GEOLOGICA CARPATHICA, FEBRUARY 2005, 56, 1, 3–16

Metamorphic petrology of metabasites from the Branisko and Čierna Hora Mountains (Western Carpathians, Slovakia)

SHAH WALI FARYAD[1], PETER IVAN[2] and STANISLAV JACKO[3]

[1]Institute of Petrology and Structural Geology, Charles University, Albertov 2, 128 43 Prague, Czech Republic; faryad@natur.cuni.cz
[2]Department of Geochemistry, Comenius University, Mlynská dolina G, 842 15 Bratislava, Slovak Republic; ivan@fns.uniba.sk
[3]Department of Geology and Mineralogy, Technical University, Letná 9, 042 00 Košice, Slovak Republic; stanislav.jacko@tuke.sk

(Manuscript received July 4, 2003; accepted in revised form March 16, 2004)

Abstract: Mineral assemblages in metabasites were used to estimate *P-T* conditions of pre-Alpine metamorphism in the Branisko and Čierna Hora Mountains which represent the easternmost exposure of the Tatric and Veporic Units. Garnet-pyroxene-bearing metabasites of the Branisko Mountains indicate high-grade metamorphism close to the boundary of amphibolite and eclogite facies conditions. They contain Ca- and Mg-rich garnet (Grs_{20-32}, Py_{18-20}), diopside and plagioclase (An_{10-40}). Garnet contains inclusions of clinopyroxene, plagioclase, ilmenite and K-feldspar. *P-T* conditions of 732±24 °C and 1.26±0.12 GPa were estimated using various exchange thermometers and equilibrium reactions. Pyroxene forms symplectite with plagioclase and amphibole in the matrix. The high-grade metamorphism was followed by amphibolite facies metamorphism at 650 °C and 0.7–0.8 GPa. Lower temperature and pressure of 610±20 °C and 0.9±0.1 GPa for Variscan metamorphism were calculated from garnet amphibolites in the neighbouring Čierna Hora Mountains. Metamorphic conditions for Alpine metamorphism in the Čierna Hora Mountains were obtained using the mineral assemblages in Permian diorite of the Choč Nappe. They contain prehnite, pumpellyite, epidote, chlorite, albite and white mica, and yield temperature and pressure of 250±25 °C and 0.3±0.02 GPa.

Key words: Variscan, Alpine metamorphism, Western Carpathians, Branisko, Čierna Hora.

Introduction

The Western Carpathian basement units were traditionally assumed to have experienced pre-Alpine medium-pressure metamorphism in greenschist to amphibolite facies conditions (Kamenický 1968; Krist et al. 1992). Because of strong Variscan retrogression and Alpine overprint, peak PT mineral assemblages are preserved only locally. The best lithologies, which may preserve prograde or peak pressure and temperature minerals, are metabasites, mainly those of the leptynite-amphibolite complex (LAC) as defined by Hovorka et al. (1993). This complex is characterized by banded amphibolite (leucocratic bands of leptynite composition) with enclaves of metaperidotite and garnet (± pyroxene) amphibolites, which are believed to represent amphibolized eclogites (Hovorka et al. 1992). Possible high-grade amphibolite facies metamorphism in the Branisko Mountains was considered by Vozárová (1993) and Faryad (1996). On the basis of Mg- and Ca-rich cores in some garnets and associated amphiboles they assumed a maximum pressure of 1.0 GPa at 700 °C. Garnet of similar composition was reported by Méres et al. (2000) from retrogressed garnet-pyroxene-bearing metabasites in this unit. Moreover, these authors found serpentinized peridotite, which is an integral part of the LAC, which presumably occurs in all basement units of the Western Carpathians. The LAC in the neighbouring Čierna Hora Mountains has not been examined yet, although some lithological features such as the occurrence of serpentinized ultramafic rocks associated with amphibolite (Jacko 1985), garnet or banded amphibolites (Fabian & Kamenický 1985) could be indicative of this complex. According to Korikovsky et al. (1990) and Jacko et al. (1990), Variscan metamorphism in the Čierna Hora Mountains reached temperatures of 620–625 °C at relatively low pressure of 0.4–0.45 GPa. However, preliminary results of thermobarometric calculation (Jacko & Faryad 1998) indicated relatively higher pressure of 0.8–1.0 GPa for the Čierna Hora Mountains.

In this work, we present results of petrologic study of metabasites from both Branisko and Čierna Hora Mountains. Geochemical constraints, of the LAC and *P-T* conditions of pre-Alpine metamorphism in the Branisko and Čierna Hora Mountains are the main subject discussed here. The degree of Alpine metamorphism in the Čierna Hora is estimated using mineral assemblages in metadiorite in upper Paleozoic formations of the Choč Nappe, which form klippes on Mesozoic sequences or overlie the basement units.

Geological setting

When considering the Alpine structure of the Western Carpathians, three northward thrust sheets or tectonic units (Tatric, Veporic and Gemeric) are distinguished (Fig. 1). The pre-Alpine basement of the Tatric–Veporic Units comprise two (Putiš 1992) or three (Bezák et al. 1997) Variscan southvergent nappes: the lower nappe containing low-grade rocks and the upper nappe consisting of high-grade rocks (gneisses and amphibolites). The leptynite-amphibolite complex (LAC, Hovorka et al. l.c.) discussed here is supposed to be a part of the

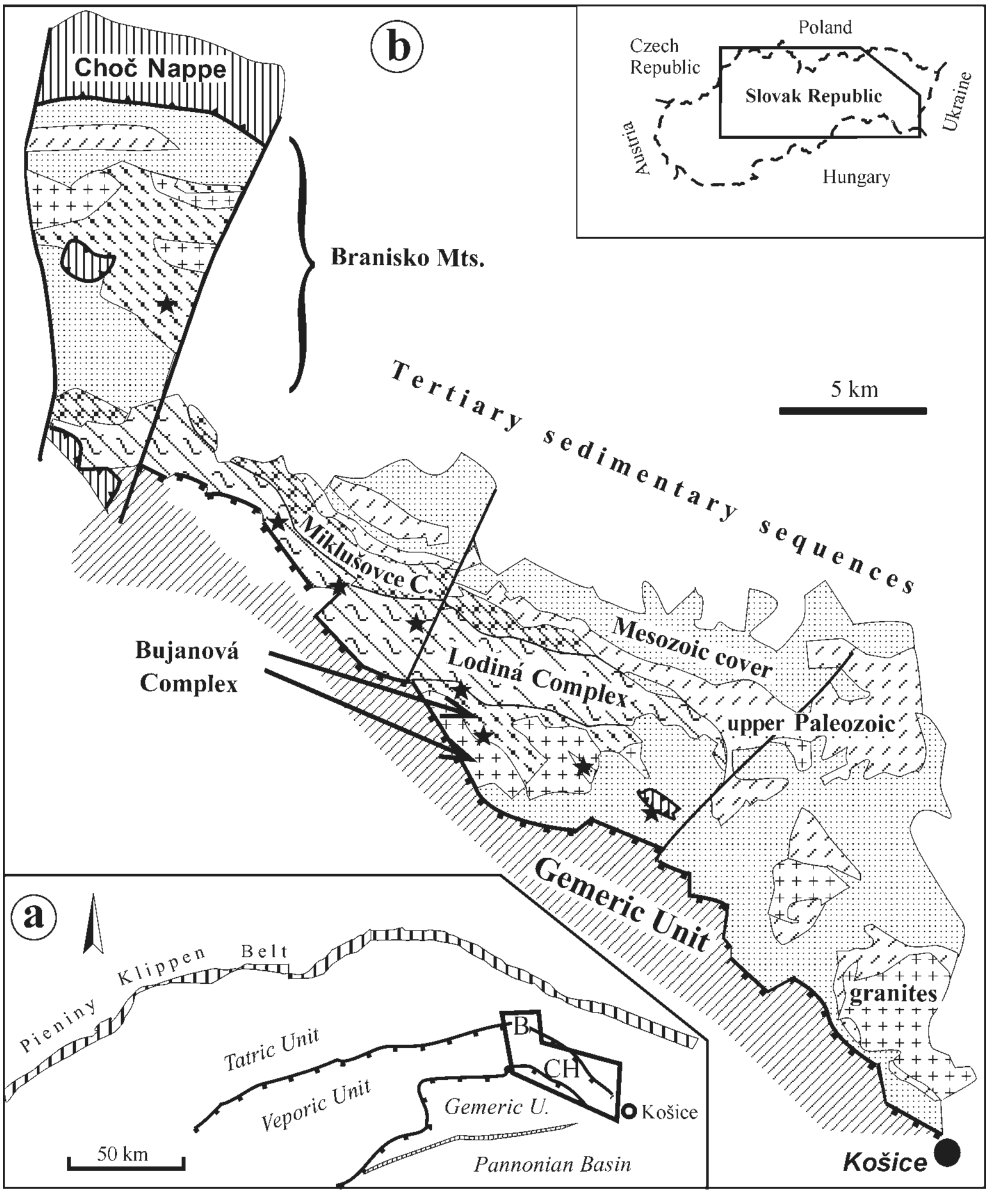

Fig. 1. a — Position of the Branisko and Čierna Hora Mountains in the framework of the Western Carpathians. B — Branisko, CH — Čierna Hora. **b** — Schematic geological map of the Čierna Hora and adjacent Branisko Mountains (Polák & Jacko Eds. 1997). Stars show sample locations.

Upper unit, which is interpreted as a reworked (migmatized and retrogressed) middle to lower continental crust of magmatic cumulate origin (Hovorka & Méres 1997).

The Branisko and the Čierna Hora Mountains represent the easternmost morphostructural elevation of the Tatric and Veporic Units in the Western Carpathians (Fig. 1). They are exposed beneath Tertiary sequences and from bottom to top comprise Variscan basement rocks, upper Paleozoic/Mesozoic cover formations and upper Paleozoic/Mesozoic piles of the Choč Nappe. The Čierna Hora Mountains are overthrust from the south-west by the Gemeric Unit. The pre-Tertiary sequences of the Čierna Hora Mountains are deeply penetrated and deformed by NW–SE trending folds. All local rocks, including the Choč Nappe sequences are strongly imbricated by NW–SE striking and SW dipping shear zones (Jacko 1978). Both the Branisko and the Čierna Hora Mountains are cut by post-Paleogene mainly NE–SW and N–S trending faults.

The basement rocks of the Branisko Mountains and partly of the Čierna Hora Mountains relate to the Upper unit (Bezák et al. 1997). The most common metamorphic rocks in the Branisko Mountains are the garnet-biotite gneisses, migmatites and relatively less abundant biotite-amphibole gneisses and amphibolites. Banded and massive amphibolites are mostly foliated forming up to 8×2 km long bodies conformly oriented with the E–W trending structural system. The garnet-pyroxene-bearing rocks and serpentinized peridotite occur in the largest amphibolite body forming oval or lens-shaped enclaves of cm to 2 m in size. Several small bodies of granodiorite are also present.

Jacko (1985) distinguished three complexes in the Čierna Hora basement rocks (Fig. 1b): **1** — the Lodiná Complex represented by diaphtorized gneisses with intercalations of amphibolites and staurolite-garnet micaschists, **2** — the Miklušovce Complex comprising strongly foliated migmatites and scarce intrafolial aplite-granite bodies, and **3** — the Bujanová Complex, which is correlated with the Branisko Mountains, consists of gneisses, migmatites and granitoids. Amphibolites are present in various amounts in all three complexes but garnet amphibolites are minor. The largest lens of amphibolite (up to 150 m thick) from the Bujanová Complex contains a body of serpentinized ultramafic rock about 1.5 m thick.

The cover sequences are represented by upper Carboniferous to Malmian formations. The Cretaceous Choč nappe pile, consisting of upper Carboniferous to upper Triassic formations, occurs mostly along the northern margin of the Branisko Mountains. In the Čierna Hora Mountains, the Choč Nappe forms isolated klippes of upper Paleozoic basal sequences with small dikes of weakly metamorphosed diorite.

Petrography and mineralogy

The samples selected for this study are from basement amphibolites (the Branisko and Čierna Hora Mountains) and metaultramafite (the Čierna Hora Mountains) and from Permian diorite of the Choč Nappe (the Čierna Hora Mountains). Minerals were analysed by Cameca Camebax microprobe at the "Zentrale Elektronen-Mikrosonde", Ruhr Universität Bochum, which is equipped with three wavelength-dispersive spectrometers. The following synthetic standards were used: pyrope (Si, Al, Mg), andradite (Ca, Fe), jadeite (Na), spessartine (Mn), K-silicate glass (K), Ba-silicate glass (Ba), NaCl (Cl) as well as natural rutile (Ti), and topaz (F). The operating voltage was 15 kV using beam currents between 10 and 15 mA. The beam was focused to 1–2 μm diameter, except for micas with 8–10 μm. Mineral formulae and ferric/ferrous iron ratios were calculated on the basis of 23 oxygens average Fe^{3+} (15-Na-K, 13-Ca-Na-K) in amphiboles, 12 oxygens and 8 cations for garnet, 12 oxygens + 1OH-group for epidote, 22 oxygens and 6 cations + Na + K + Ca for micas and 8 oxygens, 5 cations for plagioclase and 6 oxygens and 4 cations for pyroxene. The chemical formula of pumpellyite was calculated according to the general formula $W_4 X Y_5 Z_6 O_{(20+x)} OH_{(8-x)}$, where W = Ca, Na, X = Fe, Mg, Mn, Y = Fe^{3+}, Al, Cr, Ti and Z = Si (Coombs et al. 1977). Representative mineral analyses are given in Tables 2–4.

Garnet-pyroxene-bearing metabasites of the Branisko Mountains

As stated in the previous section, most metabasites from the Branisko Mountains are free from pyroxene and their comprehensive petrography has been published by Faryad (1996). These rocks show compositions comparable to tholeiitic basalts and basaltic andesite. The major and trace element compositions of the garnet-pyroxene-bearing metabasites are listed in Table 1. On the basis of the distribution of rare earth elements (REE) or high field strength elements (HFSE), the metabasites are geochemically close to island arc tholeiites (IAT). This is illustrated by a flat (primitive) chondrite normalized REE patterns (Fig. 2a) and depletion in Nb or Ta in relation to Th (subduction zone component — SZC) as result-

Table 1: Major and trace element contents in garnet-pyroxene-bearing metabasites of the Branisko and Čierna Hora Mountains and major elements in metaperidotite of the Čierna Hora Mountains.

	Branisko		Čierna Hora			Branisko		Čierna H.
	Grt-Cpx Metabasite			Metaperid		Metabasite		
wt. %	VBČH10	VBČH48	VBČH1	30/92	ppm	VBČH10	VBČH48	VBČH1
SiO_2	52.91	50.39	48.66	40.42	Zr	34	89	
TiO_2	0.61	1.59	0.65	0.55	Y	22	39	
Al_2O_3	15.47	15.3	15.24	6.85	Hf	1.15		3.5
Fe_2O_3	*11.28	*13.27	7.41	6.72	Nb	5	4	
FeO			4.45	6.88	Ta	0.058		0.104
MnO	0.21	0.23	0.19	0.07	Th	0.35		1.05
MgO	6.09	5.39	8.36	24.8	La	17.8	4.7	13.2
CaO	10.09	10.19	7.05	5.93	Ce	11.1	10.4	25.8
Na_2O	1.98	2.21	2.55	0.44	Nd	7.8	10.6	14.4
K_2O	0.35	0.18	0.77	0.1	Sm	2.05	3.9	4.4
P_2O_5	0.05	0.12	0.31	0.04	Eu	0.69	1.39	1.50
H_2O^-	0.15	0.13	0.63	7.1	Gd	2.2	4.28	
LOI	0.52	0.25	3.51		Tb	0.57	0.98	1.05
Total	99.71	99.25	99.78	99.99	Dy		6.45	
ppm					Ho	0.88	1.39	
Ni	28	49			Er		4.12	
Co	39	35			Tm	0.41	0.59	
Cr	36	65			Yb	2.55	4.02	5.2
Sc	42	47			Lu	0.39	0.6	0.81
V	254	348						

*— total iron as Fe_2O_3

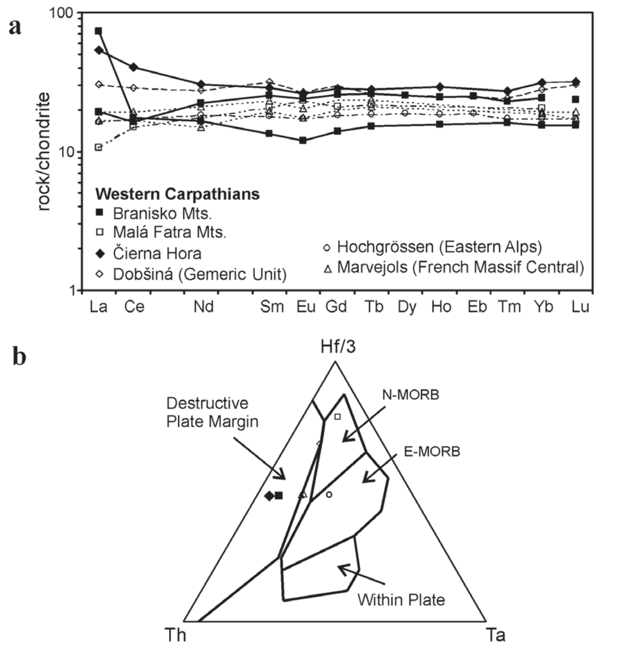

Fig. 2. a — Chondrite-normalized REE patterns of garnet-pyroxene-bearing rocks from the Branisko Mountains and other localities of the Western Carpathians. Metabasites of the Speik Complex in the Eastern Alps (Faryad et al. 2002) and French Massif Central (Pin & Marini 1993) with characteristic flat shape similar to typical oceanic basalts (N-MORB) are also indicated. Normalization by Evensen et al. (1978). **b** — Diagram Hf/3-Th-Ta (Wood 1980) for garnet-pyroxene rocks from the Branisko Mountains. Explanations as in Fig. 2a.

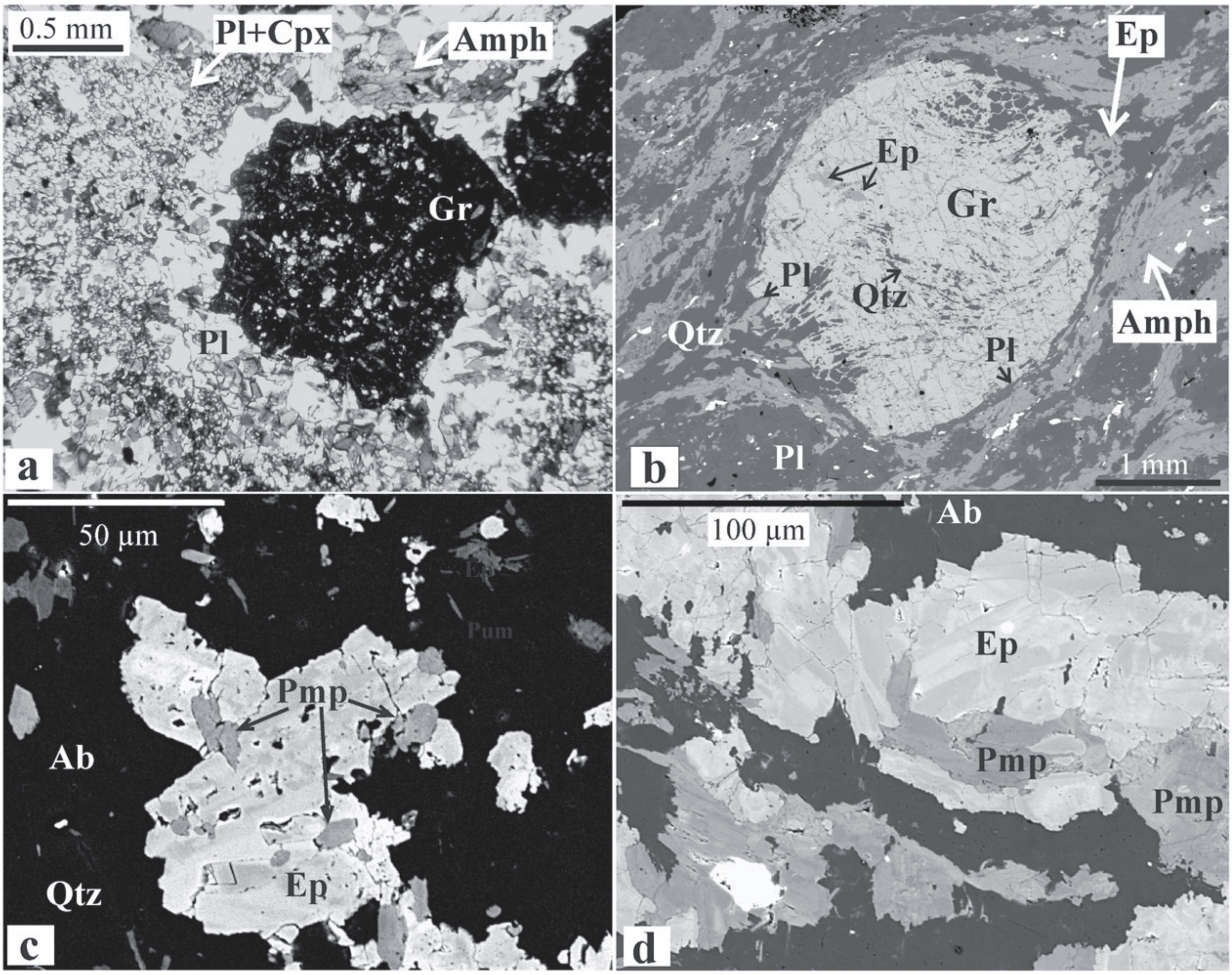

Fig. 3. a — Micrograph showing garnet and the symplectite of clinopyroxene (Cpx) + plagioclase (Pl) in metabasite of the Branisko Mountains. Garnet (Gr) with inclusions of plagioclase, epidote and rare pyroxene with reaction rims of plagioclase. **b** — Garnet showing s-shaped inclusion trails with quartz (Qtz). Epidote (Ep) replaces garnet and occurs in strain shadows of garnet (Amph — amphibole). **c** — Epidote with inclusions of pumpellyite (Pmp) occurs in albite (Ab). **d** — Similar to c but exhibiting sector zoning of epidote with lighter Fe-rich (Cz=1–9 mol %) and darker Al-rich (Cz=20–40 mol %) zones.

ed from discrimination diagrams, e.g. Hf/3-Th-Ta diagram by Wood (1980; Fig. 2b).

The pyroxene-free metabasites consist of magnesio-hornblende and plagioclase (An_{33-38}) and rare garnet (Alm_{50-57}, Grs_{25-30}, Prp_{12-22}, Sps_{1-4}, And_{1-4}), which indicate a weak decrease in $Mg/(Mg+Fe^{2+})$ ratio towards the rim. The garnet-pyroxene-bearing metabasites are massive with typical diablastic texture (Fig. 3a) and composed of garnet (up to 60 wt. %), plagioclase, amphibole, pyroxene, quartz, clinozoisite/epidote and accessory K-feldspar, rutile, ilmenite, apatite and phengite. Garnet (0.5–0.7 mm in size) is mostly cracked and partly replaced by amphibole, plagioclase and epidote. Some undeformed garnet grains contain inclusions of clinopyroxene, plagioclase, ilmenite, quartz, apatite and epidote.

Garnet is almost invariably zoned with cores rich in grossular relative to almandine (Table 2). When compared to garnet from pyroxene-free metabasites in this locality, it is relatively rich in Mg (Fig. 4a). Variations in rim-core compositions are in the range of Alm_{49-60}, Grs_{20-32}, Sps_{1-2}, Py_{18-20}. In their

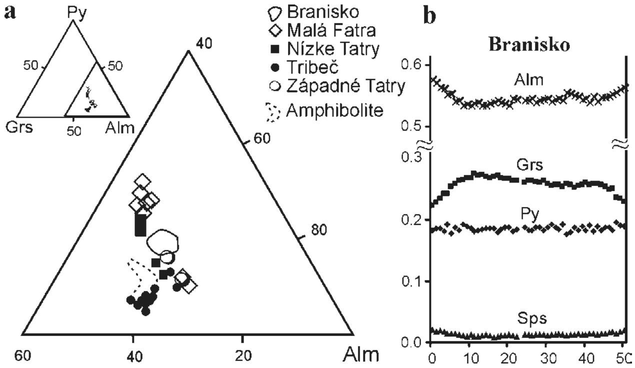

Fig. 4. a — Py-Grs-Alm diagram of garnet in pyroxene-bearing (solid field) and pyroxene-free metabasites (dashed field) of the Branisko Mountains. Compositions of garnets in pyroxene-bearing metabasites from other localities in the Western Carpathians are from literature (for references see Table 10). **b** — compositional profile of garnet from garnet-pyroxene-bearing metabasites in the Branisko Mountains.

Table 2: Core and rim composition of garnet in the garnet-pyroxene-bearing metabasites.

Locality	Branisko Mountains								Čierna Hora Mountains			
Sample	**VBČH-48**		**VBČH-17**		**VBČH-15**		**VBČH-50**		**Bujanová-214**		**Lodiná 28/92**	
Position	**c**	**r**	**c**	**r**	**c**	**r**	**c**	**r**	**r**	**c**	**r**	**c**
SiO_2	38.49	38.45	38.63	38.34	38.55	38.28	38.82	38.09	37.25	38.30	37.60	36.87
TiO_2	0.15	0.13	0.07	0.00	0.10	0.00	0.03	0.28	0.06	0.20	0.10	0.12
Al_2O_3	22.00	21.71	21.52	21.69	21.59	21.40	21.58	19.59	21.45	20.77	20.82	20.56
FeO	23.01	26.38	24.24	27.61	24.15	28.04	26.42	27.44	26.74	26.00	29.77	32.36
MnO	0.42	0.75	0.38	1.05	0.63	1.18	0.38	0.73	2.29	2.48	0.59	0.82
MgO	4.71	5.12	5.82	5.21	5.13	3.46	5.23	4.01	2.41	1.59	1.98	1.45
CaO	11.44	8.13	10.00	7.30	9.69	8.07	8.23	9.41	9.73	10.39	8.45	8.46
Total	100.22	100.67	100.66	100.80	99.86	100.43	100.69	99.58	99.95	99.73	99.85	100.79
Si	2.976	2.981	2.971	2.978	2.999	3.010	3.006	3.017	2.954	3.053	3.005	2.954
Al	2.005	1.984	1.950	1.949	1.980	1.983	1.970	1.828	2.005	1.951	1.961	1.942
Ti	0.009	0.008	0.004	0.000	0.006	0.000	0.002	0.017	0.003	0.012	0.006	0.007
Fe^{3+}	0.030	0.038	0.040	0.045	0.010	0.000	0.014	0.105	0.089	0.000	0.031	0.097
Fe^{2+}	1.458	1.673	1.519	1.748	1.561	1.844	1.697	1.713	1.675	1.733	1.955	2.061
Mn	0.028	0.049	0.025	0.069	0.042	0.079	0.025	0.049	0.154	0.168	0.040	0.056
Mg	0.543	0.592	0.667	0.603	0.595	0.406	0.604	0.473	0.285	0.189	0.236	0.173
Ca	0.948	0.675	0.824	0.607	0.808	0.680	0.683	0.798	0.826	0.888	0.724	0.726
alm	0.49	0.56	0.51	0.58	0.52	0.61	0.57	0.58	56.98	58.22	66.2	68.3
Sps	0.01	0.02	0.01	0.02	0.01	0.03	0.01	0.02	5.23	5.63	1.4	1.9
Py	0.18	0.20	0.22	0.20	0.20	0.14	0.20	0.15	9.69	6.34	8.0	5.7
Grs	0.32	0.22	0.27	0.20	0.27	0.23	0.23	0.25	28.10	29.81	24.5	24.1

Table 3: Microprobe analyses of clinopyroxene from metabasites of the Branisko Mountains and from metaperidotite of the Čierna Hora Mountains.

Locality	Branisko Mountains							Čierna Hora		
Sample	**VBČH-48**			**VBČH-17**		**VBČH-50**	**FG-2/99**	**ultramafic rock 30/92**		
Position	**in gr**	**in gr**	**matrix**	**in gr**	**in gr**	**matrix**	**in gr**			
SiO_2	53.25	53.37	52.89	54.02	52.88	53.88	52.93	52.94	53.20	53.84
TiO_2	0.21	0.12	0.17	0.16	0.23	0.09	0.25	0.20	0.22	0.10
Al_2O_3	1.33	0.74	1.20	1.10	2.36	0.79	1.81	1.17	1.12	0.76
FeO	8.72	9.57	9.70	8.40	9.28	9.74	7.01	3.77	3.80	4.01
MnO	0.05	0.03	0.17	0.13	0.11	0.08	0.03	0.18	0.10	0.12
MgO	14.20	13.86	13.46	14.45	13.23	13.68	14.03	15.80	15.83	16.89
CaO	21.73	21.53	21.39	22.37	21.48	22.37	22.56	24.39	24.53	23.36
Na_2O	0.33	0.27	0.28	0.29	0.81	0.28	0.49	0.20	0.23	0.18
Total	99.83	99.48	99.26	100.94	100.38	100.91	99.10	98.77	99.11	99.36
Si	1.983	2.002	1.992	1.989	1.959	1.996	1.975	1.963	1.965	1.979
Ti	0.006	0.003	0.005	0.004	0.006	0.003	0.007	0.006	0.006	0.003
Al	0.058	0.033	0.053	0.048	0.103	0.034	0.080	0.051	0.049	0.033
Fe^{3+}	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.004	0.005	0.006
Fe^{2+}	0.272	0.300	0.305	0.259	0.282	0.302	0.219	0.113	0.113	0.117
Mn	0.002	0.001	0.005	0.004	0.003	0.003	0.001	0.006	0.003	0.004
Mg	0.788	0.775	0.756	0.793	0.731	0.755	0.781	0.874	0.872	0.926
Ca	0.867	0.865	0.863	0.882	0.852	0.888	0.902	0.969	0.971	0.920
Na	0.024	0.020	0.020	0.021	0.058	0.020	0.035	0.014	0.016	0.013
En	39.9	39.1	39.2	40.1	36.8	38.0	41.0	44.43	44.41	44.41
Fen	13.8	15.2	16.1	13.3	14.7	15.3	11.5	6.28	6.14	6.14
Wo	43.9	43.7	44.7	44.6	43.0	44.7	47.4	49.29	49.45	49.45
Jd	2.4	2.0	2.0	2.1	5.3	2.0	3.5			
X_{Mg}	0.74	0.72	0.71	0.75	0.72	0.71	0.78	0.89	0.89	0.89

cores, garnets usually exhibit relatively flat compositional profiles with continuous increase of Fe and a decrease of Ca towards the rim (Fig. 4b). Some garnet grains show decrease in Mg towards the rim.

Pyroxene forms mostly intergrowths with plagioclase (Fig. 3a) and amphibole in the matrix. It is diopside with X_{Mg} = 0.71–0.81 or with enstatite end-member contents of 38–41 mol % (Table 3). The Mg-rich varieties form inclusions in garnet. Jadeite content in clinopyroxene is low (2–6 mol %).

Plagioclase inclusions in garnet mostly have compositions of An_{30-40}, but plagioclase of An_{10} can also be found in garnet (Table 4). Ca-rich plagioclase (An_{42-53}) occurs at garnet rim or with Ca-amphibole in the matrix. Plagioclase in symplectite is relatively poor in Ca and its composition ranges from albite to

Table 4: Plagioclase composition in garnet-pyroxene-bearing metabasites (Branisko Mountains) and pyroxene-free metabasites (Čierna Hora Mountains).

Locality	Branisko Mountains						Čierna Hora			
Sample	VBČH-48		VBČH-17		VBČH-50		Bujanová Complex		Lodiná Complex	
Position	in gr	sympl	in gr	rim to gr	in gr	matrix	214	19/92	28/92	64.7
SiO_2	59.91	62.82	65.33	56.58	60.01	63.41	37.92	59.88	62.40	63.71
Al_2O_3	26.10	24.71	21.94	28.04	25.46	23.59	20.56	25.22	23.77	22.72
FeO	0.45	0.27	0.64	0.36	0.43	0.09	0.00	0.14	0.01	0.23
CaO	7.49	5.46	2.02	10.06	6.95	5.01	8.04	6.82	4.50	4.39
Na_2O	6.32	7.13	9.42	5.33	7.26	8.02	7.05	7.53	8.91	8.92
K_2O	0.14	0.29	0.19	0.02	0.07	0.14	0.010	0.20	0.10	0.11
Total	100.44	100.51	99.58	100.45	100.23	100.27	99.79	100.12	99.69	100.14
Si	2.686	2.795	2.905	2.546	2.678	2.821	2.594	2.673	2.768	2.812
Al	1.379	1.300	1.150	1.487	1.339	1.237	1.387	1.327	1.243	1.182
Fe	0.017	0.010	0.024	0.014	0.016	0.003	0.00	0.005	0.000	0.008
Ca	0.360	0.261	0.096	0.485	0.332	0.239	0.387	0.327	0.214	0.208
Na	0.549	0.617	0.812	0.465	0.628	0.692	0.615	0.652	0.766	0.763
K	0.008	0.017	0.011	0.001	0.004	0.008	0.001	0.011	0.006	0.006
An	0.39	0.30	0.10	0.51	0.35	0.25	0.61	0.66	0.78	0.73
Ab	0.61	0.70	0.90	0.49	0.65	0.75	0.39	0.33	0.22	0.21

andesine of An_{25}. Three textural varieties of K-feldspar are present in the rock: **1** — inclusions in garnet, **2** — small grains between phengite and plagioclase and **3** — narrow veinlets in the matrix.

Amphibole mostly belongs to the retrograde phase in the rocks. Besides tabular grains, it is fine-grained and occurs in symplectites with plagioclase and pyroxene. Some amphibole inclusions in garnet contain relics of clinopyroxene. Microprobe analyses of amphibole are given in Table 5. There is no compositional variation between amphibole occurring in the matrix and that forming inclusions in garnet. On the basis of the amphibole classification by Leake et al. (1997), it is mostly tschermakite-magnesiohornblende in composition with X_{Mg}=0.61–0.67, Na^{M4}=0.2–0.3. Some amphibole grains at the contact with garnet are rich in Al (Al^{VI}=1.43 a.p.f.u.) and Fe (X_{Mg}=0.22) thus corresponding to alumino-ferrotschermakite. Actinolite and actinolitic hornblende occur with epidote or rim tschermakite. Epidote is common in the matrix being relatively low in Al with zoisite end-member content $Zo=(100[(-2+Al_{tot)})/(-2+Al_{tot}+Fe_{tot})])=0.56$. Al-rich epidote, close to clinozoisite forms inclusions in garnet and has Zo=0.8 (Table 6).

Phengite, associated with K-feldspar, plagioclase and amphibole in the matrix, has relatively high Si=3.38 a.p.f.u. (Table 6). It has low paragonite end-member with X_{Na} (Na/(Na+K))=0.025. Ilmenite has a composition close to ideal ilmenite with low MnO (0.9–2.2 wt. %) and MgO (0.1 wt. %) contents.

Amphibolites of the Čierna Hora Mountains

According to major and trace element distribution (Fig. 2a,b), the amphibolites are similar to garnet-pyroxene-bearing metabasites of the Branisko Mountains. They consist mostly of amphibole, plagioclase, variable amounts of quartz and garnet. Rutile, ilmenite, apatite and rare K-feldspar represent accessory phases. Garnet forms porphyroblasts with a maximum size of 2 mm, enveloped by amphibole and quartz, and containing inclusion trails of quartz (Fig. 3b). Peak metamorphic minerals preserved in some amphibolites are amphibole, garnet, plagioclase, ilmenite, rutile and quartz. Biotite generally replaces amphibole and it frequently occurs close to granite bodies in the Bujanová Complex. All rocks indicate variable degrees of retrogression, which resulted in the appearance of epidote, chlorite, calcite, white mica and titanite.

The *garnet* from amphibolites of the Lodiná Complex is generally rich in almandine and grossular (Alm_{52-67}, Grs_{23-31}, Py_{4-7}, Table 2). Spessartine content varies mostly between 2–10 % and the high Mn content (Sps_{18}) occurs in garnet core from sample 64.2 (Fig. 5). The Mn content decreases while Mg and X_{Mg} increase towards the rims. The majority of Ca-rich garnet Grs_{30} were found in sample Fg-25/92. In comparison with the Lodiná Complex, the garnet from amphibolite of the Bujanová Complex has relatively Mg-rich rim (Alm_{56-58}, Grs_{27-29}, Py_{6-9}, Sps_{4-5}).

The anorthite content in *plagioclase* ranges between (An_{19-43}). The Ca-rich plagioclase (An_{43}) comes from sample Fg-25/92 and Na-rich plagioclase was identified in samples 64.2. and 64.7.

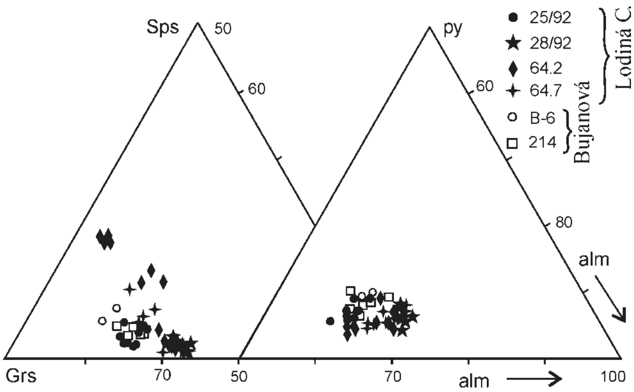

Fig. 5. Sps-Grs-Alm and Py-Grs-Alm diagrams of garnet in metabasites from the Bujanová and Lodiná Complexes in the Čierna Hora Mountains.

Table 5: Representative analyses of amphibole from garnet-pyroxene-bearing metabasites (Branisko Mountains) and garnet-bearing metabasites (Čierna Hora Mountains).

Locality	Branisko Mountains						Čierna Hora			
Sample	**VBČH-15**		**VBČH-48**		**VBČH-50**	**VBČH-17**	**Bujanová Complex**		**Lodiná Complex**	
Position	**in gr**	**in gr**	**sympl**	**sympl**	**matrix**	**matrix**	**214**	**20/92**	**28/92**	**64.2**
SiO_2	46.34	41.10	44.64	47.13	44.33	49.84	43.15	40.63	41.61	40.91
TiO_2	0.88	0.00	1.73	1.41	0.93	1.03	12.61	0.38	0.48	0.52
Al_2O_3	10.95	17.62	11.67	9.08	11.42	7.86	1.02	15.62	14.22	14.25
FeO	13.94	22.00	14.63	14.25	17.13	13.31	17.09	18.79	18.59	20.78
MnO	0.09	0.08	0.09	0.06	0.03	0.14	0.20	0.00	0.25	0.19
MgO	11.89	3.30	11.31	12.44	10.46	14.00	8.69	7.66	8.69	6.69
CaO	11.38	11.23	10.88	10.86	11.16	11.19	11.08	10.38	9.38	10.03
Na_2O	1.23	0.70	1.44	1.11	1.42	1.03	1.49	2.10	2.06	2.12
K_2O	0.56	0.63	0.77	0.53	0.55	0.07	0.54	0.33	0.46	0.18
Total	97.26	96.66	97.15	96.87	97.45	98.47	95.86	96.07	95.86	94.97
Si	6.741	6.269	6.530	6.853	6.516	7.043	6.509	6.123	6.208	6.255
Al^{IV}	1.259	1.731	1.470	1.147	1.484	0.957	1.491	1.877	1.792	1.745
Al^{VI}	0.619	1.435	0.542	0.410	0.495	0.351	0.750	0.898	0.708	0.823
Ti	0.096	0.000	0.190	0.154	0.103	0.110	0.115	0.043	0.054	0.060
Fe^{3+}	0.226	0.148	0.293	0.318	0.387	0.352	0.195	0.288	0.431	0.426
Fe^{2+}	1.470	2.657	1.496	1.414	1.719	1.221	1.961	2.051	1.844	2.141
Mn	0.011	0.010	0.011	0.008	0.004	0.017	0.025	0.000	0.032	0.025
Mg	2.578	0.750	2.468	2.697	2.292	2.949	1.955	1.721	1.931	1.525
Ca	1.774	1.835	1.705	1.691	1.758	1.694	1.790	1.677	1.500	1.642
Na^{M4}	0.226	0.165	0.295	0.309	0.242	0.282	0.210	0.323	0.500	0.358
Na(A)	0.120	0.042	0.113	0.003	0.163	0.000	0.226	0.290	0.095	0.271
K	0.104	0.123	0.143	0.099	0.103	0.013	0.105	0.064	0.088	0.036
X_{Mg}	0.64	0.22	0.62	0.66	0.57	0.71	0.50	0.46	0.51	0.42

Amphibole compositions mostly correspond to magnesiohornblende, tschermakite and ferro-tschermakite with Si = 6.0–7.0 and Ca = 1.9–1.5 a.p.f.u. (Table 5). The total Al contents in amphiboles range between 2.0–3.1 a.p.f.u. and alumino-ferrotschermakite with Al^{VI} > 1.0 occurs adjacent to the garnet. There is no regular variation in Ti contents in amphibole (Ti = 0.03–0.10 a.p.f.u.). Some amphibole varieties are rich in Na = 0.5–0.8 and Na^{M4} = 0.3–0.5 a.p.f.u. No difference exists in Na contents in amphiboles from the Lodiná and Bujanová Complexes. Except for the sample Fg-25/92, the majority of Na-rich amphibole come from garnet-bearing amphibolite. The Na content indicates a negative correlation with Si and X_{Mg} ratios in amphibole.

Biotite occurring in some amphibolites exhibits X_{Mg} = 0.48–0.65. Accessory *muscovite* with Si = 3.188 a.p.f.u. (Table 6) was found as inclusions in epidote, which occurs in garnet of the Bujanová Complex. Phengite (Si = 3.3 a.p.f.u.) replaces plagioclase.

Accessory *ilmenite* has MnO = 2.51 with 5.5 mol % geikielite content. Maximum Al_2O_3 in analysed titanite attains 1.65 wt. %. Most epidote in amphibolite has zoisite content ranging between 40–50 mol %. However, epidote associated with muscovite in garnet from the Bujanová Complex has 72 mol % zoisite content. The majority of Fe-rich epidote variety, having 13 mol % zoisite, replaces garnet.

Metaultramafic rock from the Čierna Hora Mountains

A body of serpentinized ultramafic rock about 2 m long (sample 30/92) was found to occur in amphibolite of the Bujanová Complex. It consists of amphibole, antigorite and small amounts of clinopyroxene, ilmenite-magnetite and phlogopite. Clinopyroxene and amphibole represent igneous phases in the rock. Rhombohedral pseudomorphs of antigorite, enclosed in poikilitic grains of amphibole, suggest the presence of original olivine. On the basis of modal (amphibole) and normative mineral contents, the ultramafic rock corresponds to pyroxene-amphibole peridotite with 55 vol. % amphibole, 20 vol. %

Table 6: Microprobe analyses of epidote, white mica and ilmenite from Branisko and Čierna Hora Mountains.

Locality	Branisko				Čierna H.
Sample	**FG-2/99**				**214**
	Ep		**Ph**	**Ilm**	**Ms**
Position	**in gr**	**matrix**	**matrix**	**in gr**	**In Ep**
SiO_2	38.52	39.32	50.44	0.30	48.10
TiO_2	0.05	0.10	0.06	51.78	0.01
Al_2O_3	30.67	27.50	30.80	0.14	37.14
FeO	3.15	6.08	2.06	46.05	0.84
MnO	0.09	0.04	0.00	0.83	0.08
MgO	0.00	0.00	1.70	0.10	0.18
CaO	23.17	22.67	0.04	0.18	0.00
Na_2O	0.04	0.34	0.18	0.51	0.26
K_2O	0.00	0.00	10.30	0.05	9.46
Total	95.69	96.05	95.58	99.94	96.1
Si	3.012	3.088	3.377	0.008	3.192
Ti	0.003	0.006	0.003	0.973	0.000
Al	2.826	2.545	2.430	0.004	2.905
Fe^{3+}	0.206	0.399	0.000	0.000	0
Fe^{2+}	0.000	0.000	0.115	0.962	0.046
Mn	0.006	0.003	0.000	0.018	0.004
Mg	0.000	0.000	0.169	0.004	0.018
Ca	1.941	1.908	0.003	0.005	0.000
Na	0.006	0.051	0.023	0.025	0.033
K	0.000	0.000	0.879	0.001	0.801
Zo	0.80	0.58			

olivine, and 10 vol. % pyroxene. Chemical composition of major elements is summarized in Table 1.

Some pseudomorphs are formed by phlogopite ($X_{Mg}=0.89$) and ilmenite-magnetite. Pyroxene is diopside with $X_{Mg}=0.88$ (Table 3). Amphibole corresponds to pargasite with low Na^{M4} content <0.1 a.p.f.u. In comparison with metamorphic amphiboles in amphibolites with $X_{Mg}=0.61-0.67$, it has higher $X_{Mg}=0.82-0.86$, which confirms comagmatic origin with pyroxene. Serpentine is antigorite with FeO = 4.75 wt. % ($X_{Mg}=0.94$).

Permian diorite

The diorite is a medium-grained rock with relict ophitic texture. It is formed by tabular plagioclase (2–3 mm) and pseudomorphs of chlorite and epidote after amphibole and locally after clinopyroxene. Myrmekite of quartz + K-feldspar occurs in intergranular space and also rimming plagioclase. Plagioclase is partly replaced by fine-grained epidote, pumpellyite and rare prehnite. In addition to individual grains, the pumpellyite forms inclusions in epidote (Fig. 3c,d). Locally occurring titanite forms grains up to 2 mm in size containing inclusions of plagioclase and epidote. Brownish-green amphibole is replaced by epidote, chlorite and by pale green amphibole. Relatively large quartz grains (0.5 mm) show deformation bands. Accessory phengite (Si = 3.388 a.p.f.u.), calcite and apatite are also present.

The relict igneous *pyroxene* is diopside with $X_{Mg}=0.74$ (Table 7) and the brownish green amphibole corresponds to magnesiohornblende. It has relatively high values of $Fe^{3+}=0.6$ and $Na^{M4}=0.4-0.5$ a.p.f.u. Metamorphic *amphibole* corresponds to actinolite with Si >7.0 a.p.f.u. All analysed pumpellyite grains are rich in $X_{Fe}^{3+}=0.3-0.4$ with $X_{Mg}=0.4-0.5$. Representative analyses of *pumpellyite* and *prehnite* are shown in Table 7. *Epidote* associated with pumpellyite is high in Fe^{3+} with zoisite end-member composition equal to 10–17 mol %. Some epidote grains indicate sector zoning (Fig. 3d). Microprobe analyses of *chlorite* associated with pumpellyite have $X_{Mg}=Mg/(Mg+Fe^{2+})$ around 0.5.

Metamorphic conditions

Garnet-pyroxene-bearing metabasites

Textural relations indicate that the studied metabasites have suffered retrogression and their peak mineral assemblages were mostly replaced or re-equilibrated at lower *P-T* conditions to various degree. The only possible prograde reaction:

$$Zo + Qtz = Gr + An + H_2O \quad (1)$$

can be indicated by the presence of clinozoisite inclusions in garnet. This reaction yields pressure of 1.1 GPa for 700 °C (Fig. 6) using plagioclase composition (An_{40}) and thermodynamic datasets of Berman (1988) and the TWEEQ program (Berman 1991, version 2.02), updated in 1996.

Garnet with inclusions of clinopyroxene, plagioclase and ilmenite records peak *P-T* conditions and can be used for thermobarometric calculations. Temperatures obtained using different calibrations of the garnet-clinopyroxene geothermometer are presented in Table 8. Core composition gave relatively high temperatures (650–767 °C), when compared with the garnet rim (586–717 °C). The calibrations by Ellis & Green (1979), Powell (1985), Sengupta et al. (1989) and Ganguly et al. (1996), yield higher temperatures for core composition of garnet (average 749, 742, 730 and 716 °C, respectively) than those by Ai (1994) and Ravna (2000) (average 691 and 690 °C).

Pressure estimated by garnet-clinopyroxene and plagioclase barometry of Powell & Holland (1988) and Eckert et al. (1991) using plagioclase inclusions in garnet (An_{30-40}) ranges between 0.98–1.28 GPa. Higher pressures can be obtained, if plagioclase composition in inclusions with lower anorthite content is used. Equilibrium of plagioclase and clinopyroxene with host garnet enables us to use the TWEEQ program for the reactions:

$$Alm + Grs + Qtz = Hed + An \quad (2)$$
$$Grs + Prp + Qtz = Di + An \quad (3)$$
$$Alm + Di = Prp + Hed \quad (4)$$

The intersections of these reactions give pressures of 1.28–1.40 GPa at 700–770 °C (Fig. 6). Considering equilibrium between phengite and K-feldspar, the pressure corresponding to the transition between amphibolite and eclogite facies metamorphism (1.3 GPa at 700 °C) can be derived from Si (3.38 a.p.f.u.) isopleths by Massonne & Schreyer (1987).

The ubiquitous symplectites of Na-poor pyroxene and albite-rich plagioclase are usually considered as a result of de-

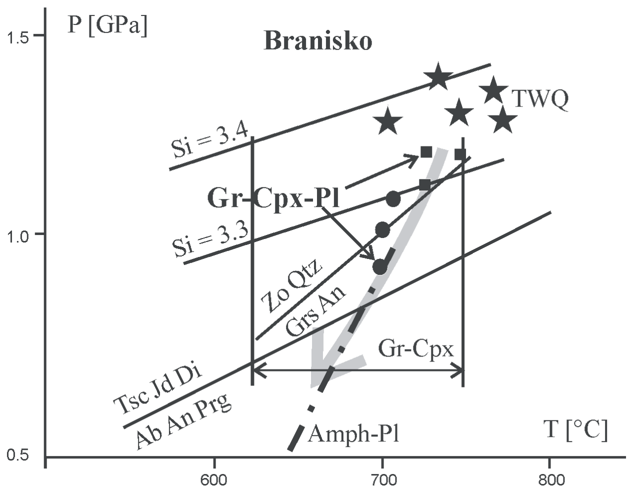

Fig. 6. Calculated *P-T* conditions for garnet-pyroxene-bearing metabasites in the Branisko Mountains. Two vertical lines show lower and upper temperature limits obtained using garnet-clinopyroxene thermometry (Table 8). Squares and circles are average temperatures and pressures, calculated for core and rim compositions of garnet using the garnet-clinopyroxene-plagioclase thermobarometry. Stars are intersections of reactions (2–4) obtained using the TWEEQ program. Isopleths of Si in phengite (Si=3.4 and 3.3) are according to Massonne & Schreyer (1987). Dashed line shows temperature of amphibole-plagioclase equilibrium at 0.5–1.0 GPa (Holland & Blundy 1994).

Table 7: Microprobe analyses of igneous pyroxene and metamorphic minerals from metadiorite of the Choč Nappe in the Čierna Hora Mountains.

	Px	Mg-Hbl	Act	Pmp	Pmp	Prh	Ep	Ep	Chl	Ms in Ab
SiO_2	52.51	44.84	51.23	36.89	35.95	43.84	36.13	37.15	25.90	49.71
TiO_2	0.28	1.02	0.13	0.06	0.05	0.02	0.08	0.02	0.00	0.07
Al_2O_3	2.13	3.79	0.34	24.43	22.05	23.11	18.40	22.98	18.54	30.87
Fe_2O_3	0.00	5.10	1.70	2.90	6.10	0.00	18.73	13.88	0.00	0.00
FeO	9.60	18.69	19.61	4.20	4.27	0.28	0.00	0.00	28.82	2.39
MnO	0.32	0.45	0.53	0.15	0.13	0.04	0.01	0.16	0.34	0.00
MgO	15.36	9.04	10.22	1.70	1.59	0.22	0.06	0.00	13.78	1.27
CaO	19.48	9.27	11.77	0.06	0.00	25.57	22.77	22.59	0.16	0.08
Na_2O	0.26	2.15	0.01	0.02	0.01	0.04	0.00	0.00	0.00	0.17
K_2O	0.02	0.72	0.06	22.82	22.66	0.00	0.00	0.00	0.06	9.59
F		0.55	0.00	0.27	0.39					
Total	99.98	95.12	95.6	93.500	93.200	93.12	96.18	96.78	87.60	94.15
Si	1.948	6.989	7.826	5.983	5.944	3.095	2.999	2.994	5.592	3.388
Al^{IV}	0.052	0.697	0.061	0.017	0.056	0.000	0.001	0.006	2.408	0.612
Al^{VI}	0.041	0.000	0.014	4.652	4.240	1.923	1.798	2.171	2.310	1.768
Ti	0.008	0.119	0.000	0.008	0.006	0.001	0.005	0.001	0.000	0.004
Fe^{3+}	0.000	0.599	0.196	0.000	0.000	0.000	1.170	0.842	0.00	0.000
Fe^{2+}	0.298	2.436	2.505	0.569	0.590	0.017	0.000	0.000	5.203	0.135
Mn	0.010	0.060	0.069	0.021	0.018	0.002	0.001	0.011	0.062	0.000
Mg	0.849	2.101	2.329	0.410	0.391	0.023	0.007	0.000	4.433	0.129
Ca	0.774	1.548	1.926	3.966	4.013	1.934	2.025	1.951	0.037	0.006
Na	0.019	0.650	0.003	0.020	0.000	0.005	0.000	0.000	0.017	0.023
K	0.001	0.143	0.011	0.005	0.001	0.000	0.000	0.000	0.000	0.834
F	0.000	0.048	0.00	0.138	0.205	0.000	0.000	0.000	0.000	0.000
X_{Mg}	0.74	0.52		0.410	0.391				0.53	
X^{Fe3}				0.384	0.562					

Table 8: Temperatures (°C) and pressures (GPa), calculated using the garnet-clinopyroxene-plagioclase thermobarometry for metabasites of the Branisko Mountains.

Sample	VBČH-48		VBČH-17		VBČH-50		FG-2/99		average	
r — rim, c — core	c	r	c	r	c	r	c	r	c	r
Ellis & Green (1979)	767	681	759	646	723	674	747	676	**749**	**669**
Powell (1985)	750	660	741	623	702	653	728	680	**730**	**654**
Sengupta et al. (1989)	711	689	713	665	738	708	703	650	**716**	**678**
Ai (1994)	710	624	705	586	650	615	697	665	**691**	**623**
Ravna (2000)	708	639	709	601	653	619	691	653	**690**	**628**
Ganguly (1996)	748	715	754	717	737	680	730	670	**742**	**696**
Powell & Holland (1988)	1.20	0.97	0.98	0.73	1.07	1.07	1.13	1.03	**1.10**	**0.95**
Eckert et al. (1991)	1.28	1.07	1.06	0.82	1.17	1.16	1.23	1.12	**1.19**	**1.04**

composition of Na-rich pyroxene during retrogression (Joanny et al. 1991; O'Brien et al. 1992). An alternative interpretation for symplectite formation through prograde reaction of amphibole + epidote + quartz = clinopyroxene + plagioclase + garnet in metabasites from Malá Fatra Mountains has been suggested by Korikovsky & Hovorka (2001). Since no relic of Na-clinopyroxene (omphacite) was found in these rocks, the mechanism of symplectite formation remains unclear. Further retrogression took place when the rocks had become accessible to externally derived fluids. The presence of magnesiohornblende, and later epidote and actinolite argues for infiltration of the rocks by fluids during the late stage of metamorphism. Temperature conditions of the symplectite formation deduced from the amphibole-plagioclase thermometer based on the equation by Holland & Blundy (1994), are 652–717 °C at 0.5 and 1.0 GPa for various samples. When considering an average temperature of 670 °C for symplectite formation, a pressure of 0.8 GPa can be assumed according to the equilibrium reaction:

$$Tsc + Jd + Di = Ab + An + Parg \qquad (5)$$

calculated using mineral composition and the TWEEQ program (Fig. 6). Lower temperatures corresponding to conditions of the greenschist facies can be considered for actinolite rimming the magnesiohornblende or occurring with epidote.

Garnet amphibolite of the Čierna Hora Mountains

The results of garnet-amphibole thermometry (Graham & Powell 1984; Perchuk et al. 1985; Ravna 2000b) are given in Table 9. Calibration by Graham & Powell (1984) yielded average temperatures of 572 °C for the Lodiná and 618 °C for the Bujanová Complexes. Lower temperatures of 475–501 °C

Table 9: Summary of calculated *P-T* conditions for garnet amphibolites of the Čierna Hora Mountains. GP — Graham & Powell (1984), P — Perchuk et al. (1985), R — Ravna (2000), KS — Kohn & Spear (1990).

	Lodiná Complex							Bujanová Complex	
	25/92	64.2	64.7	64.7	28/92	28/92	average	214	214
T (GP)	606	565	593	545	606	520	572.5	609	625
T (P)	540	499	527	481	504	458	501.5	530	545
T (R)	515	493	494	424	518	409	475.5	542	568
P (KS)	0.71	1.04	1.06	1.02	1.05	0.93	0.97	0.81	0.82
T/P (TWEEQ)	665/1.04	617/1.24	608/1.12		675/1.11		641/1.12	715/1.09	705/1.08

for the Lodiná and 530–568 °C for the Bujanová Complex were obtained by the methods of Perchuk et al. (1985) and Ravna (2000b). Metamorphic temperatures, calculated by the method of Graham and Powell are consistent with that reported by Korikovsky et al. (1990) and Jacko et al. (1990) who obtained 520–540 °C for the Lodiná Complex and 620–625 °C for the Bujanová Complex. Temperatures of 650–700 °C in the pressure range of 0.5–1.0 GPa were obtained by amphibole-plagioclase thermometry by Holland & Blundy (1994) for both complexes.

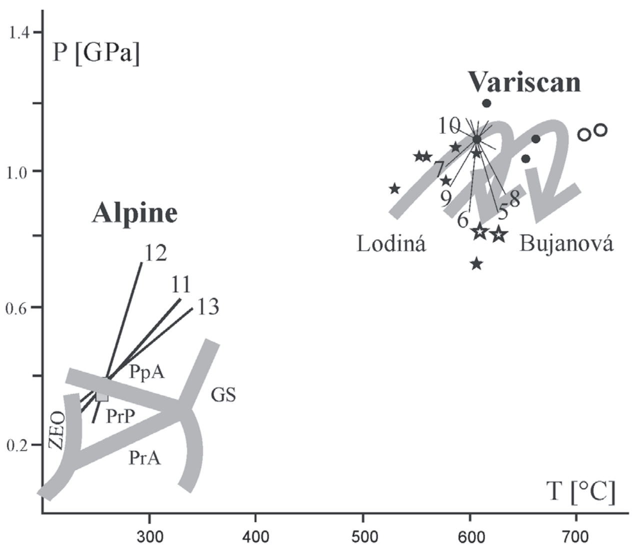

Fig. 7. Calculated *P-T* conditions for Variscan metamorphism in basement rocks of the Lodiná and Bujanová Complexes and for Alpine metamorphism of dolerite of the Choč Nappe. Numbers 6–14 correspond to reactions:

Ts = Py + Gr + An + Qtz + W	(6)
Ts + Ab = An + Py + Qtz + Prg + W	(7)
Ts + Py + Gr + Ab = An + Qtz + Prg	(8)
Prg + Ts = Ab + Gr + Py + W	(9)
Ts + Gr + Ab = An + Qtz + Prg + W	(10)
An + Qtz + Prg = Py + Gr + Ab + W	(11)
Pmp + Qtz = Cz + Chl + Pre + W	(12)
Pmp + Chl + Qtz = Cz + Tr + W	(13)
Pmp + An = Cz + Chl + Qtz + W	(14)

Circles are intersections of reactions 6–11, calculated using the TWEEQ. Stars correspond to temperatures and pressures obtained by Gr-Amph-(Pl-Qtz) thermo(barometry) as in Table 9. Open symbols are from the Bujanová and solid symbols from the Lodiná Complexes. Reactions 12–14 for pumpellyite-bearing assemblage in diorite are calculated using the Thermo-Calc Programs. The facies boundaries of low-grade rocks according to Liou et al. (1987) are: ZEO — zeolite, PrA — prehnite-actinolite, PrP — prehnite-pumpellyite, PA — prehnite-actinolite and GS — greenschist facies.

Pressures calculated by garnet-amphibole-plagioclase-quartz barometry (Kohn & Spear 1990) range between 0.7–1.1 GPa (average 0.97 GPa at 600 °C) for the Lodiná and 0.8 GPa for the Bujanová Complex. The equilibrium reactions (6–11, Fig. 7) calculated using the TWEEQ program-version 2.02 (Berman 1988) in the system CMASH yielded average temperature and pressure of 641 °C and 1.12 GPa for the Lodiná Complex. A relatively higher temperature of 710 °C at 1.09 GPa was obtained for the Bujanová Complex.

Permian diorite

The presence of prehnite + pumpellyite + epidote + albite assemblage well defines the *P-T* field of very low-grade metamorphism in Permian diorite. The metamorphic conditions for this assemblage were calculated using the software Thermo-Calc (version 3.1, Holland & Powell 1998). The activity model for pumpellyite $[4(X_{Mg}^{M2})(X_{Al}^{M2})]$ was taken from Evans (1990) and for prehnite (X_{Al}^{M2}) from Frey et al. (1991). The calculated equilibrium reaction (12) for this assemblage crosses the prehnite-pumpellyite facies at 240 °C/0.3 GPa to 360 °C/0.38 GPa (Fig. 7). The higher pressure limit based on this calculation is confirmed by the presence of only a small amount of prehnite by comparison with pumpellyite and by the reactions involving actinolite (13) and plagioclase (14) which intersect each other at 0.38–0.40 GPa/250 °C. A temperature of 250 °C for sedimentary sequences of the Choč Nappe was previously calculated using the illite crystallinity in pelitic rocks (Korikovsky et al. 1992).

Discussion

Garnet-pyroxene metabasites seem to be common constituents of leptynite-amphibolite complexes not only in the Tatric Unit, but also at many other localities of the European Variscides (Hovorka & Méres 1997 and references herein). Fig. 2a,b show chondrite-normalized REE patterns and Nb : Ta : Th distributions in leptinite-amphibolites of the Massif Central, France (cf. Pin & Marini 1993), and in amphibolized eclogite of the Speik Complex in the Eastern Alps (Faryad et al. 2002). Major and trace element distribution in garnet-pyroxene metabasites of the leptynite-amphibolite complex, including that of the Branisko Mountains indicate that their pro-

Table 10: Summary of mineral compositions and estimated maximum *P-T* conditions for garnet-pyroxene-bearing metabasites in the Western Carpathians. 1 — Janák & Lupták (1997), 2 — Hovorka et al. (1992), 3 — Hovorka & Méres (1990), 4 — Janák et al. (1996), 5 — Spišiak & Pitoňák (1990), 6 — this study.

		Malá Fatra	Tribeč	Z. Tatry	N. Tatry	Branisko
	Grs	28–33	26	23–25	26–27	20–32
Gr	Py	3–12	13–16	11–16	22–24	18–20
	Alm	57–61	55–58	56–59	48–49	49–60
Cpx	X_{Mg}	60–67	73–76	71–76	79–81	71–81
Pl	An	26–39	30–31			25–53
T/P	GPa/°C	740/1.1		750/1.7		750/1.3
References		1, 2	3	4	5	6

tolith crystallized from relatively undifferentiated basaltic magma. They are mostly comparable to IAT basaltic magma produced in the arc or back-arc geodynamic setting. Although the interpretation of the geodynamic setting could not be fully unambiguous, due to possible magma contamination with continental crust material (cf. Pin & Marini 1993), the generation of the original magma by partial melting of depleted mantle in the back-arc basin setting appears to be most likely. In this case the garnet-pyroxene-bearing rocks may represent relics of an ancient oceanic crust and their HP metamorphism may reflect metamorphic processes in a subduction zone.

The most common feature of all garnet-clinopyroxene-bearing rocks from the Western Carpathians is the presence of Mn-poor and Ca-rich garnet, which is similar to that from the Branisko Mountains (Table 10). The pyrope content is in the range of 12–20 mol %, but relatively Mg-poor garnet (Py_{3-12}) comes from the Malá Fatra Mountains. The maximum temperature and pressure estimated for the Malá Fatra Mountains were 700–750 °C and 0.8–1.0 GPa (Janák & Lupták 1997) and that of the Western Tatra Mountains ca. 1.6 GPa at 750 °C (Janák et al. 1996). Recently, Janák et al. (2003) reported the presence of omphacite as inclusions in garnet and accordingly estimated a pressure of 1.8–2.1 GPa at 670–740 °C. A possible equivalent of the LAC in the Gemeric Unit is the Klatov Group (Hovorka et al. 1984; Faryad 1990). Garnet-pyroxene-bearing metabasites were reported by Rozlozsnik (1935) and Rozložník (1965), but no mineral analyses are available from these rocks. Some garnet cores from their pyroxene-free equivalents are rich in Mg and Ca (Grs_{20-27}, Py_{19-23}, Alm_{48-60}) like those in the Branisko metabasites. Maximum pressure and temperature of 1.0 GPa and 700 °C were calculated for the Klatov Group metabasites (Faryad 1990).

Petrological study of garnet-pyroxene-bearing metabasites from the Branisko Mountains provides information on their retrograde *P-T* path. Textural relations indicate two stages for the Branisko Mountains metabasites: **1** — the high-grade stage occurred at *P-T* conditions close to the boundary of amphibolite-eclogite facies (1.3 GPa at 700–750 °C, Fig. 6), **2** — Transition to amphibolite facies conditions is indicated by the formation of symplectite of clinopyroxene and plagioclase with amphibole. The only temperature indicator in the matrix or in the intergrowths is the amphibole-plagioclase pair, which gives a temperature of ca. 600 °C. A nearly isothermal decompression down to 0.8 GPa at 670 °C is suggested by the equilibrium reaction of minerals in the symplectite. Crystallization of epidote, actinolite replacing amphibole, chlorite and Fe-oxide appear to be connected with the late stage of retrogression. The presence of metaultramafite in the Bujanová Complex of the Čierna Hora Mountains, supports the interpretation, which is in favour of lithological similarities between the Bujanová Complex and the Branisko Mountains (Jacko et al. 1990). However, the peak metamorphic conditions obtained for the Čierna Hora Mountains correspond to those of amphibolite facies.

The ages of the magmatic crystallization of garnet-pyroxene-bearing rocks and their peak *P-T* metamorphic conditions are only poorly constrained. A minimum age of 514±24 Ma for magmatic crystallization of leptynite from the LAC in the Veporic Unit was deduced from the upper intercept age of U-Pb zircon dating (Putiš et al. 2001). The lower intercept age of 348±31 Ma is related to their retrogression under amphibolite facies conditions. The possible age of the amphibole facies stage metamorphism in the Veporic Unit is also supported by Ar-Ar dating on hornblende, which yielded a cooling age of ca. 358 Ma (Dallmeyer et al. 1996). Migmatites of the Tatric Unit (in the High Tatra Mountains) showed concordant zircon ages of 356 and 330 Ma (Poller & Todt 2001), but porphyric orthogneiss gave an age of 406 Ma (Poller et al. 2000). The medium-pressure Variscan metamorphism in the Western Carpathians is confirmed by many mineral age dates as well as by acid and mafic intrusions (ca. 360–330 Ma, see Kráľ 1994, for review). Textural relations and mineral compositions, discussed in this study in combination with available information on metamorphism and geochronological data from similar rocks in other units in the Western Carpathians suggest a long-term and polyphase evolution of the Western Carpathian basement during pre-Alpine history. According to data discussed above, the Upper lithotectonic unit with a leptynite-amphibolite complex is either of lower crustal origin or it represents part of a subduction zone (?). In the latter case, the rocks can be compared with the Speik Complex in the Eastern Alps, where early Variscan (397 Ma) HP metamorphism (Faryad et al. 2002) was followed by medium-pressure metamorphism. The latter metamorphic event with relatively lower geothermal gradient of ca 30 °C/km is ascribed to lower Carboniferous continental plate collision and subsequent granite intrusions (Neubauer & Handler 2000).

In many regionally metamorphosed terranes, pumpellyite commonly coexists with prehnite, epidote and actinolite (Cho et al. 1987). Some descriptions of field relations and mineral assemblages, chemical compositions and textures of such rocks (Coombs et al. 1977; Liou et al. 1985) indicate that pumpellyite-actinolite facies occupies a *P-T* intermediate field between the prehnite-pumpellyite, blueschist and greenschist facies. In agreement with petrogenetic grid for very low-grade rocks (Cho et al. 1987; Springer et al. 1992), the minimum metamorphic temperature of 200–250 °C at 0.2–0.3 GPa established for the studied metadiorite is considered with respect to the absence of zeolite. The occurrence of only accessory prehnite in the assemblage Pmp + Act + Ep (+ Chl + Ab + Qtz) from the Choč Nappe diorite suggests a deeply buried rock sequence. This assemblage was described by Vrána & Vozár (1969) in diorite of the Choč Nappe at Nižná Boca in the Nízke Tatry Mountains.

Although the root zone of the Choč Nappe is not sufficiently known, the similarities of metamorphic conditions between the Choč diorite and underlying basement units seem to be apparent. Nevertheless, the metamorphic temperatures obtained for the Choč diorite are consistent with those estimated for the cover sequence of the Čierna Hora Mountains (Korikovsky et al. 1989). The pressure conditions of this metamorphism can be deduced from regional correlation of Alpine (Cretaceous) metamorphic overprint in the Western Carpathian basement units, which indicate medium- to high-pressure greenschist/epidote amphibolite facies conditions. The Gemeric Unit located south of the Čierna Hora Mountains (Fig. 1) underwent Alpine metamorphism at 0.5–0.7 GPa/300–350 °C (Faryad & Dianiška 1999) and the Veporic Unit (near the western border of the Gemeric Unit) reached 0.7–1.0 GPa 500–620 °C (Janák et al. 2001). The northern parts of the Tatric basement unit indicate only very low-grade conditions. This was also confirmed by metamorphic minerals in granitoid rocks of the Malá Fatra Mountains (Faryad & Dianiška 2003). Therefore, it is likely that the very low-grade metamorphism in the Čierna Hora Mountains occurred during the Cretaceous nappe thrusting in the Western Carpathians.

Conclusions

The geochemical character of the garnet-pyroxene-bearing metabasites of the Branisko Mountains is comparable with that of leptynite-amphibolite complexes in the Western Carpathians or that of the European Variscides, thus indicating affinity with the back-arc basin. The textural relations and mineral compositions of metabasites indicate a multi-stage metamorphic history of the Branisko basement rocks. The early stage is characterized by the presence of garnet, clinopyroxene, plagioclase and ilmenite, which yield *P-T* conditions of 1.26±0.12 GPa at 732±24 °C. Decompression and cooling to medium-pressure amphibolite facies conditions (650 °C and 0.7 GPa) are documented by the formation of clinopyroxene + plagioclase symplectite with amphibole. The later stage is comparable to the medium-pressure Variscan (ca. 340–360 Ma) metamorphism associated with migmatization and granite formation.

Equilibrium mineral assemblages in the Čierna Hora metabasites gave *P-T* conditions of 520–550 °C/0.8–1.0 GPa for the Lodiná Complex and 650–625 °C/1.0 GPa for the Bujanová Complex. Temperatures obtained for the Bujanová Complex metabasite with metaperidotite are relatively high, but low compared to their lithological equivalent in the Branisko Mountains.

Alpine metamorphism associated with the Choč Nappe thrusting is defined by the presence of prehnite-pumpellyite-epidote in Permian diorite. Calculated *P-T* conditions of 250 °C/0.3 GPa are comparable to metamorphic grade in the cover formations of the Tatric and northern Veporic Units (cf. Korikovsky et al. 1997).

Acknowledgments: We would like to express our thanks to the Czech and Slovak Grant Agencies for financial support of the projects: GAČR-205/03/1490, VEGA-1/8071/01 and VEGA-1/7389/20. We are also obliged to S. Vrána, S. Korikovsky and A. Vozárová for their thoughtful reviews and M. Janák for editorial comments on the manuscript.

References

Ai Y. 1994: A revision of the garnet-clinopyroxene Fe^{2+}–Mg exchange geothermometer. *Contr. Mineral. Petrology* 115, 467–473.

Berman R.G. 1988: Internally-consistent thermodynamic data for minerals in the system Na_2O-K_2O-CaO-MgO-FeO-Fe_2O_3-Al_2O_3-SiO_2-TiO_2-H_2O-CO_2. *J. Petrology* 29, 445–522.

Berman R.G. 1991: Thermobarometry using multiequilibrium calculations: a new technique with petrologic applications. *Canad. Mineralogist* 29, 833–855.

Berman R.G. 1996: TWEEQU (version 202). Thermobarometry with estimation of equilibration state. *http://www.gis.nrcan.gc.ca/twq.html*

Bezák V., Jacko S., Janák M., Ledru P., Petrík I. & Vozárová A. 1997: Main Hercynian lithotectonic units of the Western Carpathians. In: Grecula P., Hovorka D. & Putiš M. (Eds.): Geological evolution of the Western Carpathians. *Miner. Slovaca — Monograph*, Bratislava, 261–268.

Cho M. & Liou J.G. 1987: Prehnite-pumpellyite to greenschist facies transition in the Karmutsen metabasites, Vancouver Island, B.C. *J. Petrology* 28, 3, 417–443.

Coombs D.S., Kawachi Y., Houghton B.F., Hyden G., Pringle I.J. & Williams J.G. 1977: Andradite and andradite-grossular solid solutions in very low-grade regionally metamorphosed rocks in Southern New Zealand. *Contr. Mineral. Petrology* 63, 229–246.

Dallmeyer R.D., Neubauer F., Handler R., Fritz H., Muller W., Pana D. & Putiš M. 1996: Tectonothermal evolution of the internal Alps and Carpathians: $^{40}Ar/^{39}Ar$ mineral and whole rock data. *Eclogae Geol. Helv.* 89, 203–277.

Eckert J.O. Jr., Newton R.C. & Kleppa O.J. 1991: The pH of reaction and recalibration of garnet-pyroxene-plagioclase-quartz geobarometers in the CMAS system by solution calorimetry. *Amer. Mineralogist* 76, 148–160.

Ellis D.J. & Green D.H. 1979: An experimental study of the effect of Ca upon garnet-clinopyroxene Fe-Mg exchange equilibria. *Contr. Mineral. Petrology* 71, 13–22.

Evans B.W. 1990: Phase relations of epidote-blueschists. *Lithos* 25, 3–23.

Evensen N.M., Hamilton P.J. & O'Nions R.K. 1978: Rare-earth abundances in chondritic meteorites. *Geochim. Cosmochim. Acta* 42, 1199–1212.

Fabian M. & Kamenický J. 1985: Geological and petrographical conditions of crystalline in the western part of the Čierna Hora Mountains (Eastern Slovakia). *Miner. Slovaca* 17, 97–119 (in Slovak).

Faryad S.W. 1996: Petrology of amphibolites and gneisses from the Branisko crystalline complex. *Miner. Slovaca* 28, 265–272.

Faryad S.W. 1990: Gneiss-amphibolite complex of the Gemericum. *Miner. Slovaca* 22, 303–318.

Faryad S.W. & Dianiška I. 1999: Alpine overprint in the early Paleozoic of the Gemericum. *Miner. Slovaca* 31, 485–490.

Faryad S.W. & Dianiška I. 2003: Ti-bearing andradite with prehnite and epidote from the Malá Fatra granodiorite and tonalite (Western Carpathians). *Swiss Bull. Miner. Petrol.* 83, 47–56.

Faryad S.W., Hoinkes G., Melcher F., Puhl J., Meisel T. & Frank W. 2002: Relics of eclogite facies metamorphism in the Austroalpine basement, Hochgrößen (Speik Complex), Austria. *Mineralogy and Petrology* 74, 49–73.

Frey M., De Capitani C. & Liou J.G. 1991: A new petrogenetic grid for low-grade metabasites. *J. Metamorph. Geology* 9, 497–509.

Ganguly J., Cheng W. & Tirone M. 1996: Thermodynamics of alumosilicate garnet solid solution: new experimental data, an optimized model, and thermodynamic application. *Contr. Mineral. Petrology* 126, 137–151.

Graham C.M. & Powell R. 1984: A garnet-hornblende geothermometer, calibration, testing and application to the Pelona Schist, Southern California. *J. Metamorph. Geology* 2, 13–31.

Holland T.J.B. & Blundy J.D. 1994: Non-ideal interactions in calcic amphiboles and their bearing on amphibole-plagioclase thermometry. *Contr. Mineral. Petrology* 116, 433–447.

Holland T.J.B. & Powell R. 1998: An internally consistent thermodynamic data set for phases of petrological interest. *J. Metamorph. Geology* 16, 309–343.

Hovorka D., Ivan P. & Spišiak J. 1984: Nappe with amphibolite facies metamorphites in the Inner Western Carpathians. *Miner. Slovaca* 16, 73–88.

Hovorka D. & Méres Š. 1997: Alpine metamorphism in the Western Carpathians (with special attention on pre-Carboniferous complexes). In: Grecula P., Hovorka M. & Putiš M. (Eds.): Geological evolution of the Western Carpathians. *Miner. Slovaca — Monograph*, Bratislava, 79–88.

Hovorka D., Méres Š. & Caňo F. 1992: Petrology of garnet-clinopyroxene metabasites from the Malá Fatra Mountains. *Miner. Slovaca* 24, 45–52 (in Slovak).

Hovorka D., Méres Š. & Ivan P. 1993: Geodynamic setting of the main pre-Alpine basement complexes: the Western Carpathians. *Geol. Carpathica* 44, 258–259.

Hovorka D. & Méres Š. 1990: Clinopyroxene-garnet metabasites from the Tríbeč Mountains (Central Slovakia). *Miner. Slovaca* 22, 533–538.

Jacko S. 1978: Lithological and structural characteristics of the central part of Čierna Hora Mountains. *Západ. Karpaty, Sér. Geol.* 3, 59–80 (in Slovak).

Jacko S. 1985: Lithostratigraphical units of the Čierna Hora basement. *Geol. Práce, Spr.* 82, 127–133 (in Slovak).

Jacko S. & Faryad S.W. 1998: An overview of tectonometamorphic evolution of the Branisko and Čierna Hora Mountains (Western Carpathians). *Carpathian-Balkan Geol. Assoc., 16 Congress, August 2^nd^ September 02, 1998, Vienna (Austria)*, 241.

Jacko S., Korikovsky S.P. & Boronichin V.A. 1990: Equilibrium assemblages in gneisses and amphibolites from the Bujanová Complex (Čierna Hora). *Miner. Slovaca* 22, 3, 231–239.

Janák M. & Lupták B. 1997: Pressure-temperature conditions of high-grade metamorphism and migmatitization in the Malá Fatra crystalline complex, the Western Carpathians. *Geol. Carpathica* 48, 287–302.

Janák M., O'Brien P.J., Hurai V. & Reutel Ch. 1996: Metamorphic evolution and fluid composition of garnet-clinopyroxene amphibolites from the Western Tatra Mountains, Western Carpathians. *Lithos* 39, 57–79.

Janák M, Plašienka D., Frey M., Cosca M., Schmidt S.T., Lupták B. & Méres S. 2001: Cretaceous evolution of a metamorphic core complex, the Veporic unit, Western Carpathians (Slovakia): P-T conditions and in situ Ar-40/Ar-39 UV laser probe dating of metapelites. *J. Metamorph. Geology* 19, 197–216.

Janák M., Méres Š. & Ivan P. 2003: First evidence for omphacite and eclogite facies metamorphism in the Veporic unit of the Western Carpathians. *J. Czech Geol. Soc.* 48, Abstract volume, 69.

Joanny V., Van Roermund H. & Lardeaux J.M. 1991: The clinopyroxene plagioclase symplectite in retrograde eclogites — a potential geothermobarometer. *Geol. Rdsch.* 80, 303–320.

Kamenický J. 1968: Some problems of the West Carpathian crystalline complexe. *Geol. Zborn. Geol. Carpath.* 19, 7–20.

Kohn M.J. & Spear F.S. 1990: Two new geobarometers for garnet amphibolites, with applications to southeastern Vermont. *Amer. Mineralogist* 75, 89–96.

Korikovsky S.P. & Hovorka D. 2001: Two types of garnet-clinopyroxene-plagioclase metabasites in the Malá Fatra Mountains Crystalline Complex, Western Carpathians: Metamorphic evolution, P-T conditions, symplectite and kelyphitic textures. *Petrology* 9, 119–14.

Korikovsky S.P., Jacko S. & Boronichin V.A. 1989: Alpine anchimetamorphism of Upper Carboniferous sandstones from the sedimentary mantle of the Čierna Hora Mountains Crystalline Complex (Western Carpathians). *Geol. Zbor. Geol. Carpath.* 40, 5, 579–598.

Korikovsky S.P., Jacko S. & Boronichin V.A. 1990: Facies conditions of Variscan prograde metamorphosis in the Lodina complex of Čierna Hora crystalline, Eastern Slovakia. *Miner. Slovaca* 22, 3, 225–230.

Korikovsky S.P., Jacko S., Boronichin A.A. & Šucha V. 1992: Illite-paragonite layer intergrowths from the Gemericum nappe in the SE part of the Čierna Hora Mountains. Veporicum (Western Carpathians). *Geol. Carpathica* 43, 1, 49–55.

Korikovsky S.P., Putiš M., Plašienka D., Jacko S. & Ďurovič V. 1997: Cretaceous very-low grade metamorphism of the Infratatric and Supratatric domains: an indicator of thin-skinned tectonics in the Central Western Carpathians. In: Grecula P., Hovorka D. & Putiš M. (Eds.): Geological evolution of the Western Carpathians. *Miner. Slovaca — Monograph,* Bratislava, 89–106.

Kráľ J. 1994: Strontium isotopes in granitic rocks of the Western Carpathians. *Mitt. Österr. Geol. Gesell.* 86, 75–81.

Krist E., Putiš M., Korikovsky S., Janák M. & Faryad S.W. 1992: Geology and petrology of metamorphic rocks of the Western Carpathian Crystalline Complexes. *Comenius University*, Bratislava, 1–324.

Leake B.E., Woolley A.R., Arps C.E.S., Birch W.D., Gilbert M.C., Hawthorne F.C., Kato A., Kisch H.J., Krivovichev V.G., Linthout K., Laird J., Mandarino J., Maresch W.V., Nickel E.H., Rock N.M.S., Schumacher J.C., Smith D.C., Stephenson N.C.N., Ungaretti L., Whittaker E.J.W. & Youzhi G. 1997: Nomenclature of amphiboles. *Eur. J. Mineral.* 9, 623–651.

Liou J.G., Maruyama S. & Cho M. 1985: Phase-equilibria and mineral parageneses of metabasites in low-grade metamorphism. *Mineral. Mag.* 49, 321–333.

Massonne H.J. & Schreyer W. 1987: Phengite geobarometry based on the limiting assemblage with K-feldspar, phlogopite, and quartz. *Contr. Mineral. Petrology* 96, 212–224.

Méres Š., Ivan P. & Hovorka D. 2000: Garnet-pyroxene metabasite and antigorite serpentinites — evidence of leptino-amphibolite complex in the Branisko Mountains (Tatric unit, central Western Carpathians). *Miner. Slovaca* 32, 479–486.

Neubauer F. & Handler P. 2000: Variscan orogeny in the Eastern Alps and Bohemian Massif: How do these units correlate? *Mitt. Österr. Geol. Gesell.* 92, 35–59.

O'Brien P.J., Röhr C., Okrusch M. & Patzak M. 1992: Eclogite facies relics and a multistage breakdown in metabasites of the KTB pilot hole, NE Bavaria: implications for the Variscan tectonometamorphic evolution of the NW Bohemian Massif. *Contr. Mineral. Petrology* 112, 261–278.

Perchuk L.L., Aranovich L.Y., Podleskii K.K., Lavrent'eva I.V., Gerasimov V.Y.U., Fedk'in V.V., Kitsul V.I., Karsakiv L.P. & Berdnikov N.V. 1985: Precambrian granulites of the Aldan Shield, eastern Siberia, USSR. *J. Metamorph. Geology* 3, 265–310.

Pin C. & Marini F. 1993: Early Ordovician continental break-up in Variscan Europe: Nd-Sr isotope and trace element evidence from bimodal igneous associations of the southern Massif Central, France. *Lithos* 29, 177–196.

Polák M., Jacko S., Vozárová A., Vozár J., Gross P., Harčár J., Sasvári T., Zacharov M., Baláž B., Liščák P., Malík P., Zakovič

M., Karoli S. & Kaličiak M. 1997: Explanation to geological map from Branisko a Čierna Hora Scale 1:50,000. *MS D. Štúra*, Bratislava, 1–201 (in Slovak).

Poller U., Janák M., Kohút M. & Todt W. 2000: Early Variscan magmatism in the Western Carpathians: U-Pb zircon data from granitoids and orthogneisses of the Tatra Mountains (Slovakia). *Int. J. Earth Sci.* 89**,** 336–349.

Poller U. & Todt W. 2001: U-Pb single zircon data of granitoids from the High Tatra Mountains (Slovakia): implications for the geodynamic evolution. *Trans. Roy. Soc. Edinburgh-Earth Sci.* 91, 235–243.

Powell R. 1985: Regression diagnostics and robust regression in geothermometer/geobarometer calibration: the garnet-clinopyroxene geothermometer revisited. *J. Metamorph. Geology* 3, 231–243.

Powell R. & Holland T.J.B. 1988: An internally consistent dataset with uncertainties and correlations: 3. Applications to geobarometry, worked examples and a computer program. *J. Metamorph. Geology* 6, 173–204.

Putiš M. 1992: Variscan and Alpidic nappe structures of the Western Carpathian crystalline basement. *Geol. Carpathica* 43, 369–380.

Putiš M., Kotov A.B., Korikovsky S.P., Salnikova E.B., Yakovleva S.Z., Berezhnaya N.G., Kovach V.P. & Plotkina J.V. 2001: U-Pb zircon ages of dioritic and trondhjemitic rocks from a layered amphibolitic complex crosscut by granite vein (Veporic basement, Western Carpathians). *Geol. Carpathica* 52, 49–60.

Ravna E.K. 2000: The garnet-clinopyroxene geothermometer — an updated calibration. *J. Metamorph. Geology* 18, 211–219.

Ravna E.K. 2000b: Distribution of Fe^{2+} and Mg between coexisting garnet and hornblende in synthetic and natural systems: an empirical calibration of the garnet-hornblende Fe-Mg geothermometer. *Lithos* 53, 265–277.

Rozlozsnik P. 1935: Die geologischen Verhältnisse der Gegend von Dobšiná. *Geologica Hung., Ser. Geol.* 5, 1–118.

Rozložník L. 1965: Petrografie der granitisierten Gesteine der Rakovec Serie in der Umgang von Dobšiná. *Západ. Karpaty* 4, 95–144.

Sengupta P., Dasgupta S., Bhattacharya P.K. & Hariya Y. 1989: Mixing behavior in Quaternary garnet solid solution and an extended Ellis and Green garnet-clinopyroxene geothermometer. *Contr. Mineral. Petrology* 103, 223–227.

Spišiak J. & Pitoňák P. 1990: Nízke Tatry Mountains crystalline complex — new facts and interpretation (Western Carpathians, Czechoslovakia). *Geol. Zbor. Geol. Carpath.* 41, 377–392.

Springer R., Day H. & Beiersdorfer R. 1992: Prehnite-pumpellyite to greenschist facies transition, Smartville complex, near Auburn, California. *J. Metamorph. Geology* 10, 147–170.

Vozárová A. 1993: Pressure-temperature conditions of metamorphism in the northern part of the Branisko crystalline complex. *Geol. Carpathica* 44, 219–232.

Vrána S. & Vozár J. 1969: Pumpellyite-prehnite facies mineral assemblages from Nízke Tatry. *Geol. Práce, Spr.* 49, 91–100 (in Slovak).

Wood D.A. 1980: The application of a Th-Hf-Ta diagram to problems of tectonomagmatic classification and to establishing the nature of crustal contamination of basaltic lavas of the British Tertiary Volcanic Province. *Earth Planet. Sci. Lett.* 50, 11–30.