CUMMINGTONITE AMPHIBOLITES AND THEIR POSITION WITHIN THE WEST MORAVIAN MOLDANUBIAN ZONE

CUMMINGTONITOVÉ AMFIBOLITY A JEJICH POSTAVENÍ V ZÁPADOMORAVSKÉM MOLDANUBIKU

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Abstract

Němec, D., 2001: Cummingtonite amphibolites and their position within the West Moravian Moldanubian Zone. Acta Mus. Moraviae, Sci. geol., 86:93–102 (with Czech summary).

Cummingtonite amphibolites and their position within the West Moravian Moldanubian Zone

Cummingtonite amphibolite was identified in the West Moravian Moldanubian Zone within the Kotlasy amphibolite complex as a rare rock type. Cummingtonite crystallised there instead of hornblende due to unusual chemistry of its host-rock, which is characterized by low mg number and high TiO_2 and P_2O_5 contents. Whereas association of other rocks forming the Kotlasy complex corresponds to a metamorphosed ophiolite complex, the cummingtonite amphibolite departs from it chemically. Its major- and trace-element chemistry points to an original basaltic magma transitional to alkaline basalts and, concerning its geological setting, to a within-plate basalt, while the West Moravian calcic amphibolites are tholeiitic in nature and originally were MORBs. If rocks, which under conditions of the almandine-amphibolite facies yielded cummingtonite amphibolites were in the West Moravian Moldanubian Zone metamorphosed under granulite facies conditions, clinohypersthene-bearing amphibolites originated instead. Different geotectonic setting deduced for the cummingtonite and the clinohypersthene amphibolites on one side, and for the hornblende amphibolites on the other shows that the premetamorphic basic igneous activity in the West Moravian Moldanubian Zone was not a short-period event, but a long term process.

Key words: Cummingtonite, amphibolite, rock chemistry and geochemistry, genesis, geotectonic setting, Moldanubian Zone Moravia, Czech Republic.

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Introduction

Cummingtonite is a relatively rare rock-forming mineral. According to ERNST (1968) this is due to its narrow PT stability field and because its host-rocks, which are Fe- and Mg-rich and simultaneously deficient in Ca, Al and alkalies, are uncommon. In the West-Moravian crystalline complexes it was described so far only as a scarce constituent of some regionally metamorphosed iron skarns (NĚMEC 1971). The present paper deals with the cummingtonite amphibolites, which occur, in the amphibolite complex of Kotlasy. The locality is situated in the Strážek subdivision of the West Moravian Moldanubian Zone, about 8 km south of the town of Žďár nad Sázavou. The amphibolite complex has brachysynclinal fabric. Amphibole gneisses prevail in it largely. Typical amphibolites form there a breccious stripe, which rims the body (Fig. 1). In it, few small bodies of slightly metamorphosed olivine gabbros and serpentinites, only several meters or several tens meter across, appear. The region underwent metamorphism of the highest zone of

the almandine-amphibolite facies, so that sillimanite-biotite gneisses are the prevalent pelitic rock of the area.

The chemical composition of minerals was determined in the Institute of Mineralogy, Petrography and Geochemistry, Masaryk University, Brno, by Mgr Vávra, using a CanScan 4 DV SEM, coupled with a Link 10 000 EDS analyser and natural minerals as standards. Wet chemical analyses of rocks were performed by H. Červená in the Geoindustria Laboratory in Jihlava. Trace elements were stated by XRF, partly by Dr. Toscani, University of Modena, Italy, partly by Laboratories of the Czech Geological Institute, Praha.

Petrography

The cummingtonite-bearing amphibolite occurs in the NE section of the amphibolite complex (Fig. 1) near the Březí village. It was found in as few fragments only in a territory where calcic amphibolite largely predominates. The rock has a badly conspicuous schistosity. Its texture is granoblastic. In fact, the rocks consists of two separate fractions, one having cummingtonite, the other hornblende. The modal analysis of the cummingtonite fraction yielded (vol.): 56 plagioclase, 26 cummingtonite, 18 opaques (mostly ilmenite). Biotite and quartz are only exceptional. Plagioclase is andesine with variable An (28–45). Cummingtonite is colourless or slight brownish. Its mg number ranges from 40 to 48. Its CaO and Al_2O_3 contents are low but variable (Table 1). Taking total Fe as FeO, the crystal formulae of cummingtonite show an excess of divalent ions and a deficiency of trivalent and quadrivalent ions. Thus, Fe could partly be present as trivalent (compare also MOTTANA et al. 1994) and tetrahedrally coordinated. Wet chemical Fe^{3+} determinations in cummingtonites given in literature occasionally show up to several percent Fe_2O_3 (DEER et al. 1963). HAWTHORNE (1981), however, doubts about similar Fe^{3+} coordination. For ilmenite relatively high V_2O_3 content (0.70 wt %) is characteristic.
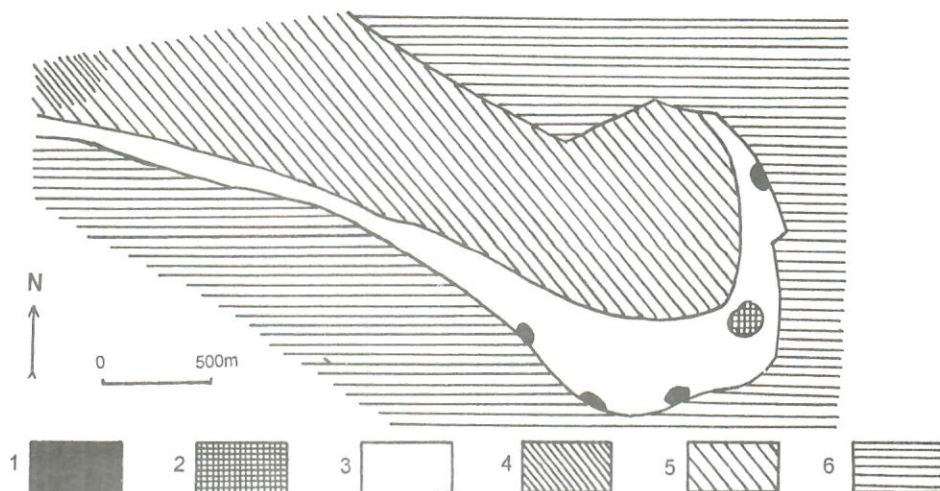

Fig. 1. Geological sketch-map of the Kotlasy amphibolite complex (according to KRUŤA and REJL 1972).
1 – serpentinite, 2 – gabbro, 3 – amphibolites, 4 – cummingtonite amphibolite, 5 – amphibole gneiss, 6 – migmatic sillimanite-biotite gneiss.
Obr. 1. Geologický náčrt amfibolitového komplexu u Kotlas (podle KRUTI a REJLA 1972). 1 – serpentinit, 2 – gabro, 3 – amfibolit, 4 – cummingtonitový amfibolit, 5 – amfibolická rula, 6 – migmatická sullimaniticko-biotitická rula.

T a b l e 1. Selected analyses of amphiboles, the cummingtonite amphibolite, Březí (wt%).
Tabulka 1. Vybrané analýzy amfibolu, cummingtonitový amfibolit, Březí (váh. %).

	Cummingtonite			Ca amphibole	
SiO_2	49.77	50.22	52.62	44.54	47.13
TiO_2	–	–	0.22	1.47	1.29
Al_2O_3	0.98	1.13	2.62	10.48	8.24
FeOtot	31.91	32.77	25.54	18.72	19.56
MnO	0.88	1.08	0.42	0.32	0.20
MgO	13.23	12.70	13.35	8.96	9.52
CaO	1.73	0.63	2.44	10.18	10.28
Na_2O	–	–	–	1.56	1.55
K_2O	–	–	–	0.42	0.28
Total	98.50	98.53	97.21	96.65	98.05
mg	40	40	48	56+	55+

+ FeO only (computed from crystal formula)

The cummingtonite fraction is closely associated with the hornblende fraction. The both fractions alternate in the rock as sharply bounded specks one to two cm across. The two amphiboles never occur intermingled. However, the both fractions have not only the same mineralogy, but also the same relative abundance of minerals, the only difference being the type of the amphibole. The modal analysis of the hornblende fraction gave
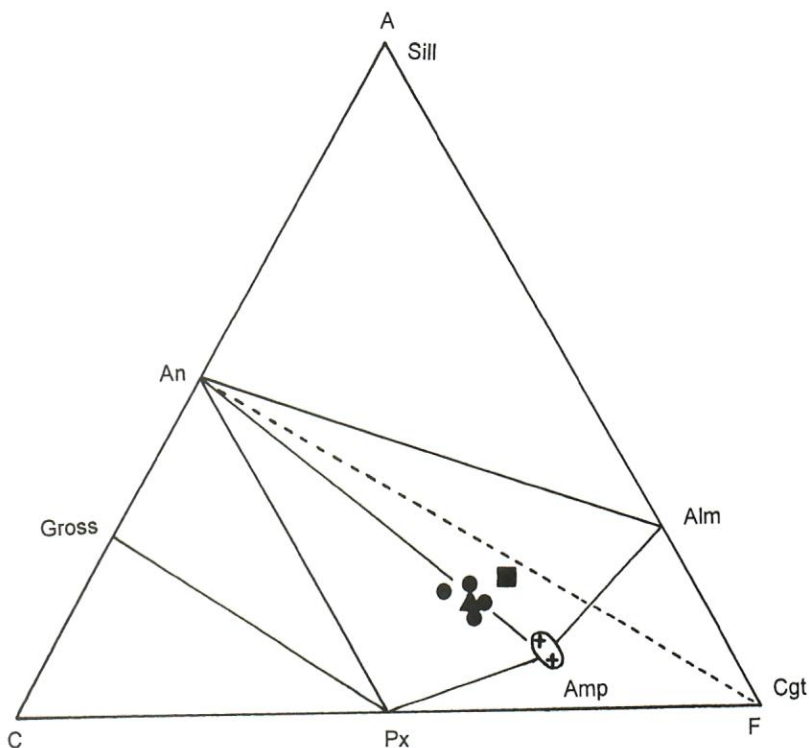

Fig. 2. ACF-diagram for rocks of the Kotlasy amphibolite complex. Dots – amphibolites, triangle – gabbro, square – cummingtonite amphibolite, crosses – hornblende.
Obr. 2. Diagram ACF hornin amfibolitového komplexu u Kotlas. Tečky – amfibolity Ca, trojúhelník – gabro, čtvereček – cummingtonitový amfibolit, křížky – hornblend.

Table 2. Chemical analyses of rocks of the Kotlasy amphibolite complex (1–6), of the clinohypersthene amphibolite, Kladeruby (7) and of a Permian basalt, Oman (8, wt %).

Tabulka 2. Chemické analýzy hornin amfibolitového komplexu u Kotlas (1–6), klinohyperstenového amfibolitu, Kladeruby (7) a permského basaltu, Oman (8, váh. %).

No	1	2	3	4	5	6	7	8
SiO_2	42.47	45.67	49.14	48.04	46.75	51.91	48.87	50.60
TiO_2	traces	0.77	1.08	2.27	2.32	4.02	3.90	2.75
Al_2O_3	14.12	14.73	14.74	12.19	14.58	14.88	13.81	13.40
Fe_2O_3	2.43	4.19	1.65	2.66	2.07	1.86	2.35	5.50
FeO	6.44	7.19	8.26	10.55	10.64	9.17	12.14	5.45
MnO	0.11	0.12	0.14	0.16	0.18	0.17	0.18	0.15
MgO	15.97	12.17	7.79	7.15	6.68	3.20	4.67	3.95
CaO	16.04	13.39	12.27	10.79	10.10	6.17	9.19	5.75
Na_2O	0.53	1.26	2.65	3.24	3.75	5.28	2.91	5.75
K_2O	0.36	0.38	0.22	0.45	0.36	0.18	0.28	0.18
P_2O_5	–	–	0.06	0.19	0.26	0.72	0.62	0.71
H_2O^+	1.08	0.57	1.53	1.28	1.54	1.20	1.09	4.85[+]
H_2O^-	–	–	0.10	0.17	0.24	0.24	0.11	–
Total	99.55	100.44	99.63	99.14	99.47	99.00	100.38	99.04
mg	77	66	59	50	49	34	37	41

[+] LOI, ztráta žíháním
1 Olivine metagabbro, olivinické metagabro, Ostrov (KRUŤA and REJL 1972)
2 Calcic amphibolite, vápenatý amfibolit, Kotlasy (KRUŤA and REJL 1972)
3 Calcic amphibolite, vápenatý amfibolit, Kotlasy
4 Calcic amphibolite, vápenatý amfibolit, Ostrov
5 Calcic amphibolite, vápenatý amfibolit, Březí
6 Cummingtonite amphibolite, cummingtonitový amfibolit, Březí
7 Clinohypersthene amphibolite, klinohyperstenový amfibolit, Kladeruby
8 Permian basalt, permský bazalt, Hamrat Duru, Oman (BÉCHENNEC et al. 1991)

Table 3. Contents of trace elements (in ppm).
Tabulka 3. Obsahy stopových prvků (v ppm).

	1	2	3	4	5
Ni	93	32	94	–	–
Cr	218	62	394	60	11
V	328	203	288	146	101
Nb	6	27	6	15	46
Zr	120	268	130	516	345
Y	31	39	30	57	45
Sr	107	282	374	250	278
Rb	–	9	12	–	4
Cu	–	19	–	16	–
Zn	–	89	–	244	–

The Kotlasy amphibolite complex – amfibolitový komplex u Kotlas:
1 – calcic amphibolite, vápenatý amfibolit, Březí
2 – Cummingtonite amphibolite, cummingtonitový amfibolit, Březí
The Náměšť granulite complex – náměšťský granulitový komplex:
3 – calcic amphibolite, vápenatý amfibolit, Senorady
4 – Clinohypersthene amphibolite, klinohyperstenový amfibolit, Kladeruby
5 – Permian basalt, permský bazalt, Hamrat Duru, Oman (BÉCHENNEC et al. 1991)

(vol. %): 54 plagioclase, 30 hornblende, 16 opaques. Biotite and quartz are lacking throughout. Amphibole is a brown low-Al hornblende, which corresponds, in the LEAKE's et al. (1997) classification, to a magnesiohornblende (FeO was recast to FeO and Fe_2O_3 according to the crystal formula computed for the sum of cations without
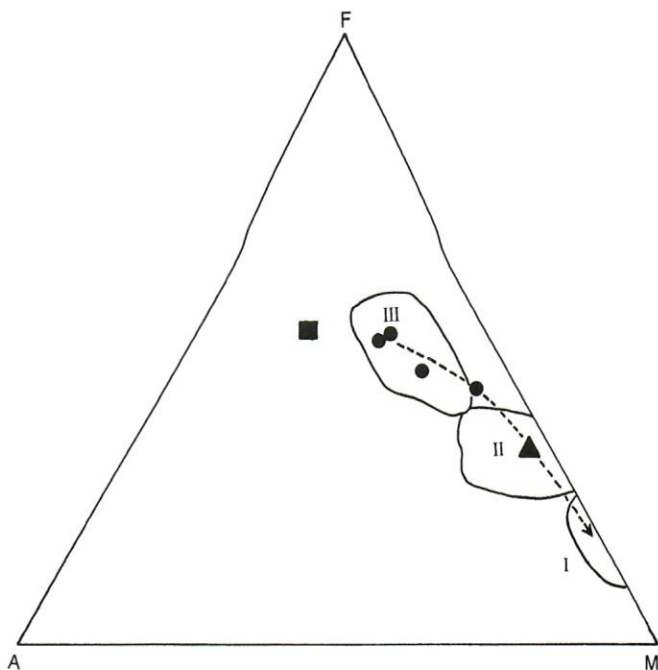
Fig. 3. AFM-diagram for rocks of the Kotlasy amphibolite complex. For symbols, see Fig. 2. I–III: Fields of rocks of the ophiolite series, Oman (according to ALLEMAN and PETERS 1972). I – ultramafites (restites and cumulitic peridotites), II – gabbros, III – basalts.

Obr. 3. Diagram AFM hornin amfibolitového komplexu u Kotlas. Značky viz obr. 2. I–II: Pole hornin ofiolitového komplexu Omanu (podle ALLEMANA a PETERSE 1972). I – ultramafity (restity a kumulitické peridotity), II – gabra, III – basalty.
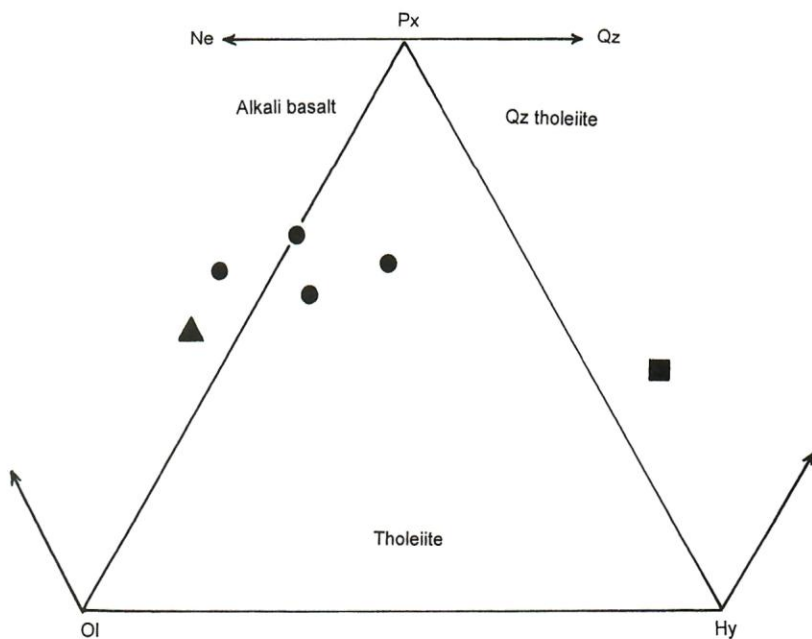

Fig. 4. CIPW norms of rocks of the Kotlasy amphibolite complex. For symbols, see Fig. 2.
Obr. 4. Normy CIPW hornin amfibolického komplexu u Kotlas. Značky viz obr. 2.

CNK equalling 13). This type of amphibole is common in Moldanubian calcic amphibolites. Plagioclase is andesine (32 An). The hornblende fraction does not differ essentially from the other calcic amphibolites of the Kotlasy complex, which only are poorer in Ti minerals and carry titanite in addition to ilmenite.

Chemical analysis of the cummingtonite amphibolite is contained in Table 2. As the both amphibolite fractions are unseparable, it gives the bulk chemistry of the whole rock. Compared with the pure calcic amphibolite from the same locality the cummingtonite-bearing amphibolite is depleted in Ca, essentially richer in Ti and P and has a lower mg number. In the ACF diagram (Fig. 2) the point of the cummingtonite amphibolite plots at An – Cgt tie line (in this diagram, also the Si-deficient rocks of the Kotlasy amphibolite complex were entered).

Genesis of the cummingtonite

In the cummingtonite amphibolite no traces of replacement of hornblende by cummingtonite or the opposite case were observed which would point to a chemical disequilibrium, a case occasionally found in several cummingtonite-bearing amphibolites (e.g. MOTTANA et al. 1994). The cummingtonite fraction and the hornblende fraction are so intimately interconnected in the rock that identical PT conditions of their crystallisation must be assumed. Thus, the modal differences must exclusively stem from different rock chemistry of the rock fractions. The question only remains to answer what is the cause of this different chemistry. The specks carrying different amphiboles are irregularly distributed within the rock that it is unprobable that they would portray some original premetamorphic inhomogenities. It is also important to note that basaltic rocks having chemical composition of the cummingtonite amphibolite exist (compare, for instance, some analyses presented by BALLA et al. 1983, BÉCHENNEC et al. 1991, CAMIRÉ et al. 1995). They were previously denoted as mugearites. Thus, it may be suggested that the original rock could be homogeneous, but it split due to metamorphism into two distinct fractions (this would be a special case of metamorphic differentiation). The chemistry of the femic silicate part of the rock likely falls between that of cummingtonite and that of hornblende. However, a compositional gap exists between the two amphiboles. The number of mineral phases in a rock is controlled by the mineralogical phase rule. Evidently, at given number of the main chemical components only one type of amphibole could exist in the rock at chemi-
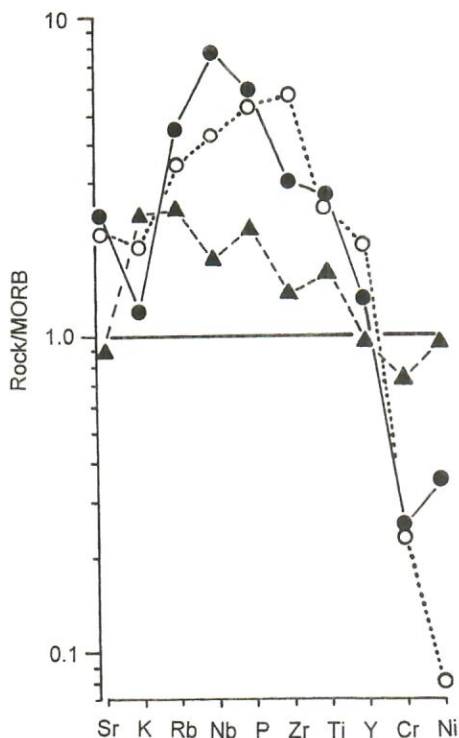
Fig. 5. MORB-normalized trace element contents in the calcic amphibolite, Březí (triangles), in the cummingtonite amphibolite, Březí (dots) and in the clinohypersthene amphibolite, Kladeruby (circles).

Obr. 5. Obsahy stopových prvků, normalizované na MORB, v amfibolitech Ca, Březí (trojúhelníky), v cummingtoniotvém amfibolitu, Březí (bod) a v klinohyperstenovém amfibolitu, Kladeruby (kroužek).

cal equilibrium. Therefore, the rock seems to split by diffusion processes into two equilibrated fractions (a case of mosaic equilibrium in the Korzhinskiy's, 1957, sense). Kanisawa (1969) also observed similar separation of hornblende from cummingtonite in the same rock in metamorphic rocks of the Abukuma zone in Japan.

Position of the cummingtonite rock within the amphibolite complex

The Kotlasy amphibolite complex includes serpentinites, slightly metamorphosed gabbros, calcic amphibolites, cummingtonite amphibolite and amphibole gneisses. The latter type is generally supposed to be metamorphosed tuffs (Silantev et al. 1985). The other rocks of the complex correspond to metamorphosed members of an ophiolite series, as is evidenced, for instance, by Fig. 3 (serpentinite was not analysed, but chemical composition of this rock type varies little). In the locality hypsometric position of individual rock types does not agree with their depth sequence found to occur in the ophiolite series (Spray 1991). However, the amphibolite stripe, which contains the serpentinite and gabbro bodies evidently was strongly affected by tectonism and often boudinaged. Possibly their bodies were carried up from depth as is also suggested by their relatively small dimensions. The rocks of the amphibolite complex have conformable chemistry (Fig. 4) pointing to basic magmas, mostly of gabbroid and pyroxenic types. The only exception is the cummingtonite amphibolite whose different character is especially stressed by its geochemical signature (Table 3, Fig. 5). While the trace-element chemistry of the calcic amphibolites correspond to the MORB tholeiites, the cummingtonite amphibolite differs from it particularly by its high contents of typical crustal elements, having been evidently originally a within-plate basalt (WPB, Fig. 6). This is also supported by the Nb/Zr ratio of 0.10, which fits well to the passive continental margin-type sedimentary environment. The WP-type of the precursor of amphibolites is sporadically also reported from other parts of
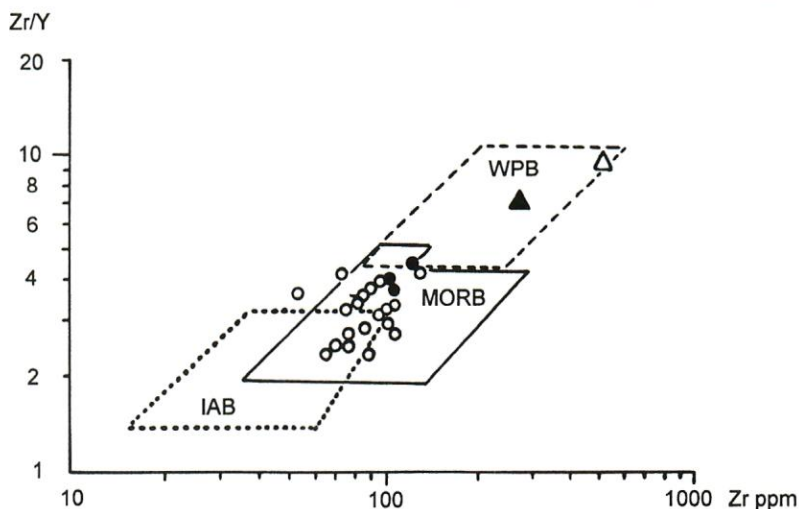

Fig. 6. Discriminant Zr/Y–Zr diagram (after Pearce and Norry 1979) for tectonic setting, for amphibolites of the Bohemian-Moravian Heights. Circles – calcic amphibolites (dots – calcic amphibolite from the Kotlasy amphibolite complex), closed triangle – cummingtonite amphibolite, Březí, opened triangle – clinohypersthene amphibolite, Kladeruby. MORB – mid-ocean ridge basalts, WPB – within-plate basalts, IAB – island-arc basalts.

Obr. 6. Diskriminační diagram Zr/Y–Zr (podle Pearce a Norryho 1979) amfibolitů moldanubika Českomoravské vrchoviny. Kroužky – amfibolity Ca (tečky – amfibolit Ca z amfibolitového komplexu u Kotlas), plný trojúhelník – cummingtonitový amfibolit, Březí, prázdný trojúhelník – klinohyperstenový amfibolit, Kladeruby. MORB – basalty středooceánských hřbetů, WPB – basalty desek, IAB – basalty ostrovních oblouků.

the Moldanubian Zone (FINGER and STEYRER 1995, KACHLÍK 1997). The situation recalls the classical ophiolite region of the Oman Mountains. There, the Permian basaltic rocks partly have the signature of WPB and partly of MORB (BÉCHENNEC et al. 1991). Rocks of the former type possess the major – and trace – element composition closely approaching that of the Březí cummingtonite amphibolite (Tables 2, 3). The presence of two types of basalts in the Oman Mountains is interpreted as a result of the thickness of the crust, which changed with time. This explanation could be perhaps also applied to the Kotlasy amphibolite complex. There, however, traces of time relations of the basic intrusions were obliterated by the strong regional metamorphism. In the surroundings of the town of Chý-nov (in the Bohemian part of the Moldanubian Zone), direct geochronological measure-ments on amphibolites were performed by JANOUŠEK et al. (1997). They showed that their protoliths originated in a long time span, from Algonkian to Cambrian-Ordovician.

Cummingtonite amphibolites and allied rocks in the Moldanubian Zone

From the West Moravian section of the Moldanubian Zone another occurrence of cummingtonite amphibolites was also reported by Fediuk (in BERNARD et al. 1981) from the Uranium Works of Dolní Rožínka. Unfortunately, no details on the rocks and the lo-cality are given. Nevertheless, this rock type can be more common in the Moldanubian Zone, as suggested by the occurrence of clinohypersthene amphibolite east of Kladeruby in the amphibolite stripe which rims the eastern contact of the Náměšť granulite complex (NĚMEC 1996). The rock displays the same geochemical signature as the cummingtonite
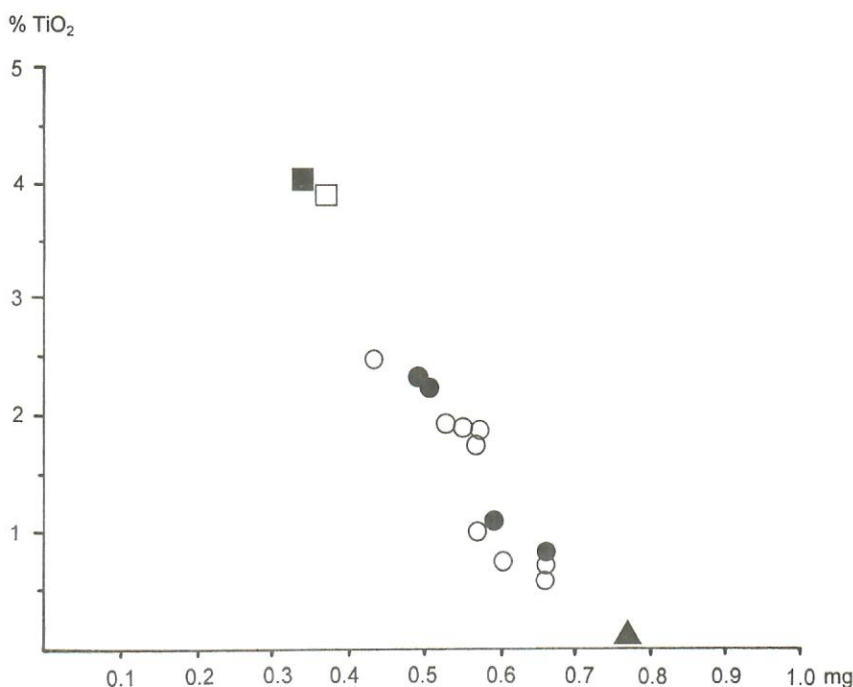

Fig. 7. mg-TiO₂ diagram of rocks of the Kotlasy amphibolite complex (triangle – gabbro, dots – calcic amphi-
    bolites, square – cummingtonite amphibolite) and of the eastern amphibolite stripe, the Náměšť granu-
    lite complex (circles – amphibolites, open square – clinohypersthene amphibolite).
Obr. 7. Diagram mg-TiO₂ hornin amfibolitového komplexu u Kotlas (trojúhelník – gabro, body – amfiboly
    Ca, čtverečky – cummingtonitové amfiboly) a východního amfibolitového pruhu v náměšťském gra-
    nulitovém komplexu (kroužky – amfibolity, prázdný čtvereček – klinohyperstenový amfibolit).

amphibolite of Březí, its salient features being high contents of TiO_2, P_2O_5 and HFS elements, low mg number and low contents of Ni and Cr (Tables 2, 3, Fig. 5). Its petrochemical position within the ambient amphibolites corresponds to the Kotlasy complex (Fig. 7). The clinohypersthene amphibolite lies at the contact with felsic granulites, within the reach of the granulite facies metamorphism, which caused crystallization of clinohypersthene in the rock. Under conditions of the almandine-amphibolite facies cummingtonite would originate instead. A similar cummintonite/orthopyroxene change with progressive metamorphism is also known from other regions (compare BARD 1970).

In the West Moravian section of the Moldanubian Zone the cummingtonite and the clinohyperstene amphibolites signal already with their mineralogy an originally basaltic, transitional to alkaline, type, differing so from the protolith of the calcic amphiboles of the region, which was tholeiitic. This simultaneously testifies to changing geological situation of the area in the time of their intrusions, which caused different geotectonic setting of these rocks. The premetamorphic igneous activity in the West Moravian section of the Moldanubian Zone evidently was not a short-period event, but a long-term process.

Conclusions

Cummingtonite amphibolite was subordinately stated among various types of metamorphosed basic and ultrabasic rocks which form the Kotlasy amphibolite complex. The occurrence of cummingtonite is there due to the chemistry of its host-rock unusual among the West Moravian Moldanubian amphibolites. The rock is characterised by high TiO_2 and P_2O_5 contents and low mg number. The cummingtonite amphibolite originally was a basalt transitional to alkaline basalts, and, consequently, had another geotectonic setting (WPB) than the calcic amphibolites of the West Moravian section of the Moldanubian Zone which were, on account of their geochemical signature, originally MORBs. If rocks, which under the almandine-amphibolite facies conditions would contain cummingtonite, were in the West Moravian section of the Moldanubian Zone metamorphosed under the granulite facies conditions, they carry clinohypersthene instead of cummingtonite. Similar amphibolite was stated at Kladeruby in the Náměšť granulite complex.

SOUHRN

V moravském moldanubiku byly zjištěny cummingtonitové amfibolity jako vzácná součást amfibolitového komplexu u Kotlas. V nich krystalizoval cummingtonit místo obecného amfibolu dík neobvyklému chemismu horniny, který je charakterizován nízkým mg a relativně vysokým obsahem TiO_2 a P_2O_5. Zatím co ostatní horniny u Kotlas odpovídají metamorfovanému ofiolitovému komplexu, cummingtonitové amfibolity se od něj odlišují chemicky. Jejich chemismus odpovídá původnímu basaltovému magmatu na přechodu k alkalickým basaltům a geologickou pozicí vnitrodeskovým bazaltům, zatím co amfibolity Ca západomoravského moldanubika jsou tholeiitické povahy a byly původně MORB. Amfibolity, které při metamorfoze v podmínkách amfibolitové facie poskytovaly cummingtonit, při metamorfoze v podmínkách granulitové facie poskytovaly v západomoravském moldanubiku klinohypersten. Odlišná geotektonická pozice odvozená na jedné straně pro amfibolické a hyperstenické amfibolity a pro amfibolity Ca na straně druhé nasvědčuje, že předmetamorfní basický magmatismus byl patrně v moravském moldanubiku dlouhodobý proces.

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