearce, 1975). It is thus very probable that various members of ophiolitic suite may originate in different tectonic settings. The same refers to rocks of spilite-keratophyre association which, in some authors opinion (Zwart, 1967, Rocci and Juteau, 1968), is Hercynotype equivalent of Alpinotype ophiolitic series.

Taking into account the above presented recent data on basalt types erupted in different geological environments, numerous authors are attempting to apply their different geochemical characteristics as criteria for distinguishing the tectonic settings of usually more or less altered Cenozoic and even Palaeozoic metabasaltic rock series. When examining in this respect ancient volcanic rocks, major element abundances which are useful in discriminating magma types of recent basalts (Pearce, 1976) are of very limited value because of their susceptibility to modification even during low-grade metamorphism. Consequently, all the discussed petrological reconstructions are based on these minor and trace elements abundances which are insignificantly affected by secondary alteration processes.

Chayes and Velde (1965) were the first to indicate the important role of Ti content in discriminating basalts of circumoceanic and ocean-island type. Detailed geochemical studies in the last few years allowed to find definite groups of immobile trace elements considerably increasing the possibilities of geochemical distinction between basalts of different origin (Floyd and Winchester, 1975; Gale and Roberts, 1974; Garcia 1978; Glassley, 1974; Herrmann et al. 1974; Jakeš and White, 1972; Miyashiro and Shido, 1975; Pearce et al. 1975; Ricci and Sabatini, 1978; Smith and Smith, 1976; Winchester and Floyd, 1976 etc.). The majority of these authors used such immobile and incompatible elements as Zr, Nb, Y and REE for discriminating magma types of ancient more or less altered basic rock series.

Among other immobile trace elements, used as petrogenetically diagnostic ones, titanium, chromium and phosphorus were recently found to be very convenient (Chazen and Vogel, 1974, Gale and Roberts, 1974; Glassley, 1974; Pearce, 1975; Pearce et al. 1975; Ricci and Serri, 1975 etc.). The first two of them are typical representatives of transitional elements of the (3d) iron group showing specific geochemical properties (Narębski, 1968a). By contrast to the above incompatible elements, tending to remain in liquid phase during partial melting or fractionation processes, they participate (similarly as P) in the latter process either forming early precipitated own minerals (ilmenite, chromite, apatite) or entering crystallizing mafic phases. Therefore, their content and behaviour can be diagnostic for the origin and evolution of paleobasaltic and spilitic rock series (Narębski, 1968a, b), especially when compared with variation of FeO/MgO ratio (Miyashiro, 1973).

One of the most important results of the present author's geochemical studies of the Lower Silesian spilite-keratophyre series consisted in finding distinctly different statistical distribution parameters and correlations of trace elements of the iron group in pillow lavas of the Góry Kaczawskie Mts. when compared with metabasic rocks of the Leszczyniec Volcanic Formation of the Rudawy Janowickie-Lasocki Grzbiet range (Narębski, 1964, 1968, 1974; Narębski and Teisseyre, 1971). The scope of this paper is to interpret different geochemical features of these two neighbouring Lower Palaeozoic initial volcanic series in terms of modern theories of origin of basaltic magmas in various tectonic environments.

GENERAL GEOLOGICAL SETTING OF THE CIRCUM-KARKONOSZE SPILITE-KERATOPHYRE SUITES

There are two initial volcanic rock series actually grouped around the Karkonosze granite massif (Fig. 1). The older of them, probably Upper Cambrian greenschist complex, belongs to one of the largest geosynclinal series of West Sudetes — the lower structural member of the Góry Kaczawskie Mts. The younger one is represented by probably Upper Silurian metavolcanic rock association of the Leszczyniec Formation. In J. H. Teisseyre's (1968) opinion, accepted by the present author, this series represents the NE continuation of less metamorphosed but very similar volcanites of Żelezny Brod and Rychorskê Hory crystalline complexes and thus belongs to the same S-SE metamorphic mantle of the Karkonosze granite. The differences in metamorphic grade are due to variable distance of various parts of this volcanic rock association from the marginal zone of granitic intrusion (Fig. 1).

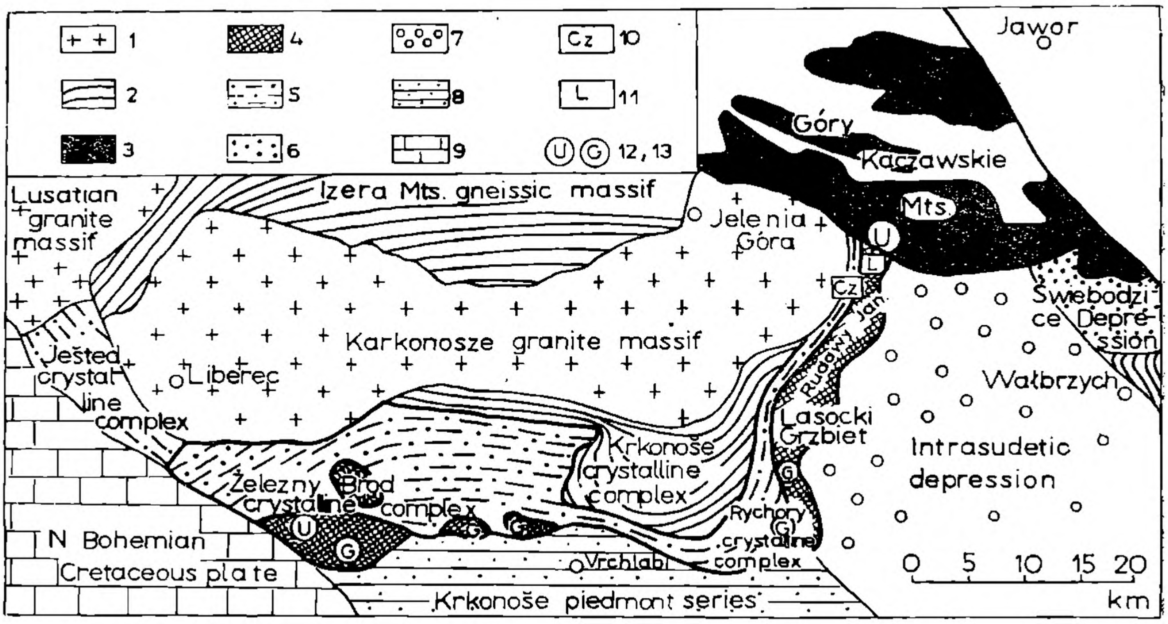

Fig. 1. Geological sketch map showing the position of Lower Palaeozoic spilite-keratophyre suites and their relations with other geological units of the Karkonosze region. 1 — granitoids, 2 — metamorphic rocks, 3 — Upper Cambrian (?) spilite-keratophyre suite, 4 — Upper Silurian spilite-keratophyre suite; 5 — mica schists and phyllites; 6 — Devonian-Lower Carboniferous deposits; 7 — Carboniferous-Permian deposits, 8 — Permian deposits; 9 — Upper Cretaceous series; 10 — Czarnów schist formation; 11 — Leszczyniec volcanic formation; 12 — glaucophane schists; 13 — ultrabasites

Fig. 1. Szkic geologiczny przedstawiający położenie dolnopaleozoicznych serii spilitowo-keratofirowych i ich stosunek do innych jednostek geologicznych w rejonie karkonoskim. 1 — granitoidy; 2 — skały metamorficzne; 3 — górnokambryjska (?) seria spilitowo-keratofirowa; 4 — górnosylurska seria spilitowo-keratofirowa; 5 — łupki mikowe i fyllity; 6 — osady dewońskie i dolnokarbońskie; 7 — osady karbońskie i permskie; 8 — osady permskie; 9 — seria górnokredowa; 10 — formacja łupkowa Czarnowa; 11 — formacja wulkaniczna Leszczyńca; 12 — łupki glaukofanowe; 13 — ultrabazyty

Table / Tabela / - 1

Average composition of basalts originated in different tectonic settings in within- and circum-oceanic environment /after Pearce,1976 - /P/, Kutolin,1972 - /K/ and Condie,1976 - /C/ in wt.% and ppm

Średni skład chemiczny bazaltów powstałych w różnych układach tektonicznych w obrębie i na obrzeżeniu oceanów /wg. Pearce 'a,1976 - /P/, Kutolina,1972 - /K/ i Condie 'go,1976 - /C/ w % wag. i ppm

Tectonic setting Układ tektoniczny	Mid-oceanic ridge Grzbiet śródoceaniczny		Ocean islands Wyspy oceaniczne				Volcanic island arcs Wulkaniczne łuki wyspowe			
Type of basalt Typ bazaltu	Ocean-floor basalt - OFB Bazalt dna oceanicznego	Mid-oceanic ridge tholeiite Toleit grzbietów śródocean.	Tholeiitic island basalt Bazalt toleitowy wysp ocean.		Alkali olivine island basalt Alk. bazalt oliwinowy wysp ocean.	Ocean island basalt-OIB Bazalt wysp ocean.	Low-K tholeiite-LKT Island-arc tholeiite IAT Toleit nisko-potasowy -toleit łuków wysp.		Calc-alkali /high-Al/ basalt CAB Bazalt wapienno-alkaliczny, wysoko-glinowy	
	/P/	/K/	/K/	/C/	/K/	/P/	/P/	/C/	/P/	/K/
SiO_2	49.6 /0.69/[1]	49.3 /0.96/	49.1 /1.3/	49.4	45.8 /2.4/	46.9 /2.7/	51.6 /2.3/	51.1	52.1 /1.9/	50.9 /2.0/
Al_2O_3	16.1 /0.84/	16.1 /1.3/	15.1 /1.0/	13.9	15.0 /2.1/	16.4 /1.6/	16.4 /2.1/	16.1	18.1 /1.6/	17.7 /1.7/
FeO_{tot}	10.2 /1.1/	8.96 /1.8/	10.6 /1.3/	12.4	11.9 /1.6/	10.9 /1.4/	10.2 /2.3/	11.8	8.89 /1.1/	9.86 /1.9/
MgO	7.69 /0.90/	7.99 /2.0/	7.75 /1.2/	8.40	7.65 /2.6/	5.55 /1.3/	5.92 /1.8/	5.1	5.00 /1.4/	5.37 /1.7/
CaO	11.3 /0.60/	11.7 /0.69/	10.6 /0.70/	10.3	10.0 /1.4/	9.96 /1.3/	10.3 /1.3/	10.8	9.67 /1.1/	9.81 /1.2/
Na_2O	2.80 /0.28/	2.82 /0.10/	2.23 /0.40/	2.13	2.91 /0.71/	3.37 /0.86/	2.03 /0.47/	1.96	2.95 /0.50/	2.69 /0.68/
K_2O	0.24 /0.14/	0.26 /0.04/	0.30 /0.15/	0.38	1.18 /0.45/	1.36 /0.84/	0.43 /0.28/	0.40	1.07 /0.33/	1.00 /0.54/
TiO_2	1.42 /0.30/	1.39 /0.17/	2.09 /0.52/	2.50	3.06 /0.86/	3.04 /0.82/	0.81 /0.39/	0.83	1.07 /0.33/	1.04 /0.43/
P_2O_5	no data	0.16 /0.01/	0.23 /0.06/	n.d.	0.48 /0.24/	no data	no data	n.d.	no data	0.19 /0.25/
Cr	300 /C/	no data	no data	250	no data	- " -	- " -	50	- " -	40 /C/
Ni	100 /C/	- " -	- " -	150	- " -	- " -	- " -	25	- " -	25 /C/
FeO_{tot}/MgO	1.33	1 12	1.36	1.33	1.56	1.96	1.72	2.08	1.78	1.84
Number of data	75	63	110	n.d.	118	75	37	n.d.	75	355

[1] in brackets - standard deviations of means; all values rounded to three numbers
w nawiasach - odchylenie standardowe średnich; wszystkie wartości zaokrąglono do trzech cyfr

Table — Tabela 2

Indicator element (oxide) contents and ratios in pillow-cores of lavas and in greenschists of metavolcanic series of the Góry Kaczawskie Mts. (in wt. %, ppm)

Zawartości i stosunki wskaźnikowych pierwiastków (tlenków) w centrach sferoidów lawowych i w zieleńcach serii spilitowej G. Kaczawskich (w % wag. i ppm)

Locality	FeO^{tot}	MgO	Na_2O+K_2O	FeO^{tot}/MgO	TiO_2	P_2O_5	K_2O	Cr	Analyst
Muchów	11.0	7,5	4.6	1.50	1.95	0.18	0.62	500	W. Narębski
Dobromierz	10.1	8.8	3.5	1.15	1.87	0.19	0.20	300	,,
Pastewnik	10.6	8.2	5.1	1.29	2.56	0.45	0.86	110	,,
Jakuszowa	9.1	6.4	4.1	1.39	1.78	0.50	0.40	200	,,
Cieszów	8.5	4.2	4.8	2.04	0.99	0.37	1.45	50	,,
Kaczorek	9.8	7.7	2.8	1.26	1.39	0.17	0.46	250	,,
Bolków	11.5	7.1	5.9	1.62	2.84	0.30	0.08	280	,,
Złotoryja	6.8	3.4	6.4	1.95	1.26	0.23	0.23	390	,,
Świerki	13.5	7.7	4.5	1.77	3.35	0.56	0.20	300	,,
Leśniak	13.2	7.5	3.9	1.74	3.01	0.43	0.33	110	,,
Marciniec	12.5	7.6	4.3	1.64	4.26	0.92	0.23	180	,,
Lubiechowa	8.7	5.5	4.4	1.59	2.06	0.31	0.32	310	,,
Grodzik	13.5	3.8	5.1	3.53	2.23	0.31	0.23	190	,,
Leśna	11.7	4.0	6.5	2.94	3.47	0.38	1.04	190	,,
Ptasiniec	10.3	6.4	5.3	1.62	2.80	0.66	1.45	30	,,
Wleń	7.7	5.2	7.2	1.50	2.63	0.48	1.93	230	,,
Janówek	9.1	1.9	6.8	4.64	2.75	0.44	0.49	190	,,
Płonina	16.0	5.8	4.4	2.76	3.90	0.51	0.62	n.d.	Klüss
Pastewnik	14.3	5.6	4.4	2.55	2.74	0.42	1.37	n.d.	Eyme
Gorzanowice	12.9	7.5	3.5	1.72	3.07	0.23	0.50	n.d.	,,
Janice	15.4	4.8	5.8	3.21	3.78	0.11	1.43	n.d.	,,
Rochowice Stare	13.7	8.0	2.8	1.71	1.95	0.44	0.33	n.d.	n.d.
Chmielarz	12.1	9.3	4.2	1.30	1.37	0.35	0.16	n.d.	,,

Table — Tabela 3

Chemical analyses of striped amphibolites of the Rudawy Janowickie-Lasocki Grzbiet range (Czarnów Schist formation), wt. % and ppm

Skład chemiczny amfibolitów smużystych pasma Rudawy Janowickie-Grzbiet Lasocki (formacja łupków z Czarnowa) % wag i ppm

Rock type	Diopside amphibolites							Biotite amphibolites		Feldspar amphibolite
						Garnet-bearing				
Locality	Wieściszowice region			Miedzianka region			Grzędziny N	Janowice Wielkie	Mniszków	Leszczyniec NW
Sample No. [1])	492 A	495	504	50	24 G	49 F	112	450	386	615 B
SiO_2	45.6	47.0	47.3	47.7	49.7	46.8	45.9	44.4	47.2	47.5
TiO_2	0.77	0.67	0.80	0.73	0.74	0.66	1.42	1.95	1.85	1.17
Al_2O_3	15.6	15.7	16.7	16.0	15.7	15.1	15.7	17.3	20.2	15.8
Fe_2O_3	2.79	3.27	2.82	1.95	2.27	2.82	2.30	5.05	2.32	1.83
FeO	7.30	7.67	2.93	7.63	7.98	6.96	9.12	8.96	6.90	8.30
MnO	0.12	0.12	0.14	0.10	0.11	0.08	0.14	0.13	0.12	0.13
MgO	7.05	7.15	5.93	7.32	6.91	6.50	6.32	5.76	4.23	6.68
CaO	15.9	12.7	15.0	12.7	11.3	16.1	11.7	9.69	5.72	10.7
Na_2O	1.93	2.55	2.56	3.80	3.94	3.52	4.92	2.75	2.76	4.82
K_2O	0.15	0.25	0.54	0.25	0.39	0.17	0.33	1.28	5.94	0.29
P_2O_5	0.02	0.04	0.09	0.06	0.07	0.08	0.25	0.22	0.35	0.27
H_2O	2.53	2.64	1.31	1.87	1.08	0.97	1.62	2.34	2.57	2.37
Total	99.72	99.76	100.12	100.11	100.18	99.76	99.72	99.83	100.16	99.86
FeO^{tot}/MgO	1.40	1.47	1.59	1.29	1.32	1.46	1.42	2.33	2.14	1.17
Cr	235	110	285	300	200	335	210	75	170	130
V	230	300	340	200	320	240	240	240	230	260
Ni	75	45	40	75	65	105	100	69	70	70

[1] all samples from J. H. Teisseyre's collection (symbol JT ommitted). Analyst: W. Narębski
wszystkie próbki z kolekcji J. H. Teisseyre'a (symbole JT pominięto)

Detailed geological and petrographical characteristics of these both series are given elsewhere (Fediuk, 1962; Svoboda and Chaloupsky, 1966; H. Teisseyre, 1967; Narębski, 1964, 1968a, 1974; Narębski and Teisseyre, 1971; J. H. Teisseyre, 1968 a, b, 1973 etc.) and in this paper only these data will be presented which are directly connected with the problem under consideration.

SPILITE-KERATOPHYRE SUITE OF THE GÓRY KACZAWSKIE MTS.

The Greenstone Formation in question overlies, according to up to date opinions, the Lower to Middle Cambrian Wojcieszów limestones representing various litofacial varieties but, in general, indicating some sea-bottom elevation (H. Teisseyre, 1967; Baranowski, 1977). Metavolcanic formation is overlain by Ordovician flyschoid deposits containing subordinate basic igneous rock intercalations whilst the highest Silurian sequence, also containing some metadiabases, is rather pelagic in character (metalydites, pelitic deposits). In general, geosynclinal deposits of the Góry Kaczawskie Mts. are predominantly aleuritic and pelitic in character, whereas psammites occur in subordinate amounts. The Greenstone Formation in question displays variable thickness — from ca. 2000 m in the east to nearly complete disappearance in the west. It consists predominantly of greenschists resembling basaltic tuffites and spilitic lavas showing locally pillowed forms (Narębski, 1964). Basic

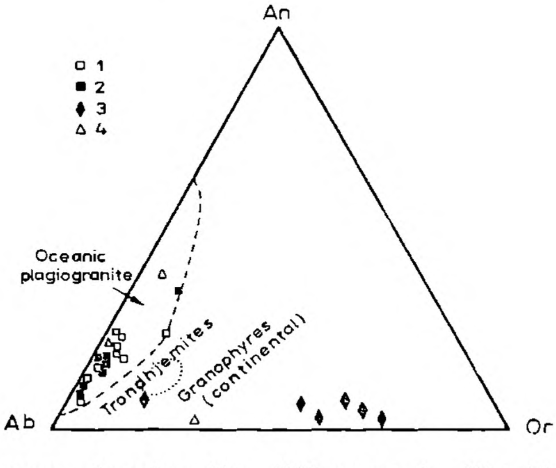

Fig. 2. Ab-Or-An diagram showing the difference in Na: K: Ca ratios in acidic rocks of the circum-Karkonosze spilite-keratophyre associations. Symbols: 1 — Paczyn gneisses; 2 — keratophyres of the Leszczyniec Formation; 3 — keratophyres of the G. Kaczawskie Mts.; 4 — metavolcanics of the Kłodzko crystalline complex (for comparison). Ocean plagiogranite, trondhjemite and continental granophyre fields after Coleman (1977, p. 51 fig. 17)

Fig. 2. Wykres Ab-Or-An ilustrujący odmienne stosunki Na : K : Ca w skałach kwaśnych wokółkarkonoskich serii spilitowo-keratofirowych. Symbole: 1 — gnejsy paczyńskie; 2 — keratofiry formacji Leszczyńca; 3 — keratofiry G. Kaczawskich; 4 — skały kwaśne krystaliniku kłodzkiego (porównawczo). Pola plagiogranitów oceanicznych, trondhjemitów i granofirów kontynentalnych wg Colemana (1977, fig. 17)

volcanics are accompanied by less abundant but very diversified acidic ones, represented eg. by predominantly potassic keratophyres (Fig. 2).

Our knowledge of geochemistry of this thick volcanic series is far from being complete. The present author's data refer to pillowy varieties occurring along and across the whole range of the Góry Kaczawskie Mts in all its tectonic units (Narębski 1964) but representing a peculiar type of paleobasaltic lavas of this formation. Other chemical data contain but major element contents and, therefore, are of limited value for reconstructing the environment of origin of the series in question. Nevertheless, even on the ground of detailed study of pillow lavas in question it was possible to establish two-stage of submarine volcanic activity in this area whereby the first was normal basaltic in character whilst the products of the second displayed distinct spilitic trend. Such evolution was supposed to be due to alkali-volatile diffusion differentiation of parent basaltic melts (Narębski 1964). Small hornblende peridotite neck occurring in S part of the Góry Kaczawskie Mts is genetically connected with Inner Sudetic Fault zone (J. H. Teisseyre, 1966).

Petrogenetically most important geochemical data concerning the rocks in question are presented in Table 2.

VOLCANIC SERIES OF SOUTH-EASTERN PART OF METAMORPHIC MANTLE OF THE KARKONOSZE GRANITE

Two larger complexes of metavolcanic rocks occur within this arc-shaped geological unit, considered by J. H. Teisseyre (1968) to be equivalent in primary lithology and age. The southern is that of Żelezny Brod while the eastern complex is actually located at the E slopes of the Rudawy Janowickie-Lasocki Grzbiet range. In the former area sedimentary rocks accompanying volcanics are less metamorphosed and dated. According to Fediuk's (1962) data, volcanic activity in this region started already in Ordovician period, being represented by small synsedimentary extrusions embedded in Tremadocian roofing phyllites and by fine intercalations of tuffites and sporadic of metadiabases in overlying pelitic and psammitic rocks as well as in graptolithic Lower Silurian metalidyte-bearing phyllites. Considerable increase of intensity of magmatic phenomena took place nearly simultaneously with the appearance of Wenlockian carbonate sedimentation, being manifested by mass eruptions of basic pyroclasts mixed with carbonates to form calcareous and dolomitic tuffites. In NE part of this region volcanic material was deposited together with detrital one to form tuffaceous chlorite-sericite phyllites. In the later stage of basic volcanism, effusive activity dominated in this area, being followed by rapid change of chemical character of lavas into keratophyric ones. The final stage of magmatism consisted in re-appearance of mafic lavas, followed again by closing weak effusions of acidic products.

In Fediuk's opinion, two rather small ultrabasic rock bodies, occurring in the Żelezny Brod region, represent post-metamorphic intrusions, petrogenetically related with volcanic Upper Silurian series.

For the present study it is very important to emphasize that pyroclastic rocks represent ca. 35% of the complex and greenschist of probably tuffaceous origin — ca. 47%, whilst distinctly effusive basic and acidic rocks — only ca. 14%.

Metavolcanic series of the Rudawy Janowickie-Lasocki Grzbiet range is the northern continuation of Lower Palaeozoic complex of the Rychorske Hory Mts. and, no matter of higher metamorphism, displays evident analogies with the Silurian-Ordovician sequence of S Karkonosze (Żelezny Brod complex). Thus, diopside-bearing and other striped amphibolites of the Czarnów Schist Formation of the Rudawy Janowickie group are, in J. H. Teisseyre's (1968a) opinion, metamorphic equivalents of basic tuffites with calcareous and dolomitic intercalations of the Żelezny Brod complex. This conclusion also results from unusually high CaO and MgO contents in these rocks (Table 3). Potassium-rich leptynites occurring in the top part of this formation are possible metamorphic equivalents of acidic tuffites.

The complex of structurally overlying Leszczyniec Volcanic Formation consists of both basic and acidic more or less metamorphosed lavas, eruptives, dykes, tuffs and tuffites, corresponding in composition to spilite-keratophyre suite (Narębski, 1968; Teisseyre, 1973). Chemical compositions of typical metavolcanics of this formation are presented in Tables 4 and 5. The Paczyn gneisses, accompanying these volcanics, are interpreted by Narębski and Teisseyre (1971) as intrusions of anatectic leucogranitic magma, very close in composition to that of nearly coeval keratophyres, corresponding to typical oceanic plagiogranites (Fig. 2). and thus, contrary to potassic acidic lavas of the Góry Kaczawskie Mts., being distinctly sodic in character.

PALEOTECTONIC INTERPRETATION OF GEOCHEMISTRY OF THE IRON GROUP ELEMENTS

The striking differences in average contents, variation coefficients and correlations of transitional 3d element of the iron group have been already emphasized and statistically evaluated by the present author (Narębski, 1974). In the light of new data on specific geochemical features of basalts originated in various tectonic settings (Table 1) these facts are, unquestionably, of petrogenetical importance.

Statistical parameters of frequency distributions of elements in the circum-Karkonosze spilite-keratophyre suites are presented in Table 6,

Table — Tabela 4

Chemical analyses of amphibolites of the Rudawy Janowickie-Lasocki Grzbiet range (Leszczyniec formation) in wt. %
Skład chemiczny amfibolitów pasma Rudawy Janowickie-Lasocki Grzbiet (Formacja Leszczyńca) (% wag.)

Rock type	Albite amphibolites						Paczyn amphibolites (metagabbros)			
Sample No. *	24 F	24 I	665 B	635/11	583 B	670	527	524 A	525	526
Locality	Miedzianka NE		Ogorzelec railway station	Leszczyniec	Stankowa SW slope		Paczyn region			
SiO_2	50.9	57.6	56.2	56.9	53.5	49.4	51.4	51.5	56.1	51.9
TiO_2	0.85	1.04	0.64	0.51	0.85	0.61	0.41	0.67	0.90	0.83
Al_2O_3	14.6	15.0	16.7	15.2	15.1	16.9	11.1	18.8	11.1	13.3
Fe_2O_3	3.58	1.66	3.97	3.26	4.24	4.67	2.65	2.87	2.40	3.03
FeO	11.2	9.07	7.39	4.38	8.61	6.92	11.6	5.81	8.74	8.32
MnO	0.14	0.18	0.10	0.09	0.12	0.13	0.19	0.12	0.18	0.19
MgO	5.38	3.58	5.08	3.76	5.62	5.32	8.15	4.16	7.25	6.20
CaO	5.57	4.15	7.01	5.21	4.87	10.0	10.2	9.48	7.20	11.1
Na_2O	5.85	6.00	3.48	4.52	3.40	1.74	1.38	3.36	3.58	1.73
K_2O	0 22	0.17	0.09	0.18	0.46	0.17	0.18	0.33	0.45	0.21
P_2O_5	0.15	0.36	0.12	0.06	0.11	0.05	0.04	0.07	0.16	0.26
H_2O	1.85	0.85	2.87	2.95	2.94	3.74	3.00	3.08	2.35	2.49
$S(CO_2)$	—	0.28	—	(2.69)	(0.35)	—	—	0.03	0.10	0.09
Total	100.29	99.64	99.65	99.71	100.17	99.67	100.30	100.28	100.51	99.85
Fe^{tot}/MgO	2.67	3.00	2.15	1.96	2.28	2.07	1.69	2.00	1.48	1.78
Cr	80	10	25	40	10	65	165	35	no data	120
V	210	100	70	35	175	95	320	170		180
Ni	35	10	35	5	5	25	25	10		25
Analyst	W. Narębski						H. Pendias (major elements)			

* — Sample No. No. from J. H. Teisseyre's collection
Numery próbek z kolekcji J. H. Teisseyre'a

Table — Tabela 5

Chemical analyses of metavolcanic rocks of the Rudawy Janowickie-Lasocki Grzbiet range (Leszczyniec formation)
Skład chemiczny metawulkanitów pasma Rudawy Janowickie-Lasocki Grzbiet (Formacja Leszczyńca) in wt. % (% wag.)

Rock type	Albite metadiabases and metaspilites							Green-schists	Metakeratospilites	
Sample No.*	486 A	487	75 A	667 C	507 M	507 O	653	95	412 A	418
Locality	Wieściszowice	Wielka Kopa	Raszów	Leszczyniec	Zielona Skała (Ogorzelec)		Ogorzelec S	Rędziny	Wieściszowice region	
SiO_2	52.3	50.7	46.9	52.2	50.3	49.9	48.6	50.4	60.8	58.2
TiO_2	0.64	0.70	0.40	0.75	0.96	0.49	0.73	0.66	0.28	0.45
Al_2O_3	15.7	15.4	14.8	16.0	15.9	16.1	14.4	16.5	16.2	15.0
Fe_2O_3	3.51	3.94	4.03	7.20	3.77	3.00	5.71	3.92	2.97	4.37
FeO	7.41	7.79	6.49	5.53	6.78	5.03	8.21	7.10	4.59	5.48
MnO	0.12	0.07	0.07	0.10	0.20	0.15	0.19	0.05	0.08	0.07
MgO	5.13	7.17	9.96	3.79	6.30	8.49	6.62	6.51	3.68	3.88
CaO	5.63	6.18	5.92	7.13	7.91	9.85	7.57	8.88	4.88	7.14
Na_2O	4.93	4.58	4.95	4.55	4.58	2.78	3.37	3.20	3.03	3.42
K_2O	0.13	0.53	1.95	0.08	0.20	1.04	0.18	0.07	1.96	0.81
P_2O_5	0.04	0.28	0.23	0.23	0.02	0.14	0.05	0.09	0.41	0.35
H_2O	4.18	1.85	1.65	2.33	3.18	2.90	4.08	2.46	1.12	0.65
CO_2	—	0.47	2.16	—	—	—	—	—	—	0.15
Total	99.72	99.86	99.67	99.89	100.10	99.87	99.71	99.84	99.92	100.07
FeO^{tot}/MgO	2.04	1.55	1.03	3.11	1.6	0.91	2.03	1.62	1.96	2.45
Cr	No data				150	720	155	No data		
V					150	110	70			
Ni					40	160	35			

* — Sample No. No. from J. H. Teisseyre's collection (JT)
Numery próbek z kolekcji J. H. Teisseyre'a

Analyst: W. Narębski

whilst their compositional variations in terms of Alk-FeO-MgO ratios — in Fig. 3. Let us illustrate these differences using several discrimination diagrams proposed by Miyashiro (1973), Glassley (1974), Pearce et. al. (1975) and Pearce (1975).

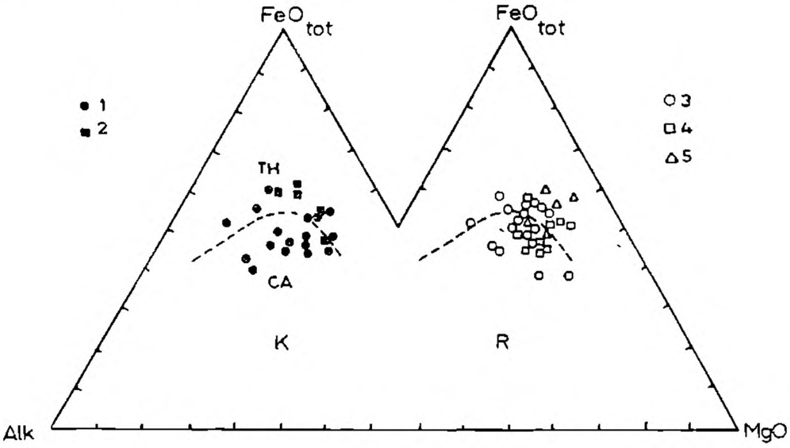

Fig. 3. AFM diagram showing evolution trends of metabasic rocks of the circum-Karkonosze spilite-keratophyre suites. Symbols: K — G. Kaczawskie Mts.: 1 — pillowed lavas (centres); 2 — greenschists; R — Rudawy Janowickie-Lasocki Grzbiet range: 3 — albite metadiabases, spilites, greenschists; 4 — striped amphibolites; 5 — Paczyn amphibolites. Dotted curve — boundary between tholeiite and calc-alcali basalt trends (TH and CA respectively)

Fig. 3. Wykres AFM obrazujący trend ewolucji składu metabazytów wokółkarkonoskich serii spilitowo-keratofirowych. Symbole: K — G. Kaczawskie: 1 — lawy sferoidalne (środki); 2 — zieleńce; R — Rudawy Janowickie i Grzbiet Lasocki: 3 — metadiabazy albitowe, spility, zieleńce; 4 — amfibolity smużyste; 5 — amfibolity paczyńskie. Krzywa kreskowana oddziela pola zmienności toleitów (TH) i bazaltów wapienno-alkalicznych (CA)

General inspection of these plots indicates that both the series are rather tholeiitic in character but evolution trend of the Kaczawskie Góry Mts. metabasites follows that of abyssal tholeiites (Miyashiro, 1973), whilst that of metavolcanics of the Rudawy Janowickie-Lasocki Grzbiet range closely resembles the trend of island-arc basalts (Fig. 4).

These tendencies are much better pronounced when applying the most distinctive iron group element — titanium (Fig. 5). Using Miyashiro's diagram supplemented by Glassley's data and those plotted by the present writer (after Kutolin, 1972), it is possible to discriminate not only between IAT and AT but also, within the latter ones, between ocean-island basalts (OIB — ranging from tholeiitic to alkalic varieties) and ocean-ridge tholeiites (ORT). It is quite evident that the projection points of the Góry Kaczawskie Mts. pillowed lavas are grouped nearly entirely within the field of ocean-island basalts whilst all the varieties of metabasites of the Rudawy Janowickie-Lasocki Grzbiet range — within that of island-arc tholeiites (Fig. 5).

This conclusion is confirmed by introducing another distinctive element — phosphorus, the content of which in basic magmas (similarly as that of titanium) depends on the percent of water in original melt,

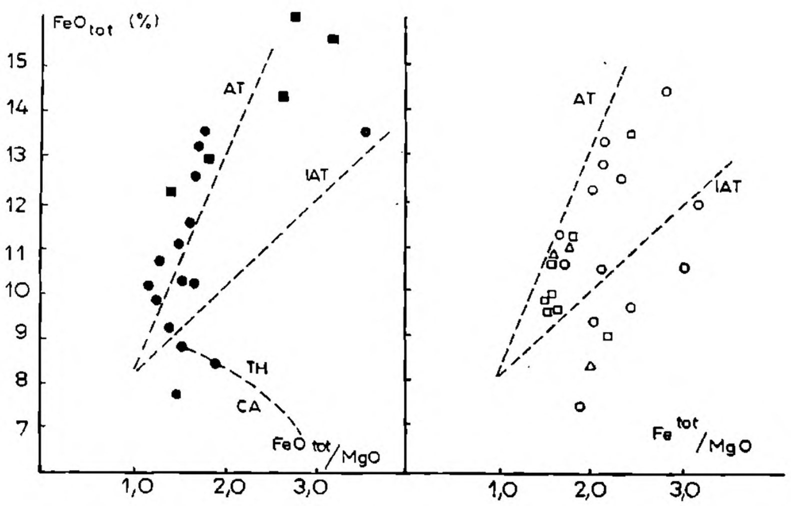

Fig. 4. Variation of total FeO with FeO$_{tot}$/MgO ratio in metabasic rocks of the circum-Karkonosze spilite-keratophyre suites. Rock symbols as in Fig. 3. AT — abyssal tholeiite trend, IAT — island arc tholeiite trend. TH/CA — boundary line between plots of rocks of tholeiitic and calc-alkalic series (after Miyashiro 1973, 1974)

Fig. 4. Zmienność całkowitego FeO względem stosunku FeO$_{całk}$/MgO w metabazytach wokółkarkonoskich serii spilitowo-keratofirowych. Symbole skał jak w Fig. 3. AT — trend toleitów abyssalnych, IAT — trend toleitów łupków wyspowych, TH/CA — linia odgraniczająca pola zmienności serii toleitowej i wapienno-alkalicznej (wg Miyashiro 1973, 1974)

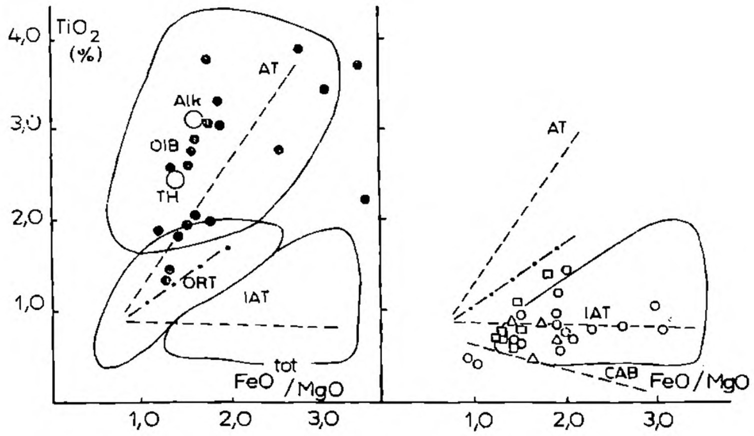

Fig. 5. Variation of TiO$_2$ with FeO$_{tot}$/MgO in metabasic rocks of the spilite-keratophyre suites in question. Symbols of rock types as in Fig. 3. AT and IAT — lines showing abyssal and island arc tholeiite trends respectively (after Miyashiro 1973, 1974). OIB, ORT and IAT — ocean island basalt, ocean ridge tholeiite and arc tholeiite fields (after Glassley 1974). Alk and TH — average plots of alkalic and tholeiitic OIB respectively (after Kutolin 1972).

Fig. 5. Zmienność zawartości TiO$_2$ ze stosunkiem FeO$_{całk}$/MgO w metabazytach omawianych serii spilitowo-keratofirowych. Symbole skał jak w fig. 3. AT i IAT — linie trendów zmienności toleitów abyssalnych i łupków wyspowych. OIB, ORT i IAT — pola bazaltów wysp oceanicznych, toleitów grzbietów śródoceanicznych i toleitów łuków wyspowych (wg Glassleya 1974). Alk i TH — średnie dla alkalicznych i toleitowych odmian OIB (wg Kutolina 1972)

depth of partial melting and fractionation degree of silicate phases since P and Ti are the only incompatible ones forming own early-stage minerals (Chazen and Vogel, 1974). In TiO$_2$/P$_2$O$_5$ diagram (after Ricci and

Serri, 1975, supplemented by the present author — Fig. 6) we also observe distinct separation of OIB field from that of less variable ORT and IAT-CA series, as well as from continental basalt field (CON).

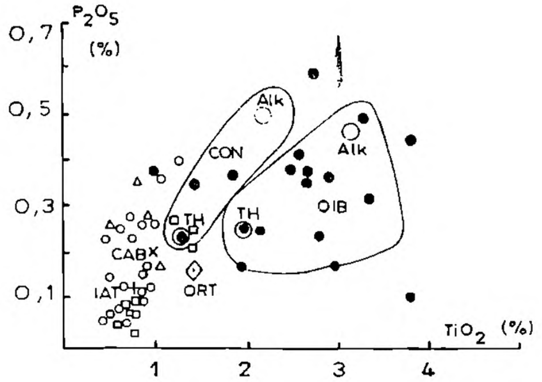

Fig. 6. TiO_2-P_2O_5 diagram for metabasic rocks of the series in question. CAB — everage calc-alkaic basalt, CON — continental basalt field (TH — average tholeiitic, Alk — average alkalic) (after Kutolin 1972); ocean island basalt (OIB) field after Ricci and Serri 1975. Other symbols as in previous figures

Fig. 6. Wykres TiO_2-P_2O_5 dla metabazytów omawianych serii. CAB — średni bazalt wap.-alkaliczny, CON — pole bazaltów kontynentalnych (TH — średnia dla odmian toleitowych, Alk — średnia dla odmian alkalicznych) (wg. Kutolina 1972); pole bazaltów wysp oceanicznych OIB wg. Ricci i Serri (1975). Inne symbole skał jak w poprzednich figurach

Table — Tabela 6

Average chemical compositions and parameters of frequency distributions of elements of metabasic rocks of the Circum-Karkonosze spilite-keratophyre associations (in wt. % and ppm)

Średni skład chemiczny i parametry rozkładów liczebności pierwiastków metabazytów wokółkarkonoskich serii spilitowo-keratofirowych (w % wag. i ppm)

	Rudawy Janowickie-Lasccki Grzbiet range			Góry Kaczawskie Mts.		
SiO_2	$X(\tilde{X})$	$S_x(S_{lgx})$	$V_x(V_{lgx})$%	$X(\tilde{X})$	$S_x(S_{lgx})$	$V_x(V_{lgx})$%
SiO_2	51.6	3.16	6.2	47.4	3.14	6.6
Al_2O_3	15.3	0.96	6.3	14.9	1.79	12.0
FeO_{tot}	11.1	1.97	18.0	10.5	2.47	23.0
MgO	5.75	1.47	26.0	6.01	1.91	31.0
CaO	6.72	1.81	27.0	8.90	2.32	26.0
Na_2O	4.35	0.98	23.0	4.23	1.19	28.0
K_2O	(0.35)	(0.296)	(80)	(0.40)	(0.300)	(85)
TiO_2	(0.83)	(0.387)	(120)	2.34	0.62	26.0
P_2O_5	(0.11)	(0.290)	(80)	0.37	0.13	35.0
Cr	(65)	(0.447)	(160)	(249)	(0.167)	(45)
Ni	(24)	(0.351)	(100)	(82)	(0.242)	(60)
FeO^{tot}/MgO	(1.95)	(0.100)	25	1.57	0.28	18

In brackets: $(\tilde{X})$ — geometric means and parameters of lognormal distributions

W nawiasach: $(\tilde{X})$ — średnie geometryczne i parametry rozkładów lognormalnych

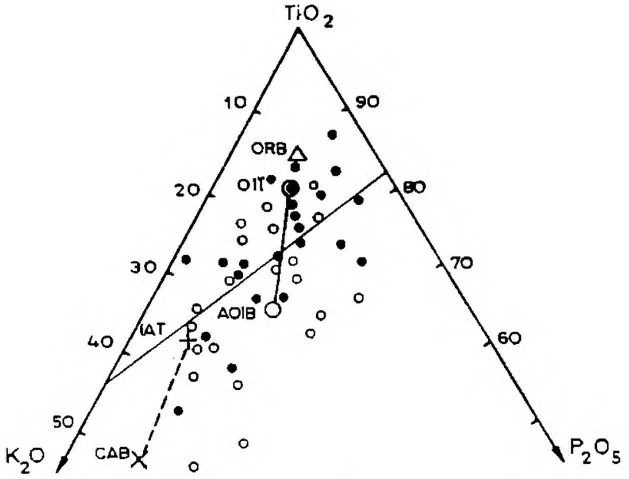

Fig. 7. TiO_2-P_2O_5-K_2O diagram with marked boundary between oceanic and non-oceanic basalt fields (after Pearce et al. 1975). ORB — average ocean ridge basalt, OIT ———— AOIB — ocean island tholeiite-alkali ocean island basalt trend, IAT — — — CAB — island arc volcanic trend (computed after Kutolin 1972). Rock symbols as in previous figures

Fig. 7. Wykres TiO_2-P_2O_5-K_2O z zaznaczoną granicą pól bazaltów oceanicznych i nieoceanicznych (wg Pearce'a i in. 1975). ORB — średnia dla toleitów grzbietów śródoceanicznych, OIT ———— AOIB — trend zmienności bazaltów wysp oceanicznych, IAT — — —CAB — trend zmienności bazaltów łuków wyspowych. Symbole skał jak poprzednio

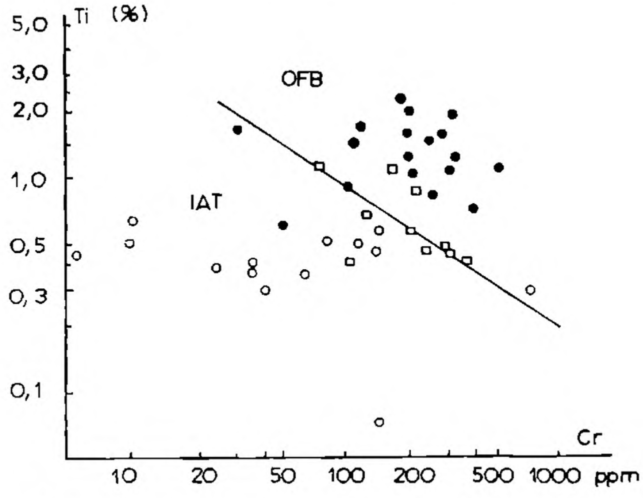

Fig. 8. Ti versus Cr diagram for metabasic rocks of the circum-Karkonosze spilite-keratophyre associations. Symbols as in previous diagrams. Boundary line between ocean floor basalt (OFB) and island-arc tholeiite (IAT) fields after Pearce (1975)

Fig. 8. Wykres zależności Ti od Cr dla metabazytów wokółkarkonoskich serii spilitowo-keratofirowych. Symbole jak poprzednio. Linia odgraniczająca pola bazaltów dna oceanicznego (OFB) i toleitów łuków wyspowych (IAT) wg Pearce'a (1975)

Less pronounced distinction between the two series under consideration is obtained by means of triangular TiO_2-P_2O_5-K_2O diagram (after Pearce et al., 1975, supplemented by the present author — Fig. 7), but even after introducing rather mobile element like potassium, we observe that the majority of the Góry Kaczawskie Mts. lavas is grouped around

OIT-AOIB trend whithin oceanic basalt field, whilst the projection points of the Rudawy Janowickie-Lasocki Grzbiet metabasalts are more dispersed and relatively displaced toward the continental basalts area. It should be emphasized that the diagram in question has been recently applied for reconstructing tectonomagmatic relations of volcanics of the Barrandian area by Fiala (1978). In his opinion pillow lavas of the G. Kaczawskie Mts. are clearly oceanic in character whilst those of the Żelezny Brod complex seem to concentrate in oceanic field but to low number of data is actually available.

Unquestionably the best geochemical discrimination between the circum-Karkonosze suites is obtained by using Ti versus Cr diagram (Fig. 8) introduced by Pearce (1975) for distinguishing IAT from OFB series.

Summing up the results of the present study it is concluded that the spilite-keratophyre suite of the Góry Kaczawskie Mts., as far as geochemistry of iron group elements is concerned, corresponds to volcanics originated in within-plate ocean-island enironment. This conclusion is supported by the presence of pillow lavas, the occurrence of both meta-eruptive and metaeffusive volcanic products and the character of accompanying metasediments. It should be emphasized that predominantly potassic character of acidic members of this suite (Fig. 2) is also consistent with its origin in within-plate setting.

On the other hand, the obtained geochemical data strongly suggest that the origin of distinctly different in many respects spilite-keratophyre association of SE metamorphic mantle of the Karkonosze granite is connected with the formation of island arc-trench system in this part of Variscan geosyncline. This paleotectonically important conclusion is confirmed by definite predominance of eruptives over effusives in this series, lack of pillowy varieties and by evolution trend of associated sediments.

One of the very convincing arguments, supporting this conclusion, consists in the presence of relics of glaucophane schist belt along southern margin of this zone from Żelezny Brod area (Pelikan 1928, Tuček 1948) to Lasocki Grzbiet range (Juskowiak 1957, Wieser 1979) which are supposed to trace Lower Palaeozoic arc-trench system with northwards dipping Benioff zone.

FINAL REMARKS

The suggested palaeotectonic conclusions are of essential importance for our knowledge of evolution of the Early Palaeozoic geosyncline in the region under consideration and, therefore, call for some more general comments.

There are very controversial opinions on the tectonic evolution of the

Variscan Meso-Europe which is actually interpreted from both plate-tectonic (Burrett, 1972; Floyd, 1972; Anderson, 1975 and others) and fixistic point of view (Krebs, 1977). Rather compromising is moderately plate-tectonic Khain's (1979) interpretation of the problem in question.

The data and resulting conclusions presented by the present author seem to support such moderately plate-tectonic approach to the solution of the problem since, apart from suggesting the formation of arc-trench system, they contain no arguments for large-scale oceanization along mid-ocean ridge. No basalts of this type were found to occur in the area under consideration. Nevertheless, predominantly tholeiitic character of metabasites of the suggested island arc actually incorporated into the SE metamorphic mantle of the Karkonosze granite indicates that some local oceanization (probably of the small basin type) had to precede the postulated subduction process. However, it should be emphasized that the present author favours increasing criticism againts schematism governing in some modern plate-tectonic interpretations. So eg. there are recently still more and more evidences against to generalized models for the magmatic evolution of the plate-tectonic systems in question (Arculus, Johnson, 1978). Besides, detailed examinations of volcanic phenomena taking place in some small basins eg. in the most interesting Tyrrhenian sea (Barberi et al., 1973; 1974; Selli, 1974) indicate that different magma types can be produced in them within rather small distances, depending on diversified character (distensive, compressive), size, depth and direction of faults or other tectonic systems favouring igneous activity.

From plate-tectonic point of view, the Early Palaeozoic Saxothuringian and Moravo-Silesian zones are supposed to be composed of rather small sea basins, separating several micro-continents (Sowie Góry Mts., Granulitgebirge Mts.) situated between larger Bohemian plate and stable East European continent (Cwojdziński, 1977). Therefore, in some respects, these zones had to resemble much more the actual Mediterranean area than that of the Pacific Ocean.

As already mentioned, among the two spilite-keratophyre series examined, the older is supposed to be formed by intraplate mantle diapirism whilst the second by partial melting of pyrolite wedge above active subduction zone in an arc-trench system of rather special type. The latter process was probably followed by anatectic formation of acid members of these associations (Narębski 1964, Narębski, Teisseyre 1971, Rösler and Werner 1978).

Further detailed regional geological and tectonical studies are needed to confirm or to supplement the ideas presented in this paper. There are no sufficient geochemical data on metabasic rocks of the Kłodzko crystalline complex (Kozłowska-Koch 1958, Wojciechowska 1966), allowing to determine their probable tectonic setting. In J. H. Teisseyre's (1968a) opinion they are Upper Silurian in age, similarly as metavolcanics of the SE part of metamorphic mantle of the Karkonosze granite, represented in our territory by the Leszczyniec Volcanic Formation. This opinion, very important for palaeotectonic reconstructions, should be checked by geochemical study.

Finally, it must also be emphasized that the reported differences in abundances of immobile elements of the iron group (Ti, Cr, Ni) can be utilized as a convenient criterion for determining the source areas of greenschist pebbles fairly abundant in clastic deposits of Świebodzice and Intra-sudetic depressions, providing statistically sufficient sample numbers are examined.

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STRESZCZENIE

Jednym z najważniejszych osiągnięć w zakresie petrologii bazaltów jest wykazanie na podstawie wszechstronnych badań ostatnich lat wyraźnej zależności cech geochemicznych tych wulkanitów od środowiska tektonicznego ich genezy. W świetle teorii tektoniki globalnej przejawy magmatyzmu zasadowego związane są ze strefami styku kier litosfery (rozbieżnymi — grzbiety śródoceaniczne i zbieżnymi — układy rów-łuk wyspowy z aktywnymi strefami Benioffa) oraz z rejonami występowania sił tensyjnych w obrębie kier — zarówno oceanicznych (wulkaniczne wyspy typu hawajskiego), jak i kontynentalnych (ryfty).

Specyficzne cechy geochemiczne bazaltów tworzących się w różnych środowiskach tektonicznych spowodowane są, jak wynika z badań doświadczalnych, odmiennymi warunkami p i t oraz stopniem parcjalnego wytapiania materiału płaszcza podczas jego diapiryzmu (układy tensyjne) i w strefach subdukcji jednej kry pod drugą (układy kompresyjne), obecnością lub brakiem w nich wody oraz stopniem dyferencjacji powstałych stopów przed ich wydostaniem się na powierzchnię.

W związku z tym wyróżnia się obecnie następujące typy bazaltów oceanicznych i wokółoceanicznych:

I. Toleity abyssalne (AT):
  1. Toleity grzbietów oceanicznych (ORT) zwane również ogólniej bazaltami dna oceanicznego (OFB)
  2. Bazalty wysp oceanicznych (OIB).

II. Wulkanity zasadowe łuków wyspowych:
  3. Toleity łuków wyspowych (IAT) lub toleity nisko-potasowe (LKT)
  4. Bazalty wapienno-alkaliczne (CAB)
  5. Wysoko-potasowe szoszonity (SHO).

Kolejność występowania trzech ostatnich uwarunkowana jest odległością od rowu i dojrzałością łuku wyspowego.

Wśród kryteriów geochemicznych, służących do odróżniania wymienionych typów bazaltów, najczęściej stosowane są zawartości i stosunki tzw. pierwiastków niedopasowanych („incompatible") — jak Zr, Nb, Y czy TR, łatwo przechodzących do stopu i na ogół trudno wchodzących do wcześnie krystalizujących faz. Duże znaczenie diagnostyczne mają też parametry rozkładu nieruchliwych podczas przeobrażeń skał macierzystych, ale uczestniczących we frakcjonacji krystalizacyjnej pierwiastków śladowych grupy żelaza —Ti, Cr i Ni.

Charakterystykę geochemiczną wyróżnionych typów bazaltów z podkreśleniem różnic w zawartości pierwiastków przejściowych grupy 3d (żelaza) podano w tab. 1.

W świetle przedstawionych danych i ich współczesnej interpretacji, stwierdzone przez autora w toku wieloletnich badań i opracowane statystycznie znaczne różnice zawartości i rozkładów liczebności Ti, Cr i Ni oraz trendów zmienności TiO_2 i $FeO_{całk}$ względem FeO/MgO w dolnopaleozoicznych wokółkarkonoskich seriach spilitowo-keratofirowych Gór Kaczawskich z jednej i Rudaw-Janowickich-Grzbietu Lasockiego z drugiej strony (fig. 1) mogą mieć duże znaczenie dla rekonstrukcji środowiska tektonicznego ich genezy. Otrzymane dane zestawiono w tabelach 2—6 oraz zinterpretowano graficznie (fig. 2—8). Najbardziej przydatne okazały się wykresy zmienności Ti względem Cr (fig. 8) oraz TiO_2 względem $FeO_{całk}/MgO$, a w mniejszym stopniu TiO_2 względem P_2O_5. Spowodowane jest to niewątpliwie nieruchliwością tych pierwiastków podczas przeobrażeń zasadowych paleowulkanitów oraz ich odmiennym zachowaniem się podczas procesów wytapiania parcjalnego w różnych środowiskach tektonicznych i późniejszej frakcjonalnej krystalizacji.

Z przeprowadzonych badań geochemicznych wynika, że zasadowe wulkanity kompleksu zieleńcowego Gór Kaczawskich odpowiadają bazaltom wysp oceanicznych a analogiczne utwory serii spilitowo-keratofirowych formacji Leszczyńca SE części osłony metamorficznej granitu karkonoskiego — toleitom łuków wyspowych.

Potwierdzeniem tych wniosków, opartych na przesłankach geochemicznych, są stosunki skał wylewnych i eruptywnych w obu omawianych seriach, charakter towarzyszących metabazytom skał kwaśnych i osadów oraz występowanie w zewnętrznej strefie S i SE części osłony metamorficznej granitu karkonoskiego (Pasmo Rudawy Janowickie-Lasocki Grzbiet-Góry Rychorskie i kompleks Żeleznego Brodu) śladów pasa metamorfizmu wysokociśnieniowego — łupków glaukofanowych. Brak serii bazaltowej typu rowów śródoceanicznych w omawianym rejonie wskazuje na to, że dolnośląsko-karkonoska część geosynkliny waryscyjskiej miała charakter raczej śródziemnomorski niż pacyficzny, a częściowa oceanizacja, poprzedzająca powstanie układu tektonicznego rów/łuk, musiała przebiegać lokalnie, w granicach niewielkich basenów (typu Morza Tyrreńskiego), oddzielających ruchome mikrokontynenty (G. Sowie, G. Granulitowe itp.), położone w strefie między większą krą Masywu Czeskiego i stabilnym kontynentem wschodnioeuropejskim. Należy podkreślić, że mimo śródziemnomorskiego, jak się wydaje, charakteru omawianej strefy we wczesnym paleozoiku, toleitowy wulkanizm postulowanego południowo-karkonoskiego łuku wyspowego miał charakter zbliżony do pacyficznego łuku wysp Tonga, powstałego na skorupie oceanicznej, co świadczy o szczególnym typie tego układu tektonicznego. Stanowi to jeszcze jeden argument przeciw zbytniemu schematyzmowi, typowemu dla prac wielu badaczy, zafascynowanych jednostronnymi rekonstrukcjami w oparciu o hipotezę tektoniki globalnej. Potwierdza to równocześnie tezę o specyficznym charakterze ewolucji tektonicznej omawianej strefy orogenu waryscyjskiego, nie pasującej ani do skrajnych schematów neomobilistycznych, ani też do równie krańcowych modeli fiksistów.

Potwierdzenie i rozwinięcie przedstawionych w niniejszej pracy wniosków paleotektonicznych i paleogeograficznych wymaga z jednej strony przeprowadzenia analogicznych badań geochemicznych metawulkanitów okolic Kłodzka i utworów piroklastycznych rejonu G. Bardzkich i in., z drugiej zaś — uzupełniających studiów geologicznych, tektonicznych i geofizycznych na Dolnym Śląsku i przyległym terytorium Czechosłowacji.

Warto podkreślić, że odmienny charakter geochemiczny metabazytów inicjalnych Gór Kaczawskich i formacji Leszczyńca może być pomocny przy ustalaniu obszaru źródłowego egzotyków skalnych, występujących w osadach detrytycznych depresji Świebodzic i niecki śródsudeckiej.