SLOVAK GEOLOGICAL MAGAZINE

Geodynamic position of acid volcanism of the Gelnica Group (Early Paleozoic, Southern Gemericum; Inner Western Carpathians)

ANNA VOZÁROVÁ[1] & JÁN IVANIČKA[2]

[1]Department of Mineralogy and Petrology, Faculty of Natural Sciences, Comenius University, Mlynská dolina, 842 15 Bratislava
[2]Geological Survey of Slovak Republic, Mlynská dolina 1, Bratislava, Slovakia

Abstract: Rhyo-dacite volcanism of the Early Paleozoic of the Gelnica Group (Southern Gemericum) has been studied on the basis of macroelements and the distribution of microelements and REE. From the viewpoint of Sr, K, Rb,Th LREE and Zr, Y, HREE, Ta, Nb, Hf distribution, we suggest that the studied volcanics belong to the magmatic suite of normal calc-alkaline continental arcs associated with a subduction zone. The assumed mantle magmatic source was enriched in the subduction zone by crustal assimilation, connected with fractional crystallisation.

Key words: Western Carpathians, Southern Gemericum, Early Paleozoic, CAB rhyolite-dacite volcanism

Introduction

The Gelnica Group makes up the predominant part of the Alpine Southern Gemeric unit. It consists of a thick flysch sequence prevailing over rhyolite-dacite volcanoclastics. Flysch deposition is indicated by structural signs as well as vertical sequence of beds suggesting that clastic detritus was transported by turbidity currents and/or downslope gravity slides (SNOPKO 1967; SNOPKO & IVANIČKA 1978, IVANIČKA et al. 1989). The acid to intermediate volcanism was largely of extrusive character. Gravity slides and turbidity currents were the key phenomena controlling the redeposition of the volcanogenic material as indicated by preserved structures: graded bedding, horizontal planparallel lamination, swarms of black-shale flow rolls amidst slide bodies and on erosional contacts, alternating layers of graded-bedded volcanoclastic greywackes with non-volcanic sandstones etc.

The Gelnica Group turbidite sequence also contains small bodies of mafic and ultramafic rocks and/or related redeposited detritus. The chemical composition and mainly the distribution of incompatible elements made it possible to distinguish metabasalts of several geotectonic settings: N-MORB, E-MORB/OIT, CAB (IVAN 1994). This wide range of metabasalts and metaultramafic rocks, originated in a considerably different geotectonic setting, is associated with mass currents and gravity slides sediments, whose detritus came from a continental source combined with coeval rhyolite-dacite volcanism.

Detrital modes of the Gelnica Group metasandstones reflect mixed sources of clastic material:continental, volcanic arc and elevated subduction complex. Heavy-mineral spectra as well as zircon-crystal typology and mean I.T. and I.A. values (in the sense of PUPIN 1980, 1985) confirmed the provenance from a orogenic-type magmatism of crustal-mantle origin (VOZÁROVÁ 1993).

Lithofacial analysis allowed to divide the Gelnica Group into three formations overlying each other - the Vlachovo, Bystrý Potok and Drnava Frms. (SNOPKO & IVANIČKA in BAJANÍK et al. 1984). This concept was also backed by biostratigraphic data - sporomorphs and acritarch assemblages indicating a relatively wide range from the Upper Cambrian to Lower Devonian age (SNOPKOVÁ & SNOPKO 1979).

Gelnica Group sediments underwent low-pressure regional metamorphism corresponding to the lower part of greenschist facies (T = 350-370 °C; P = 250-270 MPa with geothermal gradient of some 40 °C/km; SASSI & VOZÁROVÁ 1987).

Geologic setting

Over one-third (37%) of the Gelnica Group rock are acid volcanic rocks, from which only 1% are effusive equivalents, the rest are volcanoclastic rocks. They belong to the rhyolite-dacite to andesite formation, which is sporadically complemented by basic basalt volcanism.

Generally, the Gelnica Group sequences sedimented in a deep-water sedimentation environment, where transport by turbidity currents and other types of gravitational currents and slides predominated. The volcanoclastic material, along with neo-volcanic detritus, was transported from the source area by submarine channels and further on distributed by submarine fans, as proved by the preservation of distal and proximal facies with typical Bouma sequence members. The chain of volcanic centres in the source area (magmatic arc; the whole sequence is interpreted as the filling of a fore-arc basin, VOZÁROVÁ 1993), provided above all a large amount of redeposited pyroclastic material of ash and sand grain-size, but redeposited ignimbrites have been described as well (CHMELÍK in CHMELÍK & SNOPKO 1979).

The Vlachovo Formation is the oldest known lithostratigraphic horizon of Gemericum. It occurs especially in the western part of the Gelnica Group, forming there a large sedimentary-volcanogenic complex composed of three independent mesorhythms. The lowest lithologic member of the Vlachovo Fm., not found on the surface (it has been proved by boreholes in the surroundings of Vlachovo) are dark hidden-bedded and laminated sericite-chlorite phyllites. Above them, there are lying rhythmically sedimented quartzose meta-graywackes with small lenses of fine-grained meta-conglomerates - the base of the second mesorhythm, which is completely developed in the Podsúľová area. The basal complex is gradually fining upwards due to the increase of the abundancy of pelitic component, replacing the psammitic one. The rocks have the character of fine-grained metasandstones, quartzite phyllites and various types of laminated phyllites. During the sedimentation of this rock complex, intensive acid volcanism took place, the products of which strongly disturb the overall symmetry of sedimentation. Above the volcanics, there is lying a thick complex of fine-laminated phyllites with layers of lydites and allodapic carbonates.

The Bystrý potok Formation is the middle stratigraphic horizon of the Gelnica Gr. lying as a normal stratigraphic overlier on the Vlachovo Fm. It occurs in a continuous west-east belt, 2-5 km wide. From the viewpoint of the distribution of rock complexes it may be said that volcanic members are predominant west of the line Zlatý stôl - Heckerová, while sediments occur in a greater extent in the east. The most typical profile where this formation is completely developed is found in the area between Starovodská dolina Valley and Bystrý potok. Volcanic activity disturbed the symmetry of flysch facies distribution in relation to the assumed axis of the sedimentation basin. In the east it is the Kojšová hoľa volcanic complex and in the west the volcanic complex of Turecká and Lužica, reaching with its eastern margin into the Bystrý potok Valley. The products of acid volcanism are substantially represented only by volcanoclastic rocks. The vertical and lateral relationship of metarhyolite tuffs and tuffites to sediments is usually gradual, frequently finger-like. It is manifested by gradual increase in the quantity of volcanic material in the sediments, by the forming of individual layers, from which, by a gradual increase of thickness, large, several hundreds of meters thick bodies formed, affecting considerably the composition of the sedimentary mesorhythm. Above the volcanoclastic bodies there is lying a thick complex of fine-laminated phyllites, which are the most frequent lithofacies in the Bystrý potok Valley. The uppermost sequences are composed mostly of hidden-bedded metapelites, in the black- schist facies, with which there are usually associated lenses and beds of lydites and crystalline limestones.

The Drnava Formation occurs in the normal overlier of the Bystrý potok Fm. and it represents the uppermost stratigraphic horizon of the Gelnica Gr. It covers a wide zone in the southern part of the area, where, in profiles at Drnava - Smolník - Medzev, we may observe its complete development. The lowermost parts of the Drnava Fm. are composed of metasediments of sandstone facies, fining upward. First manifestations of volcanism in the Drnava Fm. started relatively early, we may observed them already in the basal coarse-psamminitc sedimentation. It gradually increased in intensity, the maximum of occurrences being in distal turbidite facies. The predominant material are transported volcanoclastics, forming several hundred meter thick bodies. During its development, the volcanism acquired a more basic character, reflected in the increasingly basic trend and the formation of basalts, their tuffs and tuffites. In comparison with acid volcanics, the metabasics are however represented only in a minor quantity. After the termination of the volcanic activity, distal turbidity sedimentation continued, represented by various petrographic types of fine-laminated phyllites. At the southern margin of the Gelnica Gr., between Medzev and Jasov, there is a complex of greenish quartzites and quartz phyllites. REICHWALDER (1969) assigned them to the Gelnica Group, as the uppermost known horizon of the Drnava Frm., and, according to SNOPKO (1969), they represent the base of the sixth mesorhythm.

Characterisation of the volcanics

Petrography

Metamorphosed acid to intermediary volcanics and their volcanoclastics, described formerly generally as porphyroids, are represented mostly by vitreous varieties, in which phenocrysts constitute maximally 1/3 of the rock volume. Among the phenocrysts, predominant are magmatically corroded high-temperature quartz, acid plagioclases and K-feldspars, their crystal form being often of sanidine type. In varieties with an affinity to intermediary composition, there is preserved above all biotite in relics. Rarely there have been determined "phantoms" after amphiboles.

The texture of these rocks is oriented, with a recrystallised and oriented original vitreous matrix, and often with pressure-deformed phenocrysts. The metamorphic mineral assemblage corresponds to the low-temperature part of the greenschist facies. It is represented by quartz + muscovite + chlorite, accompanied by a small amount of albite or K-feldspar and biotite.

Chemical composition

Macroelements: The studied rocks have an acid to intermediate composition (Tab. 1), with a relatively wide range of SiO_2 content (from 54 to 83 wt. % SiO_2), while the greater part of the analysed samples is concentrated between rhyodacites/dacites (according to WINCHESTER and FLOYD 1976, Fig.1). Within the whole sample set, there may be observed a not very marked, but still increasing acid trend in volcanics of the Drnava Fm., in comparison with the other two formations. The K_2O contents vary in the majority of rhyodacite samples in the range 1.3 - 3.5 wt. %, corresponding, according to LE MAITRE (1989), to medium-potassium types (Fig. 2). Only a small part of samples with andesite composition with low K_2O contents (below 1 wt. %) was ranged with low-potassium types. A part of rocks with rhyodacite composition belong to high-potassium types, in the range of 3.5 - 5 wt. % K_2O. The K_2O/Na_2O ratio is very variable, while K_2O predominates in 76% of samples and, on the other hand, NA_2O in 24%. However, we must consider the fact that extreme alkali contents, especially Na_2O, may be the product of superimposed metasomatic processes, although we attempted to eliminate this fact when selecting the samples. Generally, the analysed sample set is poor in CaO (less than 1 wt. %) and has varying TiO_2 and P_2O_5.

Relatively higher Al_2O_3 contents allow to assign the whole set to the peraluminous group. This trend is well visible in the MANIAR and PICCOLLI diagram (1989;Fig. 3), the varieties with lower SiO_2 contents being strongly peraluminous, and, on the other hand, those with higher

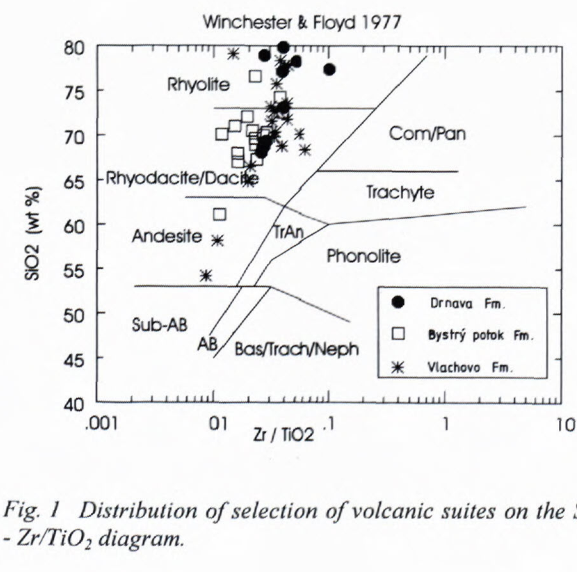

Fig. 1 Distribution of selection of volcanic suites on the SiO_2 - Zr/TiO_2 diagram.

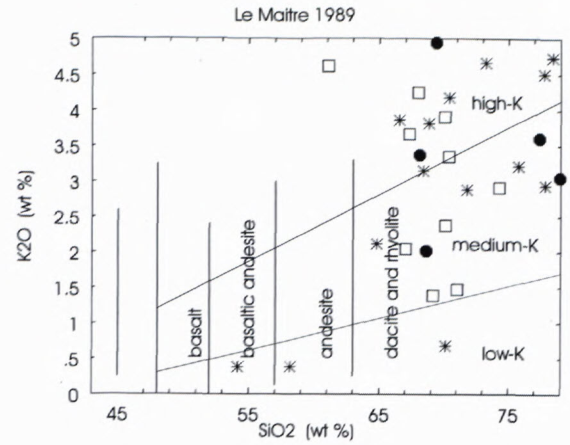

Fig. 2 Distribution of volcanic suites based on K_2O contents. Symbols as Fig. 1.

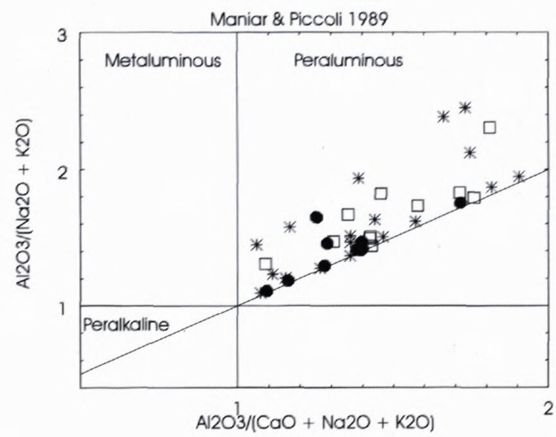

Fig. 3 Characteristics based on Shand's index. All volcanic rocks have a distinct peraluminous trend and orogenic affinity. Symbols as Fig. 1.

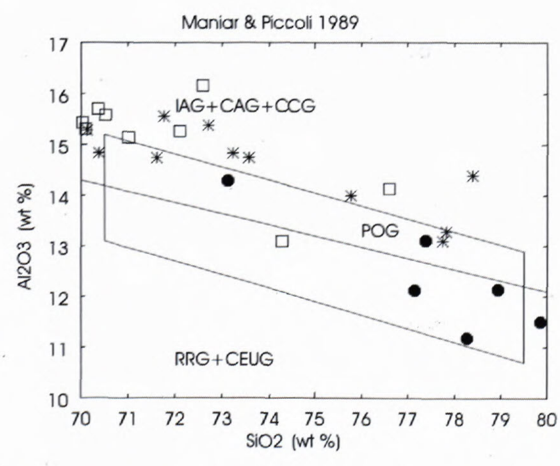

Fig. 4 Discrimination of the Gelnica Gr. volcanic rocks in Al_2O_3 versus SiO_2 diagram, which shows distinct orogenic trend for prevalent volcanics of the Vlachovo and Bystrý potok Fms. and a slight affinity of the Drnava Fm. volcanics to post-orogenic suites. Symbols as Fig. 1.

SiO_2 are approaching the boundary of metaluminous varieties. This trend is well displayed in the discrimination diagrams of MANIAR and PICCOLLI (1989), by the ratio SiO_2 : Al_2O_3 (Fig. 4), where a substantial part of rhyolites of the Vlachovo Fm. and Bystrý potok Fm. is inclined to orogenic types, and, on the other hand, rhoylites of the Drnava Fm. to post-orogenic ones. The trend is less marked in the FeO*/Fe*+MgO) ratio (Fig. 5), although the substantial part of samples falls within orogenic granites. A part of the samples from both of the above formations bears signs of relative Fe enrichment, which probably has not been caused by primary magma composition, but by later enrichment.

In the same way, normative composition in the QAP diagram (LE MAITRE 1989) confirmed that the analysed set belongs to the calc-alkaline magmatic series, of trondhjemite-granodiorite composition (Fig. 6). A part of the samples with higher alkalinity, equivalent to leucogranites, is probably genetically associated with hydrothermal-metasomatic processes, which could have been a primary phenomenon (crustal fusion in the source area) or derived from later superimposed processes. According to MANIAR & PICCOLLI (1989), this trend is typical for continental magmatic arcs. Samples extremely enriched in Si (field 1b) correspond to vitreous varieties and they have no indicative value for the geotectonic interpretation.

Microelements and REE: The contents of microelements in all three distinguished lithostratigraphic units display approximately the same regularities (Tab. 2).

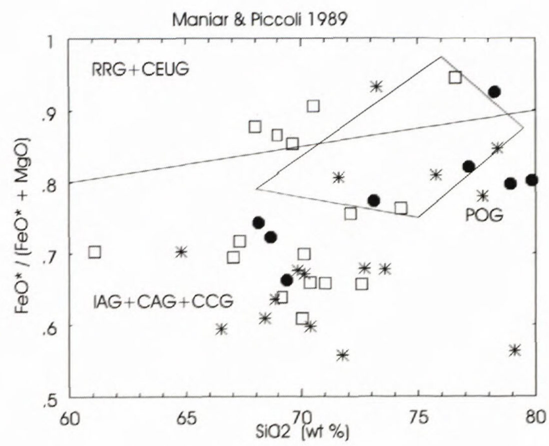

Fig. 5 Discrimination of the Gelnica Gr. volcanics in FeO /FeO* +MgO versus SiO_2 diagram. Distinct orogenic trend is attested. Symbols as Fig. 1.*

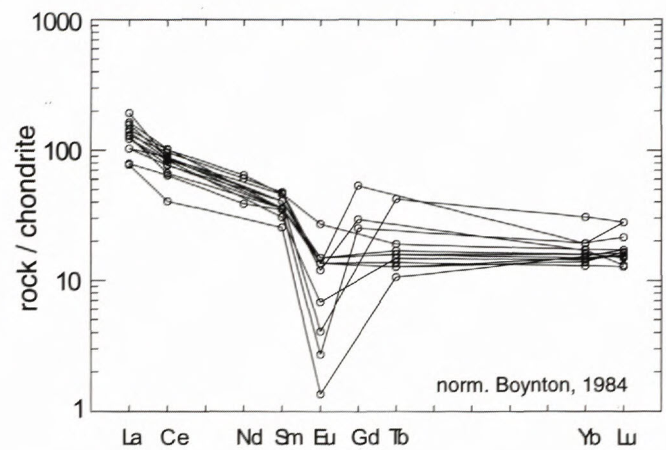

Fig. 7 Chondrite of normalized REE patterns for the Gelnica Gr. volcanites.

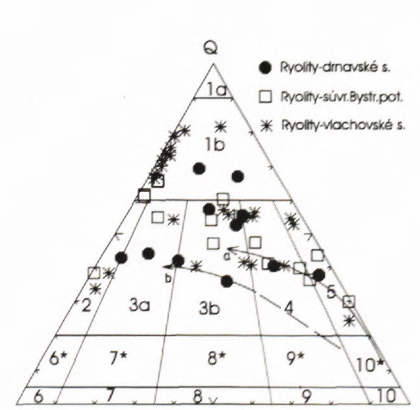

Fig. 6 QAP mesonormative diagram showing calc-alkaline-trondhjemitic (a) and calc-alkaline-granodioritic (b) (medium K) trend for prevalent part of volcanics. Arrows according to LAMEYRE & Bowden (1982). Symbols as Fig. 1.

Above all, there are lower Rb, Sr, Pb, Zr, Nb and Y contents, and, on the other hand, higher contents of Sc, V, Cr, Ni, Zn. The relationships of Ba, Rb and Sr are strongly dependent on the K-substitution, above all in feldspars, and on fractional differentiation. The increased Ba content in comparison with Rb is associated with the presence of higher-temperature potassium feldspars, where Ba is preferentially substituted by K. A characteristic feature are also only medium contents of Y, Nb, Hf and Th.

LREE enrichment and a flat HREE part of the curve is typical for the distribution curves of rare earth elements from the Drnava Fm. (chondrite normalised - BOYNTON 1984). A characteristic feature, however, is the marked negative Eu-anomaly, which, along with the relatively marked LREE/HREE ratio, indicates a REE distribution strongly controlled by fractional crystallisation of plagioclases (Fig. 7). REE totals are low (average contents: D. Fm. - 108.7 ppm; By. Fm. - 115.4 ppm; V. Fm. - 101.5 ppm). The low Rb/Zr to Nb and Y ratios (in the range of

TAB. 1 Average chemical composition (weight. %)

DRNAVA Fm.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	CO_2	S	F
X	**74.97**	**0.30**	**12.47**	**1.29**	**1.02**	**0.02**	**0.85**	**0.23**	**2.40**	**4.33**	**0.11**	**1.06**	-	-
Sx	4.85	0.27	1.94	0.41	0.95	0.01	0.68	0.28	1.36	2.27	0.08	0.34	-	-
Number of samples	10	10	10	10	10	10	10	10	10	10	10	6	-	-

BYSTRÝ POTOK Fm.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	CO_2	S	F
X	**68.83**	**0.61**	**14.86**	**2.26**	**1.89**	**0.07**	**1.45**	**0.56**	**2.70**	**3.86**	**0.17**	**0.33**	**0.010**	**0.04**
Sx	2.85	0.14	0.78	1.88	1.02	0.07	0.76	0.48	2.10	2.22	0.05	0.25	0.008	0.01
Number of samples	13	13	13	13	13	13	13	13	13	13	13	7	7	7

VLACHOVO Fm.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	CO_2	S	F
X	**74.56**	**0.28**	**12.85**	**1.82**	**0.95**	**0.05**	**1.17**	**0.33**	**1.78**	**3.61**	**0.08**	**0.34**	**0.03**	**0.04**
Sx	5.87	0.18	2.47	1.30	1.24	0.04	1.18	0.45	1.91	2.13	0.07	0.48	0.04	0.01
Number of samples	26	26	26	26	26	26	26	26	26	26	26	18	17	16

TAB. 2 Average contents of microelements (in ppm)

DRNAVA Fm.	*B*	*Be*	*Li*	*Rb*	*Sr*	*Ba*	*Sc*	*Yr*	*Y*	*Nb*	*Pb*	*V*	*Cr*	*Ni*	*Co*	*Zn*	*Ga*	*Th*	*Hf*	*Ta*	*La*	*Ce*	*Sm*	*Eu*	*Tb*	*Yb*	*Lu*
X	**24.0**	**3.3**	**20.0**	**120.0**	**29.0**	**594.0**	**5.0**	**132.0**	**39.0**	**14.0**	**5.0**	**35.0**	**30.0**	**13.0**	**6.0**	**35.0**	**16.0**	**16.0**	**4.5**	**0.8**	**36.0**	**60.0**	**7.0**	**0.7**	**0.9**	**3.7**	**0.6**
Sx	17.0	2.2	12.0	32.0	27.0	336.0	5.0	71.0	18.0	4.0	3.0	32.0	23.0	13.0	7.0	16.0	7.0	5.0	1.9	0.6	11.0	13.0	1.0	0.7	0.6	1.2	0.2
Number of samples	13	13	9	9	12	12	4	13	13	6	12	13	13	13	13	9	13	6	6	6	10	10	7	7	6	7	7

BYSTRÝ POTOK Fm.	*B*	*Be*	*Li*	*Rb*	*Sr*	*Ba*	*Sc*	*Yr*	*Y*	*Nb*	*Pb*	*V*	*Cr*	*Ni*	*Co*	*Zn*	*Ga*	*Th*	*Hf*	*Ta*	*La*	*Ce*	*Sm*	*Eu*	*Tb*	*Yb*	*Lu*
X	**24.0**	**2.5**	**27.0**	**144.0**	**54.0**	**676.0**	**20.0**	**64.0**	**26.0**	**13.0**	**11.0**	**56.0**	**46.0**	**17.0**	**6.0**	**64.0**	**15.0**	**13.0**	**6.0**	**0.5**	**38.0**	**65.0**	**7.0**	**1.1**	**0.7**	**3.3**	**0.5**
Sx	21.0	0.4	9.0	62.0	40.0	234.0	-	42.0	8.0	-	13.0	19.0	23.0	7.0	4.0	42.0	3.0	-	-	-	12.0	15.0	-	-	-	-	-
Number of samples	14	17	16	16	17	17	1	16	17	1	17	17	17	17	17	16	17	1	1	1	-	16	16	1	1	1	1

VLACHOVO Fm.	*B*	*Be*	*Li*	*Rb*	*Sr*	*Ba*	*Sc*	*Yr*	*Y*	*Nb*	*Pb*	*V*	*Cr*	*Ni*	*Co*	*Zn*	*Ga*	*Th*	*Hf*	*Ta*	*La*	*Ce*	*Sm*	*Eu*	*Tb*	*Yb*	*Lu*
X	**40.0**	**2.4**	**42.0**	**114.0**	**40.0**	**530.0**	**12.0**	**113.0**	**28.0**	**13.0**	**4.0**	**49.0**	**21.0**	**8.0**	**5.0**	**44.0**	**15.0**	**14.0**	**8.0**	**0.7**	**32.0**	**56.0**	**8.0**	**1.0**	**0.5**	**3.4**	**0.6**
Sx	33.0	1.0	50.0	55.0	34.0	580.0	8.0	62.0	11.0	0.6	7.0	48.0	20.0	5.0	8.0	30.0	5.0	1.0	3.0	0.3	10.0	20.0	1.0	0.1	0.3	0.4	0.2
Number of samples	27	32	26	26	32	32	6	32	32	3	32	32	31	31	32	25	32	3	3	3	28	28	5	5	3	5	5

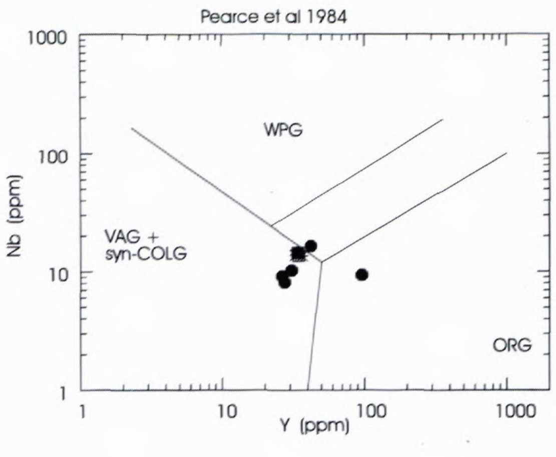

Fig. 8 Nb versus Y + Nb diagram confirms VAG trend. Symbols as Fig. 1.

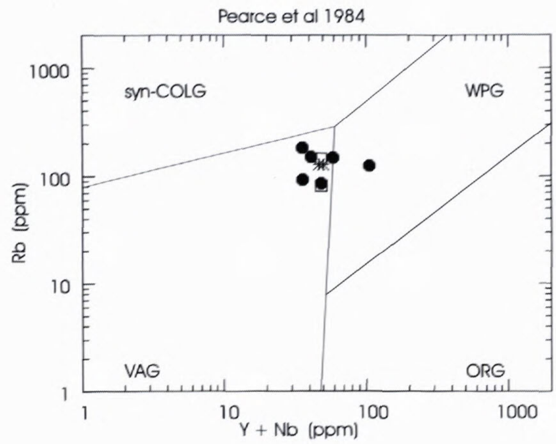

Fig. 9 Rb versus Y+Nb diagram confirms VAG trend. Symbols as Fig. 1.

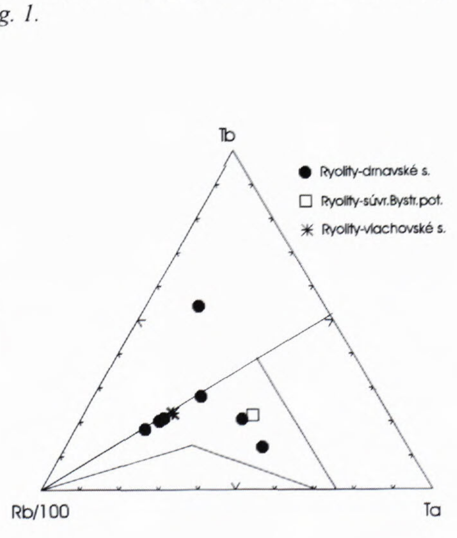

Fig. 10 Tb:Rb/100:Ta geotectonic discrimination diagram (after THIÉBLEMONT & CABANIS 1990) pointing at syn-subduction setting. Symbols as Fig. 1.

0.06-0.2, and 0.02-0.09, respectively) indicate an affinity of the studied volcanics to normal continental arcs (according to BROWN et al. 1984). A similar geotectonic interpretation may be derived from the ratios Nb : Y, Rb : (Y+Nb) and Tb : Rb/100 Ta (Figs. 8, 9, 10).

LIL, LREE and HFS contents normalised according to PEARCE et al. (1984) indicate selective enrichment in K, Rb, Th and marked depletion in Sr in all studied samples. Relative Ta, Sm contents are equal to approximately 1, or they are only slightly depleted. Nb and Ce display only slight enrichment (1.6 - 1.8). Marked depletion has been determined at Hf, Zr, Y, Yb. These rocks show a low value of the HFS/LIL element ration, especially of (Ta, Nb)/(K, Rb,La).

Conclusion

1. Geochemical variations indicate an affinity of the Gelnica Group acid volcanism to normal calc-alkaline continental arc, while, in the whole set there appear varieties inclined to the calc-alkaline, meta- to peraluminous magmatic suites.
2. Contents of lithophilous elements, as well as of LREE, are selectively enriched and HREE, Zr, Ta, Nb, Hf, Y are average or depleted. Low values of the ratios of Rb/Zr to Ta, Nb and Y are characteristic for normal continental arcs, associated with a subduction zone. The mantle magmatic source was enriched in the subduction zone by crustal assimilation connected with fractional differentiation.
3. REE distribution curves, with a trend of LREE enrichment, the negative Eu anomaly due to fractional differentiation and the flat course of the HREE part of the curve indicate rhyo-dacites associated with an active continental margin.

References

BAJANÍK, Š., IVANIČKA, J., MELLO, J., PRISTAŠ, J., REICHWALDER, P., VOZÁR, J. & VOZÁROVÁ, A. 1984: Geological map of the Slovenské rudohorie Mts., 1: 50.000. D. Štúr Inst. Geol., Bratislava.

BROWN, G. C., THORPE, R. S. & WEBB, P. C. 1984: The geochemical characteristics of granitoids in contrasting arcs and comments on magma sources. J. Geol. Soc. London, vol. 141, 3, London, 413-426.

BOYNTON, W. V. 1984: Cosmochemistry of the rare earth elements: meteorite studies. In: Rare earth elements geochemistry. Ed. HENDERSON, P., Development in geochemistry, 2, Elsevier.

CHMELÍK, L. & SNOPKO, L. 1979: Prehodnotenie chemizmu vulkanogénnych a sedimentárnych hornín gelnickej série. Manuskript, Archív D. Š. Inst. Geol., Bratislava.

IVAN, P. 1994: Early Paleozoic of the Gemeric Unit (Inner Western Carpathians): Geodynamic Setting as inferred from Metabasalt Geochemistry data. Mitt. Österr. Geol. Ges., 86, Wien, 23-31.

IVANIČKA, J., SNOPKO, L., SNOPKOVÁ, P. & VOZÁROVÁ, A. 1989: Gelnica Group - Lower Unit of Spišsko-gemerské rudohorie Mts. (West Carpathians), Early Paleozoic. Geol. Zborn. Geol. carpath., 40, 4, Bratislava, 483-501.

LAMEYRE, J. & BOWDEN, P. 1982: Plutonic rock types series: discrimination of various granitoids series and related rocks. Journ. Volc. Geoth. Res., 14, 1-2, Amsterdam, 169-186.

LE MAITRE, R.W. Ed. 1989: A Classification of Igneous Rocks and Glossary of Terms (recommend. of IUGC). Blackwell, 1-193.

MANIAR, P. D. & PICCOLI, P. M. 1989: Tectonic discrimination of granitoids. Geol. Soc. Amer. Bull., 101, 635-643.

PEARCE, J. A., HARRIS, N. B. & TINDLE, A. G. 1984: Trace elements discrimination for the tectonic interpretation of granitic rocks. J. Petrol., 25, 4, 956-983.

PUPIN, J. P. 1980: Zircon and granite petrology. Contr. Mineral. Petrology, 73, Berlin - Heidelberg-New York, 207-220.

PUPIN, J. P. 1985: Magmatic zoning of Hercynian Granitoids in France based on Zircon Typology. Schweiz. Mineral. Petrogr. Mitt., 65, 29-56.

REICHWALDER, P. 1969: Geological structure of the Paleozoic of the Spišsko-gemerské rudohorie Mts. - SE part. Manuscript, Archives GS SR (in Slovak).

SASSI, F. P. & VOZÁROVÁ, A. 1987: The pressure character of the Hercynian metamorphism in the Gemericum (West Carpathians, Czechoslovakia). Rend. Soc. Ital. Min. Petr., 42, 73-81.

SNOPKO, L. 1967: Lithostratigraphy of the Gelnica Serie. Záp. Karpaty, Sér. Geol. 7, D.Š. Inst. Geol., Bratislava, 7, 103-152 (in Slovak).

SNOPKO, L. 1969: O novom rudonosnom pruhu v okolí Vlachova. Manuskript, Archív D.Š. Inst. Geol., Bratislava.

SNOPKO, L. & IVANIČKA, J. 1978: Considerations on the paleogeography in the Early Paleozoic of the Spišsko-gemerské rudohorie Mts. In: Paleogeogr. Evol. W. Carpathians. Ed. J. VOZÁR, D. Š. Inst. geol., Bratislava, 269-280 (in Slovak).

SNOPKOVÁ, P. & SNOPKO, L. 1979: Biostratigraphy of Gelnica Group (Spišsko-gemerské rudohorie Mts.): based on palynology. Záp. Karpaty, Sér. Geol., 5, D.Š. Inst. Geol., Bratislava, 57-102 (in Slovak).

THÉBLEMONT, D. & CABANIS, B. 1990: Utilization d' un diagramme (Rb/100)-Tb-Ta pour la discrimination geochémique et l' etude pétrogenetique des roches magmatiques acides. Bull. Soc. Géol. France, (8), VI, 1, 23-25.

VOZÁROVÁ, A. 1993a: Provenance of Gelnica Group metasandstones and relationship to paleotectonics of the basin of deposition. Záp. Karpaty, sér. miner., petrogr., geochém., metalogen., 16, D. Š. Inst. Geol., Bratislava, 7-54 (in Slovak, Engl. res.).

WINCHESTER, J. A. & FLOYD, P. A. 1977: Geochemical discrimination of different magma series and their differentiation products using immobile elements. Chem. Geol., vol. 20, 325-343. rocks.