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ORIGIN OF AMPHIBOLE ROCK ENCLAVES IN THE BRYJARKA ANDESITES, PIENINY MOUNTAINS, WESTERN CARPATHIANS

Abstract: The amphibole rock enclaves abundantly occur in the porphyritic amphibole andesites on Bryjarka Mt in the Pieniny Mountains. Chemical composition of the enclaves, of andesite and the matrix glass may correspond to a calc-alkaline differentiation trend of primary magma, what together with mesocumulate texture of majority of enclaves, similarities in mineral chemistry between calcic amphiboles of enclaves and andesite as well as REE geochemistry may support the hypothesis that the amphibole rock enclaves of the Bryjarka andesite are cognate and reflect magma crystallization prior to intrusion.

Keywords: amphibole andesites, amphibole cognate enclaves, amphibole megacrysts

Andesites in Pieniny Mountains have been recognized and being studied for almost two centuries. These rocks belonging to the Neogene outer magmatic arc of Western Carpathians (Seghedi et al. 2004) intruded the flysch rocks of the Magura nappe and the Jurassic to Cretaceous deposits of the northernmost part of the Pieniny Klippen Belt, in late Middle Miocene (Birkenmajer 1957, 2003; cf Fig. 1). Andesites form numerous but relatively small hypabyssal bodies – dikes and sills. The petrology of the rocks and their enclaves has been studied by Małkowski (1921, 1958) and Kardymowicz (1957). There were observed two phases of andesite intrusion that cannot be separated in time by means of K-Ar dating (Birkenmajer, Pécskay 1999, 2000). The intrusions caused contact metamorphic and hydrothermal alterations of the surrounding sedimentary rocks (Michalik, Słaby 2003).

The samples of **andesite** and **amphibole rock enclaves** for the present study were collected in an old quarry located within 150 m thick subvertical dike of the first phase intrusion, on the slope of Bryjarka Mt above Szczawnica resort (Fig. 1). The studied rocks are porhyritic amphibole andesites consisting of big (up to 5 mm), often oscillatory zoned plates of euhedral plagioclase prevailing over a little smaller green amphibole phenocrysts set in a matrix composed of partly recrystallized volcanic glass as well as of microlitic or fine grained plagioclase, amphibole, quartz, calcite, magnetite, apatite and chlorite. In the studied andesite there occur also up to over 3 cm long, dark brown amphibole megacrysts. The rock is rich in dark amphibole enclaves, often showing mesocumulate texture. Chemical

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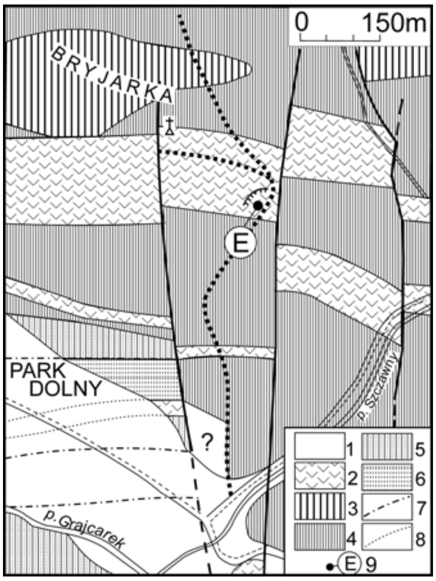

Fig. 1. Geological map of Mountain Bryjarka at Szczawnica, according to Birkenmajer (1999), modified.
1- Quaternary cover; 2- 1 st phase andesites; Magura flysch nappe: 3- Magura Fm (sandstone), 4- Szczawnica Fm; Grajcarek Unit of Pieniny Klippen Belt: 5- Jarmuta Fm.- Maastrichtian, 6- Campanian – Jurassic deposits; 7- longitudinal faults/thrusts; 8- transversal faults; 9- location of sampling of black enclaves and host andesite.

Table 1. Chemical composition of Bryjarka andesite, its glass and amphibole rock enclave (wt. %) together with CIPW norms.

	andesite		encl.	glass
	Br 1	Br *	Br 2	Gl-A
SiO_2	60.48	60.28	46.20	66.22
TiO_2	0.47	0.64	1.23	0.25
Al_2O_3	18.08	18.13	14.34	18.63
Fe_2O_3	2.29	2.22	2.66	
FeO	2.83	2.74	7.29	0.62
MnO	0.14	0.14	0.18	0.39
MgO	1.57	1.89	12.60	0.05
CaO	6.73	6.68	12.74	0.40
Na_2O	4.10	4.46	1.82	4.74
K_2O	1.49	1.67	0.99	9.27
P_2O_5	0.25	0.32	0.04	
LOI	1.80	1.00	0.60	
Total	100.23	100.17	100.69	100.57
CIPW norms				
Qtz	14.97	12.13		1.60
Or	8.95	9.96	5.85	54.54
An	26.91	24.68	27.97	1.97
Ab	35.20	38.01	8.43	39.84
Ne			3.76	
Di	4.53	5.54	27.93	
Hy	4.60	4.49		1.56
Ol			19.79	
Mt	3.37	3.25	3.85	
Ilm	0.91	1.23	2.33	0.47
Ap	0.55	0.70	0.09	
mg	0.50	0.55	0.76	0.10

*) according to Małkowski (1958).

composition of a representative enclave (Br2 in Tab. 1) corresponds to alkaline basalt, what together with andesite and a latitic matrix glass (Gl-A) may represent a calc-alkaline differentiation trend of primary magma, with significant decrease of *mg* number (from 0.76 to 0.10) The composition of **plagioclase** phenocrysts with oscillatory zoning ranges from An_{38} to An_{62}, whereas matrix plagioclase is Ca-poorer (An_{33-45}). **Amphibole** megacrysts are homogeneous pargasites showing only rapid decrease of *mg* toward hastingsitic edges (Fig. 2, Tab. 2). Coarse amphibole phenocrysts are distinctly zoned having magnesiohornblende, magnesiohastingsite or pargasite composition in core and tschermakite or magnesiohastingsite chemistry in rim, they show moreover significant rimward decrease of *mg* number. Fine matrix amphiboles are magnesiohastingsites or ferropargasites with relatively low *mg*. Large amphiboles of the studied enclaves are distinctly zoned and change from magnesiohastingsite in core to tschermakite or pargasite in rim, showing gradual and significant *mg* decrease rimwards. Coarse amphiboles in enclaves are also zoned and change from magnesiohornblende or magnesiohastinsite in core to

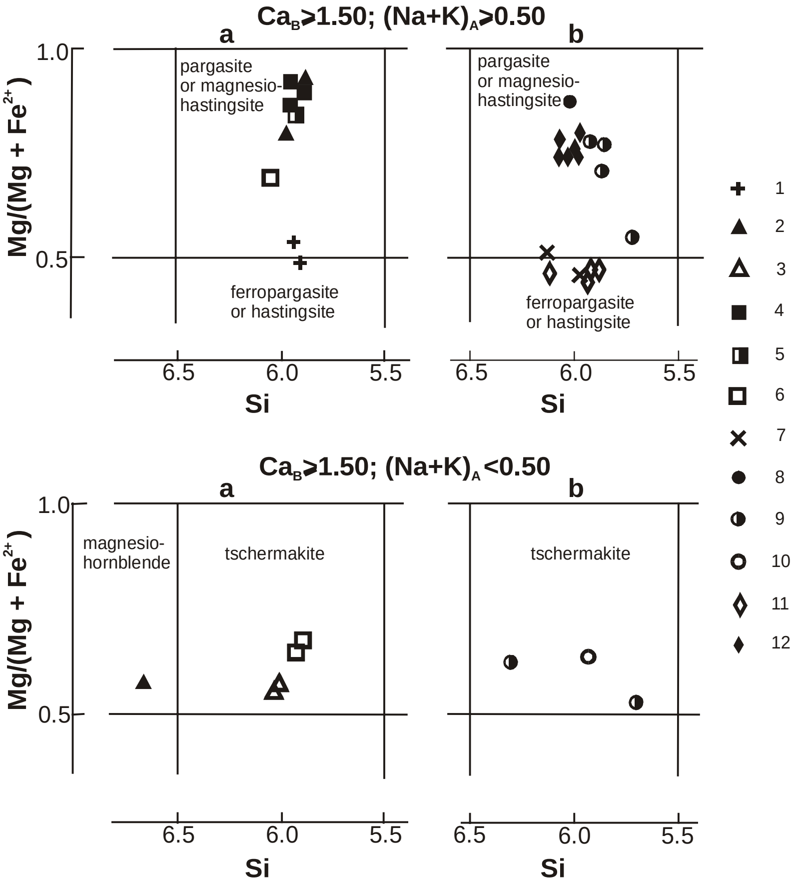

Fig. 2. Calcic amphiboles from amphibole rock enclaves (**a**) and from the host Bryjarka andesite (**b**). **a**: 1- cores of fine grains; coarse grains: 2- cores, 3- rims; large grains: 4- cores, 5- intermediate parts, 6- rims; **b**: 7- fine phenocrysts; coarse phenocrysts: 8- cores, 9- intermediate parts, 10- rims; megacryst: 11- rim, 12- core and intermediate part.

tschermakite in rim, what is accompanied by significant rimward decrease of *mg* number, while coexisting fine grained amphiboles are either magnesiohastingsites or ferropargasites. Thus there were not observed significant differences in composition and the type of zoning between calcic amphiboles of enclaves and their host andesites. Moreover, in the amphibole-rich enclaves there can be rarely found fine grains of diopside ($Wo_{52}En_{36}Fs_{12}$) as well as of plagioclase.

Chemical composition of the amphibole enclaves and their host andesites as well as the similarities between calcic amphiboles occurring in these rocks do not support the hypothesis of Kardymowicz (1957) that the amphibole-rich enclaves found in the Pieniny Mts andesites are products of metasomatism of carbonate rocks.

The analyzed amphibole-rich enclave differs clearly from the host Bryjarka andesite as far as both content and fractionation of **REE** are concerned (Fig. 3). On one hand, the Bryjarka andesite is distinctly enriched in LREE showing the range of enrichment from La = 126 ∗ (chondritic abundance) to Sm = 28 ∗ (chondritic

Table 2. Representative microprobe analyses of amphiboles from the amphibole rock enclaves and from the host Bryjarka andesite.

	enclaves					andesite				
	fine	coarse		large		phenocrysts			megacryst	
						fine	coarse			
	6 c	8.1 c	8.2 r	10.1 c	10.3 r	1 c	3.1 c	3.5 r	4.1 c	4.3 r
SiO_2	39.20	40.98	40.16	41.22	39.72	40.08	41.39	39.85	41.38	38.41
TiO_2	1.80	1.51	1.24	1.51	1.46	1.36	1.39	2.15	1.67	2.25
Al_2O_3	14.18	15.82	14.67	15.73	15.49	12.12	13.78	15.08	14.21	12.72
Cr_2O_3	0.03	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.12	0.08
Fe_2O_3	4.80	6.82	7.93	6.87	7.87	6.45	8.83	7.16	2.92	6.39
FeO	13.94	2.39	11.32	2.26	9.22	14.25	3.47	9.85	7.22	14.97
MnO	0.35	0.14	0.36	0.09	0.52	0.62	0.90	0.26	0.02	0.44
MgO	8.75	14.95	8.35	15.05	9.46	8.39	13.66	9.60	13.54	7.78
CaO	11.53	11.76	10.56	11.75	11.88	11.60	11.12	10.81	13.60	11.91
Na_2O	2.55	2.27	1.94	2.20	2.16	2.05	2.64	2.22	1.88	1.75
K_2O	0.82	1.04	1.05	1.02	0.73	0.73	0.60	0.69	1.07	0.74
Total	97.95	97.68	97.58	97.70	97.42	97.76	97.78	97.67	97.63	97.44
cations – (Ca+Na+K) = 13										
Si	5.932	5.900	6.031	5.924	5.918	6.110	6.021	5.928	6.056	5.913
^{IV}Al	2.068	2.100	1.969	2.076	2.082	1.890	1.979	2.072	1.944	2.087
^{Vi}Al	0.462	0.584	0.627	0.589	0.638	0.288	0.384	0.572	0.507	0.221
Ti	0.205	0.164	0.141	0.163	0.164	0.156	0.152	0.240	0.184	0.261
Cr	0.004	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.014	0.010
Fe^{3+}	0.547	0.739	0.896	0.743	0.883	0.740	0.967	0.801	0.322	0.740
Mn	0.045	0.017	0.046	0.011	0.066	0.080	0.111	0.032	0.002	0.058
Mg	1.974	3.209	1.869	3.223	2.101	1.907	2.963	2.130	2.954	1.785
Fe^{2+}	1.764	0.287	1.421	0.272	1.149	1.817	0.422	1.225	0.884	1.927
Ca	1.870	1.813	1.700	1.809	1.736	1.895	1.734	1.723	2.133	1.965
Na	0.130	0.187	0.300	0.191	0.264	0.105	0.266	0.277	0.000	0.035
Na	0.618	0.447	0.265	0.423	0.359	0.501	0.478	0.365	0.533	0.486
K	0.158	0.190	0.201	0.188	0.138	0.142	0.111	0.131	0.200	0.145
mg	0.528	0.918	0.568	0.922	0.646	0.512	0.875	0.635	0.770	0.481

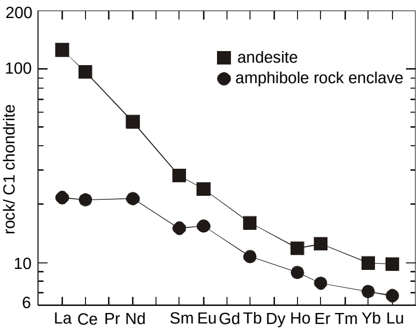

Fig. 3. REE patterns for the amphibole rock enclave and for the host Bryjarka andesite.

abundance), and relatively high fractionation of the whole REE group (La_N/Lu_N = 12.9). This rock also shows much higher degree of fractionation of LREE (La_N/Sm_N = 4.5) than of HREE (Tb_N/Lu_N = 1.6). On the other hand the enclave is much poorer in REE that are fractionated in a smaller degree (La_N/Lu_N = 3.2) than the host andesite. The enclave has weakly fractionated LREE (La_N/Sm_N = 1.4), while a little stronger fractionation of HREE is similar to that of host andesite (Tb_N/Lu_N = 1.6).

Moreover, there can be observed strong similarity in enclave–host rock relationships of HREE patterns between the studied pair and the pair consisting of cognate black clinopyroxenite enclave and of the host Księginki nephelinite (Bakun-Czubarow, Białowolska 2003).

On the basis of texture, whole rock and mineral chemistry as well as REE geochemistry the hypothesis can be put forward that the studied **amphibole rock enclaves** found in the Bryjarka andesite **are cognate** and reflect the magma crystallization prior to intrusion. However, the hypothesis that some enclaves may represent a hypabyssal country rock or a fragment of a dike with alkali basalt chemistry cannot be excluded.

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