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THE PRESENT STATE OF GEOCHEMICAL INVESTIGATIONS OF THE POLISH AMPHIBOLITES

(Figs. 1–2)

Abstract: The article informs about the present state of the investigations of amphibolites on the territory of the Polish People's Republic and gives an evaluation of their macrochemism, as well as the correlations of some macro- and microelements and the correlations of the microelements, respectively.

Резюме: Приведенная статья информирует о современном состоянии исследований амфиболитов на территории Польской народной республики и приносит оценку их макрохимизма, как и соотношения некоторых макро- и микроэлементов и соотношения между микроэлементами.

Introduction

In the collaboration between the Geological Institute of the Slovak Academy of Sciences in Bratislava and the Centre of Geological Sciences of the Polish Academy of Sciences in Warsaw, which arose spontaneously in the beginning of 1971 Professor B. C a m b e l, Dr. Sc. made a suggestion of publishing in one of the Slovak geological journals a report concerning the present state of geochemical investigations of basic and ultrabasic rocks of Poland.

The topic proved to be too complex as to be reviewed in one short report. Moreover geochemistry is the domain so closely combined with mineralogy and petrography that reviewing its results noone can overlook the mineralogical-petrological works, which usually precede geochemical investigations. The report concerning the present state of geochemical investigations of the Polish amphibolites is the first in the series of three review papers, which I would like to present to the Slovak readers. The next two papers will be devoted to the Polish basic igneous rocks (gabbros, basalts and spilites) as well as to the ultrabasic rocks respectively.

In the Polish geological papers amphibolites and amphibolite-bearing metabasite series have been often either mentioned or even described in details. Nevertheless the papers devoted *sensu stricto* to the amphibolite geochemistry are relatively scarce. But one should not forget that the petrological papers abundantly illustrated by the results of chemical analyses are also of great geochemical importance.

On the one hand the aim of geochemical investigations of amphibolites was to find indices of genesis, on the other hand the investigations were attempts at determining the amphibolite origin by means of complex commonly accepted geochemical indices as well as petrological and geological evidences.

Amphibolites occur in Poland in three regions, i. e. in the crystalline basement, in the Sudetes and in the Tatra Mts. (fig. 1). They are in greatest abundance in the Sudetes, the fact which has found its reflections in the numerous works dealing with them.

The character of the report is such, that the author decided to discuss only the works that had been published or being in press. Nevertheless the author feels obliged to

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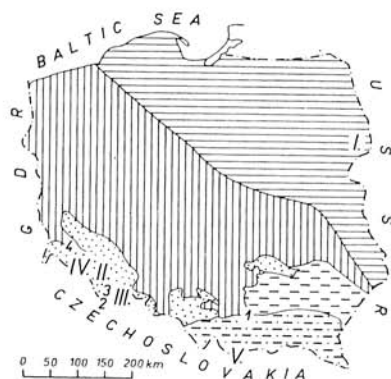


Fig. 1. Sketch map of the Polish amphibolite localities. Roman numbers stand for localities of geochemically studied amphibolites: I — the Białowieża metamorphic series, II — the Sowie Góry Mts., III — the Łądek-Snieżnik Mts. metamorphic series, IV — the Rudawy Janowickie Mts., V — the Tatra Mts. Arabic numbers stand for localities of other amphibolites, which have been mentioned in geological papers: 1 — crystalline substratum found near Cracow, 2 — the Bystrzyckie Góry Mts., 3 — the Kłodzko metamorphic series, 4 — the Iżera gneiss complex: a — area of pre-Cambrian platform, b — area of Palaeozoic platform, c — folded area of Palaeozooids, d — folded area of Alpid, fore-Carpathian area, e — folded area of Alpid, Carpathian area.

inform, that the geochemical and petrological investigations of the Sudetes amphibolites have been being carried in the former Department of Petrography and Department of Mineralogy and Geochemistry forming nowadays Institute of Geochemistry. Mineralogy and Petrology of the Warsaw University under the guidance of Prof. Dr K. Smulikowski and Prof. Dr A. Polański in the form of master theses for a long time.

The Amphibolites of the Crystalline Basement

Amphibolites of the crystalline basement have been found in North-Eastern Poland (Podlasie region) in the s. c. Białowieża metamorphic series and from crystalline substratum, which has been discovered under sedimentary rocks near Cracow (J. Burtan 1962).

As regards amphibolites occurring in the Białowieża metamorphic series they have been thoroughly investigated from the geochemical point of view by A. Dziedzic (1968). The author determined the main elements: Fe^{2+} , Fe^{3+} , Mg, Ti as well as the concentrations of the trace elements: Ni, Co, V, Cr, Mn, Cu, Zn, Pb, Sn in the whole rocks (tab. 1). Among the elements under consideration Cr and Ni show the greatest differentiation in concentrations — Cr ranges in the limit 5–2000 ppm and the figures for Ni are 15–330 ppm on the other hand Co does not show any essential dispersion. Taking into account the petrographic features of the amphibolites and their trace elements contents the Wałki amphibolites of gabbro texture can be viewed as orthoamphibolites. As compared to the other Białowieża amphibolites the Wałki orthoamphibolites display the highest concentration of trace transition elements. The Wałki amphibolites contain 5 times as much Ni, 10 times as much Cr and 6 times as much Mn as the other amphibolites. The points for projection of the Wałki orthoamphibolites are located in separate fields in the Ni/Co, Ni/Cr and Co/Cr rectangular diagrams.

The most common rocks in crystalline series found near Cracow are zoisite, epidote, garnet or biotite amphibolites. According to A. Pelczar and T. Wieser (1962) they have been formed at the expense of the extrusive rocks i. e. tuffs and spilites.

Table 1. Trace elements determinations in the Polish amphibolites and minerals isolated therefrom

Locality	Author, year	Trace elements determined in		
		whole rocks	amphiboles	plagioclases
Crystalline basement I. The Białowieża metamorphic series	A. Dziedzic, 1968	Ni, Co, V, Cr, Mn, Ti, Cu, Zn, Pb, Sn		
Sudetes II. The Sowie Góry Mts.	Z. Wichrowski, 1967	Mn, Ti, Sr, Ba	Mn, Ti, Sr, Ba	Sr, Ba
III. The Łądek-Śnieżnik Mts. metamorphic series				
a) The vicinity of Nowa Wieś	N. Bakun-Czubarow, 1968	B, Zn, Ge, Sr, Ba, Pb, Sc, Ti, V, Cr, Mn, Co, Ni, Cu, REE		
b) The vicinity of Strachocin	N. Bakun-Czubarow, 1971 b	Sc, Ti, V, Cr, Mn, Co, Ni, Cu		
c) The Czernica eclogite	N. Bakun-Czubarow, 1971 a	Sc, V, Cr, Mn, Co, Ni, Cu		
d) Białskie Góry	Z. Wichrowski, 1971		Ti, Mn, V, Cr, Sr, Ba	
IV. The Rudawy Janowickie Mts.	W. Narębski, 1968	Ti, Mn, V, Cr, Co, Ni, partly Sr, Ba, Cu, Zn		
V. The Tatra Mts.	W. Narębski and Z. Wichrowski (oral information)	Mn, Ti, V, Cr, Co, Ni, Sr, Ba, Rb, Li		

The Sudetes Amphibolites

In the oldest Sudetes metamorphic complex, i. e. in the Archeozoic gneisses of the Sowie Góry Block amphibolites are very common rocks. The petrology of the Sowie Góry amphibolites has been worked out in details by A. Polański (1955), who divided the rocks in question into paraamphibolites, diablastic garnet-bearing amphibolites and granoblastic amphibolites. The only paper published up to now dealing with geochemistry of the Sowie Góry amphibolites is that by Z. Wichrowski (1967). The author determined the Fe, Ca, Mg, Na, K, Mn, Ti, Sr and Ba contents in amphibolites and amphiboles isolated therefrom as well as the Ca, Na, K, Sr, and Ba concentrations in plagioclases. As to the trace elements Ti and Mn concentrate in amphiboles only, whilst Ba shows tendency to concentrate to a higher degree in amphiboles, but Sr concentrates preferably in plagioclases. Moreover, the more basic is the plagioclase the less Sr it contains. On the basis of chemistry the Sowie Góry amphibolites may be viewed as orthoamphibolites and a relatively high Ca abundance seems to be their regional feature only.

In the Proterozoic and old Palaeozoic metamorphic series of Łądek and the Śnieżnik

Mts. amphibolites have been found in many localities in both the main complexes, i. e. in the Stronie schists and in the migmatitic Gieraltów gneisses.

In the eastern part of the series under consideration in the vicinity of Bielice there have been found abundant amphibolites occurring in the Algonkian schists covering the Variscian granitoids. The amphibolites have been examined petrographically by B. Wierzechowski (1966), who noticed their variety and classified them tentatively into two groups, i. e. into the fine grained and laminated paraamphibolites and into the coarser grained orthoamphibolites rich in titanium minerals. The geochemistry of the amphiboles isolated from the above amphibolites has been studied by Z. Wichrowski (1971), who on the basis of the Fe, Mg, Ca, K, Na, Mn, Ti contents as well as on the basis of trace elements: Sr, Ba, V and Cr proved the great differentiation of the material. Taking into account relatively high TiO_2 abundance in the amphiboles (average 1.55 weight per cent) the author concluded that the Bielice amphibolites may have been originated under transition conditions between amphibolite and granulite metamorphic facies.

In the northern part of the Łądek-Śnieżnik Mts. metamorphic series J. Don (1964) distinguished paraamphibolites represented by fine laminated amphibolite schists with often preserved primary sedimentation features among the amphibolites commonly occurring there, which are believed to be of igneous origin probably.

In the north-western part of the discussed massif in the Krowiarki Mts. there occur concordant intercalations of amphibolites in paragneisses. The amphibolites have been petrographically examined by T. Butkiewicz (1968). In the author's opinion the majority of the Krowiarki amphibolites may be most likely looked upon as the rocks of sedimentary origin.

In the southern part of the metamorphic massif under consideration J. Ansilewski (1966) described many outcrops of amphibolites, paying special attention to their connections to the eclogites. In the Gieraltów gneisses the author found the outcrops of posteclogitic, fine grained, diablastic amphibolites often containing garnet relicts. In the both main rock types of the massif formed under amphibolite facies conditions, i. e. in the Stronie schists and in the Gieraltów gneisses, there occur relatively coarser grained ordinary amphibolites showing no connections to eclogites.

Amphibolites of the eclogite derivation occurring in the migmatitic Gieraltów gneisses have been thoroughly examined by K. Smulikowski (1964, 1967). The hornblende-plagioclase paragenesis forming ordinary amphibolites might have been originated in the last stage of the process of eclogite amphibolitization preceding the migmatitization. The passing link figured out on the basis of the sequence of the alteration of eclogite paragenesis minerals are: amphibolitized eclogites, eclogite amphibolites rich in garnet relicts and diablastic amphibolites. Since the majority of the Śnieżnik eclogites according to K. Smulikowski has been formed at the expense of sedimentary series, therefore amphibolites being eclogite derivatives may be considered as paraamphibolites. Basing on the amphibolites coming from the Nowa Wieś eclogites and those of Czernica the present author studied geochemistry of the process of the eclogite amphibolitization (N. Bakun-Czubarow 1968, 1971a). Chemistry of the process was examined statistically. The amphibolitization of the Nowa Wieś eclogites has been accompanied by distinctive increase only in K, by small decrease of Ca and by decrease of ratio Fe^{2+}/Fe^{3+} as far as main elements contents are concerned. Small changes in the trace elements concentrations could be also observed. During the amphibolitization the B, Mn, and Ba contents increase and those of Ti, Cr, Co and Cu slightly decrease, while the V, Ni, Zn, Sr and Pb concentrations seem to be stable. The results of the applying of some of

the Leake's diagrams based on Ni, Cr, Ti and Niggli's mg parameter indicate basic igneous origin of the primary material for the rock series under consideration.

Scarcity of data made it impossible to examine the chemistry of the amphibolitization of the ilmenite-bearing Czernica eclogite (N. B a k u n - C z u b a r o w 1971a).

The eclogite-amphibolite rock series forming the s. c. Strachocin metabasites in the Śnieżnik Mts. has been viewed by K. S m u l i k o w s k i (1967) on the basis of the results of his petrological examinations as series of sedimentary origin. The present author examined the Mg, Ca and Fe contents in the rocks in question as well as the transition elements of the 3rd type: Sc, Ti, V, Cr, Mn, Co, Ni and Cu (N. B a k u n - C z u b a r o w 1971b). The above mentioned transition elements can be divided into two groups by means of the correlation analysis. The first group represented by Sc, Ti, V, Mn and Co exhibits positive linear correlation with Fe, the other one containing Cr, Ni and Cu reveals trends concurrent with Mg (fig. 2). The division may be proved to some extent by the electronic structure of ions of the transition elements.

The attempt has been made to distinguish orthorocks among the Strachocin metabasites on the basis of their high content of TiO_2 (>2.2 weight per cent) or the sum $\text{Cr} + \text{Ni}$ exceeding 250 ppm.

The linear correlations between the parameters of petrogenetic importance, i. e. $\text{mg} - \lg \text{Cr}$, $\text{TiO}_2 - \lg \text{Cr}$ and $\text{TiO}_2 - \lg \text{Ni}$, which are considerable for the orthometabasites, vanish for pararocks. Furthermore it turned out, that the orthometabasites show higher concentrations of Sc, V and Mn as compared to the parametabasites. Thus the Strachocin metabasites have most likely been formed from the mixed sedimentary-tuffogenic series.

West of the Łądek-Śnieżnik Mts. metamorphic series, across the Nysa graben, numerous amphibolite intercalations have been observed by M. D u m i c z (1964) in the Bystrzyckie Góry paragneiss and mica schist complex.

In the southern part of the Kłodzko metamorphic rocks of Cambro-Silurian and probably Eocambrian age great messses of orthoamphibolites have been worked by M. K o z ł o w s k a - K o c h (1958) from the petrological point of view. They originated most probably at the expense of gabbros and biabases.

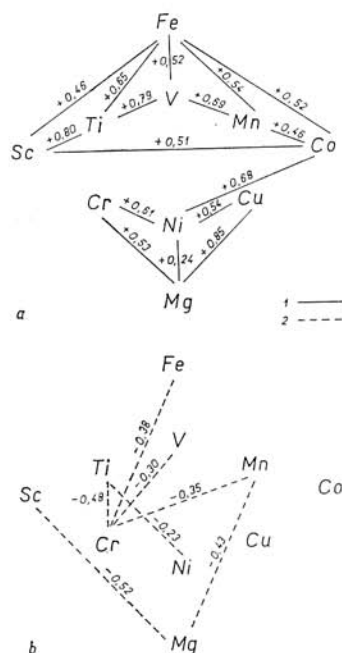


Fig. 2. Scheme of correlation of transition metals of the 3rd type in the Strachocin metabasites (N. B a k u n - C z u b a r o w 1971b). a — elements showing concurrent geochemical tendencies, b — elements showing antagonistic geochemical tendencies, 1 — positive linear correlation, 2 — negative linear correlation.

In the West Sudetes in the Iżera gneisses of polygenetic character, probably pre-Cambrian or Assyntian in age, M. Kozłowska-Koch (1961) has found and examined petrographically many intercalations of amphibolites of various origin. Furthermore M. Kozłowska-Koch (1971) worked out the metabasite dikes occurring in the Iżera rock series in the vicinity of Jelenia Góra. The author distinguished there three groups of basic rocks of various age and various degree of metamorphic alteration. Among the examined rocks the oldest Lower-Cambrian or Eocambrian basites became feldspathized amphibolites as well as the younger, Lower- or Middle-Silurian, diabases produced isochemically orthoamphibolites.

In the eastern part of the metamorphic mantle of the Karkonosze massif in the Rudawy Janowickie Mts. amphibolites play an important role. The amphibolite and related metabasic rock geochemistry has been examined by W. Narębski (1968). The author employed the most modern Leake's diagrams of the great petrogenetical importance. The diagrams are based on the trends of variation of elements and petrochemical parameters. The trends are distinctly different for sedimentary and igneous rock series. The author carried out numerous whole rock analyses as well as the determinations of the following trace elements: Ti, Mn, Cr, V, Ni, Co, Sr, Ba, Cu and Zn. Basing on the results of the complex investigations of the amphibolite series the author concluded among others that the striped amphibolites from the lower part of the rock complex can be considered as altered products of basic tuffs, which had been erupted during the initial volcanic activity of the Caledonian geosyncline. The tuff deposits had been locally enriched in carbonate and detrital material. Furthermore it should be emphasized that the rocks in question exhibit positive linear correlations of Cr and Ni with mg parameter, what is typical for igneous rocks.

The Tatra Amphibolites

The amphibolites occurring in the High Tatra Mts. have been studied petrologically by St. Jaskólski (1924). The author concluded that the Tatra amphibolites strongly homogenous in their nature are derivatives of basic magma of gabbro or diabase type. Before the rocks underwent the regional metamorphism, they had formed a comagmatic series.

The High Tatra amphibolites are being studied from geochemical point of view by W. Narębski and Z. Wichrowski (personal information). For solving the problem of the amphibolite origin as well as for deciphering their mutual relations the above mentioned scientists are determining the concentrations of the following trace elements: Ni, Co, Cr, V, Mn, Ti, Sr, Ba, Rb and Li in the whole rocks.

Basing on the results of the most modern statistical-geochemical investigations as well as on the geological position of the amphibolites the authors came recently to the conclusion that the primary material for the Polish West Tatra amphibolites had most likely been represented by basic tuffs and tuffites (W. Narębski and Z. Wichrowski 1972).

To conclude the paper I would like to add a few remarks concerning the application of geochemical indices for the petrogenesis of amphibolites. First, the indices should not be used independently of the results of detailed petrological investigation, nor should they be used disregarded of the conditions of their geological mode of occurrence. Moreover their use is strongly limited in the case of amphibolites of the mixed sedimentary-tuffogenic nature of the parent material. In the geochemical investigations

the platinum group elements can be said to be of great use in solving problems of amphibolite petrogenesis.

I would like to suggest that geochemists should pay more attention in examining the transition elements distribution among coexisting minerals to ascertain the amphibolite formation conditions which can be of great importance in deciphering basic facts about the metamorphic evolution of the host rock complexes.

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