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CONCEPTION AND AIMS OF THE STUDY OF SELECTED GRANITOID SAMPLES

During the recent 5—6 years the staff of the Geological Institute of the Slovakian Academy of Sciences worked on an integrated evaluation of ca. 130 samples of granitoids selected as being representative. The samples were chosen with respect to the following criteria and purposes:

1. From the characteristic granitoid rocks of the individual mountain ranges we endeavoured to obtain samples representing the principal rock types which are predominant in the respective mountain range. (The principal types comprise the biotite-muscovite or biotite granites and granodiorites). The representatives of leucocratic or aplitic granitoids and of the more basic quartz diorites and diorites, which are also developed here, are of negligible quantitative extent, although they are of petrological importance.

2. Samples were taken, as far as possible, from localities that are accessible and allow repeated collection and easy exploration; the rock should be relatively suitable for integrated study.

3. An integrated study was conducted by a team of experts and each of them was charged with a special part of research. The investigation required a collection of minimum 15 kg-samples (usually 20 kg was taken) so that accessory minerals could be studied from the ground and homogenized 10 kg amounts. Rock-forming minerals for chemical and mineralogical analyses were also separated from this detritus. An appropriate average sample for chemical analysis was obtained by homogenization of the ground rock. In addition, an individual sample (1—2 kg in weight) was taken from every locality, which served for chemical analysis, planimetric measurement and mineralogico-petrographical and other studies.

4. To attain a reliable comparison of the results of chemical analyses, all silicate analyses of the set of samples were made by one worker in one laboratory (E. Walzel, Geological Inst., Slovak Acad. Sci.) using definite methodical procedures. Spectral analyses were performed by J. Medveď, atomic-absorption analyses by E. Martiny, X-ray fluorescent analyses by M. Vondrovic, and gamma-spectrometric analyses by V. Kátlovský. Also the optical, geochemical, mineralogical and petrographic-petrological investigations of all samples were carried out with the use of the established methods.

5. The results achieved by individual co-workers were systematically given at disposal to the whole team, as it was desirable for co-operation and exploitation of all data obtained on each sample.

6. The documentation of samples was produced so as to preserve them for further study and allow them to be used as standards, control and comparative samples. Each sample has a "certificate" containing the investigation results, which can be complemented and used to full advantage.

7. The investigations made it possible to improve and refine the analytical

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methods and up-date the mineralogico-petrographical and geochemical studies of rocks and minerals. This was ensured by a systematic control of results by checking them against the international standards and the results achieved by co-operating institutes, both at home and abroad, as well as by controlling analyses using different methods. In this respect a considerable progress was made and the verification of analyses became prerequisite for acknowledgement of the correctness of interpretation.

8. The samples selected or their minerals were used for radiometric-geochronological measurements (K-Ar, Rb-Sr and U-Th-Pb methods), for crystal-optical and isotopic investigations, for determination of thermodynamic data on the genesis of minerals, and the contents of macro- and microelements in minerals, which facilitated the interpretation of genetic and thermal-pressure conditions of their origin.

9. The applied classification of granitoids developed in agreement with the international convention (IUGS Subcommission, 1973) led to the division of the West Carpathian granitoids into the following groups:

1. Leucogranitoids
   1. aplitic granitoids
   2. leucogranites
   3. leucogranodiorites
2. Two-mica granitoids
   1. two-mica granites
   2. two-mica granodiorites
3. Biotite granitoids
   1. biotite granites
   2. biotite granodiorites
4. Tonalites
   1. leucotonalites
   2. biotite tonalites
   3. hornblende-biotite tonalites

The use of a uniform classification of rocks based on the modal determination of minerals and the application of mesonorm in samples for which planimetric analysis was not performed made it possible to establish an internationally usable groups of analogous rocks and to correlate the results of investigations. This is at present the primary condition of international co-operation (correlation programs), which is being realized through a bilateral and multilateral agreement between socialist states.

In classifying the West Carpathian granitoids we have consistently followed the classification recommended by the IUGS Subcommission on the Systematics of Igneous Rocks. This concerns particularly the position of "biotite" and "muscovite" and prefix "leuco" in the compound names of rocks. We have adhered to the following principles:

1. The root name of the rock was deduced from the position in the Q A P diagram, and the Q A P values were calculated from the modal analysis.

2. The colour index was defined as M' = M — muscovite, where M is the sum of all mafic minerals and micas. We observed the recommended limits, i. e. the prefix "leuco-" was used for granites and granodiorites with $M' < 5\%$

and tonalites with M' < 10 %, and the prefix "mela" for M' > 20 % in granites and granodiorites. No sample of tonalite had M' higher than 25 %.

3. Every sample was characterized in its name by another typical mineral present in higher than 2 % amount (muscovite, amphibole); they were arranged in order of increasing amount, i. e. more abundant mineral was placed closer to the root name than a less abundant mineral, e. g. biotite-muscovite granodiorite contains more than 5 % mafic components (biotite) and more muscovite than biotite; biotite leucogranite contains less than 5 % mafic components (biotite) but more than 2 %. The lower limit of the mineral content (2 %) given in the name was defined according to the conventional limit of the accessory amount, as the criterium for femic and accessory minerals is not precisely characterized in Streckeisen's classification. The content of muscovite was given in actual amount irrespective of its formation by secondary alteration of other minerals. The following abbreviated division of the granitoid rocks is used in the papers:

1 — Leucocratic granitoids (granites and granodiorites)
2 — Two-mica granitoids (granites and granodiorites)
3 — Biotite granitoids (granites and granodiorites)
4 — Tonalites.

The integrated investigation of a limited number of rock samples by a team of workers provided results of higher quality and deeper insight into some problems, and brought conclusions which allow interpretations based on data of higher standard. The results gave rise to new methodical approaches and to the possibilities of correlation works, which are the fundamental objective of international correlation programs and multilateral agreements on co-operation.

Overview of the main investigation results

The scope of this report does not allow to summarize and evaluate all results obtained by the integrated investigation of the selected samples of the West Carpathian granitoids. The presented information is therefore not exhaustive and cannot give a full picture of the extent and importance of these results.

According to our investigations the granitoid rocks of the West Carpathians are a product of anatexis and palingenesis; the anatectic medium consisted of clayey-siliceous sedimentary complexes with more or less products of submarine basaltoid effusions (tholeiites, olivine basalts and their tuffs, etc.). The West Carpathian granitoids classified after the system proposed by B. W. Chappell and A. J. R. White (1974) are therefore ranged to the "I" type or to the mixed types and only rather rarely to the "S" type. The more basic types (tonalites and part of biotite granodiorites) belong prevalently to the "I" type, and the leucocratic two-mica rocks mainly to the transitional types or the "S" type. The Gemeride granitoids are definitely classed as the "S" types (J. Klomínský et al., 1981). The assignment of the West Carpathian granitoids to the "I" and "S" types, based on the Chappell and White's criteria, is substantiated in the paper of B. Cambel — I. Petrík (1982). The criteria taken into consideration were, among others, the Rb/Sr ratio, the alkali content, and the ratio of $^{87}Sr/^{86}Sr$ isotopes, etc. The studied have confirmed that the pre--metamorphic sediments contained a relatively younger detritus of basic rocks derived from the upper mantle, which had a low Rb/Sr ratio. There is why a mixed I/S characteristic issues for the Tatro-Veporide granitoids.

Another feature of the West Carpathian granitoids is their relative material and geochemical uniformity. Almost every "Core mountain range" consists of analogous rock types (leucogranitoids, two-mica and biotite granitoids and tonalites), but these are represented in different amounts. The individual acid and dyke differentiates are characterized by both the macroelement and microelement contents. Only the granitoids of the Slovenské rudohorie Mts. show particular petrochemical and geochemical characteristics. Therefore we assume the West Carpathian granitoids to belong to one formation of Variscan granitoids, except the Gemeride granitoids, which are a separate formation. Their age is not yet known but they may be a product of the Permian Variscan postorogenic magmatism or of Neoidic magmatism.

High contents of barium, strontium and low contents of alkalies, incl. Rb and Cs, the predominance of Na over K, low contents of light TR, and the high model age of the clastogenic zircon in metamorphites suggest that the clastic material from which the West Carpathian granitoids were formed derives from the Precambrian rocks. These had been of relatively primitive geochemistry and were washed down into the basins of the pre-Variscan geosynclinal sea, which spread between the North European and South European (North African) continents. This terrigenous crust material together with the products of basic volcanism of a mantle character, which sedimented in the Palaeozoic or Late Precambrian, became a source material of granitoids. They formed by anatexis and intruded towards the end of the Devonian and particularly in the Early Carboniferous into the higher parts of the earth's crust.

There is no reliable evidence available of the Caledonian progressive metamorphic (anatectic and granitization) processes, granitoid plutonism and orogenic processes, although the beginning of progressive metamorphism (anatexis) might be expected towards the end of the Silurian and in Early Devonian. The question remains open.

B. Cambel (B. Cambel – L. Vilinovičová, 1981) in accord with the view of D. F. Strong (1980), thinks it possible that the genesis of granitoids was preceded by slicing and overthrusting of schist complexes, which resulted in the thickening of the crust during the Variscan orogeny and closing of the Early Palaeozoic sea. This process began in the Late Devonian and terminated in the Middle Carboniferous and, being connected with the supply of energy from the depth, called forth the expansion of Variscan granite plutonism and progressive metamorphism.

The above considerations also explain the Variscan age of the West Carpathian granitoids (with a few exceptions) yielded by the radiometric K/Ar, Rb/Sr and U-Th-Pb methods.

The petrography of the granitoids, studied by J. Macek, and their petrochemistry was often controlled by peculiar local conditions existing during the solidification of the intruding palingenic magma. Therefore the West Carpathian granitoids appear to be products of discontinuous complex solidification, influenced by autometamorphic, autometasomatic and tectonic phenomena, which develop in the intratelluric evolution phases of the intruding magma.

They imply processes that fall in the period when the consolidation of the granitoid magma in the Variscan orogeny had not yet been completed.

If we realize that this complicated development may have been followed by processes occurring after the consolidation of magma towards the end of the Variscan orogeny or during the Alpine orogeny (endogenous, dynamometamorphic and tectonometamorphic), the intricacy and diversity of the interpretation of some features established by petrographical studies can be understood. These interpretations must obviously take into consideration the new information obtained by the integrated study of granitoids and new geological findings assembled by mapping in the field.

As concerns the association of accessory minerals, studied by J. Gbelský, the West Carpathian granitoid rocks are contaminated by minerals that are not typical of such acid granites, viz. by hornblende and pyroxene, and occasionally by metamorphic minerals – andalusite, sillimanite and scarcer garnet of metamorphic origin. With regard to the anatectic origin of the magma these minerals can be relics – xenocrysts from the pre-magmatic stage. The heterogeneity of the associations of accessories indicates the complexity of the evolution process of the West Carpathian rocks and their anatectic-palingenic origin. The diverse generations of accessory and rock-forming minerals are indicative of changes of the chemical and thermodynamic regime of the environment during the crystallization of magma, as well as the complexity of the anatectic and differentiation processes of it.

The content and quality of the accessories control the radioactivity of the granitoids. This was studied by V. Kátlovský, (1982). The research has shown that the granitoids similarly as the metamorphites in which they occur have a low radioactivity. The general uniformity of U and Th contents in different granitoid types is due to that the basic types have more zircon but with a lower U and Th content, and the leucocratic types have less zircon but richer in the radioactive component. The highest radioactivity has been established in rocks that have a higher content of monazite and autunite. The highest Th content is in granodiorites. Uranium correlates positively with SiO_2 and thus with acid rocks. Except for several siliceous types, particularly leucocratic vein types (aplitic and pegmatitic), only the Gemeride granitoids differ essentially from the Variscan granitoids in having almost 6 times higher uranium content.

The differences in the microelements between the Variscan and Gemeride granitoids led B. Cambel and J. Medveď (1981) to the opinion that the Tatro-Veporide granitoids constitute one formation and those of the Gemerides a separate one. In their paper the authors expressed the opinion that the Variscan palingenic granitoid magma had undergone differentiation during proceeding solidification, but that some features indicate that the leucocratic dyke differentiates (aplitoid and pegmatitoid, aplites and pegmatites) are unambiguously genetically associated with the differentiation of the granitoid magma of the Variscan plutonism and late orogenic intrusions. The distinctive features are e. g. high contents of Ba and Sr, low contents of alkalies including Rb, Cs and metallic components forming volatile halogenides (Mo, W, Sn), and low contents of light TR and volatiles. The Gemeride granitoids show an absolutely contrary geochemical picture; they may be either of post-orogenic (Permian) or Neoidic age and have inverse element contents: little Ba and Sr and much alkalies, TR, W, Sn, F and others.

Relevant results of petrogenetic studies of micas in granitoids have been achieved by I. Petrík (1980, 1982). They concern the thermodynamic conditions of their formation, the fugacity of oxygen in the environment of their origin, their chemistry, especially the Fe and Mg contents, which are linked with the total basicity of the rock. Biotites are thought to be products of magma crystallization and are not of relict origin, and the thermodynamic conditions of the formation of biotite in the granitoids have been determined. He presumed that biotite crystallized between 700—800 °C.

J. Macek (1975) using the two-feldspar method of T. F. W. Barth determined the temperature of K-feldspar formation in the granitoids at 500—600 °C or less. The crystallization of aplites and pegmatites took place between 600 and 700 °C. The investigations have revealed that the determination of the depth where the processes occurred is rather model, normative than actual, particularly the determination of intrusive processes in orogenic areas (B. Cambel — M. Dyda — J. Spišiak, 1981).

According to M. Dyda (1980, 1981), metamorphic processes (periplutonic contact metamorphism) in the area of the Malé Karpaty Mts. occurred under the conditions of the amphibolite facies between 500 and 600 °C, and the granitoids were thus intruded into a sufficiently heated horizon, in the proximity of the intrusions.

Of interest are the results of dating by means of uranium fission tracks in apatites; dating of the samples on the basis of zircon was performed in Slovakia for the first time. These studies (J. Kráľ, 1980, 1981; J. Burchart — J. Kráľ, 1982) lend support to the finding that the FT analysis allows to establish the succession of the uplifts of the Core mountains from the Late Cretaceous (the Veporides), through the Oligocene and Eocene (the Nízke Tatry Mts.) to the Miocene (external Core moutain ranges). It is of interest that uranium is equally distributed as in apatites so in metamorphic (gneisses) and granitoid rocks.

In the granitoids of the West Carpathians as in other world's areas there are numerous occurrences of polymetallic ores. The basic question in prospecting for ore resources is therefore the recognition of the relationship between the granitoids and their ore content. The results of the study of the West Carpathian granitoids have shown that the Variscan granite magma itself is in the Tatro-Veporides in a high degree sterile, but that the granite plutonism and intrusive processes of the granitoid magma cause activation and mobilization of the metallogenic elements from the sediments to suitable spaces where ore can be accumulated. Except for the young Gemeride granitoids and some occurrences of leucogranites in the Malé Karpaty Mts. (vein types) the granitoid bodies of the West Carpathians have a small own metallogenetic potential. This. assessment follows from the method of L. V. Tauson (1977) based on the content of F, Li+Rb and Sr+Ba (B. Cambel et al., 1981).

Evaluation of petrochemical classifications

The results of petrochemical classifications of the West Carpathian granitoid samples have already been published in the course of investigations (B. Cambel — L. Vilinovičová, 1981).

In the sense of this study the samples examined belong, after the Niggli's classification, to the calc-alkaline series, either to the leucogranitic or granitic to granodioritic and trondhjemitic magma. Of the 127 samples 55 % are of trondhjemite magma type, 21 % of leucogranite, 13 % granodiorite and 10 % of granite types of magma.

On the basis of Zavarickij's diagram, 26 % of the West Carpathian samples corresponds to the rocks of normal composition, which comply to the condition

$$CaO + Na_2O + K_2O > Al_2O_3 > Na_2O + K_2O.$$

74 % of rocks are of a peraluminous character, i. e. they are oversaturated with respect to aluminium; they comply with the condition

$$Al_2O_3 > CaO + Na_2O + K_2O.$$

The predominance of peraluminous granitoids is typical of the West Carpathians.

According to the CIPW classification the West Carpathian granitoids belong in class I (granites and leucogranites, granodiorites and leucogranodiorites). The tonalites and granodiorites are the representatives of class II. The synoptic table of the percentage distribution of the West Carpathian samples according to the CIPW classification presents the following results:

Symbol	Number of analyses	%	Symbol	Number of analyses	%
I.4.2.4.	32	29	I.3.2.3.	4	3
I.4.2.3.	23	20	I.3.2.4.	5	4
I.4.3.4.	8	7	I.3.1.3.	7	6
I.4.1.3.	11	9	I.3.1.4.	8	7
I.4.1.4.	6	5	II.4.2.4.	3	5

5 % of samples belong to other rock types of classes I and II.

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