Original paper

High-pressure metabasic rocks from the Kutná Hora Complex: geological position and petrology of exotic lithologies along the segmented Moldanubian margin, Bohemian Massif

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New occurrences of high-pressure metabasites in the Kutná Hora Unit (KHC) are described. These HP rocks include eclogites (± Ky), Cpx–Grt amphibolites, metagabbros and Cpx-bearing granulites. All the eclogite samples studied are formed of well-preserved HP mineral assemblages with variable degree of subsequent metamorphic overprint.

Eclogites from the inner part of the KHC (Roztěž, Bořetice) mostly had a Mg-rich tholeiitic protolith. Chemical, mineralogical and metamorphic data reveal that these eclogites are petrologically similar to the eclogite samples from the better known Běstvina Unit. Eclogites from Bořetice, Poličany and Roztěž preserve relict mineral assemblage from a pre-eclogite stage, enclosed in garnet with prograde zoning pattern. They bear mineralogical evidence of a very high-pressure history, even substantially higher (maximum 8.4 wt. % of Na_2O in Cpx, P~ 4.3 GPa) than the previously described eclogites from Spačice and Úhrov in the Běstvina Unit.

A set of three eclogites from the northern margin of the Moldanubian Zone south of Chotěboř was used for comparison (Bída, Borovský Creek, Krátká Ves). They preserve also a peak pressure record that corresponds to minimum pressures above 2.0 GPa.

Better understanding of regional relationships amongst the discussed units can be achieved only using isotopic and geochronological data.

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1. Introduction

Published and unpublished reports dealing with the contact of the Moldanubian Zone (MZ) with the Kutná Hora–Svratka Super-unit (KHS) provide an increasing number of geological arguments for regional interpretations. The latter stem from correlations of local units with other well described crustal segments, e.g., in Polish Sudetes (Mazur et al. 2005). A majority of petrological studies have been focused on the eastern parts of the boundary east of the Přibyslav mylonite zone and the Železné Hory Mts., while the western Kutná Hora Complex (KHC) remained of only limited interest. Fišera (1977, 1981) endured detailed studies of some parts in this area; his fieldwork remains an important contribution to the mapping of the territory and was also one of the stimuli triggering initiation of this study.

The KHC is a complex unit whose internal high-grade Malín and Běstvina units were defined by Losert (1967), and tectonometamorphic subdivision was proposed by Synek and Oliveriová (1993). The small, but petrologically attractive Běstvina Unit in the eastern tip of the KHC preserves a variegated collage of high-grade metamorphic lower-crustal and mantle rock assemblages, including granulites, eclogites, pyroxenites, spinel and garnet peridotites. Both the units display petrological and metamorphic features common with most of the inner KHC area, geological setting of which is not sufficiently explained so far. This contribution presents results of study of several new high-pressure metabasites occurrences from the KHC undertaken in 2003–2008.

The main aim is to summarize new geological data on the KHC metabasites, and to gather an evidence for HP/UHP metamorphism in the central part of the KHC. In addition, the new petrological, mineralogical and whole-rock geochemical data support interpretation of the KHC as an independent tectonic segment of the Kutná Hora–Svratka Super-unit, demonstrate the differences in metamorphic evolution between the KHC and the adjacent eastern margin of the Moldanubian Zone as well as the classical occurrence of the Gföhl Unit in the south-eastern part of the MZ (Matte et al. 1990; Medaris et al. 2005; Schulmann et al. 2005).

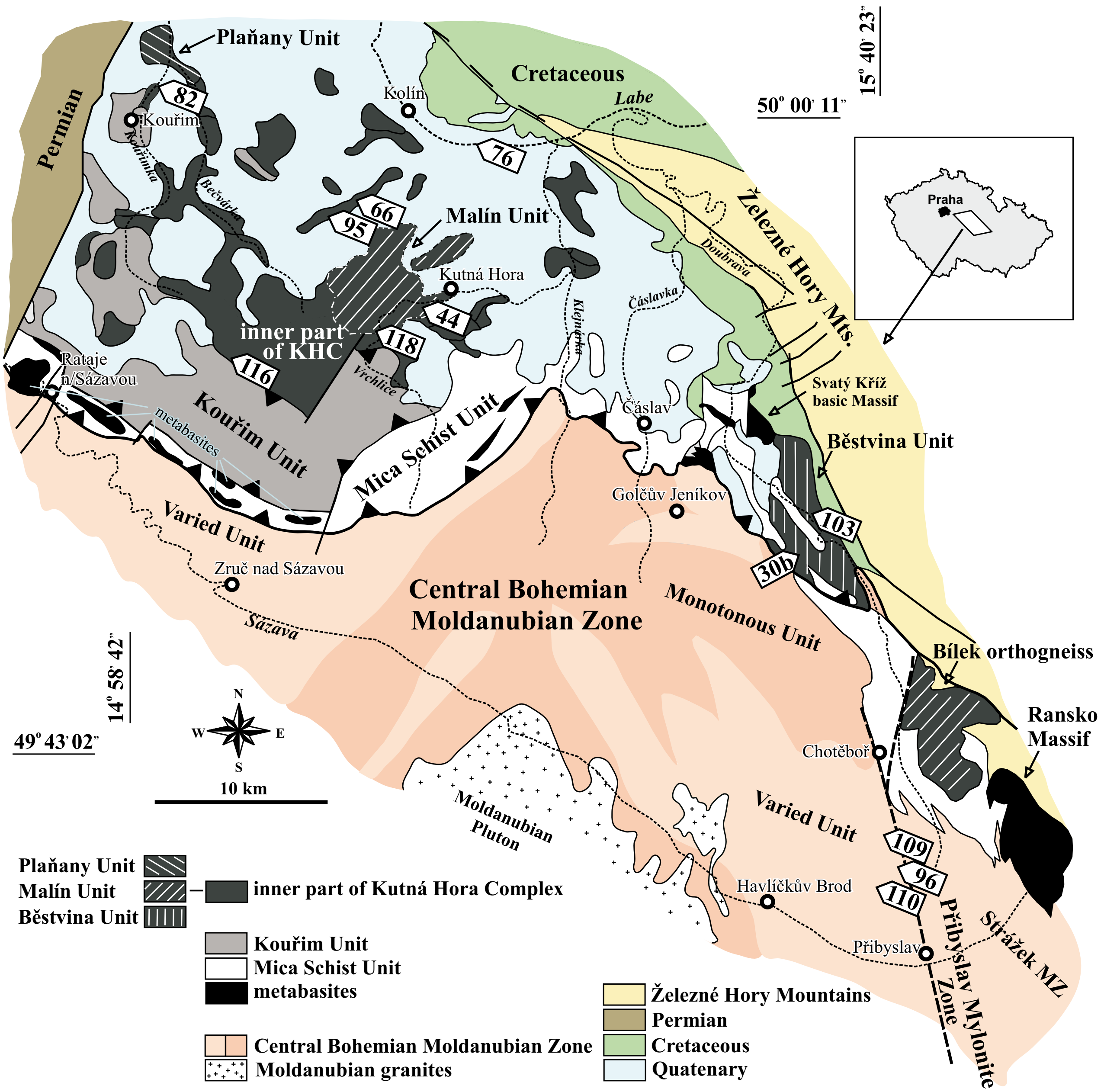


Fig. 1 Geological scheme of the Kutná Hora Complex and Moldanubian Zone with location of the sampled high-pressure rocks. Based on Synek and Oliveriová (1993), modified after Losert (1967) and Štědrá ed. (2009). Labelled localities correspond to numbers of the "KMV" rock sample series (see Tab. 1).

2. Geological setting of the KHC

The most recent tectonic and structural subdivision of the KHC was proposed by Synek and Oliveriová (1993). Recent mapping and related field work enabled close examination of the distribution of the exposed rock bodies which, on the relevant scale, do not always fit with the geological scheme published by these authors. Therefore, this chapter provides adjusted version of the geological division of the KHC.

Going from the southern boundary with the Varied Unit of the Moldanubian Zone northwards, the Kutná Hora Complex (Fig. 1) consists of four units.

1. Almost continuous outer **Mica Schist Unit** separates the KHC from the sillimanite-in isograd of the Varied Unit. The dominant mica schists enclose numer-

ous lenses of amphibolites, whose metamorphic grade does not exceed the garnet-amphibolite grade and most of which indicate a calc-alkaline source (Kachlík 1999). The penetrative shear deformation accompanied by relatively low-grade metamorphism also overprinted the rocks of the neighbouring Varied Unit, so that its contact is difficult to detect at present. However, the presence of medium-grade varied marine sedimentary members like marbles, calc-alkaline amphibolites, and calc-silicates can be a lithological indication of the Varied MZ para-autochthon.

Synek and Oliveriová (1993) classified the outer Mica Schist Zone a part of the KHC on basis of tectonic and structural characteristics without respect to its lithological overlap with the Varied Unit. The Mica Schist Unit continues to the SE along the Běstvina Unit almost as far as the Ransko Massif, in places being strongly tectonically reduced.

2. A nappe-like unit north of the Mica Schist Unit consisting of mineralogically simple, metaigneous rock assemblage was defined as a **Kouřim Nappe** (Synek and Oliveriová 1993). This unit definitely differs from other segments of the KHC; it is formed exclusively by quartzo-feldspathic orthogneiss and migmatites, which do not contain any index alumosilicate minerals or garnet but do contain micas. It also differs in its structural characteristics, as it exhibits strong refoliation, rotation of older planar elements into the predominating late trend plunging to the NW, and dominant P-L deformation locally passing into westerly dipping pure constrictional patterns developed in orthogneisses (see also Synek 1991). Thus, the typical coarse-grained pencil and augen orthogneisses alternate with fine-grained stromatitic muscovite and two-mica polymetamorphic migmatites with planolinear fabrics, resembling syntectonic injections of granitic melt into intensely sheared neck-zones between boudinaged older migmatitic domains. The rocks generally ascribed to the Kouřim Unit form the almost homogeneous SW flank of the KHC adjacent to the outer Mica Schist Unit. In addition, they are scattered throughout the central KHC area, where they usually dip under the metabasic, migmatitic and metasedimentary rocks of the KHC core.

3. The third rock assemblage of the **KHC** forms its **inner zone** and partially corresponds to the high-grade units defined by Losert (1967). It is characterized by the presence of a heterogeneous mixture of kyanite-bearing garnetiferous mica schists, migmatized paragneisses, refoliated migmatites, eclogites, garnet peridotites, garnetiferous amphibolites, massive augen gneisses or banded felsic orthogneisses, and fine-grained mylonitized Ky-Grt orthogneisses. Metamorphic events in some rock types of the assemblage (kyanite–garnet migmatites, granulites and mylonitized orthogneisses) are described in a specialized contribution (Vrána et al. this volume). This series exhibits many features in common with the Běstvina Unit at the northeastern margin of the KHC, as was repeatedly pointed out in the literature (Pouba et al. 1987; Medaris et al. 2005, 2006; Vrána et al. 2005; Machek et al. 2006; Faryad 2009). This relatively well-exposed Běstvina Unit is separated in detailed geological maps from the main body of the KHC by younger sedimentary cover that obscures structural relationship between prevailing retrograde granulitic gneisses of the Běstvina Unit and the rest of KHC. In this work, the Běstvina Unit is discussed as an integral part of the inner part of the KHC. Eclogites from Úhrov and Spačice in the Běstvina Unit and from Dobešovice and Bečváry in the inner KHC were studied in detail by Medaris et al. (1998). Their thermobarometric data for the peak metamorphic event correspond to 1030–1200 °C and 17–22 GPa for kyanite eclogite from Úhrov (Medaris et al. 2006), 800–850 °C and 1.7–1.9 GPa for Spačice eclogite, 1160–1180 °C a 1.7–1.9 GPa for the quartz-rich eclogite, and 960 °C a 1.9 GPa for other eclogites. Faryad (2009) determined peak conditions of kyanite eclogite and associated felsic granulite from Spačice at 3.4 GPa and 900–960 °C. Lower peak conditions were inferred for eclogite associated with serpentinite from Borek south of the contact between the Běstvina Unit and the adjacent Moldanubian Zone (650 °C and 1.4–1.5 GPa; Medaris et al. 1998).

Apparently, small bodies of eclogites, garnet peridotites and amphibolites frequently associate into the zones of strong deformation marked by mica schist and phyllonite belts. Mutual relationships of these rock zones incorporating UHP mantle peridotites and eclogites with the prevailing medium-grade metasediments, HP/HT rocks and migmatites are mostly rather unclear due to the thick Upper Cretaceous shallow-sea and Quaternary aeolian sedimentary cover. A small erosion window at the northern tip of the KHC revealed the occurrence of Cpx-granulite (sample 82 in Fig. 1), the only known exposure of this kind in KHC outside the Běstvina Unit.

4. The fourth poorly exposed **northern segment of the KHC –** the Plaňany Unit (Fišera 1977) – is extensively covered by the sediments of the Bohemian Cretaceous Basin. It crops out only in a dimension stone quarry and in a series of minor erosion windows north of Plaňany. The definition of this unit was based mainly on an unusual occurrence of Ti-rich amphibole–pyroxene migmatite enclosing a number of small peridotite and pyroxenite enclaves (Fišera 1981). Another indicative feature is the presence of a metasedimentary sequence containing calc-silicate rocks, and distinct type of massive nebulitic migmatites, both overprinted by strong localized shearing accompanied by late sillimanite crystallization. This poorly exposed northernmost segment of the KHC may indicate an inversely zoned metamorphic pattern, or a

higher tempered thrust slice possibly corresponding to the Monotonous Unit of the MZ.

The Moldanubian Zone adjacent to the south-western and southern margin of the KHC is formed of the Varied Unit that extends in an arcuate belt between Český Šternberk and Čáslav. Further to SE, the Moldanubian margin is partially covered by the Quaternary sediments and the area was usually ascribed to the Monotonous Unit; however, its regional setting is ambiguous. This ambiguity was expressed, for instance, by a proposal of "Transitional Zone" between the Moldanubian Zone and KHC by Mísař in Ondřík et al. (1996). Behind the Přibyslav Mylonite Zone, the Moldanubian Monotonous Unit borders on the Strážek part of the MZ. Some Moldanubian lithological members, such as felsic Ky–Grt orthogneiss, garnetiferous orthogneisses, eclogites, pyroxenites and garnet peridotites, though indicating similar sources, exhibit somewhat different tectonometamorphic history from those documented from the KHC rock assemblage (Štědrá in Pertoldová et al. 2007).

3. Geological position of HP metabasic bodies

3.1. Metabasites in the KHC

High-grade metabasic rocks of the KHC and neighbouring MZ include eclogites, garnet pyroxenites and pyroxene granulites from already known and newly found localities, disseminated mostly in the inner part of the KHC and in the Malín and Běstvina units along the KHC margin. These eclogites form minor ellipsoidal boudins with amphibolized mantle and strongly sheared outer host rocks and are accompanied in places by completely recrystallized amphibolites. Occurrences of elongated bodies of low- to medium-grade metabasites, on the other hand, are scattered along the outer Mica Schist Zone in the Kutná Hora Complex and in the Varied Unit along the north-eastern margin of the Moldanubian Zone. Garnet (± Cpx) amphibolites and amphibolites with HP relicts form a large body outcropping near Mančice, Polní Voděrady, and Lošany southwest of Kolín (see Kratochvíl 1952; Novák and Vrbová 1994). Several occurrences of amphibolized metabasites beyond the scope of this paper were also found near the E margin of the KHC north (Fišera 1977) and southeast of Kouřim.

The KHC eclogites underwent various degrees of post-HP metamorphic stages including allochemical retrograde changes (amphibolization, chloritization and biotitization). In spite of their limited size, the boudins still provide us with well-preserved HP mineral assemblage.

Generally, most of the occurrences of eclogites were found in the inner KHC zone. They are frequently spatially associated with garnet peridotites, either loosely bound (e.g., locations at Bohouňovice, Roztěž, Doubravčany, Chotouchov, Poličany, Vrbův Mlýn, Kutná Hora, Úhrov, Spačice–Doubrava), or as layers directly incorporated in the peridotite bodies like garnet pyroxenites from Bečváry (Paděra 1972; Beard et al. 1992; Medaris et al. 1995a) and the UHP mantle-derived sequence from Spačice in the Běstvina Unit (Faryad 2009). Some local occurrences of peridotite-related eclogites and granulites were studied in detail by Medaris and his co-workers, who included isotope data (1995a, 1995b, 1998 and 2006). The present study deals only with the metabasites loosely related to peridotite lenses.

In the north, the Plaňany Unit yields rare garnet peridotites and MP garnetites in nodules enclosed in migmatitic host rocks but true HP rocks have not been found so far. There are also occurrences of HP rocks along the northern boundary of the KHC (adjacent to the buried western continuation of the Železné Hory Fault Zone), exposed by scarce erosion windows, e.g., near Miškovice by Plaňany, Tři Dvory east of Kolín, and Týnec nad Labem. The structural settings of these bodies as well as recognition of the main regional boundaries delineating the individual basement units (KHC vs. Moldanubian and Teplá-Barrandian zones) are uncertain because of the platform cover. However, petrological features indicate similar provenance and metamorphic path of these rocks, namely to the high-grade rocks in the KHC. The basic typology of occurrences of the studied HP rocks is included in the Tab. 1.

3.2. Eclogites in the NE margin of the Moldanubian Zone

High-pressure metabasites associated with garnet peridotites were also found in course of the geological mapping campaign in 2003–2005 in the Moldanubian Zone southeast of Chotěboř, in the triple junction between the Strážek Unit, the Central Bohemian MZ, and the southeastern tip of the Moldanubian Varied Unit. All these samples used for comparison are from locations west of the Přibyslav Fault Zone.

4. Methods and sample selection

The studied eclogites mostly represent the KHC Inner Zone (Bořetice, Poličany, Roztěž), and a few are from locations scattered along the northern margin of the KHC and the Běstvina Unit (Miškovice, Tři Dvory, Spačice–Doubrava and Úhrov).

As new rock samples from the above-mentioned Chotěboř part of the Moldanubian Zone were available from ongoing geological mapping, the reference sample

Tab. 1 List of studied samples, their location and mineral assemblages

Sample	Locality	Unit	Rock type	Loc. type	Peak mineral assemblage	Omp/sympl. (vol. %)*	Rock assemblage	X-coordinate	Y-coordinate
KMV44	Poličany	KHC	eclogite	quarry	Grt–Omp–Qtz–Hbl–Rt	5/95	felsic gneiss, migmatite, mica schist, garnet amphibolite	49°56'01.45"N	15°15'39.46"E
KMV66	Bořetice	KHC	eclogite	outcrop	Grt–Omp–Rt–Qtz	25/75	mica schists, gneisses	49°59'08.34"N	15°11'12.31"E
KMV95	Bořetice	KHC	Ky eclogite, mylonitized	blocks	Grt–Omp–Rt–Ky–Qtz	85/15	garnet peridotite, gneiss	49°58'20.65"N	15°10'06.86"E
KMV118	Roztěž	KHC	eclogite	blocks	Grt–Omp–Qtz–Rt	90/10	migmatized paragneiss, mica schist, Grt peridotite	49°54'41.33"N	15°11'59.41"E
KMV82	Miškovice	KHC	Cpx granulite	outcrop	Grt–Omp–Rt–Pl–Bt	?	Grt-Bt gneiss, felsic Qtz granulite	50°01'54.01"N	14°59'35.07"E
KMV76	Tři Dvory	KHC	eclogitized metagabbro	outcrop	Grt–Omp–Rt–MgOpx–Hbl–Zo–Ky–Pl	5/95	gabbro-amphibolite	50°02'03.28"N	15°14'58.49"E
KMV116	Doubravčany	KHC	Cpx-Grt amphibolite	outcrop	Grt–Amp–Qtz–Cpx	(Cpx)	migmatite, orthogneiss	49°57'32.98"N	15°00'01.86"E
KMV30b	Úhrov	KHC-BU	eclogite	quarry	Grt–Omp–Qtz–Rt	90/10	garnet peridotite, granulite, gneiss	49°48'55.58"N	15°34'48.52"E
KMV103	Spačice-Doubrava	KHC-BU	Ky eclogite	outcrop	Grt–Omp–Rt–Ky–Qtz	15/85	granulite, gneiss, migmatite	49°48'46.29"N	15°35'57.26"E
KMV96	Bída	MZ	eclogite	blocks	Grt–Omp–Rt–Amp	5/95	refoliated migmatite	49°39'59.80"N	15°42'46.46"E
KMV109	Borovský Creek	MZ	Ky eclogite	outcrop	Grt–Omp–Rt–Ky	10/90	refoliated migmatite, mylonite, garnet peridotite	49°38'09.28"N	15°45'35.36"E
KMV110	Krátká Ves	MZ	eclogite	blocks	Grt–Omp–Rt–Opx–Bt–Amp	20/80	Ky-Grt gneiss, refoliated migmatite	49°37'31.38"N	15°40'23.02"E

*Estimation of the relict omphacite/secondary Cpx–Pl symplectite volume

set also includes eclogites from this area (Borovský Creek, Bída, Krátká Ves).

Complete list of the samples studied is given in Tab. 1 and their locations within the KHC and the adjacent part of the Moldanubian Zone are depicted in Fig. 1. All the relevant data are given in Tabs 2–4.

The KHC samples were studied using field observations, structural relationships, microprobe qualitative determination, mineral composition data, whole-rock geochemical analyses, and the conventional exchange geothermobarometry combined with construction of the Thermocalc P-T pseudosection. The ratio of the major elements typical of basic rocks is shown in the binary plots and the AFM (Irvine and Baragar 1971) and Al–Mg–Fe+Ti diagrams (Jensen 1976, Fig. 2) using the GCDkit package by Janoušek et al. (2006). Additional eclogite whole-rock analyses, also shown in Fig. 2, are taken from Štědrá et al. (2007) and come from the localities Spačice (Běstvina Unit), Vrbův mlýn, V Hutích and Chotouchov (inner KHC).

Newly obtained P-T data were compared with the information on the HP eclogite/granulite/peridotite assemblages from the KHC published previously (Medaris et al. 2005, 2006; Faryad 2009). The PX-NOM programme (Sturm 2002) was employed for the temperature estimates using the garnet–pyroxene equilibria, the GPT spreadsheet (Reche and Martinez 1996) for the orthopyroxene-garnet pair, and the geothermobarometer for the Grt–Cpx–Ky–Qtz/Co eclogites (Ravna and Terry 2004) were used for suitable rocks.

Pseudosection modelling was undertaken using Thermocalc 3.31 (Powell et al. 1998, recent upgrade) and the internally consistent thermodynamic dataset 5.5 (Holland and Powell 1998, November 2003 upgrade) in the Na_2O–CaO–FeO–MgO–Al_2O_3–SiO_2–H_2O–TiO_2–O (NCFMASHTO) system for basic rocks. Some parts of the pseudosection may be metastable with respect to melt-bearing assemblages under high-T conditions, and thus the absence of an appropriate melt model for basic systems must be considered. In order to include fluid-bearing

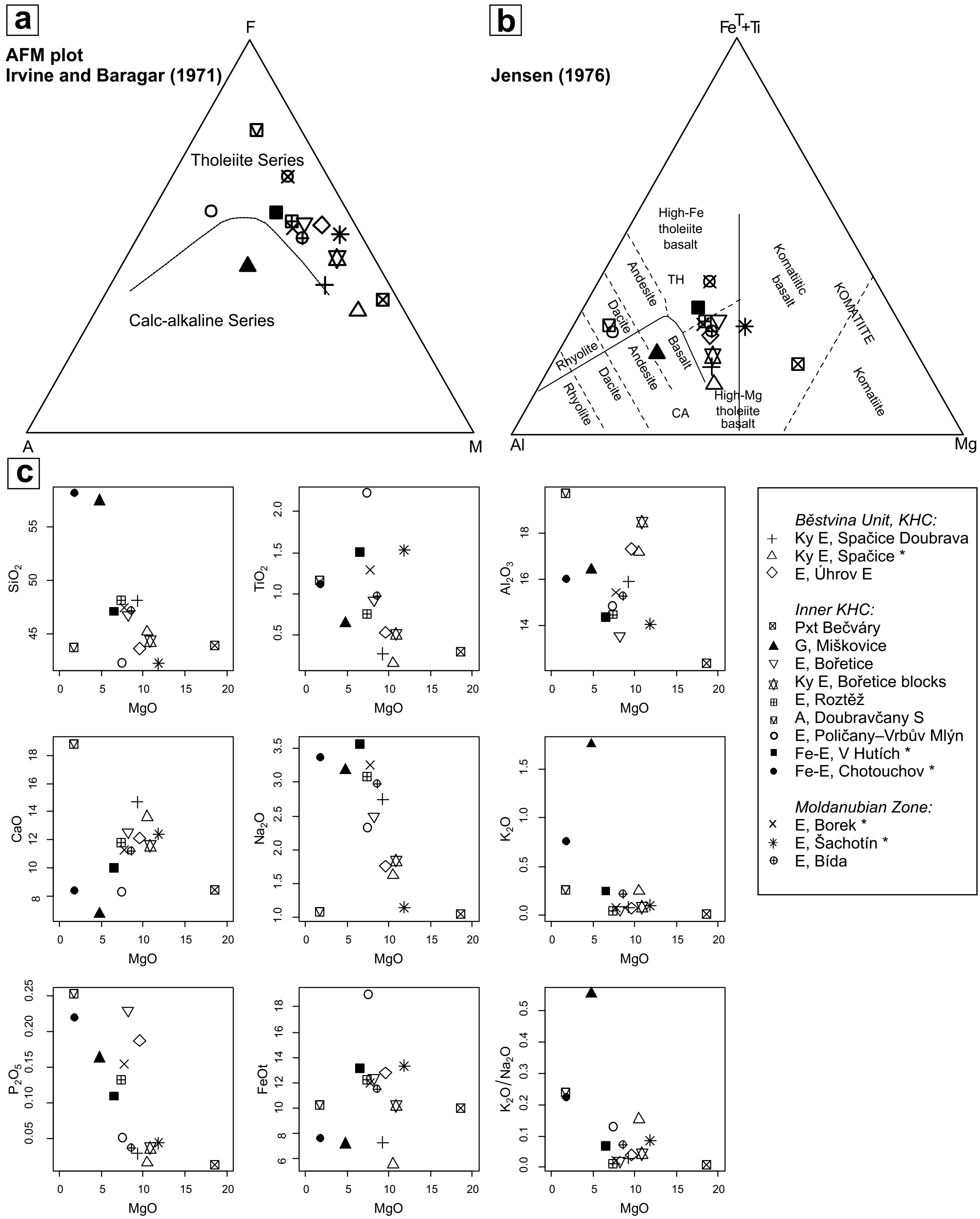


Fig. 2 Whole-rock chemical composition of the high-pressure metabasic rocks from the Kutná Hora Complex and the adjacent part of the Moldanubian Zone: **a** – AFM plot after Irvine and Baragar (1971) (A: Na_2O+K_2O, F: FeOt, M: MgO) showing tholeiitic composition of the studied eclogites and amphibolites; **b** – Compositional variations of metabasites in the multicationic plot of Jensen (1976) for volcanic rocks; **c** – Binary plots of MgO vs. major- and minor-element oxides.

* complementary data from Štědrá et al. (2007). Abbreviations of rock types in the legend: A – amphibolite, E – eclogite, G – granulite, Pxt – pyroxenite.

Tab. 2 Whole-rock major-element compositions of the KHC metabasites (wt. %)

Sample	KMV66	KMV95f	KMV118	KH53b	KK85	KMV 82b	KMV5	KMV116	KMV103	KMV30b	KMV26	KMV96
Locality	Bořetice outcrop	Bořetice blocks	Roztěž	Vrbův Mlýn	Doubravčany	Miškovice	Bečváry	Chotouchov	Spačice Doubrava	Úhrov	Borek u Chotěboře	Bída
Petrology***	E	Ky E	E	E	Fe A	Cpx G	Grt Pxt	Fe E	Ky E	E	E	E
Unit****	KHC	KHC	KHC	KHC	KHC	KHC	KHC	KHC	KHC BU	KHC BU	MZ	MZ
SiO_2	46.72	44.26	48.12	42.14	43.70	57.46	43.90	58.21	48.07	43.56	47.41	47.16
TiO_2	0.92	0.51	0.75	2.22	1.16	0.64	0.30	1.11	0.27	0.53	1.29	0.97
Al_2O_3	13.56	18.46	14.48	14.82	19.70	16.42	12.36	15.99	15.89	17.31	15.43	15.25
Fe_2O_3	1.59	1.40	13.62	21.12	11.40	1.42	2.31	0.95	2.00	1.95	2.96	2.24
FeO	10.92	8.92	–	–	–	5.85	7.92	6.77	5.49	11.05	9.32	9.51
MgO	8.20	10.85	7.36	7.53	1.73	4.78	18.58	1.77	9.28	9.59	7.73	8.61
MnO	0.31	0.15	0.23	0.36	0.25	0.11	0.24	0.16	0.16	0.28	0.24	0.22
CaO	12.55	11.57	11.79	8.27	18.84	6.70	8.45	8.33	14.67	12.11	11.26	11.19
Li_2O	n.d.*	0.01	0.01	n.d.	n.d.	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Na_2O	2.50	1.84	3.09	2.33	1.08	3.18	1.05	3.36	2.75	1.76	3.26	2.98
K_2O	0.05	0.08	0.04	0.29	0.26	1.76	0.01	0.75	0.08	0.07	0.07	0.21
P_2O_5	0.23	0.04	0.13	0.05	0.25	0.16	0.01	0.22	0.03	0.19	0.15	0.04
F	0.005	0.032	n.d.	n.d.	n.d.	0.077	0.002	0.004	0.013	0.014	0.003	0.005
LOI	1.00	1.43**	0.49	0.07	0.56	1.33	4.14	2.18	0.70	0.57	0.66	1.39
H_2O^-	0.12	0.13	0.17	0.10	0.10	0.14	0.66	0.11	0.10	0.07	0.11	0.21
Total	98.67	98.25	100.28	99.30	99.03	100.04	99.93	99.90	99.50	99.05	99.90	99.99

* n.d. = not detected; ** H_2O^+; *** E = eclogite, Ky E = kyanite eclogite, Fe A = Fe amphibolite, Cpx G = clinopyroxene granulite, Grt Pxt = garnet pyroxenite, Fe E = Fe eclogite; **** KHC = Kutná Hora Complex, KHC BU = Běstvina Unit, MZ = Moldanubian Zone

HP/MP minerals (i.e. amphibole) observed under a microscope, an estimated amount of 1 wt % of H_2O (3.43 mol. %) was added to the system. A recent clinopyroxene model based on the study of Green et al. (2007), plagioclase model of Holland and Powell (2003), amphibole model of Diener et al. (2007), garnet model of White et al. (2007), epidote model of Holland and Powell (1998), chlorite model of Holland et al. (1998), magnetite model of White et al. (2002) as well as ilmenite with hematite model of White et al. (2000) were all invoked to calculate the pseudosection for the eclogite from Roztěž.

5. Petrology of eclogites

5.1. Description of the studied samples

5.1.1. KMV44 Poličany

The eclogite was sampled in an old quarry north-west of the village of Poličany. A boudin reaching some 200 m in length is the largest of all the eclogite bodies studied. The country rocks include felsic gneisses, garnet- and kyanite-bearing mica schists, amphibolites and migmatites. The whole-rock basaltic composition of the sample from the Vrbův Mlýn quarry nearby accounts for relative enrichment of eclogite in FeO and TiO_2, as well as low CaO within the studied set (Fig. 2, Tab. 2). The HP mineral assemblage consists of garnet, omphacite, high-pressure amphibole, quartz, and accessories rutile, ilmenite, zircon and apatite (Fig. 3a). Compositionally zoned garnet (two grains: older stage $Alm_{43–62}$, $Prp_{8–23}$, $Grs_{12–30}$ and $Sps_{2–6}$ mol. %, and younger stage: $Alm_{43–49}$, $Prp_{20–25}$, $Grs_{22–27}$ and Sps_1 mol. %) forms large rotated porphyroblasts with pre-eclogite stage inclusions in the core of the first grain (Bt, Amp), and later HP mineral inclusions (Omp, Rt) close to the outer rim. Omphacite was extensively replaced by Pl–CpxII symplectite and was amphibolized subsequently. Samples from Poličany-Vrbův Mlýn and V Hutích shown in Fig. 2 are spatially closely related to the Poličany eclogite, within 1 km distance.

5.1.2. KMV66 Bořetice NE

A several-metres-long elongated eclogite boudin is exposed at the bottom of the Polepka Creek valley north of Bořetice, 80 m west of the railway bridge. The host rocks are felsic migmatites and mica schists; a quarried body of garnet peridotite is located within a distance of 400 m. The whole-rock composition of eclogite corresponds to tholeiitic protolith with low Al_2O_3 and K_2O and high Cr_2O_3, NiO and P_2O_5 components. The eclogite is banded, with alternating HP amphibole- (Na_2O in amphibole up to 4.5 wt. %) and omphacite-dominated layers, both

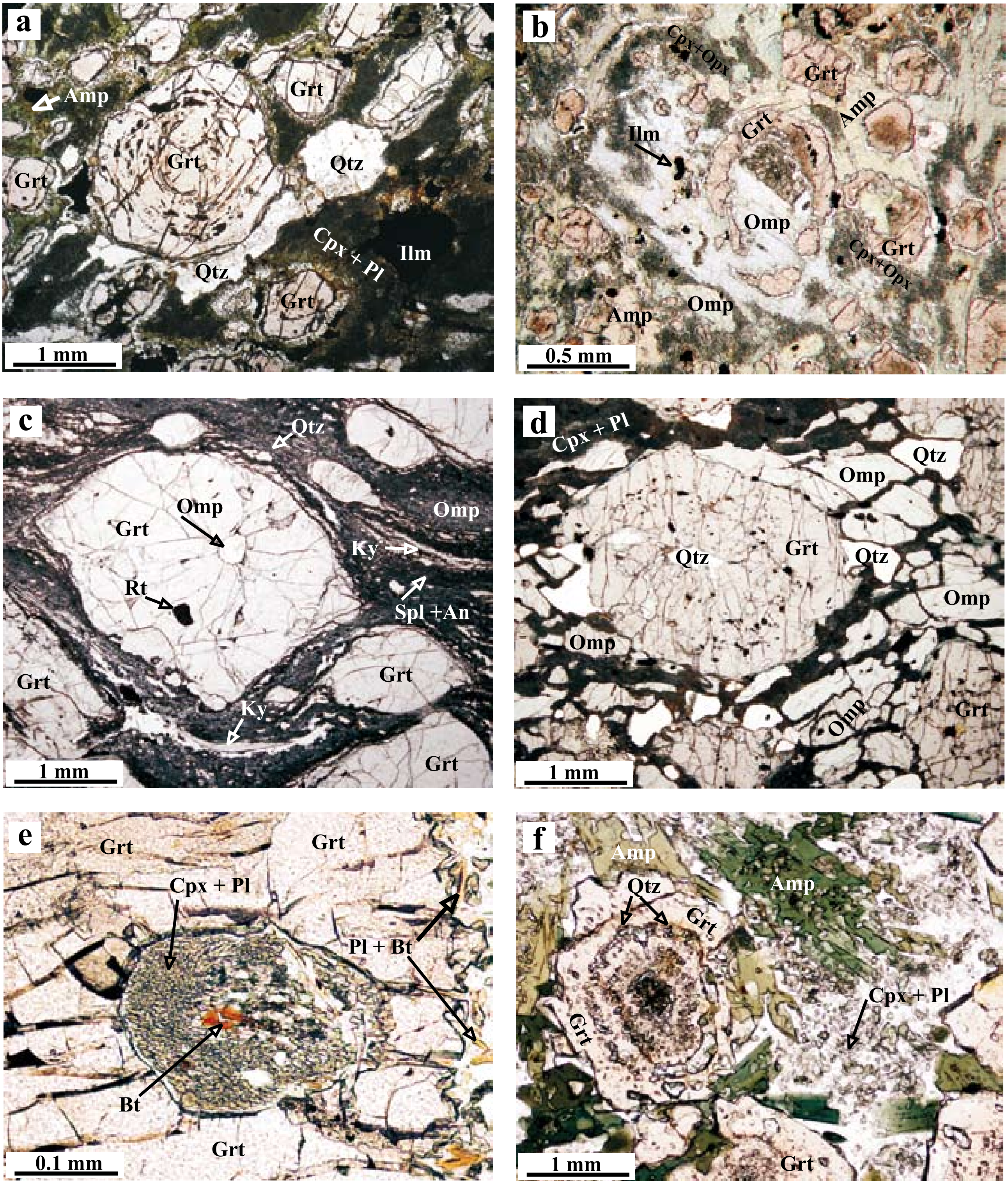


Fig. 3 Photomicrographs of high-pressure metabasites from the inner part of the Kutná Hora Complex (plane polarized light). **a** – Retrogressed eclogite KMV44 from Poličany with inclusions of pre-HP minerals in garnet; **b** – Eclogitized metagabbro KMV76 from Tři Dvory with skeletal garnet and well preserved matrix Na-Cpx (Omp); **c** – Strongly mylonitized Ky-eclogite KMV95d from Bořetice showing matrix composed of fine-grained omphacite, elongated grains of kyanite, and recrystallized chains of Grt II; **d** – Eclogite KMV118 from Roztěž with zoned garnet poikiloblasts with Qtz inclusions and preserved matrix omphacite in places transformed to dark symplectite; **e** – Clinopyroxene granulite KMV82 from Miškovice – a detail of the Na-clinopyroxene, biotite and plagioclase aggregate after omphacite enclosed in garnet. Garnet rim is corroded and replaced by multiphase reaction corona including plagioclase, biotite, and clinopyroxene; **f** – Pyroxene-bearing Fe-rich amphibolite KMV116 from Doubravčany displays aggregate distribution of Cpx droplets in plagioclase.

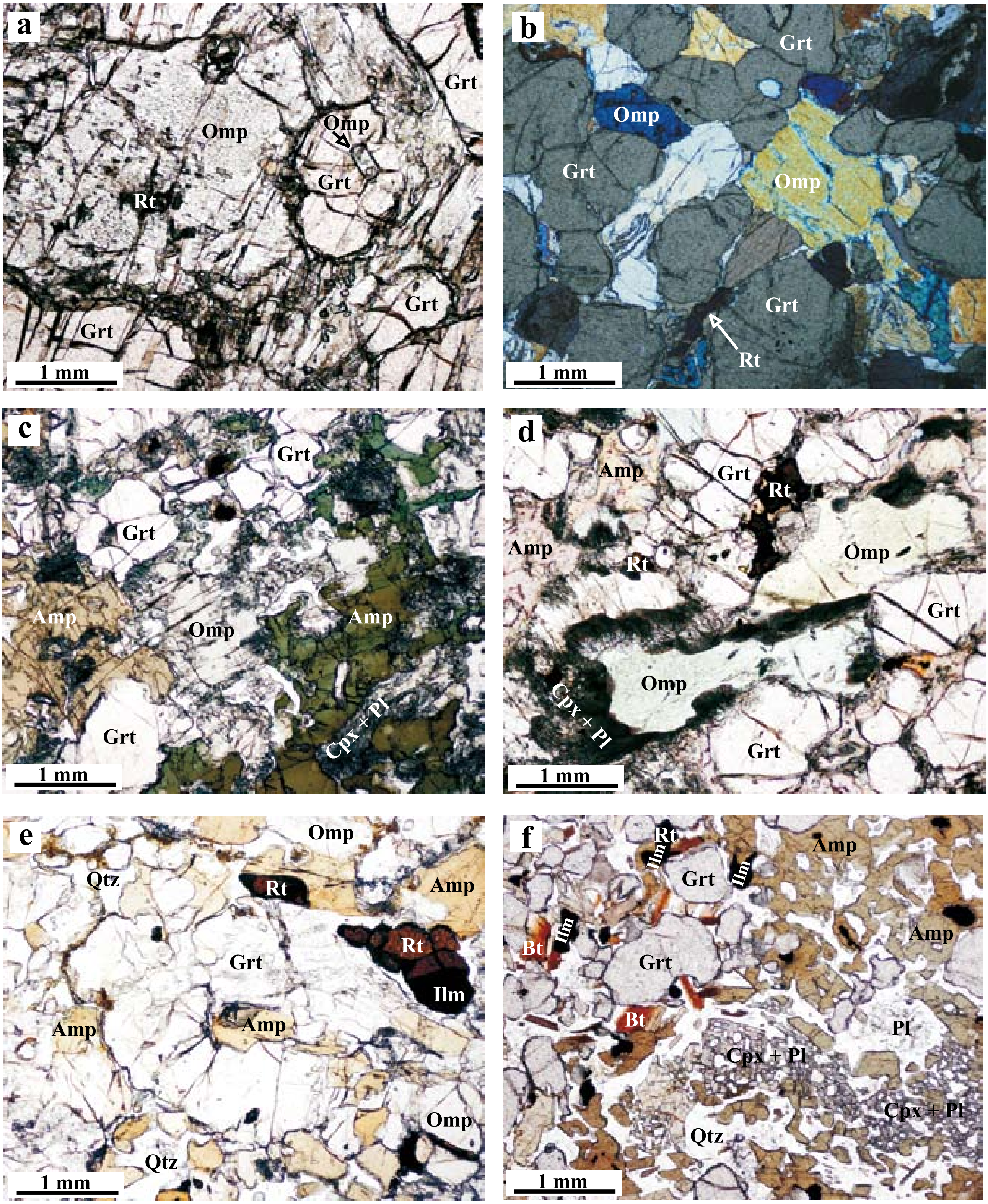


Fig. 4 Photomicrographs of HP metabasites from the Běstvina Unit (eastern KHC, a–b) and the adjacent part of the Moldanubian Zone (c–f). Plane polarized light if not stated otherwise. **a** – Well preserved eclogite KMV30b from Úhrov with lamellar Ab exsolutions in the matrix omphacite; **b** – Fresh eclogite KMV103d from Spačice–Doubrava showing equilibrium garnet (in grey), dominant matrix omphacite, and an initial exsolution of albite from the latter (crossed nicols); **c** – Partially amphibolized eclogite KMV96 from Bída with relict of pale green omphacite; **d** – Eclogite KMV109b from the Borovský Creek; **e** – Ti-rich amphibole- and biotite-bearing HP granulite KMV110b from Krátká Ves; **f** – Ti-rich high-pressure Grt–Cpx–Hbl–Bt–Qtz–Rt–Ilm rock from Oudoleň with relict plagioclase (right centre), and a poikilitic aggregate of CpxII (lower right).

of which are rich in garnet ($Alm_{50–55}$, $Prp_{16–18}$, $Grs_{24–32}$, $Sps_{1–2}$), ilmenite and rutile. Peak relict omphacite is highly sodic (max. X_{Jd} = 38.5 mol. % for 6.2 wt. % Na_2O) and reaches Na_2O contents as high as 6.7 wt. % in relict cores. The sodium content decreases through medium X_{Jd} = 15 to minimum X_{Jd} = 2 mol. % in the very late globular Cpx grains. The intensity of hydration increases along fractures and towards the mantle of the eclogite boudin, bearing newly crystallized poikiloblastic low-Na amphibole, epidote, clinozoisite, plagioclase and titanite.

5.1.3. KMV95 Bořetice

Small blocks of strongly deformed coarse-grained Ky-bearing eclogite (Grt–Omp–Qtz–Ky–Rt) were found in direct contact with garnet peridotite, just above the "excursion" quarry in the deformed peridotite north of Bořetice. As the eclogite is found in loose blocks, it is not possible to determine whether it occurs inside or along the outer margin of the peridotite lens. The medium-grained rock with light matrix around garnet is strongly deformed to "augen" eclogite (Fig. 3c), which seems to be an analogue of the deformational fabrics in the peridotite boudin with linear structures in the quarry. Garnet, quartz and kyanite grains are strongly sheared and recrystallized into curved ribbons between floating grains of augen-like garnet porphyroclasts. Two analysed garnet grains display different compositions, the second with high pyrope content (a smaller grain: $Alm_{33–42}$ $Prp_{30–26}$ $Grs_{31–27}$ $Sps_{\leq 1}$, the second, bigger grain preserves Fe–Mn rich core and differs also in rim compositions: $Alm_{48–30}$ $Prp_{34–44}$ $Grs_{09–25}$ $Sps_{2–0.5}$, Fig. 5c).

In some samples, the total amount of kyanite increases up to 10 vol. % and corresponds to high whole-rock Al_2O_3 (18.5 wt. %). Kyanite grains enclosed in garnet are generally almost euhedral and undeformed, except for twinning and undulatory extinction, in contrast to matrix kyanite grains where plastic elongation reaches an aspect ratio of *c*. 1 : 20. Deformation must have taken place under still very high P-T conditions taking into account the recrystallization of euhedral fine-grained garnet chains in pressure shadows, and relative stability of omphacite. The latter mineral is very fine-grained due to mylonitization, forms 90–60 % of the matrix, but subgrains are fresh and well preserved. The highest Na content in the matrix omphacite grains was detected in several samples (7–8 %, max. 8.04 wt. % Na_2O, X_{Jd} = 55 mol. %). It is slightly higher than that of Omp inclusion locked in garnet (7.3 wt. % Na_2O, X_{Jd} 50 mol. %, Fig. 6). Though the mineral composition indicates a lack of hydrated phases, rare nucleation of fine-grained high-Na amphibole was observed. The whole-rock chemical composition exhibits high Al_2O_3, MgO and Cr_2O_3 contents accompanied by depletion in Zr and Y of the tholeiitic basaltic protolith. The unusual HP mineral assemblage and the metamorphic record of this eclogite are a subject of further detailed petrological study. A sample of kyanite eclogite described from Dobešovice and dated to 338 Ma by the Sm-Nd method by Medaris et al. (1995a) could, in fact, be a similar rock type. The composition of the eclogite minerals is shown in Tabs 3 and 4.

5.1.4. KMV76 Tři Dvory

A resistant core of the previously quarried gabbro-amphibolite body remains exposed in the flat relief dominated by Quaternary and Cretaceous sediments at the NW limit of Tři Dvory. It is formed by layered eclogite, strongly affected by annealing, replacement by MP minerals and final retrogression. The presence of fine-grained granular Opx or Cpx–Hbl aggregates in the centres of skeletal garnets indicates that the pre-eclogite protolith of the rock could have been two-pyroxene or olivine-bearing gabbro – possibly from the family of the Svatý Kříž Massif metabasites (Holub and Munschi 1984). Numerous relict grains constitute the Grt–Na-Cpx–Qtz–Ky–Zo–Rt HP assemblage. Garnet grains with inclusions of Rt, Ti and Hbl are either skeletal (Fig. 3b) or round, the latter exhibiting strong and complex zoning patterns with the Sps- and Grs-rich core and Mg increasing towards the rim ($Alm_{47–56}$ $Prp_{6–27}$ $Grs_{15–34}$ $Sps_{0–12}$). The Na-clinopyroxene (maximal X_{Jd} = 18.2, Na_2O = 3.0 wt. %) was almost completely transformed into seriate lamellar symplectites, quartz preserving intergranular lobate forms, and prismatic kyanite and needle-shaped zoisite retrogressed to almost opaque spinel-bearing clusters of fine-grained secondary minerals. Amphibole in the matrix is secondary. The microstructure and mineral assemblage of the eclogite indicates a post-HP increase in temperature, which can be related to the final partial melting of the rock producing recrystallized coarse-grained amphibolite with Pl-rich melt pockets in the mantle of the boudin.

5.1.5. KMV118 Roztěž

A block of medium-grained eclogite was encountered in the middle of a newly constructed Roztěž golf course west of Malešov. The boudin was probably enclosed together with small bodies of garnet peridotites, skarns, and eclogites in highly sheared migmatitic biotite gneisses along a tectonic zone south of Kutná Hora (Štědrá ed. 2009). Its whole-rock composition indicates Qtz-rich tholeiitic protolith with slightly increased FeO, Na_2O, SiO_2, and low K_2O (Fig. 2). The main matrix minerals are omphacite, garnet, rutile and quartz (Fig. 3d). Amphibole, plagioclase, clinopyroxene, epidote, ilmenite, zircon and Fe-sulphide are also present, in part as relict or secondary phases. Large garnet grains (up to 2 mm across) are

Tab. 3 Garnet compositions from the studied eclogites (wt. % and apfu recalculated to 12 O equivalents)

Unit*	**inner part of KHC**							**KHC –- Běstvina Unit**						**MZ**	
Sample	**KMV 118 Roztěž**			**KMV 95d Bořetice**				**KMV 30b Úhrov**			**KMV 103d Spačice**			**KMV 96 Bída**	
Mineral	**Grt**			**Grt 1**		**Grt 2**		**Grt**			**Grt**			**Grt**	
Position	**core**	**inner part**	**outer rim**	**core**	**rim**	**core**	**rim**	**core**	**rim**	**diff. rim**	**core**	**rim**	**diff. rim**	**core**	**rim**
(wt. %)															
SiO_2	38.01	38.22	38.50	39.01	39.18	38.72	40.79	39.27	39.57	39.99	39.23	39.27	38.98	38.73	39.56
TiO_2	0.07	0.11	0.03	0.25	0.35	0.02	0.14	0.16	0.11	0.09	0.07	0.08	0.07	0.05	0.06
Cr_2O_3	0.02	0.02	0.00	0.02	0.03	0.03	0.06	0.02	0.03	0.04	0.01	0.07	0.05	0.03	0.00
Al_2O_3	21.46	21.18	21.59	21.85	21.57	21.89	22.07	21.87	22.04	21.96	22.39	21.91	21.51	21.84	22.20
Fe_2O_3	1.47	1.60	0.89	0.97	0.00	1.95	0.00	0.40	0.37	0.14	1.99	0.84	0.61	1.39	0.19
FeO	20.07	20.82	23.72	17.75	20.44	23.77	15.26	18.11	18.14	19.78	18.55	19.70	23.49	22.35	22.24
MnO	1.75	0.71	0.53	0.47	0.47	0.99	0.32	0.39	0.41	0.42	0.53	0.53	0.69	0.64	0.65
MgO	4.89	5.87	7.05	7.64	7.13	9.57	11.71	8.05	8.44	8.70	9.03	8.75	6.64	6.62	6.56
CaO	11.60	10.70	7.19	11.40	10.26	3.50	9.40	11.07	10.67	9.51	9.15	8.57	8.02	9.03	9.97
Na_2O	0.02	0.02	0.00	0.08	0.03	0.00	0.08	0.01	0.03	0.00	0.02	0.05	0.09	0.00	0.00
Total	99.37	99.27	99.50	99.45	99.46	100.44	99.83	99.34	99.82	100.63	100.96	99.75	100.14	100.68	101.43
apfu (per 12 O)															
Si	2.966	2.975	2.986	2.980	3.012	2.957	3.031	2.996	3.000	3.014	2.949	2.990	3.006	2.969	2.999
Ti	0.004	0.007	0.001	0.014	0.020	0.001	0.008	0.009	0.006	0.005	0.004	0.005	0.004	0.003	0.003
Cr	0.001	0.001	0.000	0.001	0.002	0.002	0.003	0.001	0.002	0.002	0.000	0.004	0.003	0.002	0.000
Al	1.974	1.944	1.974	1.968	1.955	1.971	1.933	1.967	1.970	1.951	1.984	1.966	1.955	1.974	1.984
Fe^{3+}	0.086	0.094	0.052	0.056	0.000	0.112	0.000	0.023	0.021	0.008	0.112	0.048	0.036	0.080	0.011
Fe^{2+}	1.310	1.355	1.538	1.134	1.314	1.518	0.948	1.155	1.150	1.247	1.166	1.254	1.515	1.432	1.410
Mn	0.116	0.047	0.035	0.031	0.031	0.064	0.020	0.025	0.026	0.027	0.033	0.034	0.045	0.042	0.042
Mg	0.569	0.681	0.815	0.870	0.816	1.089	1.297	0.916	0.954	0.978	1.011	0.993	0.763	0.756	0.741
Ca	0.970	0.893	0.597	0.933	0.845	0.286	0.748	0.905	0.867	0.768	0.737	0.699	0.662	0.742	0.810
Na	0.003	0.003	0.000	0.012	0.004	0.000	0.011	0.002	0.005	0.000	0.002	0.007	0.013	0.000	0.000
(mol. %)															
Prp	0.18	0.22	0.26	0.28	0.26	0.34	0.41	0.30	0.31	0.32	0.32	0.32	0.25	0.24	0.24
Alm	0.42	0.43	0.50	0.36	0.42	0.48	0.30	0.38	0.38	0.40	0.37	0.41	0.49	0.46	0.47
Grs	0.31	0.28	0.19	0.30	0.27	0.09	0.24	0.30	0.28	0.25	0.23	0.23	0.21	0.24	0.27
Sps	0.04	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
$X_{Fe}(Fe_{TOT})$	0.70	0.66	0.65	0.57	0.62	0.58	0.42	0.56	0.55	0.56	0.54	0.56	0.67	0.65	0.66

* KHC = Kutná Hora Complex, MZ = Moldanubian Zone

occasionally rimmed by kelyphitic rims of plagioclase, amphibole and clinopyroxene, and contain several populations of inclusions. Plagioclase enclosed in the garnet core is almost pure albite, whereas plagioclase from garnet symplectite or in the matrix contains about 15 mol. % of anorthite component. Omphacite grains are enclosed in the intermediate zone of garnet and in the matrix and display high Na content (Na_2O = 5.79 wt. %, X_{Jd} = 40 mol. %, Fig. 6). Secondary clinopyroxene occurring in symplectite or in the matrix is predominantly Na-diopside (X_{Jd} ~10 mol. %) or diopside. Amphibole enclosed in the garnet core is ferroan pargasite, whereas poikiloblastic amphibole in the matrix is edenitic hornblende, and the amphibole forming the kelyphitic garnet rim is pargasite to pargasitic hornblende (Leake et al. 1997).

Zoned garnet ($Alm_{42–50}$ $Prp_{19–29}$ $Grs_{32–19}$ $Sps_{4–1}$ mol. %) contains a Ca–Mn rich core (Fig. 5a), which is rich in tiny inclusions of amphibole, albite and ilmenite (Fig. 5b). The intermediate zone of the grain encloses quartz and rarely epidote inclusions. A clearly expressed zone of rutile and ilmenite is located towards the rim and fine omphacite inclusions were also trapped in a vicinity of rutile. Inclusions of epidote, allanite and zoisite were found close to the rim of the grain and are possibly not primary. Garnet along the outer rim reacted with the (secondary?) fluid-bearing matrix minerals and was locally transformed to the amphibole–plagioclase kelyphite. Accessory zircon is common within the kelyphite. Numerous small inclusions of Fe-, Ni- and Cu-sulphides are present in the matrix.

Tab. 4 Clinopyroxene compositions from the KHC eclogites (wt. % and apfu recalculated to 6 O equivalents)

Unit*	inner part of KHC				KHC – Běstvina Unit			Moldanubian Zone		
Sample	KMV 118 Roztěž		KMV 95d Bořetice		K 30b Úhrov	KMV 103d Spačice		KMV 96 Bída		
Mineral	Omp	Cpx	Omp		Omp	Omp	Cpx	Omp	Omp	Cpx
Position	incl. in Grt	symplectite	matrix	matrix	matrix	matrix	symplectite	incl. in Grt	incl. in Grt	symplectite
(wt. %)										
SiO_2	55.28	53.19	55.55	54.80	52.59	54.65	53.04	53.59	54.50	49.66
TiO_2	0.04	0.09	0.15	0.21	0.44	0.26	0.43	0.28	0.12	0.77
Cr_2O_3	0.04	0.00	0.04	0.06	0.04	0.00	0.00	0.04	0.00	0.10
Al_2O_3	9.47	1.44	14.92	8.26	11.26	9.47	3.32	9.26	10.92	5.61
Fe_2O_3	0.46	2.61	0.64	2.45	0.93	0.29	0.64	1.88	3.65	3.23
FeO	3.49	4.65	0.95	2.87	3.75	4.80	5.27	4.58	1.66	5.47
MnO	0.01	0.05	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.08
MgO	9.36	13.63	6.94	9.72	9.12	9.81	14.00	9.43	8.65	12.64
CaO	14.88	22.15	12.36	17.16	16.51	16.11	21.98	16.54	14.70	20.16
Na_2O	5.79	1.36	8.04	5.08	4.86	4.92	1.24	4.88	6.68	1.59
Total	98.82	99.17	99.68	100.63	99.51	100.30	99.91	100.47	100.89	99.30
apfu (per 6 O)										
Si	1.993	1.978	1.952	1.962	1.905	1.960	1.951	1.940	1.949	1.867
Ti	0.001	0.002	0.004	0.006	0.012	0.007	0.012	0.008	0.003	0.022
Cr	0.001	0.000	0.001	0.002	0.001	0.000	0.000	0.001	0.000	0.003
Al	0.403	0.063	0.618	0.349	0.481	0.400	0.144	0.395	0.461	0.249
Fe^{3+}	0.013	0.073	0.017	0.066	0.025	0.008	0.018	0.051	0.098	0.091
Fe^{2+}	0.105	0.145	0.028	0.086	0.114	0.144	0.162	0.139	0.050	0.172
Mn	0.000	0.002	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.003
Mg	0.503	0.756	0.363	0.519	0.492	0.524	0.768	0.509	0.461	0.708
Ca	0.575	0.883	0.465	0.658	0.641	0.619	0.866	0.642	0.563	0.812
Na	0.405	0.098	0.548	0.352	0.341	0.342	0.088	0.342	0.463	0.116
(mol. %)										
Jd	0.40	0.04	0.55	0.31	0.32	0.33	0.07	0.29	0.37	0.03
En	0.25	0.38	0.18	0.26	0.25	0.26	0.38	0.25	0.23	0.35
Fs	0.05	0.07	0.01	0.04	0.06	0.07	0.08	0.07	0.02	0.09
Wo	0.28	0.43	0.21	0.31	0.28	0.29	0.41	0.29	0.26	0.35
$X_{Mg}(Fe_{TOT})$	0.81	0.78	0.89	0.77	0.78	0.78	0.81	0.73	0.76	0.73

* KHC = Kutná Hora Complex

5.1.6. KMV82 Miškovice

A flat rocky formation was exposed in massive and resistant light Ky–Grt granulite mostly retrogressed into Bt–Ms granulite gneiss at the bottom of the valley, in western outskirts of the Miškovice village. One of the outcropping blocks in the middle of a stream is formed by darker quartz-rich kyanite–garnet granulite with Na-rich clinopyroxene and ternary feldspars, the latter containing lamellar mesoperthitic exsolutions. The chemical composition of this mafic granulite is different from the other studied HP rocks. It has calc-alkaline andesitic to basaltic character and is rich in SiO_2, Na_2O, K_2O and depleted in MgO, NiO and CaO (Fig. 2). The Cpx-granulite shows both the relict Grt–Ky–Pl–Qtz–Cpx mineral assemblage and several types of fine-grained replacement aggregates of sillimanite, margarite, clinopyroxene II, biotite, muscovite and plagioclase, indicating polymetamorphic overprint (Fig. 3e).

5.1.7. KMV116 Doubravčany South

The Grt–Cpx–Qtz–Hbl–Rt rock is a new occurrence of banded metabasite found within the Kouřim Unit orthogneiss, indicating the conditions of upper amphibolite facies in the area. Chemically, this rock is dacitic and distinct from other HP rocks in high Al_2O_3, CaO, P_2O_5, FeOt and FeO/(FeO + MgO) and Sr; on the other hand, it is depleted in MgO, SiO_2, Na_2O, Cr, Ni and Y. Rounded-to-subhedral garnet consists mostly of Alm–Grs

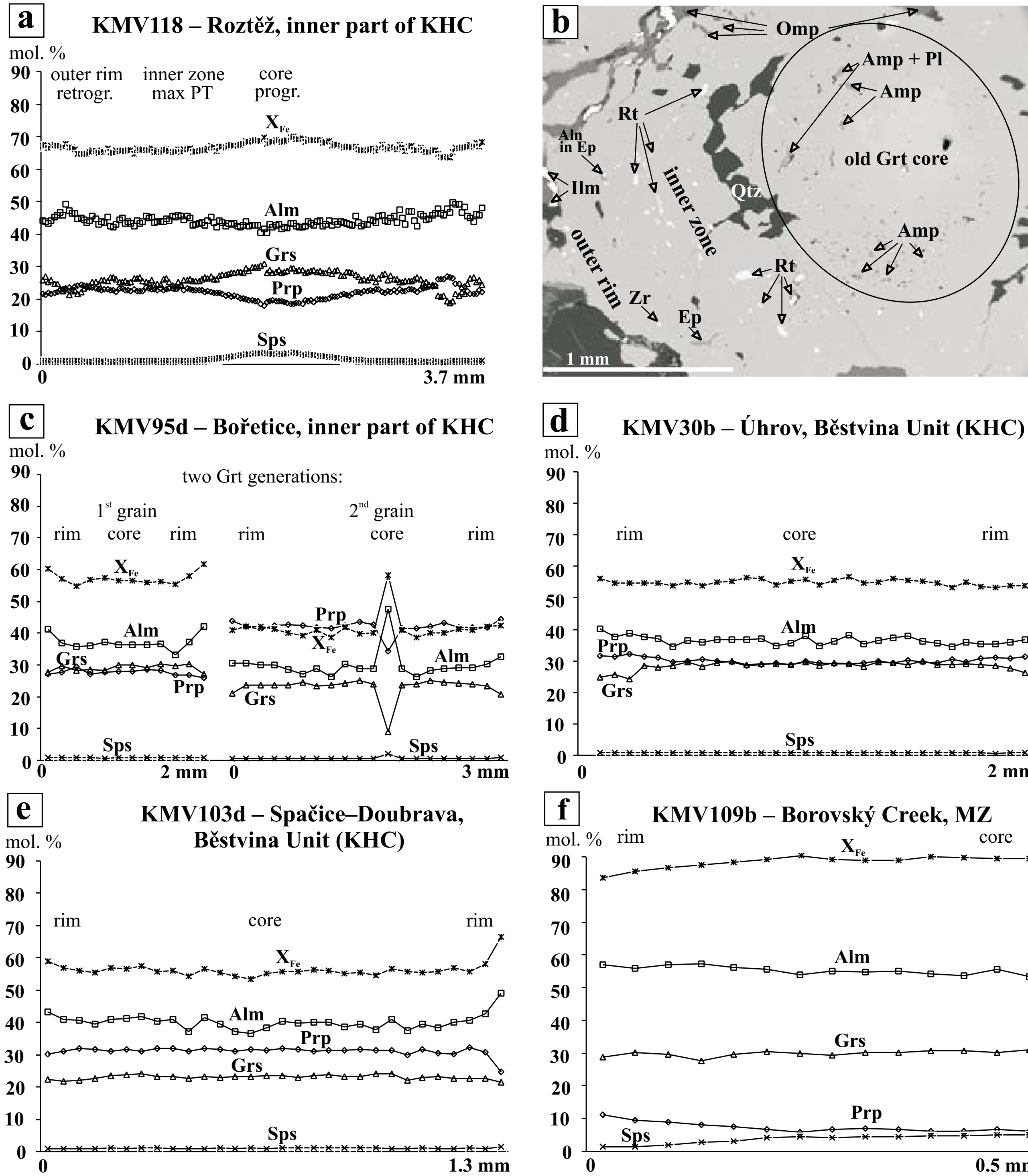


Fig. 5 Composition of eclogite garnet from the Kutná Hora Complex (KHC) and the adjacent part of the Moldanubian Zone (MZ). **a** – Garnet zoning pattern in the eclogite KMV118 from Roztěž (inner part of the KHC); **b** – Back-scattered electron image of garnet from the Roztěž eclogite showing distribution of relict inclusions.

Garnet zoning patterns of additional eclogite samples: **c** – KMV95d from Bořetice (KHC); **d** – KMV30b from Úhrov (KHC – Běstvina Unit); **e** – KMV103d from Spačice-Doubrava (KHC – Běstvina Unit); **f** – KMV109b from the Borovský Creek (MZ).

components ($Alm_{43–51}$ $Prp_{3–6}$ $Grs_{34–44}$ $Sps_{2–7}$ mol. %) with inclusions of hornblende (1 wt. % of Na_2O) and quartz. Garnet is in equilibrium with green euhedral and lath-shaped, iron-rich amphibole, globular low-Na diopsidic clinopyroxene and quartz (Fig. 3f). Matrix plagioclase occurs mostly in aggregates with small Cpx crystals, which may suggest some replacement mechanism. As the major-element composition is similar to some skarns from KHC (see also Pertoldová et al. this volume), the banded rock may belong to calc-silicate rocks.

5.1.8. KMV30b Úhrov

The Běstvina unit of the KHC generally provided several locations with very well-preserved eclogites and garnetites carrying equilibrium HP assemblage, some of them almost without retrograde reactions. One such eclogite sample was found in blocks above a temporarily opened small quarry in garnet peridotite near Úhrov. The chemical composition reveals similarities with kyanite eclogites from the Běstvina Unit and corresponds to tholeiitic basalt enriched in Al_2O_3, FeO, MgO, P_2O_5 and depleted in SiO_2 and K_2O (Fig. 2). Both exsolution of lamellar sodic plagioclase from omphacite and Hbl–An kelyphite nucleation along garnet rims are only at initial stages, and most of the peak minerals are well preserved (Fig. 4a). Garnet grains show almost flat compositional pattern with a rimward decrease in Grs balanced by an increase of both Alm and Prp ($Alm_{38–40}$ $Prp_{30–32}$ $Grs_{30–25}$, $Sps_{\leq1}$ mol. %, Fig. 5d), and maximum X_{Jd} in the omphacite reaches 32 % (4.86 wt. % Na_2O).

5.1.9. KMV103 Spačice – Doubrava River

A several-metre-long lens of kyanite eclogite was found on the right bank of the Doubrava River near Spačice. The river section exposed slightly banded fresh eclogites with penetrative amphibolization along the fractures bearing numerous rutile grains up to 1 cm in size. Eclogite is basically of the Grt–Omp–Qtz–Rt type (Fig. 4b), but kyanite, apatite, Kfs and Hbl are present in limited amounts. Retrograde changes affected omphacite (X_{Jd} = 31 mol. %, Na_2O = 4.97 wt. %), thus producing seriate lamellar Cpx–Pl symplectites. Kyanite was transformed into small fibrous clusters with dominant margarite. The amount of garnet varies in the individual bands, some of them being almost monomineralic garnetite. The main garnet components display low variations ($Alm_{37–44}$ $Prp_{30–33}$ $Grs_{22–24}$ $Sps_{0.5–0.8}$ mol. %) except of a narrow diffusion rim (Fig. 5e). The chemical composition exhibits similarities to HP rocks from the Běstvina Unit, but contains higher SiO_2, CaO, MgO, Sr, and low TiO_2, K_2O, FeOt, Zr, and Y and high-Mg tholeiite basaltic whole-rock composition. This occurrence is newly described, so the characteristics of this eclogite are compared to other eclogites from the Běstvina Unit, newly sampled from already known locations like Spačice and Úhrov.

5.1.10. KMV96 Bída

Migmatite-dominated area along the boundary of the MZ and KHC in the SE part of the studied area provided several findings of eclogites and granulites, most of them in loose blocks. One of them is from the Bída Hill near Hájek, northeast of Česká Bělá. This retrogressed Grt–Omp–Rt eclogite consists of symplectitic matrix and rounded and irregular garnets ($Alm_{46–48}$ Prp_{24} $Grs_{24–27}$ Sps_1) with secondary plagioclase (Fig. 4c). Omphacite in rare relict grains displays a highly sodic composition reaching up to 6.68 wt. % of Na_2O (X_{Jd} = 37 mol. %). Chemically is this eclogite slightly depleted in CaO and is similar in most of major elements to the magnesian tholeiitic eclogites of the Běstvina Unit (Fig. 2).

5.1.11. KMV109 Borovský Creek

Well-preserved HP rocks were sampled from the upper ramp of the Borovský Creek Valley (left bank) west of Havlíčkova Borová (Štědrá ed. 2009). Medium- to fine-grained eclogites consist of Omp–Grt–Qtz–Rt–Ky assemblage (Fig. 4d). Omphacite grains (Na_2O = 5.13 wt. %, X_{Jd} = 35 mol. %) are partially replaced by symplectite along rims. Equant garnet grains are either homogeneous or zoned (Fig. 5f), containing inclusions of Cpx and Rt (sample KMV110a: $Alm_{30–48}$ $Prp_{38–44}$ $Grs_{11–22}$ $Sps_{\leq1}$, sample KMV110b: $Alm_{54–57}$ $Prp_{6–11}$ $Grs_3$0 $Sps_{\leq 0.5–1.5}$). The garnets are rimmed by decompression plagioclase and kelyphitic corona of pargasitic amphibole and Ca-plagioclase. Accessory kyanite was replaced by minor dark aggregates of Sp–An symplectite. Matrix minerals enclose irregular grains of accessory sulphides chalcopyrite, pyrite and pentlandite.

5.1.12. KMV110 Krátká Ves

Eclogite, found in blocks together with Ky–Grt gneiss, shows a high content of garnet ($Alm_{39–44}$ $Prp_{25–27}$ $Grs_{27–30}$ $Sps_{\leq0.1}$), quartz, rutile, apatite, and pyroxene in cores of grains with external zones replaced by HP brown amphibole rich in Na and Ti, and relict biotite and ilmenite (Fig. 4e). The sodic Cpx reaches just medium Na_2O contents of *c.* 2 wt. % (X_{Jd} = 0.13 mol. %). Garnet grains are rimmed by a typical coarse-lamellar corona of Hbl–Ca-Pl and, in the second stage, by domainal Opx–An corona. Plagioclase in matrix is secondary. Several generations of younger olive green to green amphibole, together with

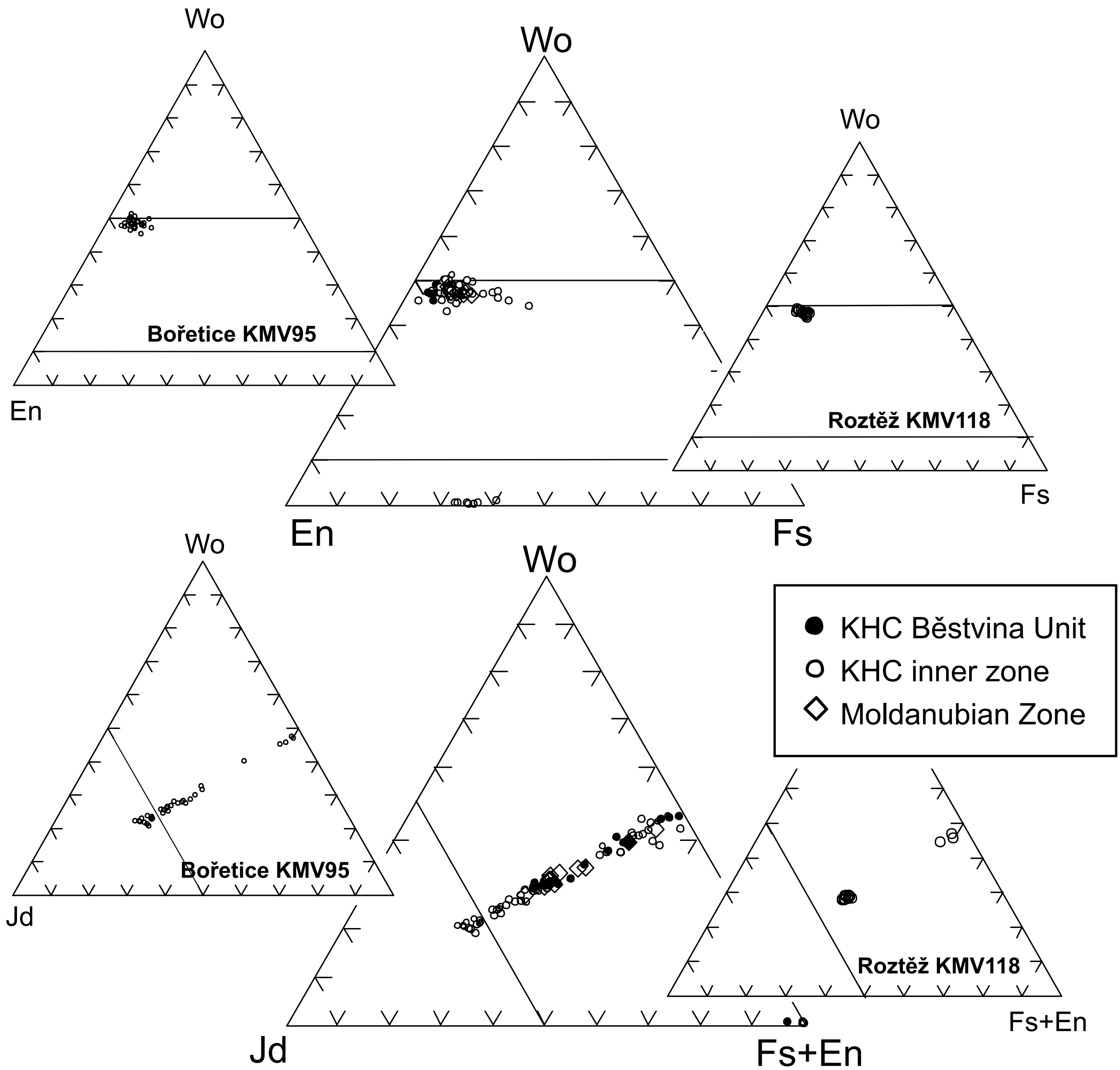


Fig. 6 Composition of clinopyroxene and orthopyroxene from the studied eclogites in the ternary diagrams En–Fs–Wo (above) and Jd–(Fs + En)–Wo (below). The composition of pyroxenes from the KHC, Běstvina Unit and Moldanubian eclogites shown in the central diagrams is similar, although each sample may contain secondary Opx and several generations of Cpx with variable X_{Jd}. The composition of HP clinopyroxene from the Roztěž eclogite and the Bořetice kyanite-bearing eclogite are shown separately in smaller diagrams.

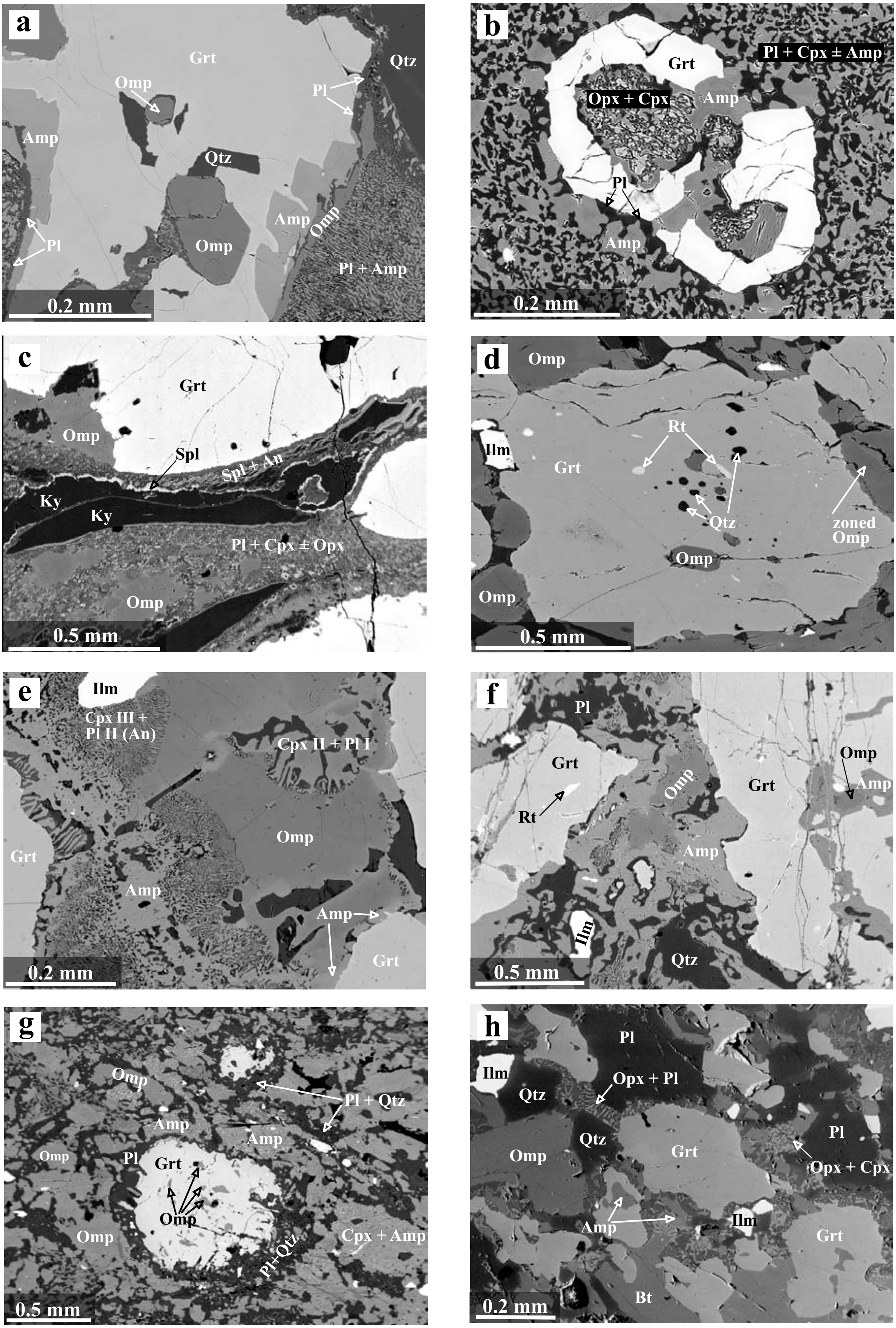
chlorite, carbonates, epidote, titanite, Ti-magnetite and sulphides are randomly distributed within the matrix, due to retrogression. The rock resembles a gabbroic rock with HP and later retrograde overprint.

Several blocks of HP rock with the assemblage Grt–Omp–Hbl–Bt–Pl–Ru–Ilm was found near Oudoleň NW of Krátká Ves. This mafic granulite complementing the set of eclogite samples from the Moldanubian Zone is also shown (Fig. 4f).

5.2. Metamorphic record in eclogites

5.2.1. Conventional geothermobarometry

Conventional exchange geothermobarometry allows only limited application to HP metabasic rocks either due to simple mineral composition, or presence of amphiboles. The validity of the most relevant calibrations using microprobe data was widely discussed by a number of au-


a
Grt
Omp
Pl
Qtz
Amp
Qtz
Amp
Omp
Omp
Pl
Pl + Amp
0.2 mm
b
Grt
Pl + Cpx ± Amp
Opx + Cpx
Amp
Pl
Amp
0.2 mm
c
Grt
Omp
Spl
Spl + An
Ky
Ky
Pl + Cpx ± Opx
Omp
0.5 mm
d
Omp
Rt
Ilm
Grt
Qtz
zoned
Omp
Omp
Omp
0.5 mm
e
Ilm
Cpx III +
Pl II (An)
Cpx II + Pl I
Omp
Grt
Amp
Amp
Grt
0.2 mm
f
Pl
Grt
Omp
Grt
Omp
Amp
Rt
Amp
Ilm
Qtz
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g
Omp
Pl + Qtz
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Cpx + Amp
Pl+Qtz
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Opx + Pl
Pl
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Omp
Grt
Opx + Cpx
Amp
Ilm
Grt
Bt
0.2 mm

thors, some of which were highly critical about the usage of raw data with only total iron determined (e.g. Sobolev et al. 1999). With time, however, some of them admitted the legitimacy of these methods for rocks with suitable composition (e.g., Štípská and Powell 2005) or proposed new net transfer calibrations using Mg-end member minerals (Ravna and Terry 2004). Some metabasites studied contain HP assemblages with kyanite, and thus satisfy conditions for application of the latter method. On the other hand, the absence of phengite in these eclogites sets limits of the method and increases error intervals.

The studied eclogites show a variable degree of equilibration under the HP conditions and subsequent stages (Fig. 7). Especially rocks derived from a gabbroic protolith retain the microtextural and mineralogical indications of the precursor (Tři Dvory, Krátká Ves). These rocks contain pyroxenes with lower X_{Jd} and pseudomorphs after magmatic minerals (Cpx, Pl, Ol).

Garnets in all the samples are usually well crystallized, form rounded, oval or occasionally corroded grains, except for skeletal types from Tři Dvory and Doubravčany. Deformed garnet from porphyroclastic and recrystallized mylonite from Bořetice represents the other exception (Fig. 3c). Minerals included in garnet are important tracers of metamorphic history together with the growth compositional zoning. The samples from Miškovice, Krátká Ves and Oudoleň contain plagioclase as an equilibrium phase, thus indicating granulite-facies conditions. In case of Cpx-amphibolite from Doubravčany, the maximum P-T correspond to upper amphibolite facies.

The growth-zoning pattern of a large garnet grain (3.7 mm in diameter) from Roztěž eclogite suggests several oscillations in P-T conditions. The garnet composition supported by presence of mineral inclusions present in the respective zones, were utilized for reconstruction of the P-T path. The inclusions document a generally prograde trend from amphibolite (Amp–Ab) to eclogite facies (Rt–Omp) with omphacites of the highest X_{Jd} in the outer zone. Some Grt grains from the Poličany eclogite (KMV44) also contain the oldest core ($Alm_{43–62}$ $Prp_{8–23}$ $Grs_{12–30}$ $Sps_{2–6}$ mol. %); on the other hand, there is also evidence for subsequent thermal relaxation and retrogression.

The rather good state of preservation of clinopyroxenes in most samples allows us to record variations in X_{Jd} and to provide evidence for a robust pressure record in metabasic rocks in the KHC core. Values of X_{Jd} in omphacite of 35–50 mol. % were found for several eclogites for the first time. These numbers are even higher that in the Běstvina Unit, so far assumed to indicate the most extreme P-T conditions in the KHC (Fig. 6). Surprisingly high X_{Jd}^{Cpx} was found in eclogites from minor occurrences at Bída, Krátká Ves and the Borovský Creek in the Moldanubian Zone (X_{Jd} = 35–37 mol. %).

Several generations of amphiboles can be observed. The oldest metamorphic history is documented by their inclusions in garnet, although these minor grains were partly affected by diffusion. Green and brownish amphiboles of pargasitic and tschermakitic composition often form kelyphites around garnets, and olive green high Na-edenites formed during the final stages of the HP event. The youngest population of the actinolite–tremolite series replaces garnets and clinopyroxenes during local low-grade retrograde recrystallization.

Pressure were estimated on the basis of the Cpx–Qtz equilibrium (Holland 1980). The minimum P derived from X_{Jd} in Cpx from the Roztěž eclogite (Gasparik and Lindsley 1980) at T = 1000 °C is 2.16 GPa. For the main rock-forming minerals, conventional methods can yield only minimum pressure estimates depending on incorporation of the jadeite component into Cpx, and by thermometry from the Grt–Cpx pairs. The linear dependence of the jadeite–quartz thermometer and its intersection with the garnet–clinopyroxene Fe/Mg exchange thermometers by Krogh (1988) and Ganguly et al. (1996) was used. The equilibrium temperatures inferred for cores of Omp inclusion (with composition analogous to matrix grains, i.e., not substantially affected by later diffusion) and neighbouring garnet were calculated. Both the thermometers provided a good fit; the resulting data indicate a thermal interval of 750–810 ºC at 2.15–2.35 GPa for this eclogite (Fig. 8). These two calibrations were used also for other eclogites from the KHC and MZ with following results: eclogite from Bída – 660 °C/1.9–2.0 GPa resp. 825 °C/2.2 GPa, eclogite from Úhrov – 825 °C/2.3 GPa resp. 947 °C/2.55 GPa, and Ky eclogite from Spačice – 845 °C/2.3 GPa resp. 920 °C/2.5 GPa.

Relatively good prospects for calculations of P-T conditions are provided by the kyanite eclogite from Bořetice. This rock is extremely rich in Al_2O_3 (18.46 wt. %) and

⇦

Fig. 7 Back-scattered electron images for the studied eclogites (KHC = Kutná Hora Complex, BU = Běstvina Unit, MZ = Moldanubian Zone). **a** – A detail of a garnet grain with an inclusion of Omp and incipient growth of secondary Hbl and Pl along garnet rim in the eclogite KMV118 from Roztěž (KHC); **b** – Skeletal Grt around the relict Opx–Cpx aggregate and the partially amphibolized diablastic matrix in the eclogite KMV 76 from Tři Dvory (KHC); **c** – A garnet grain with multiphase inclusions, extremely elongated kyanite grains rimmed by fine-grained Sp–Pl symplectite, accompanied by grain-size reduction of omphacite due to mylonitization in the kyanite eclogite KMV 95 from Bořetice (KHC); **d** – Qtz, Rt and Omp inclusions in garnet grain in the eclogite KMV103d from Spačice–Doubrava (BU); **e** – Several evolutionary stages of decompressional symplectites gradually replacing omphacite in the eclogite KMV30b from Úhrov (BU); **f** – An irregular disequilibrium texture of Grt, Omp, CpxII, Hbl, Pl and Qtz in the partially retrogressed eclogite KMV96 from Bída (MZ); **g** – High-pressure garnet with omphacite inclusions and partially retrogressed matrix in the eclogite KMV109b from the Borovský Creek (MZ); **h** – Formation of reaction textures in the Hbl-bearing eclogite KMV110b from Krátká Ves (MZ).

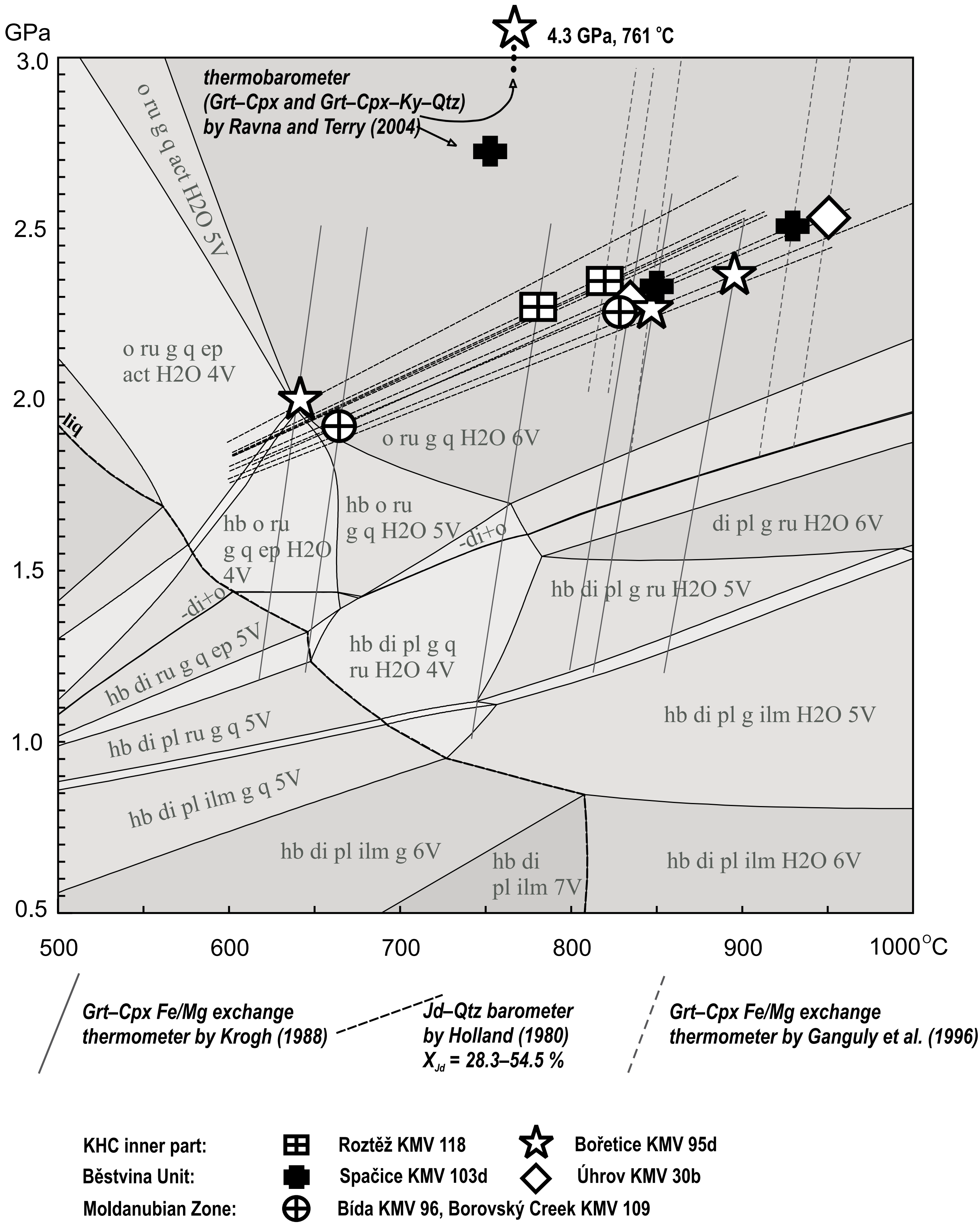

Fig. 8 Results of conventional geothermobarometry for the representative eclogite samples from the inner part of the Kutná Hora Complex, the Běstvina Unit, and from the adjacent part of the Moldanubian Zone in the P-T diagram. Background multivariant fields correspond to the simplified pseudosection shown in Fig. 9.

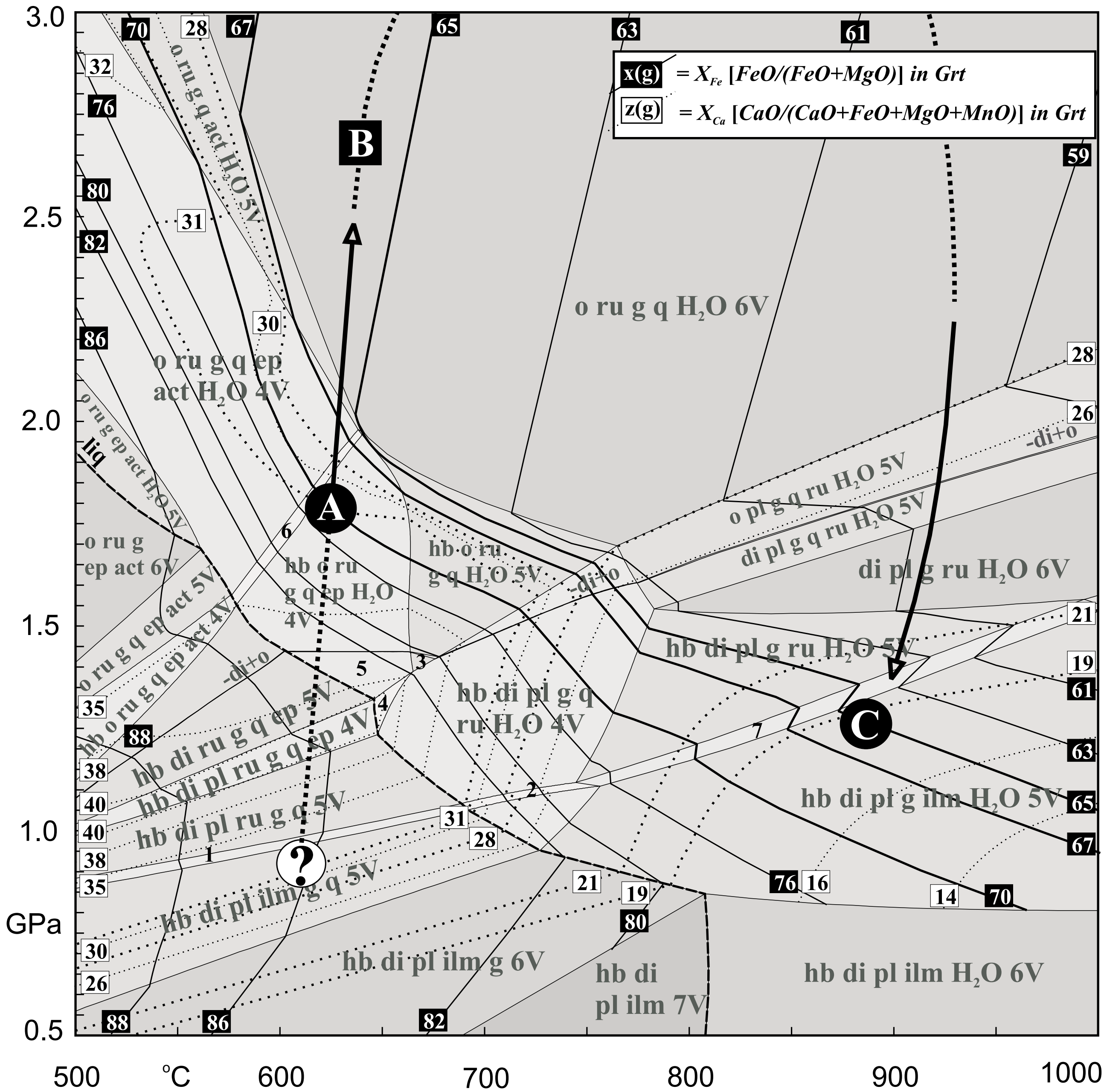

Fig. 9 The PTX pseudosection of the Roztěž eclogite (sample KMV118) calculated by the Thermocalc 3.31 NCFMASHTO system (3.43 H_2O, 49.28 SiO_2, 8.45 Al_2O_3, 12.94 CaO, 11.24 MgO, 10.50 FeO, 3.07 Na_2O, 0.58 TiO_2, 0.52 O mol. %). Thin dotted lines mark isopleths of grossular component "z(g) = X_{Ca} [CaO/(CaO + FeO + MgO + MnO)]", thin solid lines are X_{Fe} isopleths "x(g) = X_{Fe} [FeO/(FeO + MgO)]". The outlined heavy isopleths are important for P-T path definition**: point A** is the intersection of the garnet core values (X_{Ca} = 31, X_{Fe} = 70) indicating the continuous prograde part of the P-T path at 1.75 GPa and 630 ºC (bold dotted line to A). Considering the plagioclase presence in the Grt core, garnet must have started to grow at plagioclase stability field below 1.15 GPa ("?"), **line B** represents a possible area of max. P-T conditions estimated from X_{Fe} inner zone values (X_{Fe} = 65–66) isopleths are directed from 2.2 GPa to (ultra-) high pressure at *c.* 600–650 ºC (bold full and dotted line). The Grs value of the inner rim (X_{Ca} = 28) corresponds to the whole Omp–Rt–Grt–Qtz–H_2O (or liq) stability field in the pseudosection, **point C** at the intersection of outer rim garnet isopleths (X_{Ca} =19, X_{Fe} = 65) represents the retrograde MP/HT conditions at 1.25 GPa and 890 ºC.

Mineral abbreviations in the diagram: hb – hornblende, act – actinolite, o – omphacite, di – diopside, pl – plagioclase, g – garnet, q – quartz, ru – rutile, ilm – ilmenite, ep – epidote, H_2O – water. **Numbered fields**: 1 – hb di pl ilm ru g q 4V, 2 – hb di pl ilm ru g q H_2O 3V, 3 – hb di ru g q H_2O 5V, 4 – hb di pl ru g q ep H_2O 3V, 5 – hb di ru g q ep H_2O 4V, 6 – hb o ru g q ep act H_2O 3V, 7 – hb di pl g ru ilm H_2O 4V (V = field variance).

contains more minor and accessory minerals. The calculation of the P-T conditions using the conventional Jd-in–Cpx barometer (Gasparik 1984) yielded a minimum pressure of ~1.8 GPa. Using the thermometers after Krogh (1988) and Ganguly et al. (1996) combined with the Holland (1980) barometer, the results for this sample correspond to 640 °C/2.0 and 890 °C/2.3 GPa for two different Grt–Cpx couples, resp. 830 °C/2.25 GPa, with Krogh's temperature values systematically lower (Fig. 8). The results are rather exceptional for the KHC core, but generally correspond to the data for the Běstvina Unit published, for instance, by Medaris et al. (1998, 2005).

The assemblage with kyanite allows an application of the geothermobarometer designed for Grt–Cpx–Qtz/Co–Ky–Phe eclogites (Ravna and Terry 2004). Using this method, we reach 761 °C and UHP pressures above 4.3 GPa for the Bořetice sample KMV95, values rather acceptable for such an extreme rock associated with a garnet peridotite. For comparison, this method was applied also to the kyanite eclogite KMV103 from Spačice–Doubrava, and resulting values correspond to 753 °C and 2.73 GPa. Calibration errors of ± 85 °C and ± 0.35 GPa for the phengite-free mineral assemblage should be considered.

5.2.2. Thermodynamic modelling of the KHC eclogite from Roztěž

The eclogites from the inner KHC zone generally display a good state of preservation of the HP mineral assemblage. One of the best-preserved samples is the eclogite from Roztěž (KMV118).

The mineral assemblage of this eclogite was used for subsequent estimation of the P-T conditions using a P-T pseudosection calculated for its bulk-rock composition. The P-T conditions of the sequence of metamorphic events were specified by intersection of the X_{Ca} ~z(g) = [CaO/(CaO + FeO + MgO + MnO)] and X_{Fe} ~x(g) = [FeO/(FeO + MgO)] isopleths of garnet. The compositional garnet profile (core → inner zone → outer rim: $Grs_{31\rightarrow28\rightarrow19}$ $Prp_{18\rightarrow22\rightarrow26}$ $Alm_{42\rightarrow44\rightarrow50}$ $Sps_{4\rightarrow1\rightarrow1}$ $X_{Fe\ 70\rightarrow66\rightarrow65}$) is depicted in Fig. 5a and the corresponding data given in Tab. 3.

It is assumed that the mineral assemblage with plagioclase and amphibole preserved in the garnet core reflects the metamorphic conditions at the beginning of a prograde path. In the pseudosection (Fig. 9), this assemblage corresponds to the Hbl–Di–Pl–Ilm–Grt–Qtz stability field at approx. 0.8 GPa and 600 ºC. The core grossular values (X_{Ca} = 31) plot in the LP/LT (Hbl–Di–Pl–Ilm–Grt–Qtz) stability field within the X_{Fe} = 82–88 interval. They do not intersect the measured core values of X_{Fe} = 70 (Fig. 9) probably due to variation in the Fe content in the garnet core during diffusion-related processes. Considering the presence of plagioclase inclusions, it could be assumed that the garnet started to grow at plagioclase stability conditions, below 1.15 GPa.

Following the prograde path, the X_{Fe} and X_{Ca} isopleths intersect in the Hbl–Omp–Rt–Grt–Qtz–Ep–H_2O stability field at *c.* 1.75 GPa and 630 ºC (Fig. 9, point A). This trend is supported by an occasional presence of epidote–clinozoisite inclusions at the boundary between core and inner zone. The constructed course of the P-T path crosses the epidote stability field during pressure increase. Thus, the garnet core composition shows an evidence for a prograde part of the P-T path to the point A at relatively low temperature (600–630 ºC).

The second, inner zone of the garnet includes the relict assemblage corresponding to the peak Omp–Rt–Grt–Qtz–H_2O (liq) stability field. The grossular values in this inner zone yield X_{Ca} = 28. This entire stability field is characterized by this latter value of the grossular isopleth, and thus the maximum P-T conditions can be estimated only from inner zone X_{Fe} values (X_{Fe} = 65–66). The relevant garnet isopleths pass within the interval of 600–650 ºC from 2.2 GPa presumably to even higher pressures, as is supported by conventional geothermobarometry (Fig. 9, heavy dotted line B).

The third outer zone with kelyphite-forming reaction representing the result of decompression under MP/HT conditions falls into the Hbl–Di–Pl–Grt–Ilm–H_2O stability field at 1.25 GPa and 890 ºC, and also agrees with the intersection of the outer rim garnet isopleths (X_{Ca} = 19, X_{Fe} = 65) in the pseudosection (Fig. 9, point C).

6. Conclusions

The current work summarizes the information on the occurrences of numerous newly described, relatively small lenses of MP–HP–UHP metabasic rocks in the inner part of the KHC, and compares them with similar lithologies in the Běstvina Unit and at the adjacent northern margin of the Moldanubian Zone.

The P-T path of eclogite from the new Roztěž locality in the KHC was estimated by means of the pseudosection modelling supported by conventional thermobarometry. The Roztěž eclogite indicates minimum pressures above 2.15–2.3 GPa and temperatures of 600–650 °C reached during the prograde part of metamorphism. The peak of metamorphism is bracketed by T ~650–900 °C, including a stage of decompressional, higher tempered granulite-facies overprint.

The jadeite-rich clinopyroxene in the kyanite-bearing eclogite KMV95 from Bořetice indicates even higher pressures than those inferred from Roztěž eclogite and from the Běstvina Unit (761 °C/4.3 GPa, Ravna and Terry 2004). The eclogite found in blocks displays similar relict

HP deformational structures as garnet peridotite cropping out nearby, so the genetic relationship is probably close. When we compare whole-rock composition of this Ky eclogite and garnet pyroxenite from peridotite from Bečváry, there are substantial differences in MgO, Al_2O_3, Na_2O and CaO contents.

Although partially affected by thermal overprint and retrogression, the eclogite samples from the inner KHC (Bořetice outcrop, Roztěž and Poličany) clearly indicate a prograde metamorphic path. Such record is missing in the studied eclogites from the Moldanubian Zone and its Gföhl Unit.

The major-element composition exhibits differences in the HP rock group and the previously described garnet pyroxenite-forming layers in garnet peridotite from Bečváry.

Eclogites in the inner KHC occur along with garnet peridotites in the parent mylonitized gneisses and mica schists. The rock assemblage indicates presence of deep-seated tectonic shear zones that incorporated the lower-crustal and mantle-derived rock bodies. This is a new finding namely for the Malešov–Roztěž eclogite occurrence.

Three eclogites from the northern margin of the Moldanubian Zone S of Chotěboř (especially the Bída and Borovský Creek localities) exhibit geochemical characteristics similar to the Mg-rich eclogites from the Běstvina Unit and the inner part of the KHC. A high-pressure mineral assemblage and the peak metamorphic conditions recorded in these eclogites correspond, on an average, to the highest pressures found in this part of the MZ and adjacent KHC (minimum P > 2.0 GPa, T = 700–750 °C). These eclogites are associated with Cpx-granulites and Ky–Grt gneisses, and altogether indicate the presence of a refoliated and so far hidden local high-grade domain in this part of the MZ.

The study provides also new data on other types of metabasites – Cpx-bearing amphibolites – and compares their chemical and mineralogical composition with the HP group. Cpx-bearing garnet amphibolite from Doubravčany South in the inner part of the KHC probably belongs to another metabasite group enriched in Fe, with compositional affinity to MP–MT calc-silicate rocks (see Pertoldová et al. 2007).

Based on comparison of the eclogites and amphibolites, two types of metabasites in the KHC and the adjacent MZ can be distinguished. The zones of prevailingly conform lenses of calc-alkaline amphibolites of volcanosedimentary origin and MP-MT metamorphic record related to the outer Mica Schist Unit can be distinguished from the Fe- and Mg- rich tholeiitic series associated with mantle rocks and occasionally also with felsic to pyroxene-bearing granulites in the Běstvina Unit and the inner high-grade part of the KHC. Another newly described HP metabasite from Tři Dvory east of Kolín is probably an eclogitized two-pyroxene metagabbro. The eclogite assemblage indicates somewhat lower pressures than the other HP rocks – around 1.2–1.5 GPa. The rock might be related to the coronitic metabasites reported from the Svatý Kříž Massif (Holub and Munschi 1984).

Acknowledgments The paper stems from fieldwork of Milan Fišera, who mapped the northern part of the KHC, namely the Plaňany and Běstvina units, and found numerous remarkable localities. The occurrence of kyanite eclogite near Bořetice was first noticed by Zdeněk Běhal, who brought some samples to the first author; his deep knowledge of garnetiferous rocks in the area and cooperation are highly appreciated.

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Electronic supplementary material. The GPS coordinates of the studied samples, and the chemical data (Tabs 2–4) are available online at the Journal web site *(http://dx.doi.org/10.3190/jgeosci.047).*

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