Eclogite facies metaultramafite from the Veporic Unit (Western Carpathians, Slovakia)

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Abstract: Metaultramafic rocks closely associated with eclogites in the Veporic unit of the Western Carpathians record a complex *P*–*T* evolution, including the effects of high-pressure (HP) metamorphism. The investigated metaultramafite is chemically similar to pyroxenite, has a fine- to medium-grained texture, is composed predominantly of olivine and amphibole, and contains minor amounts of garnet, orthopyroxene, spinel, chlorite, ilmenite and carbonates. The high-pressure mineral assemblage is garnet (X_{Mg}=0.46–0.47)+olivine (X_{Mg}=0.71–0.73)+low-Al orthopyroxene (X_{Mg}=0.77–0.78; Al=0.02–0.03 apfu)+ilmenite+chlorite (X_{Mg}=0.87–0.89)+Cr-spinel. Chromium-rich spinel is most likely a relict from the pre-HP metamorphic stage, possibly of magmatic origin. Calculations using a garnet–orthopyroxene Fe–Mg exchange thermometer, Al-in-orthopyroxene barometer, and thermodynamic modelling in the system SiO_2–TiO_2–Al_2O_3–FeO–MgO–CaO–H_2O indicate that the peak conditions of metamorphism reached 2.4±0.4 GPa and 702±20 °C. Subsequent decompression and retrogression is recorded by the formation of aluminous orthopyroxene, replacement of garnet by symplectites of Al-spinel and amphibole (hornblende), transformation of Cr-spinel to Al-spinel and formation of abundant amphibole in the matrix. Metaultramafic rocks in the Veporic unit thus provide evidence, in addition to that from associated eclogites, for high-pressure metamorphism in the pre-Alpine basement of the Western Carpathians, which is most likely of Variscan age.

Keywords: Metaultramafite, eclogite, high-pressure metamorphism, subduction, Western Carpathians.

Introduction

“Orogenic” or “Alpine-type” peridotites represent mantle fragments that were tectonically incorporated in collisional mountain belts worldwide. These peridotite complexes commonly experienced high-pressure (HP) and ultrahigh-pressure (UHP) metamorphism that stabilized garnet in the various ultramafic lithologies, which include lherzolites, harzburgites, wehrlites, dunites and pyroxenites. In some instances, these ultramafic rocks, which are commonly associated with eclogites, were transferred from an overlying mantle wedge into subducting continental and oceanic crust, where all rock types experienced HP conditions that stabilized garnet in ultramafic rocks (garnet peridotite), omphacite in mafic rocks (eclogite), and coesite in silicic rocks (Brueckner & Medaris 2000; Scambelluri et al. 2010). Alternatively, lower-pressure spinel peridotites may be carried to deeper levels within a subducting host continental slab and develop garnet-bearing assemblages at HP (Medaris & Carswell 1990) or HP/UHP metamorphic conditions (e.g., Van Roermund & Drury 1998; Zhang et al. 2003; Janák et al. 2006; Faryad 2009). A third scenario is one in which ultramafic crystal cumulates (e.g., ophiolite components or ultramafic differentiates of mafic intrusions) were subducted “ab initio” together with other crustal rocks to HP conditions, producing garnet peridotites (e.g., Goddard et al. 1996; Ravna et al. 2006). Note that in all three of these tectonic situations, mafic rocks associated with peridotites are transformed to eclogite.

The pre-Alpine basement of the Western Carpathians represents an important segment of the Variscan orogeny in Europe, which marks the collision of Laurasia with Gondwana-affiliated terranes during the Paleozoic. Evidence for pre-Alpine subduction and high-pressure metamorphism is provided by eclogites, which are mostly retrogressed to garnet amphibolites and occur in all major tectonic units – Tatric, Veporic and Gemeric (Hovorka & Méres 1990; Hovorka et al. 1992; Janák et al. 1996, 2007, 2009; Janák & Lupták 1997; Faryad et al. 2005, 2020). Metaultramafic rocks occur sporadically in the pre-Alpine basement complexes of the Western Carpathians (Hovorka 1994; Korikovskij et al. 1998) but typical “Orogenic” or “Alpine-type” garnet peridotites of mantle origin are unknown.

Following our previous study of eclogites (Janák et al. 2007), we have investigated rare, garnet-bearing metaultramafic rock associated with eclogites in the leptyno-amphibolite complex (LAC) of the North Veporic unit. Described here are the textures, mineral assemblages, and mineral compositions of a sample of garnet–orthopyroxene–olivine–amphibole metaultramafite. The peak *P*–*T* conditions evaluated by conventional thermobarometry and thermodynamic modeling are similar to those of accompanying eclogites, revealing that both lithologies experienced high-pressure metamorphism, most probably during the Variscan orogeny.

Geological background

The investigated metaultramafic rocks occur in the northern part of the Veporic unit (Fig. 1), where the pre-Alpine basement is overlain by an Upper Paleozoic–Triassic sedimentary cover. The magmatic and metamorphic history of the Veporic unit was polyphase, comprising pre-Variscan, Variscan, Permian and Alpine events (e.g., Bezák et al. 1993; Plašienka et al. 1997, 2016; Putiš et al. 1997; Janák et al. 2001; Jeřábek et al. 2008a, b; Vojtko et al. 2016; Plašienka 2018).

The northern part of the Veporic unit is composed of several basement complexes covered by Permian and Mesozoic rocks (Fig. 1). The eclogites are part of the basement that is variously referred to as the Hron complex (Klinec 1966), leptyno-amphibolite complex (Hovorka et al. 1994, 1997) or layered metaigneous complex (Putiš et al. 1997). In this paper we use the term "leptyno-amphibolite complex" (LAC). In the investigated area, the LAC is composed of several rock types, the most abundant of which are amphibolites and gneisses (both ortho- and para-gneisses) that are strongly deformed and retrogressed to epidote amphibolites, mica

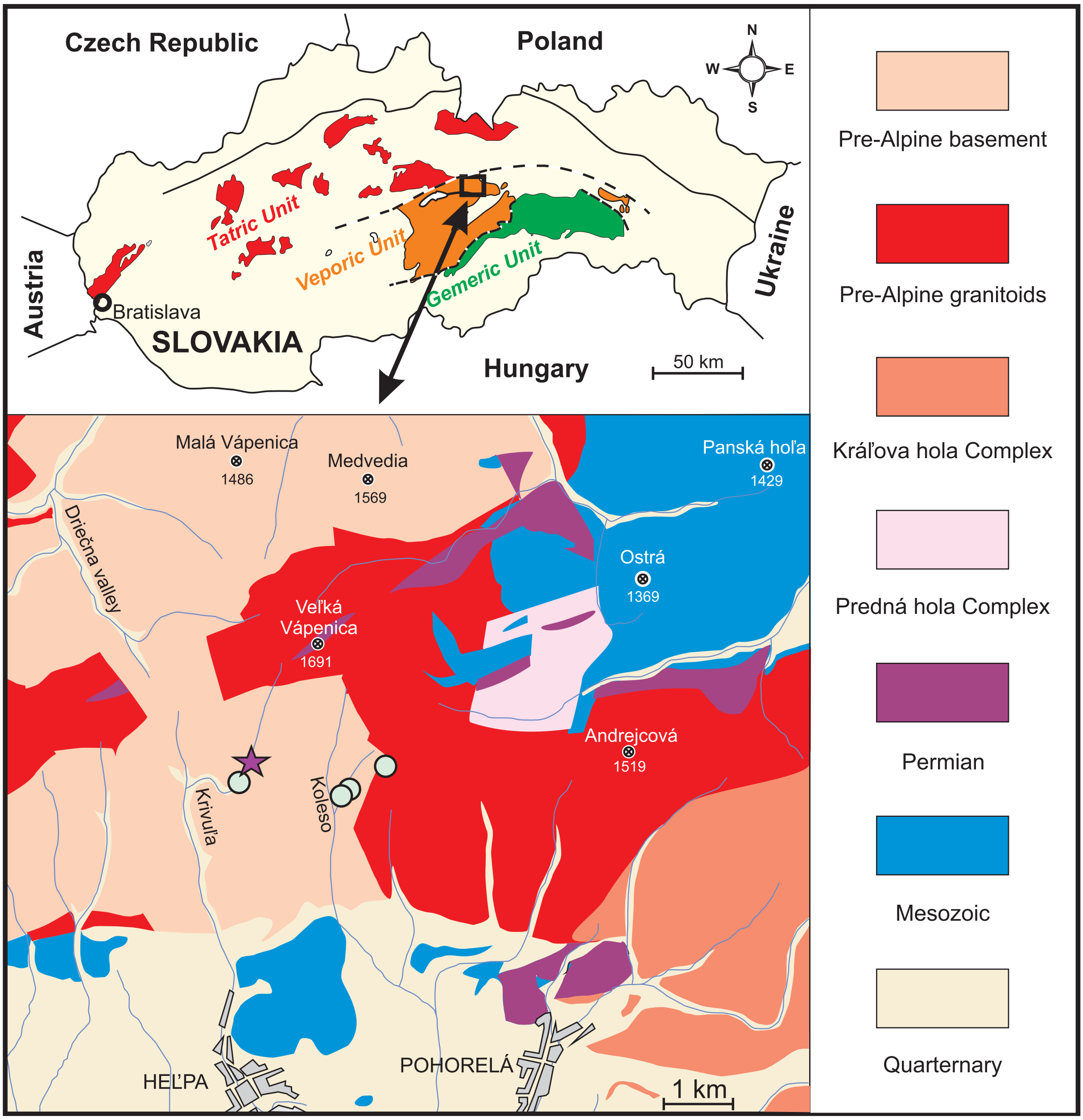

Fig. 1. Simplified geological map of the northern parts of the Veporic unit showing the locations of metaultramafite (star) and eclogite (circle) modified from Biely et al. 1992).

schists and phyllites. Garnet amphibolites with relicts of eclogites and ultramafic rocks (olivine gabbro, troctolite) occur in sporadic outcrops of metre to tens of metres size (Ivan et al. 1996; Méres et al. 1996; Janák et al. 2007). Pre-Alpine granitoids and associated gneisses and mica schists belonging to the Kráľova hoľa complex were strongly affected by Alpine mylonitization. The intrusion age of these granitoids is 350 Ma, based on SHRIMP dating of zircons (Gaab et al. 2006). The Predná hoľa complex is composed of phyllites, metasandstones, basic volcanics and volcanoclastics that were recrystallized at low grades of metamorphism. Permian rocks include metamorphosed conglomerates, sandstones, arkoses and greywackes locally with volcanogenic material. Mesozoic rocks consist of Triassic carbonates and quartzites that were affected by low-grade metamorphism in Cretaceous time (Lupták et al. 2003).

Petrography and mineral chemistry

The investigated sample VV255 occurs as a loose block of ca. 1–1.5 m size within the LAC in the Krivuľa valley, Low Tatra Mountains (Fig. 1). This metaultramafic rock (Fig. 2) has a medium-grained granoblastic texture and is composed predominantly of olivine and amphibole. Accessory spinel is zoned, with green spinel containing cores of brown spinel (Fig. 3). Minor mineral phases include orthopyroxene, garnet, chlorite, ilmenite and carbonates. Unlike typical gabbroic

Fig. 2. Photograph of metaultramafite sample VV255.

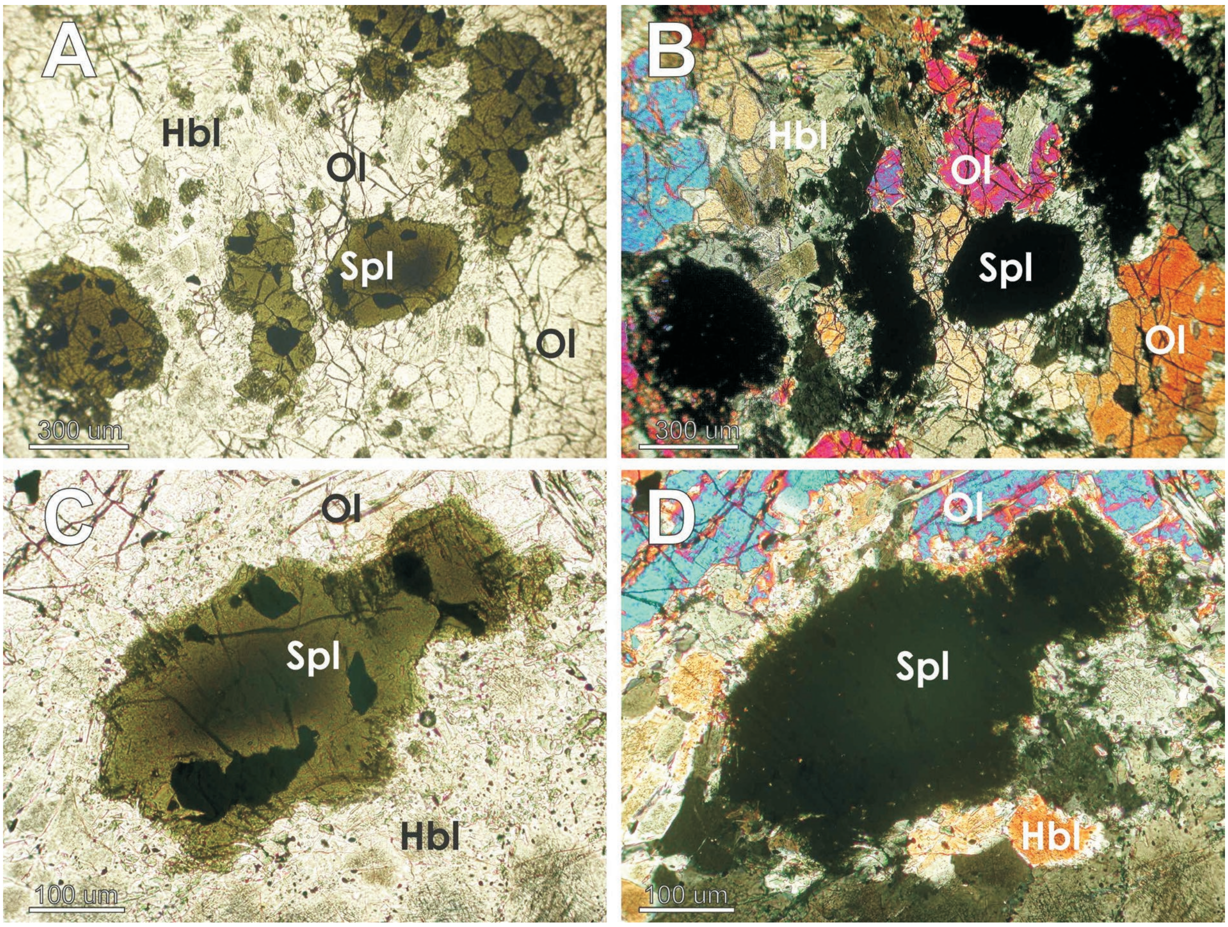

Fig. 3. Photomicrographs of metaultramafite texture with olivine, hornblende and spinel in the matrix; green spinel shows dark-brown cores. **A, C** — Plane polarized transmitted light; **B, D** — cross polarized light.

rocks (olivine gabbro, troctolite) within the LAC in the area (Ivan et al. 1996), the investigated metaultramafite shows no corona texture or remnants of plagioclase.

The compositions of the main mineral phases were determined using a CAMECA SX-100 electron microprobe at Dionýz Štúr Institute of Geology in Bratislava. Analytical conditions were 15 kV accelerating voltage and 20 nA beam current, with a peak counting time of 20 seconds and a beam diameter of 2–10 μm. Raw counts were corrected using a PAP routine. Calibration standards included natural minerals (Si, Ca: wollastonite, Na: albite, K: orthoclase, Fe: fayalite, Mn: rhodonite), pure element oxides (TiO_2, Al_2O_3, Cr_2O_3, MgO), and metals (Ni). Mineral abbreviations are according to Whitney & Evans (2010).

Garnet occurs as tiny irregular grains or accumulations of several grains (Fig. 4). The composition of garnet is relatively

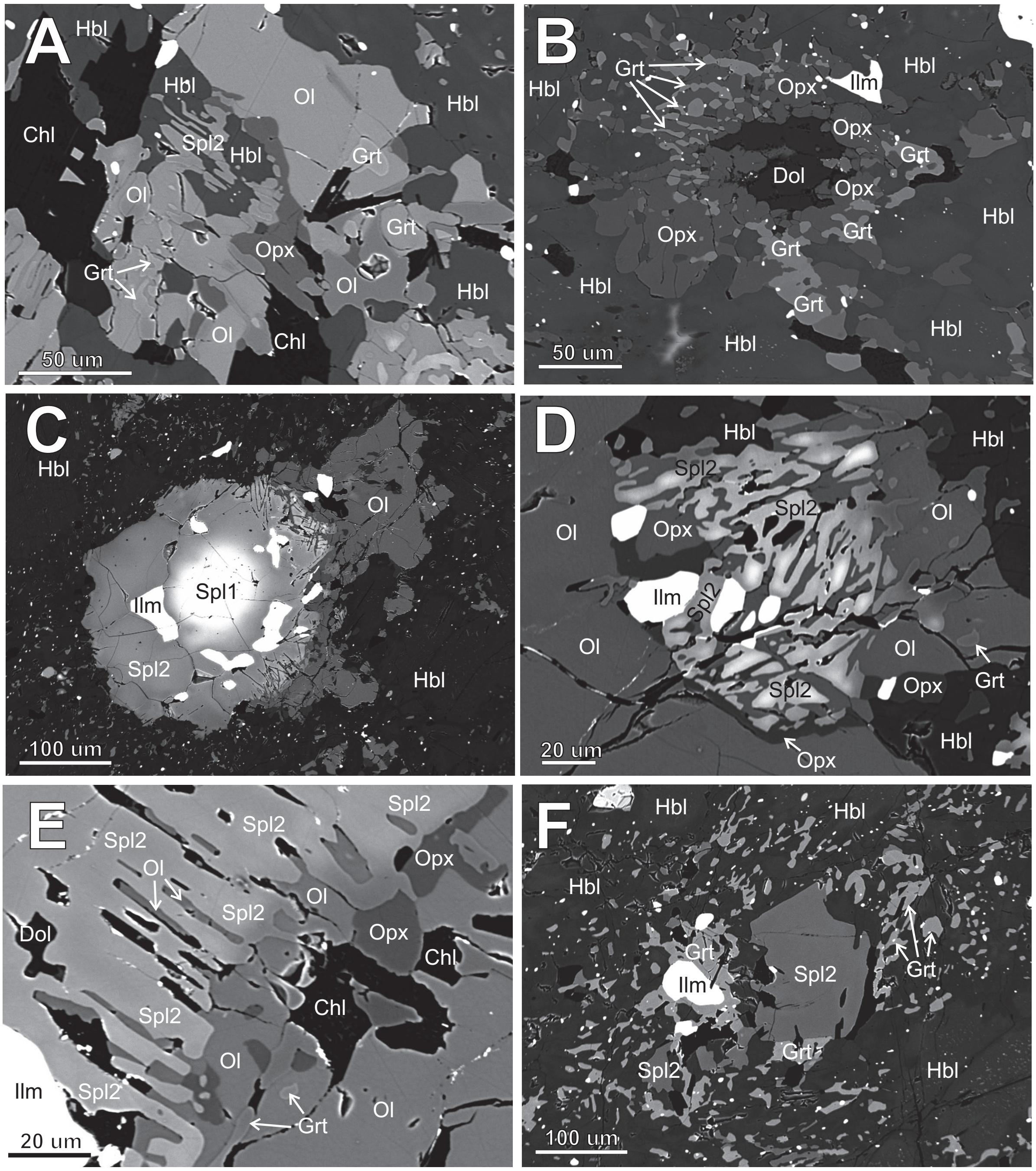

Fig. 4. Back-scattered electron (BSE) images of metaultramafite. **A** — Olivine (Ol), orthopyroxene (Opx) and garnet (Grt) partly replaced by Al-spinel (Spl2) and hornblende (Hbl) symplectite. **B** — Garnet, orthopyroxene, chlorite, carbonate and hornblende in the matrix. **C** — Cr-spinel (Spl1) rimmed by Al-spinel (Spl2). **D, E** — Garnet, olivine, orthopyroxene, ilmenite and chlorite partly replaced by Al-spinel. **F** — Garnet, ilmenite and Cr-spinel in the hornblende-rich matrix.

homogenous (X_{Prp}=0.37–39, X_{Alm}=0.42–0.44, X_{Grs}=0.15–0.18, X_{Sps}=0.3–0.04) with X_{Mg}=Mg/(Mg+Fe) ranging from 0.46 to 0.47 (Table 1). Orthopyroxene (Fig. 4) has a composition with X_{Mg}=0.77–0.78 and Al_2O_3=0.5–1.0 wt. %, with the lowest Al concentrations (0.02–0.03 apfu) occurring in the cores of the grains (Table 2). Olivine occurs as anhedral grains (Fig. 4), with a nearly homogeneous composition (X_{Mg}=0.71–0.73; Table 3). Spinel occurs in two textural varieties: discrete anhedral grains of variable size (~100–500 μm) and small (~20 μm) anhedral grains in symplectite (Fig. 4). Discrete spinel is continuously zoned from brown, chromian spinel cores (Spl1) to green, aluminous rims (Spl2; Fig. 4), whose compositions decrease in Cr* number (=100×Cr/(Cr+Al)) from 37 in cores to 5–6 in rims (Figs. 5, 6; Table 4). Aluminous spinel (Cr*=2–3) occurs in symplectites (Fig. 4), where hornblende and orthopyroxene (Al_2O_3≥1 %) replace garnet and olivine. Ilmenite inclusions are common in spinel and tend to be located in the aluminous rims (Fig. 4); ilmenite occurs also in the matrix. Chlorite, carbonate and pale green amphibole are present in the matrix (Fig. 4); chlorite is Mg-rich with X_{Mg}=0.88–0.90 (Table 4), carbonate is mostly dolomite, and amphibole is hornblende (Table 5).

Metaultramafite whole–rock geochemistry

Whole-rock analysis determined by the ICP–ES/MS method (Bureau Veritas, Canada) yields the following major element composition: SiO_2=43.20, TiO_2=1.74, Al_2O_3=7.84, Cr_2O_3=0.30, Fe_2O_3=13.90, MgO=22.10, CaO=8.54, Na_2O=0.67, K_2O=0.17 (wt. %), which lies within the picrite-meimechite compositional fields (Fig. 7) according to the chemical classification of Le Bas (2000). However, these terms refer to volcanic rock types, and there is no evidence that the sample had a volcanic origin. Consequently, the Veporic "ultramafite" has been compared with other Variscan ultramafic rock types, including Veporic eclogite, eclogite and garnet pyroxenite layers in peridotite in the Gföhl nappe, Moldanubian zone, Bohemian Massif (Medaris et al. 1995), eclogites from the Mariánské Lázně metaophiolite complex at the boundary between the Saxothuringian and Teplá–Barrandian terranes,

Table 1: Representative el. microprobe analyses of garnet.

SiO_2	40.42	40.19	40.03	39.95	40.42
TiO_2	0.06	0.04	0.02	0.00	0.06
Al_2O3	22.20	22.24	22.49	21.97	22.20
Cr_2O_3	0.44	0.14	0.15	0.33	0.44
FeO	19.91	19.97	20.17	20.24	19.91
MnO	1.31	1.47	1.44	1.85	1.31
MgO	9.59	9.79	9.82	9.59	9.59
CaO	6.60	6.38	6.01	5.42	6.60
Total	100.53	100.22	100.13	99.35	100.53
12 Oxygens					
Si	3.035	3.028	3.018	3.039	3.035
Ti	0.003	0.002	0.001	0.000	0.003
Al	1.965	1.975	1.998	1.970	1.965
Cr	0.026	0.008	0.009	0.020	0.026
Fe	1.250	1.258	1.272	1.288	1.250
Mn	0.083	0.094	0.092	0.119	0.083
Mg	1.073	1.099	1.104	1.088	1.073
Ca	0.531	0.515	0.485	0.442	0.531
Total	7.967	7.979	7.978	7.966	7.967
X_{Mg}*	0.46	0.47	0.46	0.46	0.46
X_{Prp}	0.37	0.37	0.37	0.37	0.37
X_{Grs}	0.18	0.17	0.16	0.15	0.18
X_{Alm}	0.43	0.42	0.43	0.44	0.43
X_{Sps}	0.03	0.03	0.03	0.04	0.03

*X_{Mg}=Mg/(Mg+Fe)

Table 2: Representative el. microprobe analyses od orthopyroxene.

SiO_2	56.10	56.05	56.55	55.63	55.57
TiO_2	0.00	0.02	0.03	0.01	0.05
Al_2O_3	0.51	0.65	0.74	1.04	0.91
Cr_2O_3	0.03	0.05	0.05	0.10	0.10
FeO	15.00	15.37	14.57	14.91	14.92
MnO	0.40	0.42	0.36	0.44	0.38
MgO	28.36	28.15	28.40	27.95	28.04
CaO	0.26	0.16	0.25	0.31	0.26
Total	100.66	100.86	100.95	100.38	100.24
6 Oxygens					
Si	1.997	1.994	2.000	1.986	1.987
Ti	0.000	0.001	0.001	0.000	0.001
Al	0.022	0.027	0.031	0.044	0.038
Cr	0.001	0.001	0.001	0.003	0.003
Fe	0.446	0.457	0.431	0.445	0.446
Mn	0.012	0.013	0.011	0.013	0.012
Mg	1.505	1.493	1.498	1.488	1.494
Ca	0.010	0.006	0.010	0.012	0.010
Total	3.992	3.991	3.983	3.990	3.991
X_{Mg}	0.77	0.77	0.78	0.77	0.77

Table 3:. Representative el. microprobe analyses of olivine.

SiO_2	38.57	38.58	38.23	38.23	38.70
TiO_2	0.00	0.03	0.00	0.00	0.00
Al_2O_3	0.00	0.00	0.00	0.00	0.00
FeO	25.58	23.71	25.05	24.08	24.46
MnO	0.42	0.39	0.33	0.30	0.35
MgO	35.17	36.31	35.47	36.32	36.90
NiO	0.14	0.28	0.15	0.16	0.28
CaO	0.02	0.07	0.04	0.05	0.06
Total	99.89	99.36	99.25	99.13	100.74
4 Oxygens					
Si	1.019	1.017	1.014	1.011	1.008
Ti	0.000	0.001	0.000	0.000	0.000
Al	0.000	0.000	0.000	0.000	0.000
Fe	0.565	0.522	0.556	0.533	0.533
Mn	0.009	0.009	0.007	0.007	0.008
Mg	1.385	1.426	1.403	1.432	1.433
Ni	0.003	0.006	0.003	0.003	0.006
Ca	0.000	0.002	0.001	0.001	0.002
Total	2.981	2.982	2.985	2.988	2.989
X_{Mg}	0.71	0.73	0.72	0.73	0.73

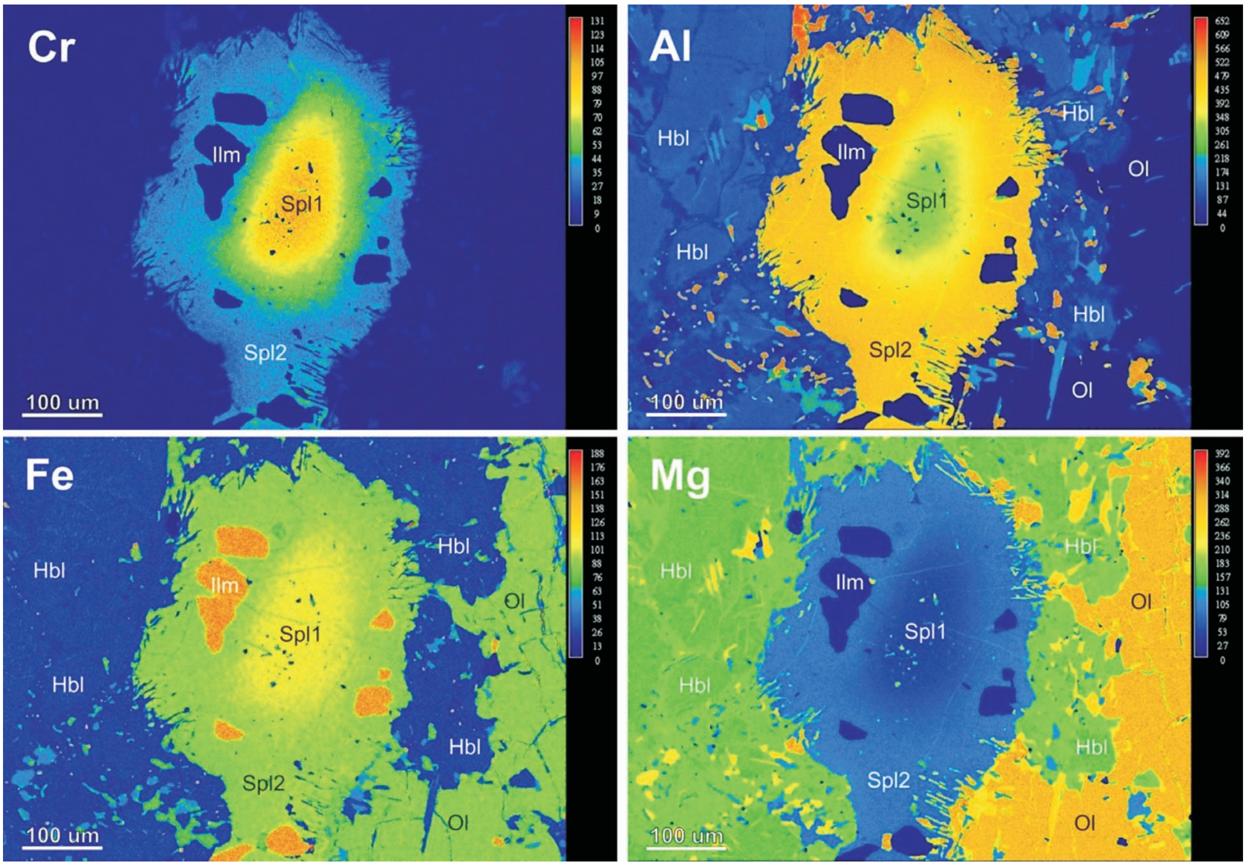

Fig. 5. Compositional X-ray maps of spinel showing the distribution of Cr, Al, Fe and Mg.

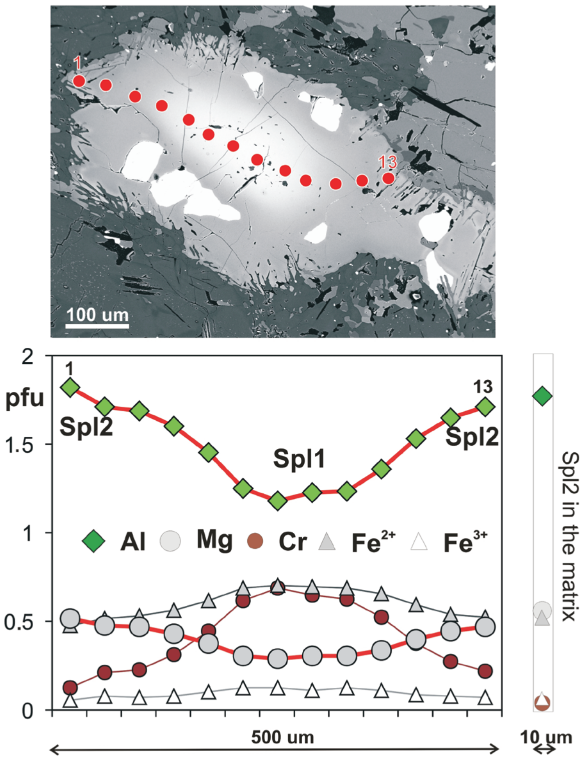

Fig. 6. Back-scattered electron (BSE) image of spinel with analysed points shown in the compositional profile across spinel.

Bohemian Massif (Beard et al. 1995), and eclogites in the pre-Alpine nappe stack of the Getic–Supragetic basement, South Carpathians (Medaris et al. 2003). The whole rock composition of the Veporic metaultramafite lies within the combined compositional field for eclogite–pyroxenite–peridotite suites (Fig. 7). In general, it has a closer chemical similarity to pyroxenite, rather than eclogite, except that it has a higher TiO_2 content than the pyroxenites, and its Mg# is at the boundary between those for pyroxenites and eclogites.

P–T conditions

Peak metamorphic *P–T* conditions have been calculated using conventional geothermobarometry and thermodynamic modelling.

A combination of the garnet–orthopyroxene Fe–Mg exchange thermometer (Harley 1984), and the Al-in-orthopyroxene barometer (Brey & Köhler 1990) was applied, using the compositions of garnet with the highest pyrope content and orthopyroxene with the lowest Al content. Due to the uncertainties in Fe^{3+} concentrations in these phases obtained via electron microprobe analysis, all Fe is taken to be Fe^{2+} in the calculations.

Application of the garnet–orthopyroxene geothermometer together with the Al-in-orthopyroxene geobarometer yields

Table 4: Representative el. microprobe analyses of chlorite and spinel.

Mineral	Chl	Chl	Chl	Spl	Spl	Spl
SiO_2	34.03	29.03	30.5	0.03	0	0.1
TiO_2	0.02	0.02	0.07	0.02	0.17	0.04
Al_2O_3	16.74	21.15	19.4	57.31	32.45	59.33
Cr_2O_3	1.51	0.12	0.27	5.84	28.12	2.83
FeO	7.76	6.5	6.74	23.53	32.05	23.22
MnO	0.06	0	0.02	0.2	0.32	0.13
MgO	30.67	28.9	29.74	12.83	6.36	13.56
CaO	0.09	0.09	0.06	0.05	0	0
Total	90.88	85.81	86.8	100.06	100.01	99.51
Oxygens	14	14	14	4	4	4
Si	3.138	2.818	2.929	0.001	0	0.003
Ti	0.001	0.001	0.005	0	0.004	0.001
Al	1.82	2.42	2.197	1.822	1.181	1.873
Cr	0.11	0.009	0.02	0.125	0.686	0.06
Fe	0.598	0.528	0.541	0.582	0.953	0.579
Mn	0.005	0	0.002	0.005	0.008	0.003
Mg	4.215	4.181	4.257	0.516	0.293	0.541
Ca	0.009	0.009	0.006	0.001	0	0
Na	0	0	0	0	0	0
K	0	0	0	0	0	0
Total	9.896	9.966	9.957	3	3	3
X_{Mg}	0.88	0.89	0.89			
Cr* = Cr(Cr+Al)				6.42	36.74	3.10

Table 5: Representative el. microprobe analyses of amphibole.

SiO_2	51.84	45.92	47.50	51.48	50.89
TiO_2	0.31	0.43	0.54	0.25	0.28
Al_2O_3	7.67	12.60	10.80	7.26	7.77
FeOt	6.35	6.82	6.68	5.72	6.10
MnO	0.12	0.07	0.17	0.09	0.05
MgO	19.28	16.66	17.52	19.13	19.29
CaO	12.47	12.59	12.56	12.63	12.70
Na_2O	0.63	1.01	0.89	0.56	0.61
K_2O	0.19	0.57	0.33	0.18	0.22
Total	98.86	96.67	96.98	97.29	97.91
23 Oxygens					
Si	7.443	6.593	6.673	7.232	7.129
Ti	0.034	0.046	0.057	0.026	0.029
Al	1.298	2.133	1.787	1.201	1.283
Fe	0.762	0.819	0.785	0.672	0.714
Mn	0.015	0.009	0.020	0.010	0.006
Mg	4.126	3.566	3.669	4.006	4.028
Ca	1.919	1.936	1.890	1.901	1.907
Na	0.175	0.281	0.243	0.152	0.166
K	0.034	0.104	0.059	0.032	0.039
Total	15.807	15.487	15.182	15.233	15.302

intersecting *P–T* values at 2.1–2.9 GPa and 674–731 °C, with average values of 2.4±0.4 GPa and 702±20 °C.

Thermodynamic modelling was performed with the Perple_X thermodynamic software (Connolly 2005: version 6.8.6) and internally consistent thermodynamic database of Holland & Powell (2011). Solid-solution models for garnet, orthopyroxene and olivine (Jennings & Holland 2015), chlorite, ilmenite (White et al. 2014), and amphibole (Dale et al. 2005) were used, as available from the Perple_X datafile (solution_model.dat). The bulk rock composition, as given above, was used in the calculations, which were performed in the system SiO_2–TiO_2–Al_2O_3–FeO–MgO–CaO–H_2O, assuming pure H_2O fluid saturation.

The calculated phase diagram (Fig. 8) shows the stability fields of the mineral assemblages and the compositional isopleths of garnet (X_{Mg}^{Grt}), orthopyroxene (X_{Mg}^{Opx}), (X_{Al}^{Opx}), olivine (X_{Mg}^{Opx}) and chlorite (X_{Mg}^{Chl}). The calculated mineral compositions corresponding to the measured ones (Tables 1–4) and the peak *P–T* conditions resulting from conventional geothermobarometry (2.4±0.4 GPa; 702±2 °C) plot within the stability field of garnet+orthopyroxene+olivine+ilmenite+chlorite (Fig. 7).

Discussion

The textural characteristics and thermobarometric results for the investigated garnet-bearing ultramafite reveal a complex *P–T* evolution.

The assemblage garnet+olivine+low-Al orthopyroxene+ilmenite+Mg-rich chlorite+Cr-spinel is interpreted to represent the stable mineral assemblage at peak metamorphic conditions. Cr-spinel may represent a mineral relict from the pre-HP metamorphic stage (Spl_0), possibly of magmatic origin, although it may have been stable at peak metamorphic conditions because chromium shifts the spinel–garnet transition towards higher pressures (Klemme 2004). Garnet crystallized from lower pressure phases during prograde metamorphism via a reaction such as,

Spl_0+high-Al Opx+Cpx (or Amp)=Grt+Ol+low-Al Opx+ Spl_1

Due to decompression during exhumation, Cr-spinel (Spl_1) was transformed to Al-spinel (Spl_2) and garnet was replaced by Al-spinel, high-Al orthopyroxene, and amphibole. Continued decompression and cooling led to formation of abundant amphibole in the matrix. Consequently, the high-pressure metaultramafite has been extensively retrograded in the amphibolite facies and the rock now consists largely of amphibole and olivine.

Peak *P–T* conditions of metaultramafite are similar to those of the associated eclogites (2.5 GPa, 700 °C; Fig. 9), thus providing further evidence for high-pressure metamorphism in the pre-Alpine basement of the North Veporic unit. Although the timing of eclogite facies metamorphism has not yet been determined, existing data support a pre-Alpine age. Microprobe dating of monazite from the kyanite-bearing para- and ortho-gneisses in the northern Veporic unit (Janák et al. 2002) yielded two groups of ages. The older one (ca. 470 Ma) is interpreted as recording pre-Variscan (Ordovician) magmatism, whereas the younger one (ca. 340 Ma), as Variscan (Carboniferous) metamorphism. In addition, zircon grains in orthogneisses also reveal a Variscan (Carboniferous)

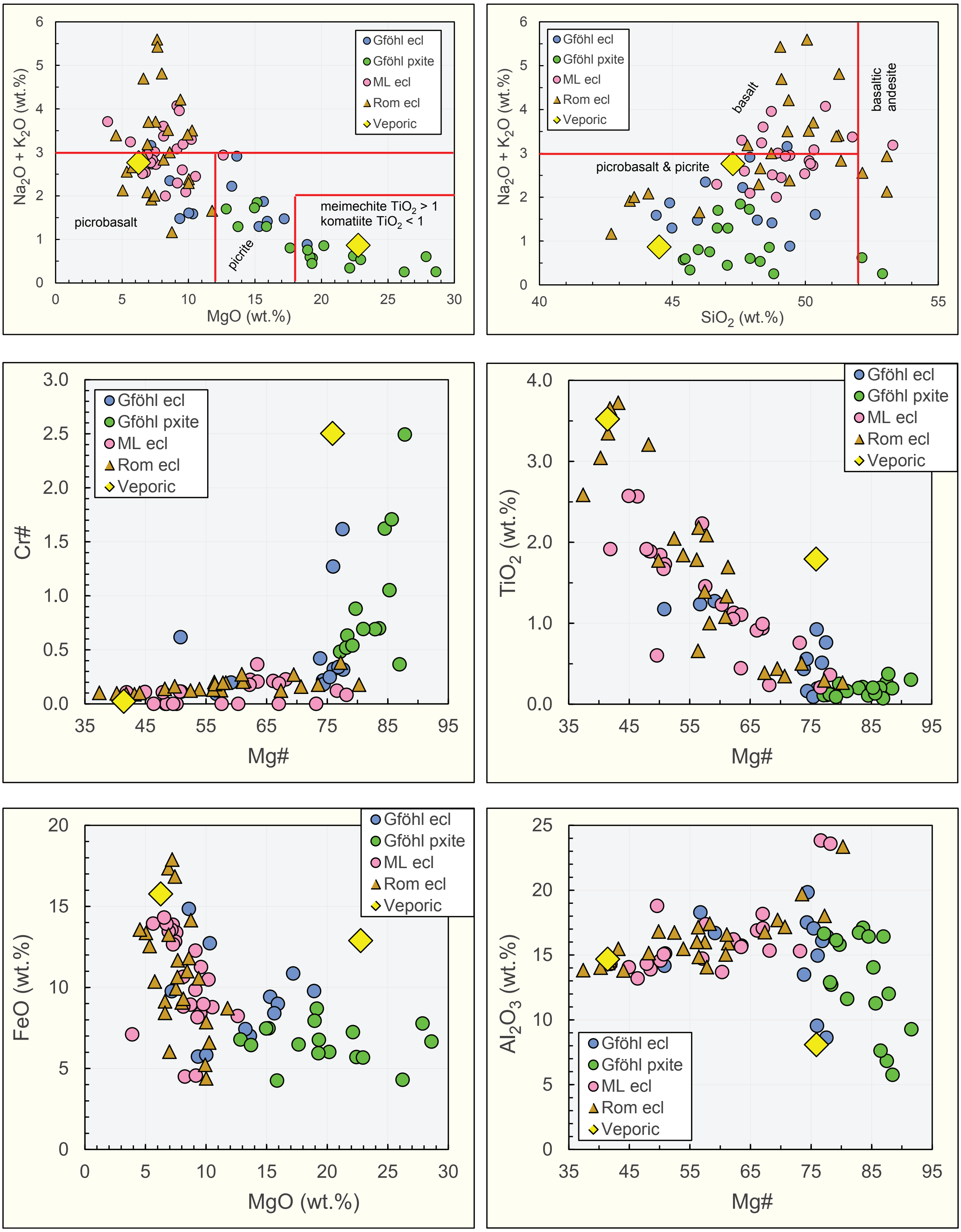

Fig. 7. Whole–rock analyses of Variscan eclogites and pyroxenites: Gföhl ecl and Gföhl pxite — eclogite and pyroxenite layers in massif peridotites in the Moldanubian Gföhl nappe, Bohemian Massif; ML ecl — eclogite in the Mariánské Lázně complex, Bohemian Massif; Rom ecl — eclogites in the pre-Alpine nappe stack of the Getic–Supragetic basement, South Carpathians, Romania; Veporic — eclogite and metaultramafite of this investigation.

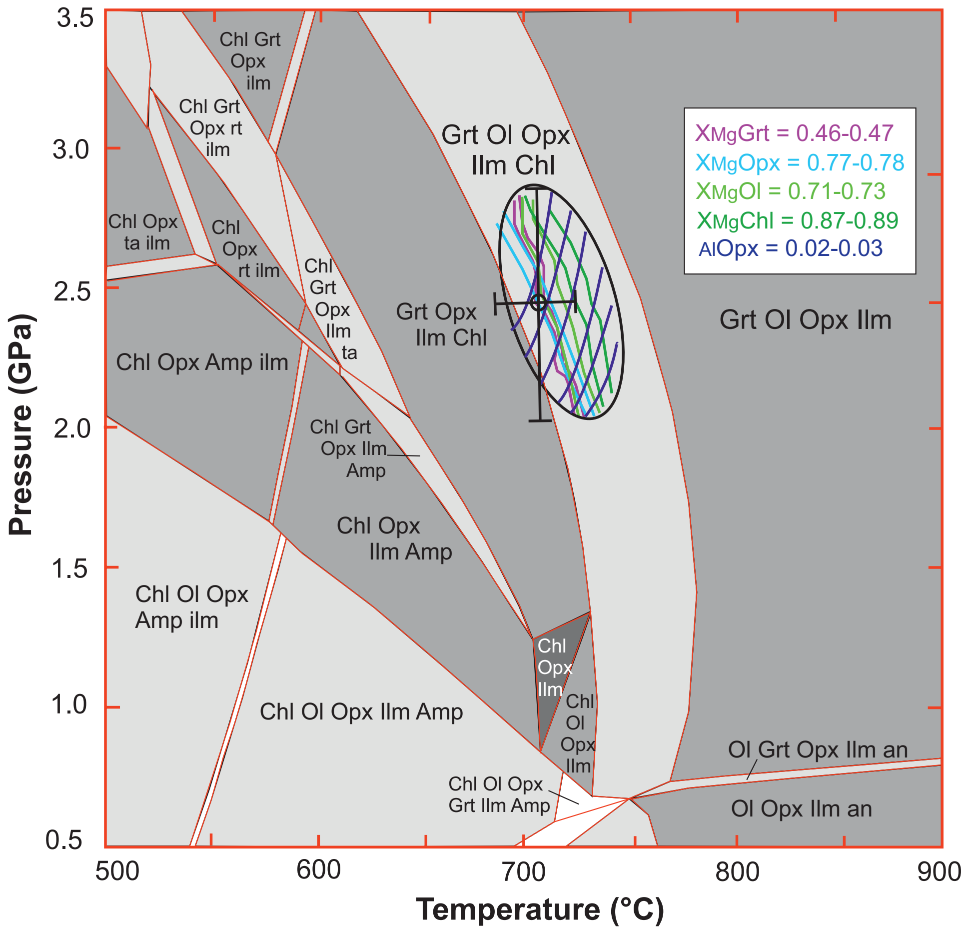

Fig. 8. *P–T* section of the metaultramafite in the system CFMASTH (CaO=9.0, FeO=10.30, MgO=32.39, Al_2O_3=4.54, SiO_2=42.5, TiO_2=1.29 mol. %, H_2O in excess) with compositional isopleths of garnet, orthopyroxene, olivine and chlorite at the peak metamorphic stage (ellipse). Results from conventional geothermobarometry (cross) are also shown. See text for more details.

metamorphic overprint (Gaab et al. 2006; Putiš et al. 2008), and Ar–Ar data on amphiboles from the northern Veporic unit yield mostly pre-Alpine ages (Kráľ et al. 1996). In contrast to Variscan metamorphism, Alpine metamorphism resulting from crustal thickening in Cretaceous time attained maximum *P–T* conditions of 1–1.2 GPa and 600–620 °C in the southern part of the Veporic unit (Janák et al. 2001; Jeřábek et al. 2008b, 2012). To summarize, *P–T* conditions and available age data suggest that the high-pressure rocks in the northern part of the Veporic unit were subducted to depths of about 80 km during the Variscan orogeny.

Variscan metamorphism is well documented in the pre-Alpine basement complexes of the Tatric unit where Alpine recrystallization was relatively weak. Variscan structure is preserved in the Western Tatra, where a high-grade unit comprising eclogites, kyanite-bearing gneisses and migmatites has been thrust top-to-the south over a lower-grade mica schist unit, showing an inverted metamorphic sequence (Janák 1994; Janák et al. 1996, 1999). The Sm/Nd dating of garnet from eclogite in the Western Tatra yields an age of 342 Ma (Moussallam et al. 2012). It is therefore inferred that HP metamorphism resulted from subduction in Variscan time. Similar, southward thrust vergency of the Tatric and Veporic pre-Alpine basement complexes has been considered to reflect exhumation of the LAC along a northward dipping subduction zone (Bezák et al. 1997; Putiš et al. 1997). In this case, the LAC represents the overriding plate with segments of the lower continental crust including eclogites (Hovorka et al. 1997) that were involved in the subduction zone. Faryad et al. (2020) proposed that the LAC was exhumed either along a hypothetical subduction zone located within the Tatric–Veporic realm or along the “Rakovec suture“ (a suture zone formed by the closure of a Devonian oceanic basin), prior to the Upper Carboniferous. It should be noted that the eclogite investigated by Faryad et al. (2020) occurs as a pebble in Upper Carboniferous conglomerate from Rudňany in the Gemeric unit.

The pre-Alpine basement of the Western Carpathians has been affected by Alpine tectonic events, and its original position and connection to the Variscan orogenic belt in Europe is uncertain. Similarities to the Bohemian Massif have been recognized in high-grade metamorphic rocks exposed in the Tatra Mountains (Moussallam et al. 2012), suggesting an eastern extension of the Moldanubian zone. Southeast of the

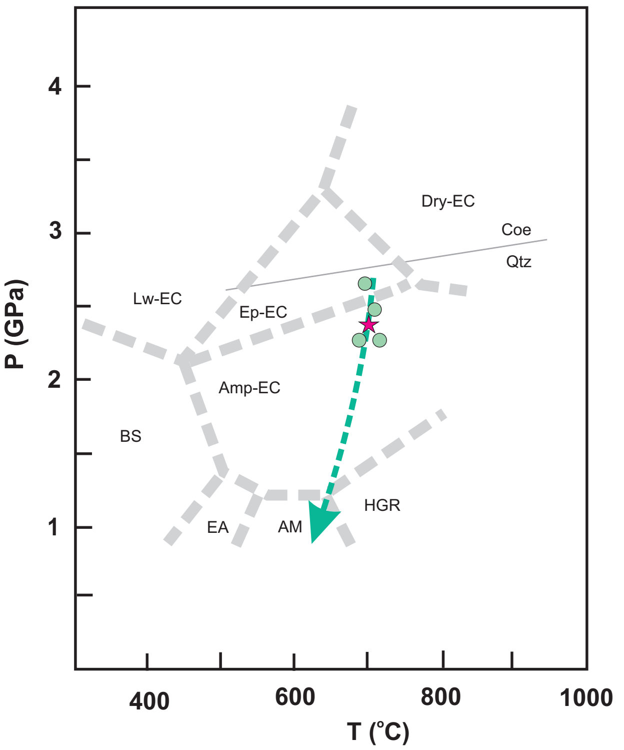

Fig. 9. Peak metamorphic *P–T* conditions of metaultramafite (star) and eclogite (circle) in the northern Veporic unit. The post-peak decompression is shown by an arrow. *P–T* conditions of eclogites are from Janák et al. (2007). Metamorphic facies grid is from Okamoto & Maruyama (1999). BS: blueschist facies, EA: epidote amphibolite facies, AM: amphibolite facies, HGR: high-pressure granulite facies, Lw-EC: lawsonite eclogite facies, Ep-EC: epidote eclogite facies, Amp-EC: amphibole eclogite facies, Dry-EC: dry eclogite facies. The quartz–coesite curve is calculated from thermodynamic data of Holland & Powell (2011).

Western Carpathians, evidence for Variscan subduction is provided by occurences of (U)HP rocks (eclogites, garnet peridotites) of Variscan age, e.g. in the Rhodopes (Janák et al. 2011) and the Southern Carpathians (Medaris et al. 2003).

Conclusions

The investigated metaultramafite from the Veporic unit shows eclogite facies, high-pressure metamorphism. This is manifested by a peak metamorphic mineral assemblage of garnet (X_{Mg}=0.46–0.47)+olivine (X_{Mg}=0.71–0.73)+low-Al orthopyroxene (X_{Mg}=0.77–0.78; Al=0.02–0.03 apfu)+ilmenite+chlorite (X_{Mg}=0.87–0.89)+Cr-spinel; metamorphic *P–T* conditions reached 2.4±0.4 GPa and 702±20 °C GPa. Decompression and retrogression from the HP stage is manifested by the formation of more aluminous orthopyroxene, Al-spinel and abundant amphibole (hornblende). Metaultramafic rocks in the North Veporic unit thus provide further evidence for high-pressure metamorphism, probably of Variscan age, in the pre-Alpine basement of the Western Carpathians.

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