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MAJOR-ELEMENT GEOCHEMICAL TRENDS IN THE VARISCAN GRANITIC MASSIFS OF THE SUDETEN MOUNTAINS AND SUDETIC FORELAND (SOUTH POLAND)

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Abstract. Six major plutonic massifs related to the Variscan orogeny occur in the Sudeten Province of Poland. Starting with 116 major-element analyses available from literature and with the aid of a parametric diagram, the chemical structure of these massifs has been studied. A comparison of the main chemical trends has allowed us to classify the massifs into three major groups. Two of these groups are related to the sub-alkaline igneous series and the third to the calc-alkaline series. It is suggested that the geochemical trends of the massifs might be related to their structural position.

INTRODUCTION

The Sudeten Mountains, which are located at the north-eastern border of the Bohemian Massif, have a complex internal structure. They consist of different structural blocks belonging to several orogenies (from Precambrian to Paleozoic). Six major Variscan granitic massifs occur in this zone (Fig. 1). These massifs occur as both large plutons (Karkonosze, Strzegom-Sobótka, Strzelin and Kudowa) and small stocks and sheet-like intrusions (Niemcza-Złoty Stok and Bielice).

From field observations and a few radiometric dates these massifs have been classified into two major groups: the synorogenic massifs (Niemcza – Złoty Stok and Bielice) and the late- to post-orogenic massifs (Karkonosze, Strzegom – Sobótka, Strzelin and Kudowa) (Przewłocki *et al.*, 1962; Depciuch, 1971 – 1972; Depciuch, Lis, 1971 – 1972; Lis, Sylwestrzak, 1978).

In a general way all the massifs are composite, being composed of various igneous rock-types from diorites to leucogranites. It is however possible to group the massifs according to their petrographic associations (Borkowska, 1966; Dziedzicowa, 1963; Wierzchołowski, 1966). The massifs of Karkonosze, Strzegom – Sobótka, Strzelin and Kudowa are composed of the association: granodiorite

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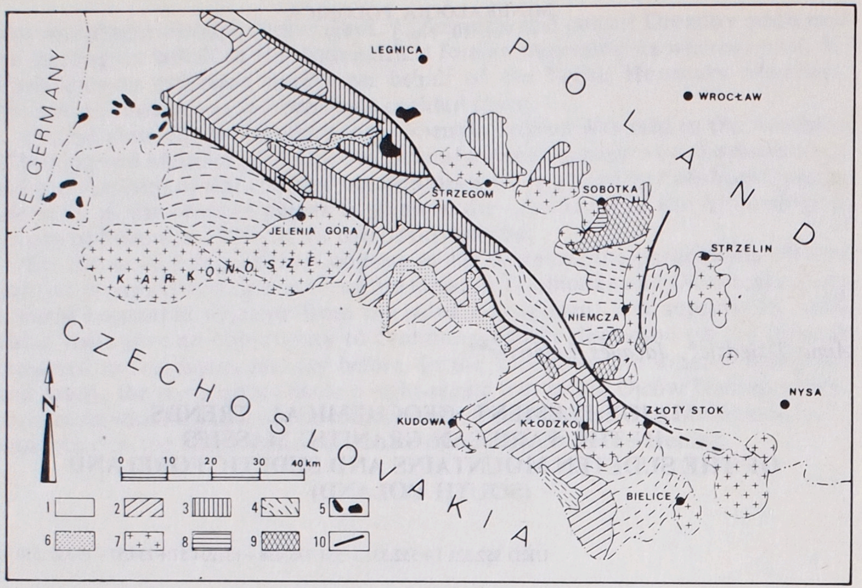

Fig. 1. Distribution of the Variscan plutonic massifs in the Sudeten mountains. South Poland (Przewłocki *et al.*, 1962)

1 – Tertiary sediments, *2* – Late Paleozoic and Mesozoic formations, *3* – Early Paleozoic formations, *4* – Metamorphic schists, *5* – Tertiary basalt, *6* – Permian porphyrics and melaphyres, *7* – Variscan plutons, *8* – gabbro, *9* – serpentinite, *10* – major faults

(locally, tonalite), biotite granite, leucogranite and, for the two first-named massifs, two-mica granite. It is to be noted that all these plutons have been strongly affected by hydrothermal late- to post-magmatic alteration such as albitization and muscovitization. On the other hand the last two massifs are more basic in composition. The Bielice massif is composed of syenodiorite and tonalite whereas the Niemcza – Złoty Stok appears to be composed of two different rock series: a finegrained series of syenodiorite and granodiorite and a medium-grained series of diorite, tonalite, granodiorite and some monzogranite. According to geochronological data (K – Ar) the medium-grained series has been dated at 300 MA and the fine-grained series at 270 MA (Borkowska, 1975).

In spite of a large number of studies (Borkowska, 1959, 1966, 1975; Majerowicz, 1963, 1972; Smulikowski, 1958) there remains controversy over the origin of these massifs. It has been considered that the Karkonosze, Strzegom and Strzelin massifs were related to a crustal magma that has intruded and differentiated in the upper part of the crust. A two step origin has been proposed for the Kudowa pluton with a metasomatic granitization of the metamorphic basement followed by an anatectic process. The magma was then able to differentiate and intrude its surroundings. Finally, a syntectic origin has been evoked for the two massifs of Bielice and Niemcza. This process would be related to a partial assimilation of basic to intermediate surrounding rocks by an acid crustal magma (Dziedzicowa, 1963; Wierzchołowski, 1966).

Few occurrences of mineralization are associated with these massifs and they are represented by small ore-bodies with Sn, W and Cu in the Strzegom massif and with U, Th, Be and Zr in the Karkonosze massif (Lis, 1970; Pendias and Walenczak, 1956).

The paper we present here constitutes a first attempt to determine the main petrochemical trends of the Variscan massifs of Poland. We have used, for this study, analytical data available from the literature, excluding however analyses made before 1940. In such a way 116 major-element analyses were retained.

CHOICE OF A PARAMETRIC DIAGRAM

The chemical analysis of rocks gives a destructured information. However most of the geochemical treatments, such as the study of the relationships between mineralogical and geochemical evolutions, need a certain degree of structure.

As was shown by de la Roche (1978), it is very easy to define parametric systems that are strongly coherent with the mineral facies of the rocks. According to this idea a parametric diagram has been defined to study the evolution of igneous series.

The first objective was to display the degree of silica saturation or undersaturation and this was achieved by defining the chemical function of the critical plane of silica saturation (Yoder and Tilley, 1962). This function, which must equal zero for olivine, clinopyroxene and plagioclase (which define the plane), has been written (de la Roche and Leterrier, 1973):

$$F = 4\,\mathrm{Si} - 11\,(\mathrm{Na}+\mathrm{K}) - 2\,(\mathrm{Fe}+\mathrm{Mg}+\mathrm{Ti}) - 6\,\mathrm{Ca} - \mathrm{Al}$$

where Si, Al, Fe... represent the number of millications calculated from raw oxide percentages.

The second objective was to maintain coherence between chemical and mineralogical evolutions which produce, during differentiation of igneous rock series:

- a progressive increase of the ratio $\mathrm{Fe}/(\mathrm{Fe}+\mathrm{Mg})$.
- an increase in the $(\mathrm{Ab}+\mathrm{Or})/\mathrm{An}$ ratio with a concomitant decrease in the An content of the plagioclase.

This objective was reached by partitioning the function F between two parameters R_1 and R_2. The choosen partition parameters (de la Roche and Leterrier, 1973) were defined by:

$$X = R_1 = 4\,\mathrm{Si} - 11(\mathrm{Na}+\mathrm{K}) - 2(\mathrm{Fe}+\mathrm{Ti}),$$
$$Y = R_2 = 6\,\mathrm{Ca} + 2\,\mathrm{Mg} + \mathrm{Al}.$$

In the R_1 versus R_2 parametric diagram (Fig. 2), olivine, clinopyroxene and feldspars are distributed along the first bisecting line which thus corresponds to the projection of the critical plane. This line devides the graph into two domains: the silica-saturated domain on the quartz side and the silica-undersaturated domain on the nepheline side. In this diagram the different igneous series are easily distinguishable and the diagram has been applied to the classification of igneous rocks (Fig. 3) (de la Roche, 1976; de la Roche *et al.*, 1979).

Finally, it is important to note that this diagram includes a well-defined mineralogical network and thus may be used to plot modal data as well as chemical data. In such a way, the location of the representative point of a rock can easily be approximated by a simple geometric construction starting with its modal composition and the chemical composition of its minerals (essentially the An content of the plagioclase and the Fe/Fe+Mg ratio of the coloured minerals). We have largely

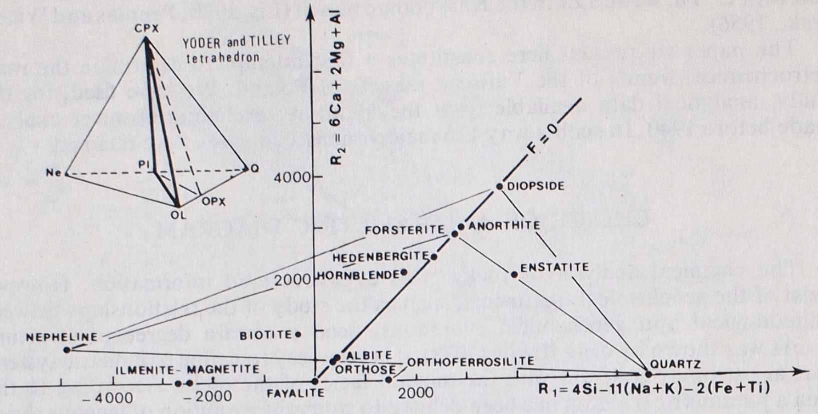

Fig. 2. Parametric diagram, R_1 R_2, derived from the chemical transposition (de la Roche and Leterrier, 1973) of the normative tetrahedron of Yoder and Tilley (1962)

The parameters are calculated in terms of millications per 100 g of rock or mineral. The minerals are plotted as ideal end-member compositions

used this method for our study on the Variscan granitoids of Poland because of the paucity of chemical data available for some massifs. The good coherence between chemical and modal data is well illustrated in Figure 4.

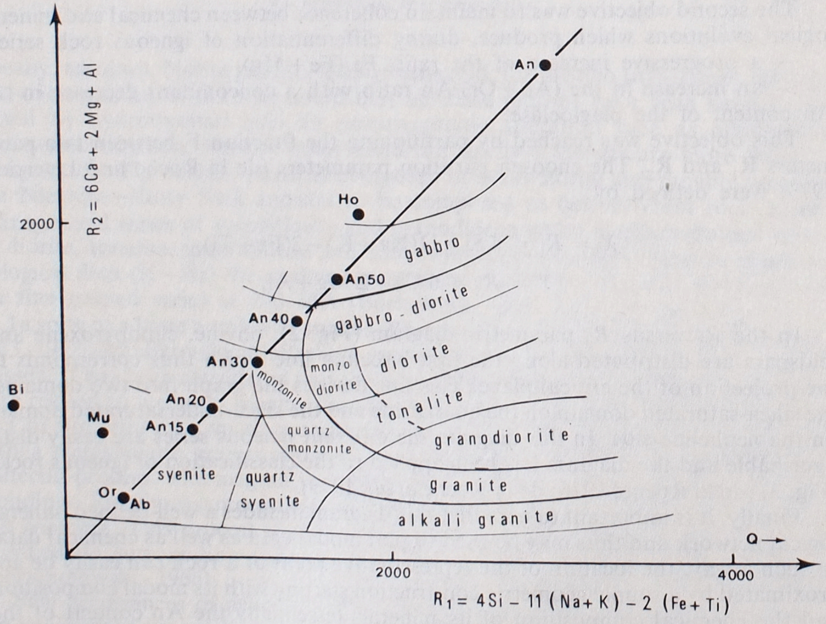

Fig. 3. Partial classification grid for plutonic rocks (de la Roche *et al.*, 1979)

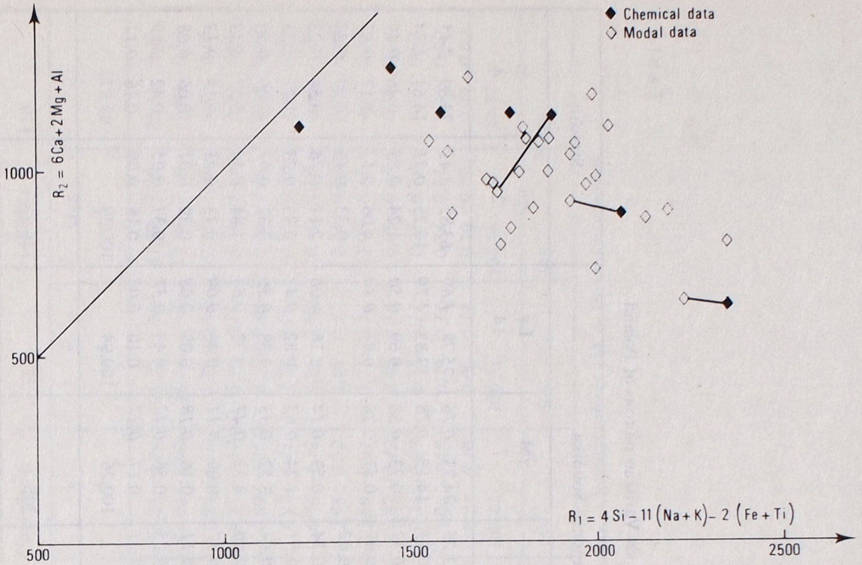

Fig. 4. Distribution in the R_1 R_2 diagram of samples from the Bielice massif

The points were plotted using chemical data or modal data (see the text for explanation). Tie lines join samples for which we have both chemical and modal analyses

PRESENTATION OF THE RESULTS

The primary purpose of this study was to obtain an initial broad synthesis of the petrochemical properties of the Variscan plutons of Poland. Consequently, a general diagram, with the contoured areas and the representative points of the average compositions of the main rock types of the different massifs, is presented (Fig. 5). The average compositions are given in Table 1.

Some major features may be deduced from the distribution of the massifs in Figure 5.

1. From the chemical data, the Niemcza – Złoty Stok massif may be divided into two chemically-distinct units. The first one, composed of monzonites transitional through monzodiorites to tonalites, is characterized by a high alkali content (Na + K varies between 180 and 190 millications). The second unit, comprising diorites, tonalites and some granodiorites, has a lower alkali content (Na + K varies between 138 and 162 millications). Unfortunately, the field and petrographic relationships between these two units are unknown because of the general lack of geological information accompanying the chemical data.

In the same way the tonalitic rocks of the Strzegom – Sobótka pluton seem to define a geochemically-distinct unit. This hypothesis accords well with recent studies of that pluton (Majerowicz, 1972).

2. Starting with the elongation of their distribution areas, the massifs may be divided into three major groups.

The first group, with an approximately horizontal elongation (i.e. relatively

Table 1

Mean compositions of the main rock types constituting the six Variscan plutons of Poland

Massif	Karkonosze				Strzegom–Sobótka				Strzelin	
facies	γδ 5*	γ 14	Lγ 7	T 1	γδ 10	γ 11	γM 7	Lγ 14	γδ 2	γ 4
SiO_2	70.11 *1.79*	73.26 *2.76*	76.46 *1.25*	63.96	71.90 *1.70*	72.59 *2.25*	74.23 *0.76*	75.78 *1.69*	63.82 *3.42*	73.89 *2.45*
Al_2O_3	13.88 *0.31*	13.63 *1.34*	13.68 *1.08*	15.88	14.48 *0.99*	13.79 *0.95*	14.15 *0.78*	13.83 *1.79*	16.25 *0.31*	14.64 *1.24*
Fe_2O_3	2.32 *0.92*	1.23 *0.44*	0.52 *0.50*	1.93	1.05 *0.74*	1.54 *0.52*	0.73 *0.58*	0.69 *0.50*	1.24 *0.88*	0.46 *0.49*
FeO	1.74 *0.96*	0.95 *0.53*	0.17 *0.28*	3.68	1.53 *0.44*	1.12 *0.67*	0.57 0.28	0.41 *0.44*	4.06 *0.13*	1.17 *0.83*
MnO	0.01 *0.02*	0.02 *0.08*		0.02		0.01 *0.02*			0.33 *0.46*	0.20 *0.23*
MgO	1.30 *0.28*	0.74 *0.38*	0.18 *0.19*	1.42	0.73 *0.34*	0.60 *0.24*	0.53 *0.14*	0.16 *0.06*	2.11 *0.76*	0.54 *0.23*
CaO	1.96 *0.39*	1.82 *0.69*	0.77 *0.38*	4.80	1.90 *0.46*	1.62 *0.81*	1.24 *0.63*	0.82 *0.42*	5.75 *0.23*	1.77 *1.25*
Na_2O	3.36 *0.77*	3.35 *0.67*	3.12 *0.70*	4.39	3.92 *0.14*	3.76 *0.44*	3.52 *0.33*	4.38 *0.39*	3.32 *0.01*	3.06 *0.50*
K_2O	3.83 *0.25*	3.99 *0.74*	4.41 *0.62*	2.18	4.22 *0.95*	4.30 *0.60*	4.31 *0.47*	3.77 *0.64*	1.84 *0.50*	3.37 *1.33*
TiO_2	0.38 *0.33*	0.13 *0.16*	0.01 *0.02*	0.76	0.09 *0.10*	0.16 *0.17*	0.09 *0.11*	0.48 *0.09*	0.73 *0.25*	0.13 *0.13*
P_2O_5	0.12 *0.11*	0.05 *0.07*	0.02 *0.04*	0.20	0.08 *0.08*	0.15 *0.11*	0.16 *0.18*	0.09 *0.08*	0.39 *0.01*	0.06 *0.08*
H_2O^+	0.53 *0.60*	0.15 *0.20*	0.34 *0.36*	0.53	0.30 *0.12*	0.42 *0.25*	0.56 *0.42*	0.43 *0.37*	0.37 *0.05*	0.42 *0.19*
H_2O^-	0.09 *0.08*	0.06 *0.07*	0.11 *0.11*	0.03	0.11 *0.06*	0.23 *0.21*	0.17 *0.17*	0.10 *0.07*	0.18 *0.09*	0.16 *0.11*
Total	99.63	99.38	99.79	99.78	100.31	100.29	100.26	100.94	100.39	99.87
Na + +K***	190	193	194	188	216	213	205	222	146	170

Massif	Kudowa				Niemcza – Złoty Stok		Bielice		
facies	T 4*	γ 3	Lγ 6	Mzδ 6	T 6	δ 5	T 4	Mzδ 5	γδ 2
SiO_2	65.48 *2.37***	70.42 *0.53*	74.22 *0.63*	56.16 *1.20*	62.57 *2.07*	58.25 *3.24*	64.32 *1.65*	57.37 *1.39*	66.32 *3.37*
Al_2O_3	15.61 *0.98*	14.44 *0.56*	13.82 *0.39*	15.83 *1.17*	15.03 *1.17*	14.96 *1.08*	14.84 *1.58*	17.19 *1.19*	15.09 *0.83*
Fe_2O_3	1.79 *0.51*	1.50 *0.14*	1.08 *0.30*	3.04 *1.58*	2.44 *0.75*	2.94 *1.30*	2.29 *0.64*	2.23 *1.08*	1.13 *1.25*
FeO	2.45 *1.10*	1.30 *0.24*	0.21 *0.08*	4.37 *1.16*	3.98 *0.57*	4.31 *0.33*	3.50 *1.15*	4.74 *1.41*	3.77 *2.08*
MnO				0.13 *0.13*	0.06 *0.08*	0.09 *0.06*	0.16 *0.30*	0.10 *0.14*	0.02 *0.03*
MgO	3.23 *0.84*	1.19 *0.36*	0.26 *0.25*	4.52 *0.46*	2.85 *0.90*	4.92 *1.21*	2.89 *0.39*	3.71 *0.79*	1.85 *0.76*
CaO	2.54 *0.57*	2.46 *0.76*	1.60 *0.45*	6.10 *0.56*	3.73 *1.26*	6.74 *1.12*	4.56 *0.60*	6.11 *0.74*	3.41 *1.18*
Na_2O	4.75 *0.62*	4.42 *0.65*	4.66 *0.68*	3.19 *0.23*	3.32 *0.40*	2.98 *0.52*	2.55 *0.37*	3.74 *0.60*	3.12 *0.04*
K_2O	3.40 *0.95*	3.67 *0.24*	4.01 *0.31*	3.84 *0.53*	3.85 *0.58*	2.69 *0.84*	3.71 *0.34*	3.03 *0.17*	4.08 *0.15*
TiO_2	0.18 *0.37*		0.03 *0.07*	0.71 *0.37*	0.70 *0.17*	0.87 *0.42*	0.68 *0.37*	0.65 *0.37*	0.36 *0.04*
P_2O_5	0.11 *0.13*	0.10 *0.04*	0.03 *0.07*	0.38 *0.15*	0.26 *0.20*	0.34 *0.19*	0.15 *0.17*	0.35 *0.19*	0.13 *0.02*
H_2O^+	0.94 *0.19*	0.90 *0.40*	0.56 *0.10*	1.15 *0.88*	1.60 *0.37*	1.06 *0.68*	0.79 *0.31*	0.84 *0.71*	0.35 *0.02*
H_2O^-	0.22 *0.20*	0.24 *0.06*	0.21 *0.09*	0.37 *0.57*	0.28 *0.25*	0.27 *0.10*	0.09 *0.12*	0.10 *0.07*	0.14 *0.02*
Total	100.70	100.64	100.69	99.79	100.67	100.42	100.53	100.16	99.77
Na + K***	226	221	236	185	189	153	161	185	188

δ – diorites, Mzδ – monzodiorites, T – tonalites, γδ – granodiorites, γ – biotite granites, Lγ – leucogranites, γM – two-mica granites.

* Number of samples.

** Standard deviation.

*** Number of millications.

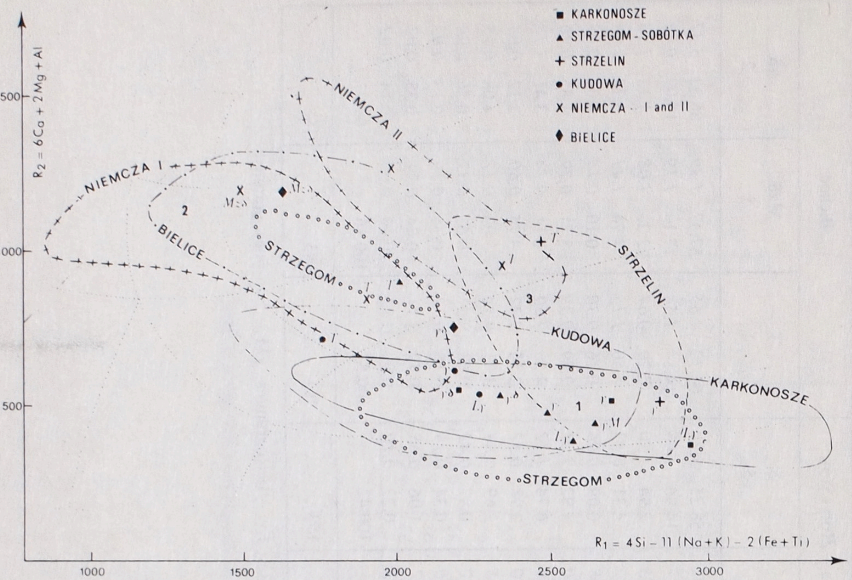

Fig. 5. Distribution in the R_1 R_2 diagram of the six major Variscan plutonic massifs of Poland
Each massif is defined by a field enclosing all the analyses used. Also shown are the mean compositions of rocks types within each massif: δ – diorites, Mzδ – monzodiorites, T – tonalites, γδ – granodiorites, γ – biotite granites, Lγ – leucogranites, γM – two-mica granites. The massifs are distributed in three groups according to their main evolutionary trends: group *1* – massifs of Karkonosze, Strzegom and Kudowa, group *2* – massif of Bielice and first unit of the Niemcza massif, group *3* – massif of Strzelin and second unit of the Niemcza massif

constant R_2 value), is defined by the three plutons of Kudowa, Karkonosze and Strzegom – Sobótka (excluding, from this latter pluton, the tonalites). This elongation reflects the evolution from granodiorites through biotite granites then to leucogranites and some two-mica granites. It is to be noted that the granodiorites from these plutons occupy an abnormally low position in the R_1 R_2 diagram (i.e. low R_2 values) being located in the area normally restricted to granite sensu stricto (see Fig. 3). This may be explained by the fact that the An content of the plagioclase in these rocks is low (An 12 – 15) with respect to normal granodioritic rocks (An 25 – – 30). Such peculiarity may be related, at last partially, to the widespread hydrothermal alteration, more particularly albitization, that has affected these three plutons.

The second group, the elongation of which is oblique with regard to that of the first group, is typified by the Bielice pluton, one of the two units of the Niemcza massif and the tonalites of the Strzegom pluton. This elongation is determined by the evolution from monzonites through monzodiorites to tonalites and some granodiorites.

The third group, the elongation of which is the most vertical includes the Strzelin massif and the second unit of the Niemcza massif. The elongation reflects the evolution from diorites through tonalites to granodiorites and some granites (in the Strzelin massif). It must be noted that this group may be distinguished from the two previous ones by its lower total alkali content (Table 1).

DISCUSSION OF THE RESULTS

Granitoid magmas can be essentially formed by the action of two different petrogenetic processes: (a) by differentiation of basic or intermediate magmas, and (b) by anatexis and/or syntexis of pre-existing crustal rocks. The first-mentioned process is, in general, expected to have yielded only a relatively small amount of granites available for study. However, the basic or intermediate magma, during its rise through the crust and its differentiation, may be strongly transformed by an hybridization process with anatectic crustal magma. The proportion of granitoids may then be strongly increased.

In the Bielice, Niemcza and Strzelin massifs true granitic rocks are scarce with regard to basic and intermediate rocks, then the first genetic process may be assumed. On the other hand, granites and granodiorites are the only or the most predominant rock types in the Karkonosze, Strzegom – Sobótka and Kudowa plutons. In such cases, the second hypothesis of granite formation might be more appropriate. However some important features of these plutons must be considered. Firstly, in the pluton of Strzegom, tonalites, chemically equivalent to those which are present in the Bielice massif (and in the first unit of the Niemcza massif), are associated with the granitic rocks. The Strzegom pluton has intruded a gabbroic pluton whose exact age and petrogenetic characteristics are unfortunately unknown. In addition, the granitoids of the Karkonosze pluton contain abundant basic enclaves. This indicates that, even if a crustal origin appears to be the best genetic hypothesis for the three granitic plutons, the participation of intermediate or basic material can not be discounted.

The granitoid rocks may be subdivided into three major groups: the calc-

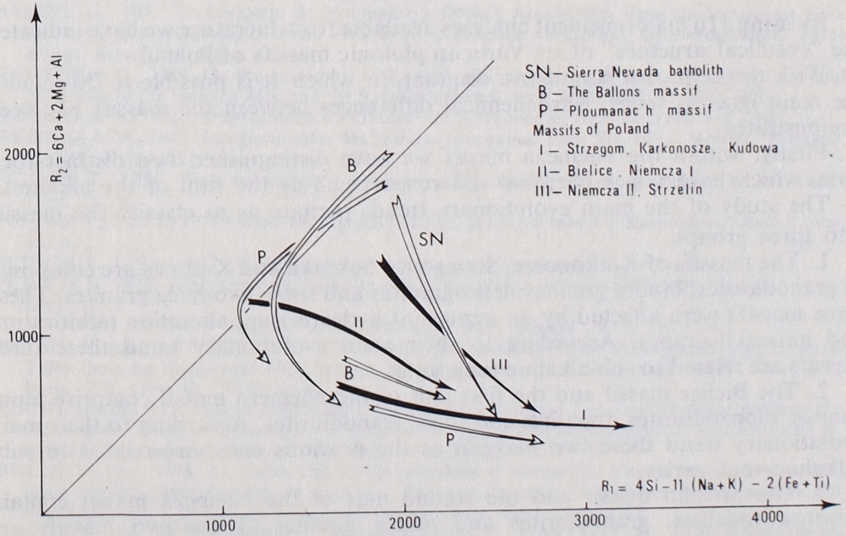

Fig. 6. Comparison of the main evolutionary trends of the three major groups defined for the Variscan massifs of Poland with main trends of some well-known igneous series: calc-alkaline series – the Sierra Nevada Batholith (Bateman *et al.*, 1963); two sub-alkaline series – the plutons of Ploumanac'h, Brittany (Barrière, 1977) and of The Ballons, Vosges (Pagel and Leterrier, 1979)

alkaline granites, the sub-alkaline granites and the alkaline (to peralkaline) granites. The first two groups are typically present in orogenic zones; the calc-alkaline granites are essentially synorogenic and the sub-alkaline granites are often assumed to be late-to post-orogenic. On the other hand alkaline granites are typically anorogenic.

All the Variscan massifs of Poland are orogenic and it is possible to define their type of magmatism by comparison with some well-studied plutonic series. In order to illustrate the calc-alkaline trend we have chosen the Sierra Nevada Batholith series (Bateman *et al.*, 1963) and, for the sub-alkaline trend, two Hercynian French plutons of Ploumanac'h, Brittany (Barrière, 1977) and The Ballons, Vosges (Pagel and Leterrier, 1979) (Fig. 6).

The mean evolutionary trend defined for the three plutons of Karkonosze, Strzegom and Kudowa corresponds well with the trends of the two monzogranites of Ploumanac'h and The Ballons plutons which are related to a sub-alkaline series. In addition, the three Variscan plutons of Poland are characterized by their high total alkali content, as are the two French monzogranites. It must be noted that, for the two French monzogranites, a hypothesis involving hybridization between a sub-alkaline intermediate magma and a crustal magma has been proposed (Barrière, 1977; Pagel and Leterrier, 1979).

The mean trends for the Bielice massif and the first unit of the Niemcza massif are also characteristic of a sub-alkaline series with an equally high total alkali content. On the other hand, the mean trend defined for the Strzelin massif and the second unit of the Niemcza massif appears to be near a calc-alkaline. These massifs are also characterized by a lower total alkali content than the two previously discussed series.

CONCLUSION

By using 116 major-element analyses available from literature we have indicated the "chemical structure" of six Variscan plutonic massifs of Poland.

With the help of a parametric diagram, in which it is possible to distinguish the main igneous series, petrochemical differences between the massifs has been demonstrated.

Firstly, within the Niemcza massif we have distinguished two distinct rock series which have major chemical differences (such as the sum of the alkalies).

The study of the main evolutionary trends permits us to classify the massifs into three groups.

1. The massifs of Karkonosze, Strzegom – Sobótka and Kudowa are composed of granodiorites, biotite granites, leucogranites and some two-mica granites. These three massifs were affected by an important hydrothermal alteration (albitization and muscovitization). According to their main evolutionary trend these three massifs are related to sub-alkaline rock series.
2. The Bielice massif and the first unit of the Niemcza massif comprise monzonites, monzodiorites, tonalites and some granodiorites. According to their main evolutionary trend these two massifs, as the previous ones, are related to sub-alkaline rock series.
3. The Strzelin massif and the second unit of the Niemcza massif contain diorites, tonalites, granodiorites and minor granites. These two massifs are related to calc-alkaline rock series.

The massifs of the first two groups, being related to sub-alkaline rock series, are thus likely to have formed as late- to post-tectonic massifs. On the contrary, the massifs of the third group, being related to calcalkaline rock series are therefore considered to be syntectonic massifs.

This essentially chemical classification of the Variscan massif of Poland presents some major differences with the chronological and structural classification previously presented. These differences concern essentially the Bielice and Strzelin massifs respectively classified by previous authors as synorogenic and post-orogenic. On the contrary, we consider on chemical evidence that the Bielice massif may be post-orogenic and the Strzelin massif may be synorogenic.

Such divergence between the two classifications might be explained if the major element chemistry of the massifs is, in fact, atypical of their original tectonic setting. However, it is important to note that the Strzelin massif appears to be related, such as the Niemcza massif, to a major variscan fault.

Finally, the resolution of this problem requires further precise age determinations for all the Variscan massifs of Poland.

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GŁÓWNE GEOCHEMICZNE TRENDY W WARYSCYJSKICH GRANITOWYCH MASYWACH SUDETÓW I ICH PRZEDPOLA

Streszczenie

Rozpatrywano geochemiczną strukturę masywów granitoidowych Sudetów, posługując się parametrycznym diagramem R_1/R_2 (de la Roche, Leterrier, 1973). Jest to transpozycja normatywnego tetraedru Yodera i Tilley'a (1962) uwzględniająca mineralogiczną i chemiczną stronę dyferencjacji. Jak wykazał de la Roche (1978), można w stosunkowo prosty sposób zdefiniować parametryczny system, który pozostaje w ścisłym powiązaniu z facjami mineralnymi i może służyć do badań serii magmowych.

Porównanie głównych geochemicznych trendów przeprowadzono w oparciu o pełne analizy chemiczne i mikrometryczne dostępne w literaturze. Pozwoliło to zakwalifikować badane masywy do trzech grup; dwie związane są z subalkaliczną serią magmową, trzecia z serią wapienno-alkaliczną. Geochemiczne trendy masywów o złożonej genezie są związane z ich strukturalną pozycją.

OBJAŚNIENIA FIGUR

Fig. 1. Rozmieszczenie waryscyjskich masywów granitoidowych w Sudetach (wg Przewłockiego i in., 1962)

1 – utwory trzeciorzędowe, *2* – późnopaleozoiczne i mezozoiczne formacje, *3* – wczesnopaleozoiczne formacje, *4* – metamorficzne łupki, *5* – bazalty trzeciorzędowe, *6* – permskie porfiry i melafiry, *7* – masywy związane z orogenezą waryscyjską, *8* – gabro, *9* – serpentynit, *10* – główne uskoki

Fig. 2. Parametryczny diagram R_1 R_2 pochodzący z chemicznej transpozycji (de la Roche i Leterrier, 1973) normatywnego tetraedru Yodera i Tilley'a (1962)

Parametry są obliczone w milikationach na 100 g skały lub minerału

Fig. 3. Schemat klasyfikacyjny dla skał magmowych (de la Roche i in., 1979)

Fig. 4. Rozmieszczenie na diagramie R_1 R_2 próbek z masywu Bielic

Punkty naniesiono na wykres na podstawie danych z analizy chemicznej i mikrometrycznej. Linią połączono punkty reprezentujące wyniki analiz z tej samej próbki

Fig. 5. Rozmieszczenie na diagramie R_1 R_2 sudeckich masywów waryscyjskich w Polsce

Każdy masyw zdefiniowany jest przez pole obejmujące wszystkie przeliczone analizy. Wykazano także średni skład chemiczny skał w każdym masywie: δ – dioryty, $Mz\delta$ – monzodioryty, T – tonality, $\gamma\delta$ – granodioryty, γ – granity biotytowe, $L\gamma$ – leukogranity, γM – granity dwumikowe. Masywy rozmieszczone są w trzech grupach zgodnych z ich ewolucyjnymi trendami: *1* – Karkonosze, Strzegom, Kudowa, *2* – Bielice, Niemcza I, *3* – Strzelin, Niemcza II

Fig. 6. Porównanie ewolucyjnych trendów trzech głównych grup określonych dla waryscyjskich masywów w Sudetach z głównymi trendami niektórych, dobrze znanych magmowych serii: wapienno-alkalicznej – batolit Sierra Newada (Bateman i in., 1963) oraz dwóch subalkalicznych – Kompleks Ploumana'ch, Masyw Armorykański (Barriere, 1977) i masyw Ballon, Wogezy (Pagel, Leterrier, 1979)

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ГЛАВНЫЕ ГЕОХИМИЧЕСКИЕ ТРЕНДЫ В ВАРИСЦИЙСКИХ ГРАНИТНЫХ МАССИВАХ СУДЕТОВ И ИХ ПРЕДПОЛЬЯ

Резюме

Геохимическая структура гранитоидных массивов Судетов рассматривалась при использовании параметрической диаграммы R_1/R_2 (де ла Рош, Летерье, 1973). Это транспозиция нормативного тетраэдра Йодера и Тилла (1962), учитывающая минералогическую и химическую стороны диференциации. Как показал де ла Рош (1978), можно сравнительно простым образом определить параметрическую систему, которая тесно связана с минеральными фациями и может служить для исследований магматических серий.

Сравнение главных геохимических трендов было произведено на основе полного химического и микрометрического анализов, доступных в литературе. Это дало возможность отнести исследуемые массивы к трём группам: две из этих групп связаны с субщелочной магматической серией, третья — с кальциево-щелочной серией. Геохимические тренды массивов со сложным генезисом связаны с их структурной позицией.

ОБЪЯСНЕНИЕ К ФИГУРАМ

Фиг. 1. Размещение варисцийских гранитоидных массивов в Судетах (по Пшевлоцки и др., 1962)

1 — третичные образования, *2* — позднепалеозойские и мезозойские формации, *3* — раннепалеозойские формации, *4* — метаморфические сланцы, *5* — третичные базальты, *6* — пермские порфиры и мелафиры, *7* — массивы, связанные с варисцийским орогенезисом, *8* — габро, *9* — серпентиниты, *10* — главные сбросы

Фиг. 2. Параметрическая диаграмма R_1 R_2, исходящая из химической транспозиции (де ла Рош и Летерье, 1973) нормативного тетраэдра Йодера и Тилла (1962)

Параметры рассчитаны в миликатионах на 100 г породы или минерала

Фиг. 3. Схема классификации магматических пород (де ла Рош и др., 1979)

Фиг. 4. Размещение на диаграмме R_1 R_2 проб из массива Белице

Пункты нанесены на график на основании данных химического и микрометрического анализов. Линией соединены пункты, представляющие результаты анализов одной и той же пробы

Фиг. 5. Размещение на диаграмме R_1 R_2 судетских варисцийских массивов в Польше

Каждый массив определён полем, охватывающим все пересчитанные анализы. Показан также средний химический состав пород каждого из массивов: δ — диориты, $Mz\delta$ — монцодиориты, T — тоналиты, $\gamma\delta$ — гранодиориты, γ — биотитовые граниты, $L\gamma$ — лейкограниты, γM — двуслюдяные граниты. Массивы размещены в трёх группах согласно с эволюционными трендами: *1* — Карконоше, Стшегом, Кудова, *2* — Белице, Немча 1, *3* — Стшелин, Немча II

Фиг. 6. Сравнение эволюционных трендов трёх главных групп, определённых для варисцийских массивов в Судетах с главными трендами некоторых хорошо известных магматических серий: кальциево-щелочной — батолит Сьерра Невада (Батеман и др., 1963), а также двух субщелочных — комплекс Плоуманах, массив Армориканский (Барьер, 1977), массив Баллон, Вогезы (Пагель, Летерье, 1979)