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Fe-rich Amphibolites with Tholeiitic Affinity from the SE Margin of the Bohemian Massif

By OLGA MATĚJOVSKÁ*)

With 11 Figures und 2 Tables

Bohemian Massif
Moldanubicum
Amphibolites
Granulites
Mineral anlyses
Major element analyses
Trace Element analyses
REE concentrations

Contents

Zusammenfassung

Am Rande der Böhmischen Masse treten zahlreiche Amphibolitkörper auf, welche oft in dünnen Bändern mit Biotitgneisen, Marmoren, Kalksilikatgesteinen, oder Quarziten wechsellagern. Die Amphibolite kommen gewöhnlich zusammen mit sauren pyroxenfreien Granuliten, Eklogiten und Serpentiniten (±Granat) vor. Untersucht wurden die Haupt- sowie Neben- und Spurenelemente in den Amphiboliten. Ihr Gehalt ist ähnlich wie in den tholeiitischen Metabasalten. Der vorherrschende Teil der untersuchten Proben kann mit den mittelozeanischen Basalten des Übergangstyps (T-type MORB) verglichen werden. Die untersuchten Amphibolit-Proben sind leicht mit LIL und LREE angereichert. Das Verhältnis $(La/Yb)_N$ schwankt von 1 bis 2.8. Nur die Probe 5 zeigt höheren LIL- und LREE-Gehalt mit $(La/Yb)_N$ = 3.5 und eine positive Anomalie des Nb- und Ta-Gehalts. Die geochemischen Verhältnisse der untersuchten Proben deuten auf den möglichen Ursprung der Amphibolite aus der ozeanischen Kruste. Die Gemeinschaft der Amphibolite mit den Metarhyoliten, die Abwesenheit der andesitischen Metavulkanite und auch die Natur der umliegenden Metasedimente zeugen, daß die heutigen Metabasite an einem Rift am Rand der kontinentalen Kruste, oder bei der Kollision der kontinentalen Kruste und der ozeanischen Lithosphäre entstehen konnten.

Abstract

Numerous amphibolite bodies alternating with the thin layers of biotite gneisses, crystalline limestones, calcsilicate rocks and quartzites, and accompanied with the acid granulites, eclogites and serpentinites occur in the high crystalline complex in the SE marginal area of the Bohemian massif. On the basis of the major, minor and trace element contents, the amphibolites correspond to metabasalts of tholeiitic character. The predominant part of the studied samples is comparable with the mid-ocean ridge basalts of transitional character (T-type MORB). They exhibit slight enrichment in LIL and LREE. $(La/Yb)_N$ equals from 1 to 2.8. Only sample 5 has higher LIL and LREE concentrations with $(La/Yb)_N$ = 3.5 and a positive anomaly in the Nb and Ta contents. The geochemical characteristics of the studied metabasalts point at their origin from the ocean crust. Their association with the metarhyolites, absence of andesitic metavolcanites, and the character of the metasediments adjacent to the amphibolites and granulites indicate that the present metabasites could have originated during the rifting in the marginal part of the continental crust or during collision of the continental crust and oceanic lithosphere.

1. Introduction

Numerous bodies of amphibolites associated with serpentinites (±garnet), eclogites and garnet-biotite acid granulites are common constituents of moldanubian high-grade metamorphic terrain in the SE part of the Bohemian Massif (fig. 1). These lens-shaped layers with dimensions varying from metres to kilometres and with variable thickness, are intimately associated with metasediments. Particularly in the western part of the studied area, the amphibolites are often interlayered with metasediments. Particularly in the western part of the studied area, the amphibolites are often interlayerd with calc-silicate rocks, crystalline limestones, quartzites and gneisses. Many bands have been fragmented to varying degrees by boudinage. In the surrounding regions, outcrops of garnet-biotite gneisses (+perthite) and leucocratic migmatitic rocks are found. Field relationships were studied during geological investigations for maps on a scale of 1 : 25.000 (JENČEK

*) Author's address: OLGA MATĚJOVSKÁ, Geological Survey of Czechoslovakia, Malostranské nám. 18, 11821 Praha 1, ČSSR.

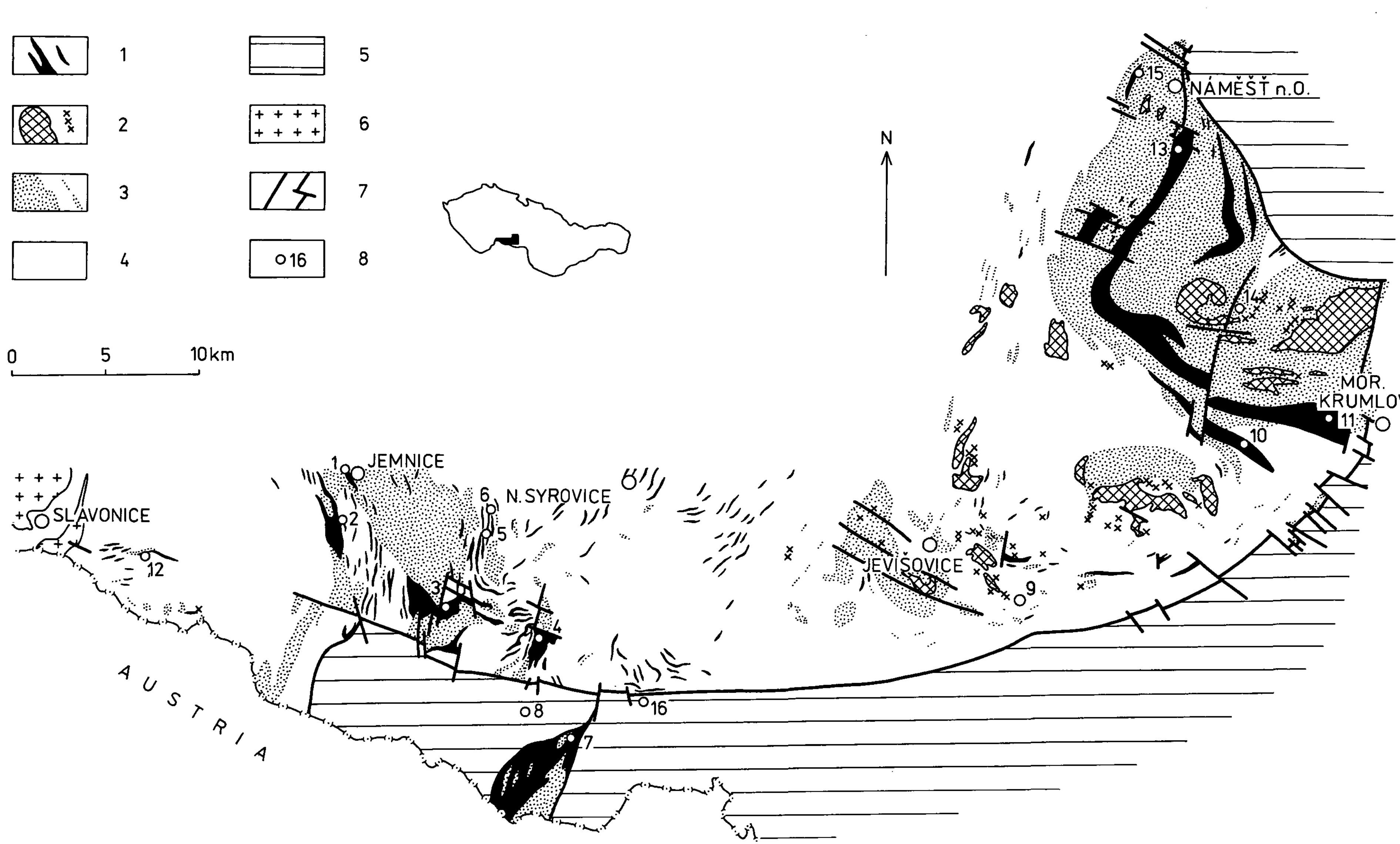

Fig. 1.
Distribution of amphibolite occurrences in the highly crystalline unit on the SE margin of the Bohemian Massif compiled from the unpublished maps of MATĚJOVSKÁ and from JENČEK (1980).
1 = amphibolites; 2 = serpentinites; 3 = acid granulites; 4 = complex of paragneisses and migmatites; 5 = Moravicum of Thaya and Svratka Domes; 6 = Variscan two-mica granite; 7 = faults and thrusts; 8 = sampling points, numbered.

Table 1.
Representative mineral analyses of amphibolites from the SE margin of the Bohemian Massif.
Mineral chemical data were obtained by electron microprobe analysis performed on an ARL-SEMQ machine at the Geological Survey in Prague (analysts JILEMNICKÁ, JAKEŠ). The determination of Fe^{2+}/Fe^{3+} was carried out using the CHÁB-KOTRBA (1980) program.

	1. Jemnice						2. Menhartice			3. Police					4. Bítov n.D.		
	Amphibole			Garnet			Amphibole			Amphibole		Garnet			Amphibole		
	rim	core	rim	rim	core	rim	rim	core	rim								
SiO_2	44.24	44.8	45.62	38.66	38.51	39.43	43.43	45.65	42.96	45.3	44.64	40.27	39.43	39.45	41.04	43.17	42.83
TiO_2	1.7	0.97	0.81	0.18	0.24	0.09	2.49	1.03	2.03	2.86	2.21	0.32	0.06	0.32	2.34	0.95	0.99
Al_2O_3	11.72	11.22	10.86	20.24	20.66	21.89	13.65	12.52	13.55	8.87	8.68	22.33	21.74	22.12	12.48	9.0	8.99
FeO^{tot}	16.82	17.47	18.04	24.1	23.8	22.83	9.86	10.33	10.28	17.41	16.81	18.82	18.9	18.9	15.69	14.3	14.62
MnO	0.21	0.00	0.31	2.75	2.64	1.41	0.09	0.18	0.01	0.21	0.27	0.52	0.54	0.54	0.27	0.48	0.47
MgO	10.49	10.64	10.34	3.02	2.4	2.91	13.39	13.92	13.14	8.28	9.49	11.29	10.72	10.78	11.61	14.44	14.72
CaO	9.31	9.15	8.96	9.08	9.31	9.87	11.08	10.79	9.24	12.39	12.3	5.93	5.21	5.65	11.87	10.73	10.00
Na_2O	1.41	1.5	1.23	0.02	0.04	0.02	1.07	1.12	1.07	1.55	1.95	0.00	0.00	0.01	1.54	3.19	3.11
K_2O	0.86	0.74	0.53	0.01	0.02	0.01	1.28	0.34	1.23	1.27	1.28	0.00	0.00	0.00	1.05	1.14	1.06
Σ	96.76	96.49	96.70	98.06	97.62	98.46	96.34	95.88	93.51	98.14	97.63	99.48	96.60	97.77	97.89	97.4	96.79
Si	6.51	6.59	6.72	5.16	6.18	6.19	6.30	6.56	6.40	6.80	6.74	6.05	6.10	6.04	6.05	6.35	6.27
Ti	0.19	0.11	0.09	0.02	0.03	0.01	0.27	0.11	0.23	0.32	0.25	0.04	0.01	0.04	0.26	0.11	0.11
Al	2.03	1.95	1.89	3.18	3.90	4.05	2.33	2.12	2.38	1.57	1.55	3.94	3.96	3.98	2.17	1.56	1.55
Fe^{3+}	0.81	0.94	0.74				0.55	0.80	0.44	0.00	0.00				0.82	1.02	1.46
Fe^{2+}	1.26	1.21	1.49				0.64	0.44	0.84	2.18	2.12				1.11	0.74	0.33
Fe^{tot}				2.68	3.18	2.99						2.36	2.44	2.41			
Mn	0.03	0.00	0.04	0.31	0.36	0.19	0.01	0.02	0.01	0.03	0.03	0.07	0.07	0.07	0.03	0.06	0.06
Mg	2.30	2.33	2.27	0.60	0.58	0.69	2.89	2.98	2.92	1.85	2.14	2.54	2.49	2.47	2.55	3.17	3.21
Ca	1.47	1.44	1.41	1.30	1.60	1.66	1.72	1.66	1.47	1.99	1.99	0.95	0.86	0.93	1.88	1.69	1.57
Na	0.40	0.43	0.35	0.00	0.00	0.00	0.3	0.31	0.45	0.57	0.25	0.00	0.00	0.00	0.44	0.91	0.88
K	0.16	0.14	0.1	0.00	0.00	0.00	0.24	0.06	0.23	0.24	0.25	0.00	0.00	0.00	0.20	0.21	0.20
(MG)–	0.52	0.52	0.5				0.7	0.7	0.69	0.45	0.5				0.56	0.64	0.64
$Mg/(Mg+Fe^{2+})$	0.65	0.66	0.61				0.82	0.87	0.78	0.46	0.50				0.70	0.81	0.91

	5. Hornice			6. Třebelovice			7. Starý Petřín									8. Podhradí	
	Amphibole			Amphibole			Amphibole						Garnet			Amphibole	
	rim	core	rim							from symplectites						rim	rim
SiO_2	44.87	42.68	44.03	43.07	43.47	43.54	44.1	44.32	44.85	40.42	40.17	45.91	39.69	39.92	39.14	41.66	41.62
TiO_2	2.06	2.24	2.18	1.75	1.82	1.82	1.73	1.7	2.44	2.47	2.00	1.39	0.00	0.21	0.13	1.01	0.95
Al_2O_3	10.12	11.84	10.5	13.33	12.9	12.69	12.62	12.61	10.16	15.55	15.34	8.01	20.91	21.57	21.68	13.32	12.81
FeO^{tot}	20.6	20.69	20.96	14.25	13.89	14.19	16.5	16.74	16.14	15.16	15.48	17.41	22.7	22.18	22.97	18.21	17.84
MnO	0.47	0.43	0.42	0.5	0.48	0.00	0.3	0.21	0.08	0.00	0.00	0.17	1.67	0.22	0.77	0.31	0.33
MgO	8.29	7.3	7.53	12.3	13.00	12.08	9.56	9.76	11.18	10.17	10.24	11.52	4.24	6.83	4.41	9.45	9.46
CaO	9.92	9.85	9.86	10.23	9.91	9.88	10.91	10.68	10.39	10.66	9.95	10.47	9.11	8.46	10.99	10.18	10.14
Na_2O	1.45	1.37	1.46	1.87	2.09	2.15	1.28	1.28	1.68	1.9	1.9	1.37	0.00	0.06	0.03	1.21	1.19
K_2O	1.03	1.29	1.3	0.67	0.69	0.63	0.68	0.73	0.87	1.18	1.23	0.61	0.00	0.02	0.00	1.57	1.38
Σ	98.81	97.69	98.24	97.97	98.25	96.98	97.68	98.03	97.79	97.51	96.31	96.86	98.32	99.47	100.12	96.92	95.72
Si	6.61	6.40	6.57	6.17	6.18	6.31	6.47	6.46	6.56	5.94	5.94	6.76	6.24	6.16	6.06	6.19	6.25
Ti	0.23	0.25	0.24	0.19	0.19	0.20	0.19	0.19	0.27	0.27	0.22	0.15	0.00	0.02	0.02	0.11	0.11
Al	1.76	2.09	1.85	2.25	2.16	2.17	2.18	2.17	1.75	2.69	2.67	1.39	3.87	3.92	3.95	2.33	2.27
Fe^{3+}	0.78	0.76	0.70	1.25	1.37	1.04	0.57	0.71	0.70	0.76	1.08	0.97				1.11	1.10
Fe^{2+}	1.76	1.83	1.91	0.45	0.28	0.68	1.46	1.33	1.28	1.11	0.83	1.18				1.15	1.14
Fe^{tot}													2.97	2.85	2.97		
Mn	0.06	0.05	0.05	0.06	0.06	0.00	0.04	0.03	0.01	0.00	0.00	0.02	0.22	0.03	0.10	0.04	0.04
Mg	1.82	1.63	2.67	1.63	2.75	2.61	2.09	2.12	2.44	2.23	2.26	2.53	1.00	1.58	1.03	2.09	2.12
Ca	1.57	1.58	1.58	1.57	1.51	1.53	1.72	1.67	1.63	1.68	1.58	1.65	1.54	1.40	1.82	1.62	1.63
Na	0.41	0.40	0.42	0.52	0.58	0.60	0.36	0.36	0.48	0.54	0.54	0.39	0.00	0.00	0.00	0.35	0.35
K	0.19	0.25	0.25	0.12	0.13	0.12	0.13	0.14	0.16	0.22	0.23	0.11	0.00	0.00	0.00	0.30	0.26
(MG)–	0.41	0.38	0.39	0.6	0.62	0.6	0.5	0.5	0.55	0.54	0.54	0.54				0.48	0.48
$Mg/(Mg+Fe^{2+})$	0.51	0.47	0.47	0.85	0.91	0.79	0.59	0.61	0.66	0.67	0.73	0.68				0.65	0.65

The Podhradí samples (Nr. 8) were taken from the Moravicum.

Table 2.
Analyses of amphibolites from the SE margin of the Bohemian Massif.
Calculated FeO in No 1 = 1,48; in No 2 = 11,52; No 5 = 8,77; No 6 = 7,73; No 8 = 8,19.

	1	2	3	3a	4	5	6	7	7a	8	9	10	11	12	13	14	15	16
SiO_2	46.06	47.87	48.93		48.24	52.18	48.76	48.73		49.53	47.09	47.60	47.02	52.45	46.72	51.30	48.43	47.89
TiO_2	1.45	1.93	1.73		2.07	2.50	1.59	2.31		1.90	0.31	1.61	0.67	2.21	1.74	2.38	1.81	1.66
Al_2O_3	16.19	14.33	14.41		14.67	15.98	16.12	14.58		15.53	15.50	14.50	18.02	13.59	15.73	13.12	15.88	14.64
Fe_2O_3*)	11.82	13.34	1.54		1.66	10.72	10.52	2.83		11.51	3.71	2.83	2.08	1.70	3.39	1.37	2.26	2.63
FeO			9.05		8.48			9.34			13.58	7.97	5.85	9.40	6.70	12.00	8.59	9.26
MnO	0.21	0.22	0.18		0.16	0.35	0.18	0.20		0.20	0.12	0.20	0.16	0.19	0.19	0.22	0.24	0.21
MgO	7.87	6.92	7.04		6.16	5.15	6.94	5.98		5.74	2.88	7.34	8.31	6.17	7.36	5.55	6.36	9.96
CaO	12.82	10.81	10.70		11.35	8.43	10.10	10.23		9.71	10.80	11.85	13.68	8.48	12.28	8.74	10.62	7.64
Na_2O	2.53	2.66	2.75		2.43	1.77	3.94	2.43		3.33	2.46	3.06	1.70	2.96	2.46	2.82	2.76	2.94
K_2O	0.35	0.51	0.62		1.47	1.51	0.78	0.75		1.58	1.13	0.26	0.28	0.72	0.63	0.49	0.35	0.36
P_2O_5	0.13	0.19	0.17		0.24	0.49	0.16	0.20		0.23	0.10	0.13	0.07	0.26	0.27	0.38	0.25	0.12
Σ	99.43	98.78	97.12		96.93	99.08	99.09	97.58		99.26	97.68	97.35	97.84	98.13	97.47	98.37	97.55	97.31
Trace elements [ppm]																		
Rb	<5	<5	13	24	7	49	6	2	28	63								
Sr	161	331	237	150	251	326	289	160	290	196								
Ba	70	130	143	328	67	670	200	104	345	180								
Y	27	35	31	26	18	32	24	41	9	30								
Nb	6	<5	<5	<5	<5	36	6	7	<5	11								
Zr	66	100	87	103	73	199	82	111	18	127								
V	313	409	318	310	357	221	305	422	354	290								
Cr	235	108	254	76	250	93	181	154	100	119								
Ni	114	43	41	35	70	62	74	49	20	39								
Co	44	58	45	36	31	34	44	35	38	39								
Cu	79	64	40	46	22	17	26	39	22	17								
Zn	101	119	69	99	121	107	26	92	108	104								
Pb	<5	<5	<5	8	29	<5	7	15	17	7								
Hf	2.36	3.54	4.78		2.75	7.29	1.83	3.45	1	2.57								
Ta	<1	<1	<1		<1	2.36	<1	<1	<1	1.16								
La	4.20	11.0	17.3		4.95	38.7	9.73	8.07	7.65	12.4								
Ce	23.6	30.3	27.1		22.0	66.2	19.5	19.9	21.5	33.6								
Sm	3.16	4.28	3.66		2.72	7.18	2.94	4.30	2.28	4.12								
Eu	1.29	3.53	1.26		0.98	2.39	1.14	1.62	1.06	1.58								
Tb	<1	1.45	1.13		<1	1.45	<1	1.51	<1	<1								
Yb	2.09	3.11	3.00		4.41	2.52	19.5	4.70	1	2.16								
Lu	0.31	0.60	0.58		0.47	0.53	0.39	0.70	0.26	0.40								
Th	<1	<1	2.47		2.32	3.96	<1	<1	<1	1.90								
Sc	41.9	47.4	34.9		34.3	26.7	32.9	39.4	32.1	36.6								
Cs	1.13	<1	<1		<1	2.76	1.32	<1	1.98	<1								
Sb	<1	<1	1.65		<1	<1	1.24	<1	<1	2.57								
U	<3	<3	<3		<3	<3	<3	<3	<3	<3								
Au	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05								

*) Fe_2O_3 was determined as total content.

et al., 1979, 1980, MATĚJOVSKÁ et al., 1978, 1980, 1983, 1985, DORNIČ et al., 1985). On the southern and eastern margins of this crystalline area, a significant fault separates the Moldanubicum from the less metamorphosed unit of Moravicum. The mutual relationship between the Moldanubian and Moravian units are rather complex and have not yet been completely elucidated (DUDEK, 1962, JENČEK & DUDEK, 1971; FUCHS & MATURA, 1976, THIELE, 1976).

Moldanubian metasediments and meta-igneous rocks were metamorphosed at high pressures during the Precambrian and then affected by lower-pressure metamorphism connected with migmatization. The granulite-amphibolite metamorphic facies are dominant. The present mineral association can be seen to have polymetamorphic character and the minerals of both metamorphic stages are still distinct. Amphibolites are represented by the hornblende + plagioclase ± garnet ± clinopyroxene ± quartz, mineral assemblage. Diablastic intergrowth of amphibole and plagioclase, which was observed in several places, may point to an earlier higher metamorphic stage of the present-day amphibolites. The regional migmatization common here, has not essentially affected the amphibolites, probably because of their more resistent character. Similar metamorphic development is also assumed for the adjacent high-pressure acid granulites and granulite gneisses. Their mineral assemblage contains quartz, K-feldspar (perthite), plagioclase (±antiperthite), biotite, garnet, kyanite and/or sillimanite (MATĚJOVSKÁ, 1967).

Some of the premetamorphic history of the present rocks can be revealed by careful interpretation of entire rock geochemistry. This paper presents some major and trace element data for the amphibolite bodies from the SE margin of the Moldanubian high crystalline area, to complete an earlier geochemical study of acid granulites (FIALA et al., 1987) adjacent to amphibolites.

Fourteen localities were chosen for the geochemical study of the Moldanubian amphibolites and two further ones were taken for comparison from the neighbouring Moravicum unit. Of the samples, only most homogeneous and least migmatized were analysed. The numbers of the individual localities correspond to the numbers of mineral and rock analyses listed in table 1 and 2.

2. Petrographic Characteristics

The most common amphibolites are dark, almost black, finegrained, sometimes thinly layered rocks. They range from weakly to strongly foliated. The predominant mineral is dark green or brown-green amphibole. Subordinate minerals include plagioclase, K-feldspar, sometimes clinopyroxene, accessoric quartz, titanite, apatite, zirkon, magnetite, ilmenite and rutile. Symplectites of plagioclase with light-coloured green amphibole are present in garnet rich amphibolites, which occur in places. Amphiboles belong to the Mg-richer members of the calcic amphiboles group (LEAKE, 1978), with a $Mg/(Mg+Fe^2)$ ratio of 0.46–0.9. Their componente si exhibit a variability which corresponds to magnesio-hornblende, tschermakitic hornblende and tschermakite (alumino-tschermakite) – fig. 2. The correlation between the chemistry of amphiboles and rocks is positive. The garnets present are characterized by relatively high Fe content and very variable Mg content, up to 2.54 (see table 1 and fig. 3). The changes in the garnet composition seem not correlate with the MgO contents in the rocks. The amphibole and garnet chemical analyses are listed in table 1.

Brief Characteristics of the Sample Localities

1) Outcrop from the SW periphery of the town of Jemnice. Finegrained, dark amphibolite rich in garnet, up to 1 cm in size. The vicinity of the outcrop contains frequent interlayers of biotite-amphibolite gneiss. An amphibolite body, one hundred meters in size, associated with acid granulites.
2) Menhartice Brook valley 1500 m NE of Menhartice. Finegrained amphibolite, rich in garnet over 1 cm in size forms boudines about one metre in size in grey crystalline limestone enclosed in a large amphibolite body about one kilometer in size. The vicinity contains acid granulite.
3) Quarry in the valley of the Želetavka River, 1500 m SE of Police. Dark, almost black, fine-grained, garnet bearing amphibolite alternates with metre-thick beds of hornblende-biotite gneiss and biotite gneiss. Amphibolite body about one kilometer in size enclosed in acid granulite.
4) Borehole 17 km NW of Bítov. Dark, fine-grained amphibolite partly with light-coloured thin layers, often alternating with biotite paragneisses. Amphibolite body wiht dimen-

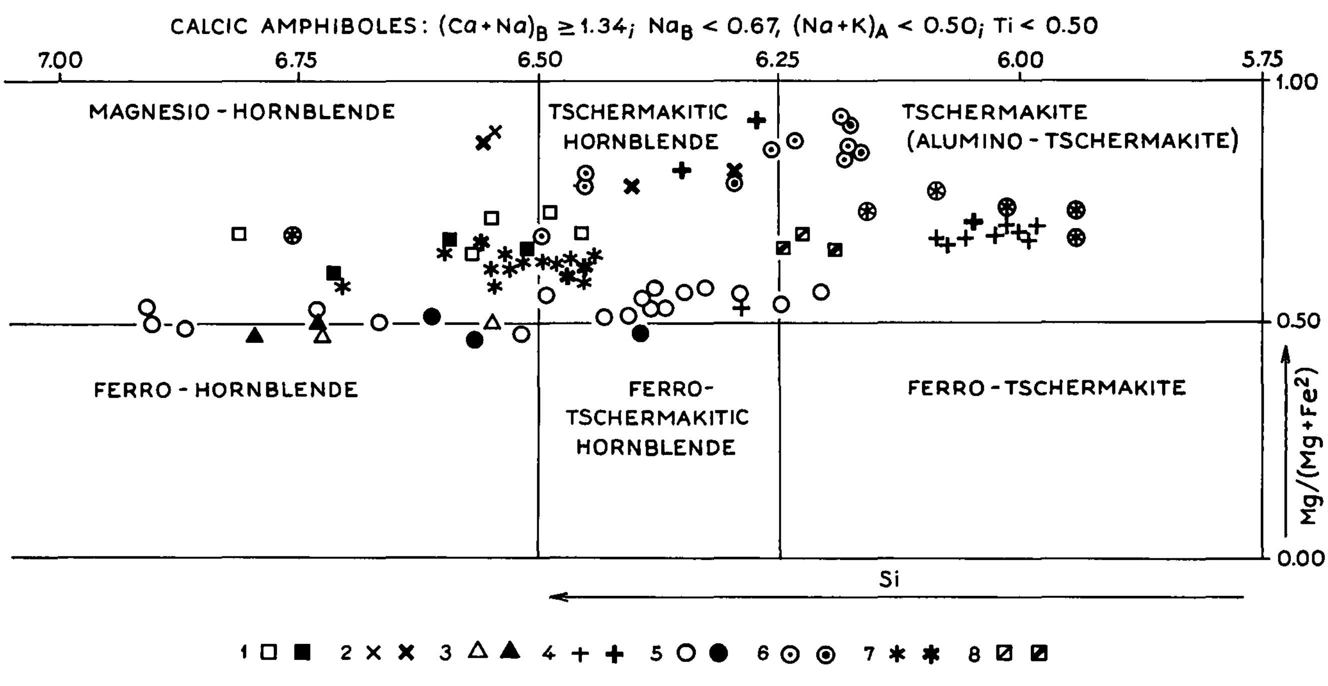

Fig. 2.
Composition of amphiboles from amphibolites of the SE margin of the Bohemian Massif. Plot of Si and $Mg(Mg+Fe^2)$ according to LEAKE's classification (1978). 1 = Jemnice; 2 = Menhartice; 3 = Police; 4 = Bítov; 5 = Hornice; 6 = Třebelovice; 7 = Starý Petřín; 8 = Podhradí (Moravicum).
Full symbols are introduced in table 1.

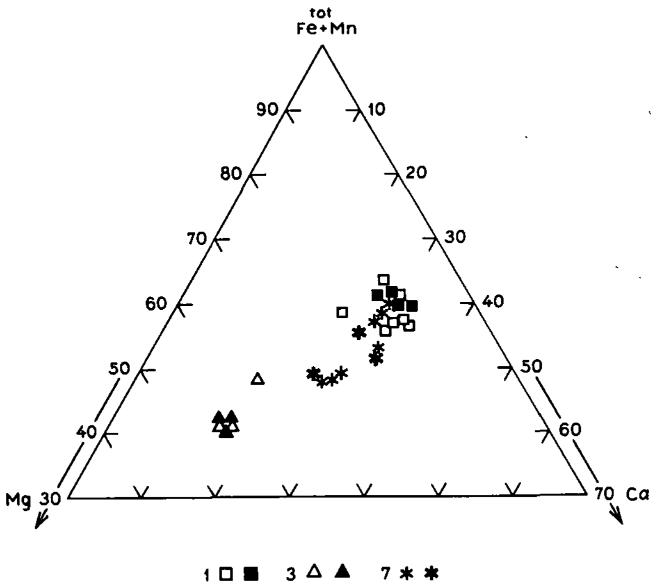

Fig. 3.
Composition of garnet from amphibolites from the SE margin of the Bohemian Massif, plotted in terms of Ca/(Ca+Fe+Mg+Mn); Fe(Ca+Fe+Mg+Mn); Mg(Ca+Fe+Mg+Mn).
1 = Jemnice; 3 = Police; 7 = Starý Petřín.
Full symbols are introduced in table 1.

sions of several kilometers in the vicinity of acid granulite bodies.

5) The outcrops in the valley of the Bihanka River, 700 m west of Hornice. Dark, fine-grained amphibolite alternating with bands of biotite and quartz-gneisses. Tiny amphibolite strip in biotite gneiss.
6) Outcrop 1.5 km south of Třebelovice. Fine-grained, black amphibolite, in some places light-coloured thinly laminated. Tiny amphibolite layer in biotite gneiss.
7) Outcrops north of Starý Petřín. Tectonically limited block of Moldanubicum rocks inside Moravicum unit. Black, very fine-grained, massive amphibolite forms an almost two-km-wide body, associated with acid granulite.
8) Moravicum unit. Outcrops in the Dyje valley, north of Podhradí n. D. Black amphibolite with light-coloured bands in some places and interlayered by biotite gneiss or amphibole-biotite gneiss with a thickness of about one cm.
9) Outcrop in the Jevišovka River valley, 200 m east of Vevčice. Black amphibolite full of garnet grains (2–4 mm large). In the surroundings, small acid granulite occurrences, surrounded by leucocratic migmatitic rocks.
10) Quarry SW of Tulešice. Amphibolite body about one km in size. Massive, black amphibolite in the vicinity of an acid granulite body.
11) Dobřínsko Brook valley north of Dobřínsko. Black massive amphibolite very rich in garnet about one cm in size. Big amphibolite strip about one km in size on the periphery of an acid granulite body.
12) Quarry near the road E of Slavonice. Fine-grained, black amphibolite in beds several tens of metres in size, alternating with biotite gneiss. Tiny amphibolite strip in leucocratic migmatitic rocks. In the vicinity small, several hundred-meter large acid granulite bodies.
13) Outcrops 2.5 km SE of Sedlec (over the Jihlava river). Black massive amphibolite partly with light-coloured bands. Big amphibolite body several kilometers in size, inside the acid granulite body.
14) Outcrops in the brook valley 1 km south of Lhánice. Fine-grained amphibolite, garnetiferrous, with some occurrences of rare clinopyroxene. Tiny amphibolite layer in the large granulite body.
15) Quarry 1 km NE of Vícenice. Fine grained amphibolite with subordinate light-coloured interlayers partly migmatized. Amphibolite body about one kilometer in size in the large acid granulite body. In the vicinity migmatized amphibolite of various types.
16) Moravicum unit. Quarry in the bank of the Vranov dam SW of Štítary. Massive amphibolite is accompanied in places by light-coloured bands.

3. Geochemistry

Previous studies of amphibolite chemistry were preliminary and were connected with geological investigations for geological maps on a scale of 1 : 25.000. The

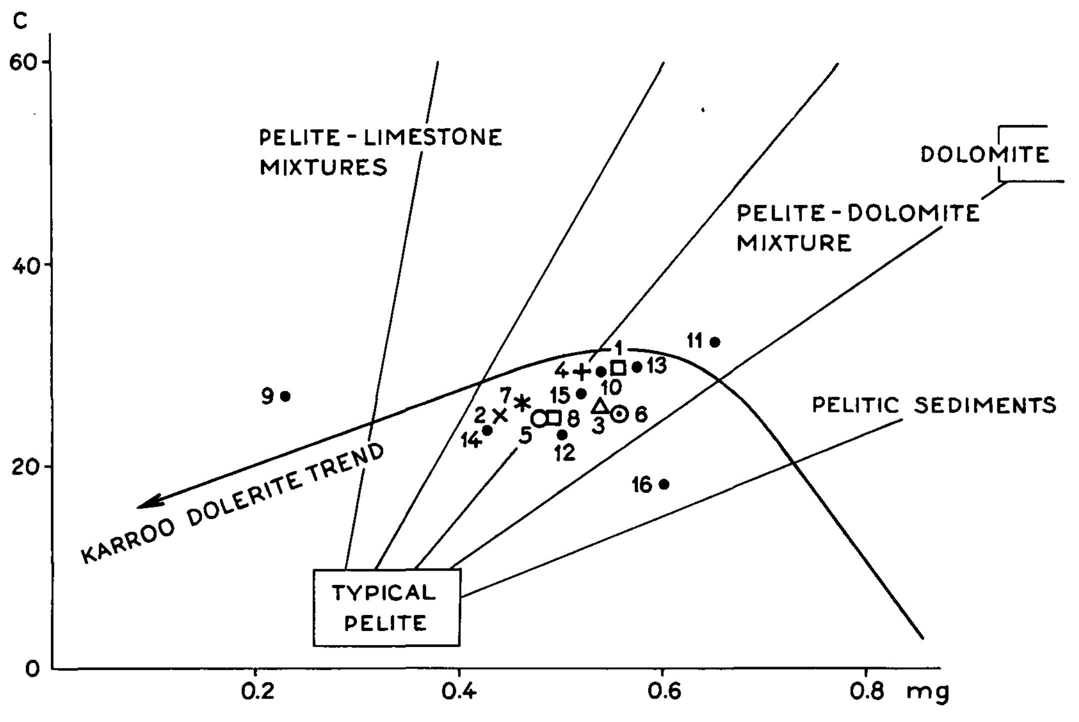

Fig. 4.
Plots of NIGGLI's values of c and mg in amphibolites of the SE margin of the Bohemian Massif.
Marked fields of pelitic and carbonaceous rocks after LEAKE (1964). Numbers of analysed samples from table 2; symbols 1–8 as in fig. 2.

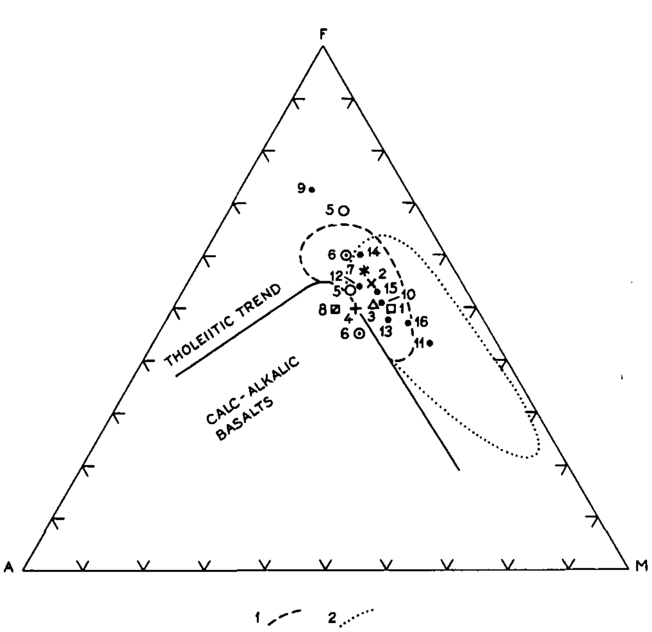

Fig. 5.
Composition of amphibolites from the SE margin of the Bohemian Massif in terms of A (Na_2O+K_2O), F (FeO^{tot}) and M (MgO).
Tholeiitic trend after KUNO (1960). For numbers of samples see table 2, symbols 1–8 as in fig. 2.
1 = field of amphibolites from the surroundings of Náměšť n.O. and Moravský Krumlov (SE part of the Bohemian Massif) after ŠICHTÁŘOVÁ (1981); 2 = field of amphibolites from the southern part of the Bohemian Massif (South Bohemia) after SUK (1971).

only chemical data (major elements) were collected by ŠICHTÁŘOVÁ (1981) for her thesis on amphibolites from Náměšť n. O. and Moravský Krumlov (eastern part of the studied area).

The present study of the amphibolites is based on 17 major element analyses and 8 trace and REE element analyses. The distribution of the studied localities in the field is shown in fig. 1. The contents of the major elements were determined by wet chemical analyses in the chemical laboratories of the Geological Survey in Prague (analyst M. HUKA). The contents of trace elements Rb, Sr, Ba, Y, Nb, Zr, Ti, V, Cr, Ni, Co, Cu, Zn, Pb were determined by XRF using the internal standard method, in the laboratories of the Geological Research in Brno (analyst L. JANÁČKOVÁ). The concentrations of REE were obtained by INAA (instrumental neutron activation analysis) in GIP in Černošice (analyst J. MOUČKA).

The character of the major, minor and trace element distribution is usually considered as a significant criterion for the determination of the chemical affinity and geotectonic type of the source rock material. In metamorphosed rocks, the interpretation must be made with caution and petrogenetic considerations should be limited mainly to those elements which were immobile during metamorphism (e. g. Ti, Zr, Y, Cr, V, Ni and REE).

The bulk chemistry of the studied samples indicates the relative uniform nature of the contents of major and minor elements (tab. 2). The amphibolites in the studied

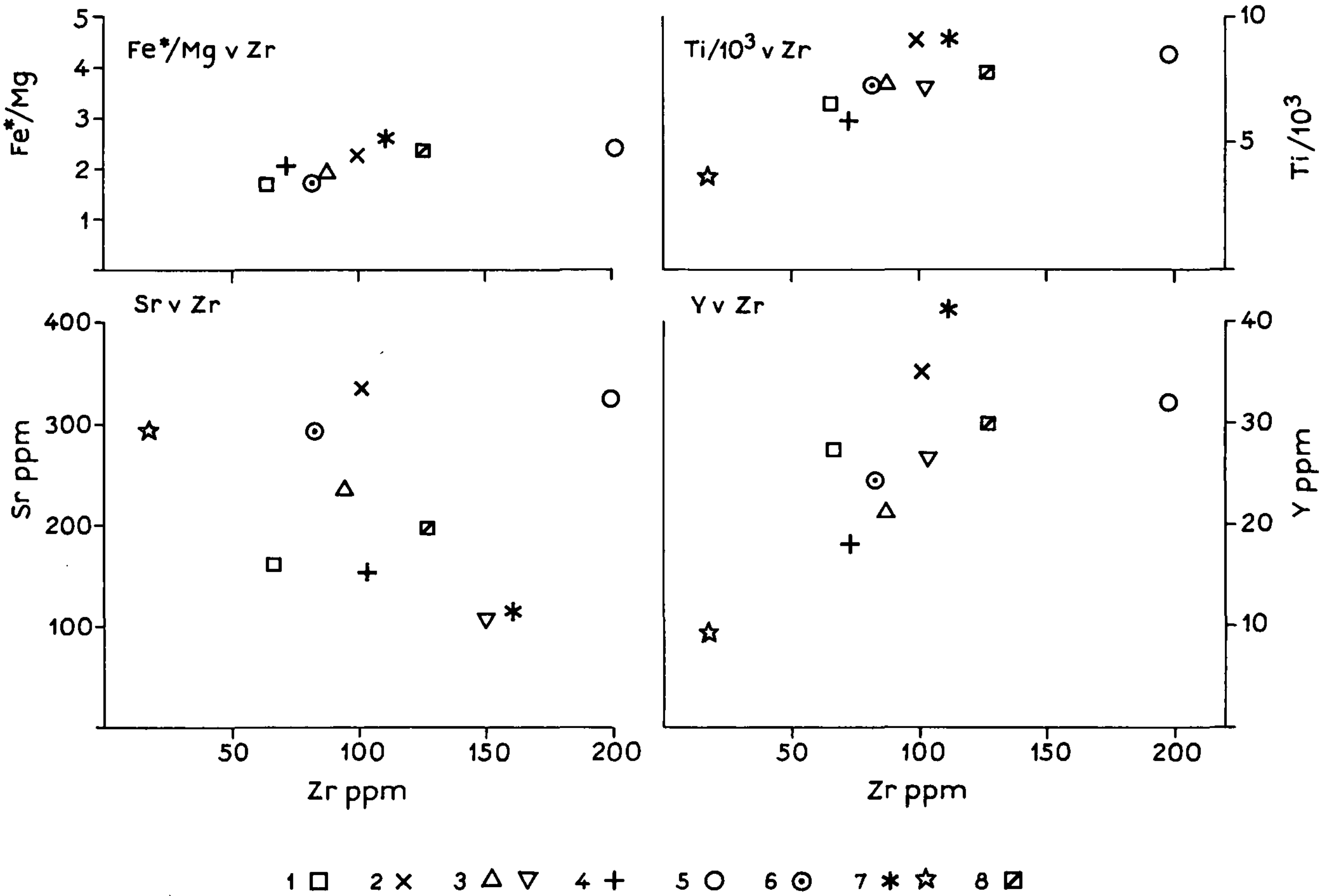

Fig. 6.
Fe^{tot}/Mg, Sr, TiO_2, Y with Zr relations. Rock analyses are listed in table 2.
1 = Jemnice; 2 = Menhartice; 3,3a = Police; 4 = Bítov; 5 = Hornice; 6 = Třebelovice; 7,7a = Starý Petřín; 8 = Podhradí (Moravicum).
Symbols as in fig. 2.

area are generally considered as the metamorphic derivates of basic magmatic rocks (volcanics). This origin is also confirmed by the major element concentrations in the studied samples. They follow the chemical trend of magmatic differenciation in the diagram of the Niggly c-mg values for the various rocks (fig. 4). The chemical affinity of the studied metabasalts to tholeiites is demonstrated in the ternary AFM diagram (fig. 5). The samples are enriched in iron and mostly depleted in alkalies. Only in samples no. 4, 5, 9 are the K_2O contents higher than 1 % (1.47, 1.51 and 1.13 %). The tholeiitic character is demonstrated by the presence of normative hypersthene and is supported by the positive correlation of Fe^{tot} vs. Fe^{tot}/Mg. Al_2O_3 is represented by values in the range 13–18 %. The similarity with tholeiites also reveals lower contents of SiO_2 (46–52 %) in the studied samples. TiO_2 values lie between 1.5 and 2.5 % and are below 1 % in only two samples. The CaO content is relatively constant, close to 10 %, MnO is less than 0.35 %, P_2O_5 is in the range 0.07 to 0.49 %.

When we compare the major element concentrations of the studied amphibolites with amphibolites from another part of SW Moravian Moldanubicum (ŠICHTÁŘOVÁ, 1981) and from the south Bohemian Moldanubicum (SUK, 1971), they are found to have a tholeiitic nature and have a very similar position in AFM diagram (fig. 5).

The trace element contents (table 2) indicate relatively higher values of the large-ion lithophile (LIL) elements, Rb ranges from 2 to 63 ppm, Th is up to 3.9 ppm, Ba is very variable and has some much higher values (67–670 ppm). U contents are less than 3 ppm and Sr contents are 150–331 ppm. The compatible elements – Cr and Ni are present in higher concentrations – 76 to 254 ppm and 20 to 114 ppm respectively. Variations of some major and minor elements are shown in fig. 6.

The chemical characteristics of the minor and trace element contents is also given in the multielement plot (fig. 7), normalized to the normal type (N-type) of mid-ocean-ridge basalt (MORB). The patterns mostly follow almost uniform trace element distribution with LIL element enrichment relatively to HFS (high-field strength elements), with higher abundances of Rb, Th, Ba, La and Ce. Some deviation was found for sample no. 5 and also sample no. 8, from the neighbouring Moravic geological unit. They have higher contents of LIL (Rb, Ba) and some HFS elements (Nb and Ta).

Rare-earth elements (REE) normalized to chondrite exhibit a differenciated character of distribution compared to the primitive distribution of chondrite (fig. 8). Neither Eu nor Ce anomalies have been observed although some enrichment in Ce and La can be traced.

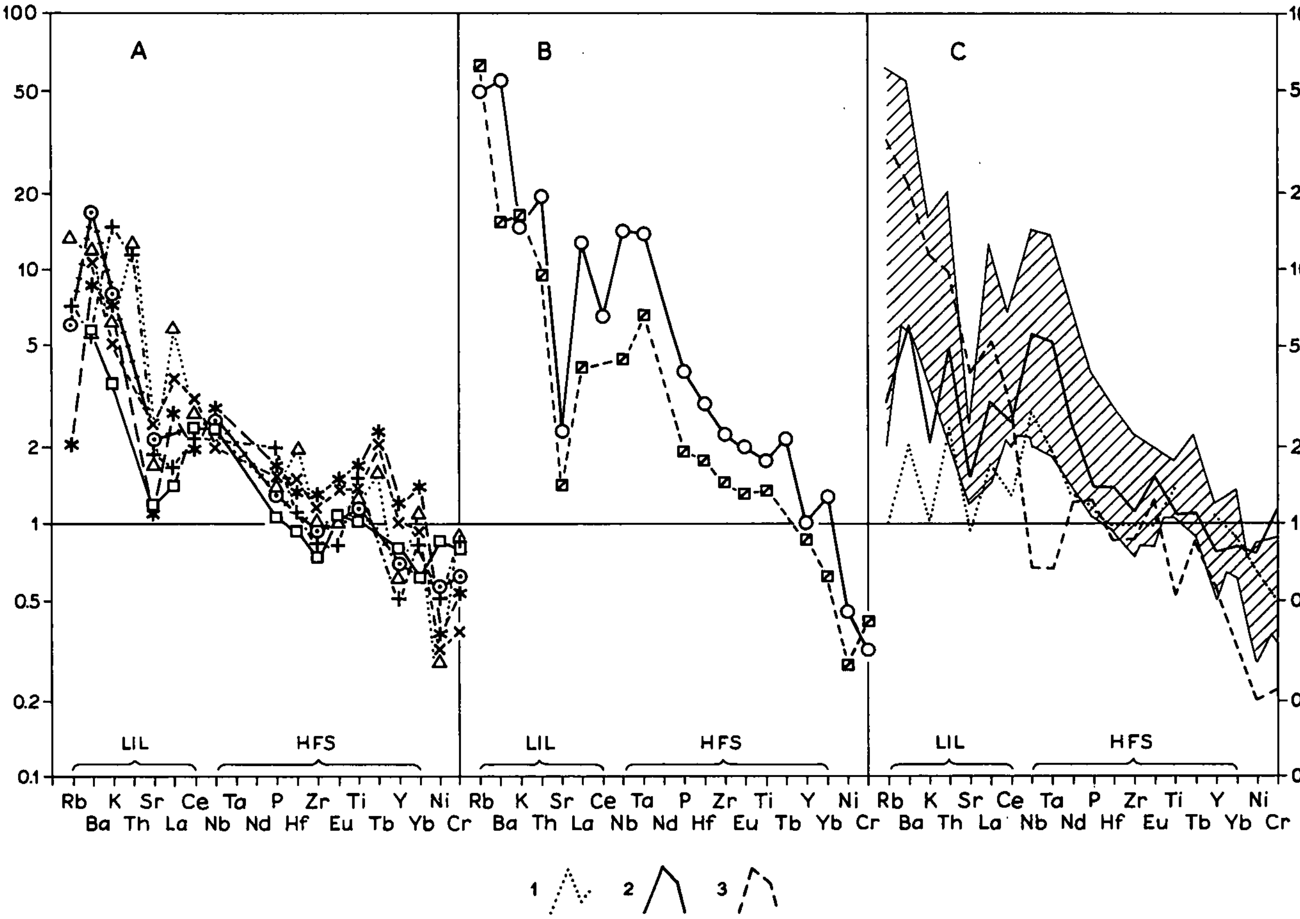

Fig. 7.
Multielement diagrams of minor and trace elements of the amphibolites from the SE margin of the Bohemian Massif, normalized to N-type MORB. The normalizing values are taken from SAUNDERS & TARNEY, 1984, in: MILLWARD et al., 1984.
A = samples 4,6,7; B = samples 5 and 8 (Moravicum); C = the field of the studied amphibolite samples compared with 1 = oceanic flood basalts from the Nauru Basin (SAUNDERS, 1984, in: MILLWARD et al., 1984), 2 = T-type MORB (Reykjanes), taken from WOOD et al. (1979), in: MILLWARD et al. (1984), 3 = island arc basalts – Mariana arc (SAUNDER & TARNEY, 1984, in: MILLWARD et al., 1984).
The diagonally hatched area corresponds to the field of the studied samples.

The majority of samples exhibit distribution patterns comparable with the filed of MORB (N-type basalts after MILLWARD et al., 1984). Their $(La/Yb)_N$ ratio is <2.8 and $(La/Sm)_N$ ratio is <2.6. In detail two varieties can be distinguished: Type A_1 (samples 1, 4, 7, 7a), closer to MORB with $(La/Yb)_N$ equal to 1, and Type A_2 (samples 2, 3, 6) with slightly higher La, Ce values with $(La/Yb)_N$ higher than 1. In the diagram (fig. 8) type A also corresponds to the field of eclogites associated with the studied amphibolites. Only two samples (no. 5 and no. 8) have another type of REE distribution, with higher contents of Sm (no. 5), La and Ce. Their $(La/Yb)_N$ ratios are 3.5 and 5.3; $(La/Sm)_N$ is 1.65 and 2.96. In the diagram (fig. 8) they correspond to the Type B.

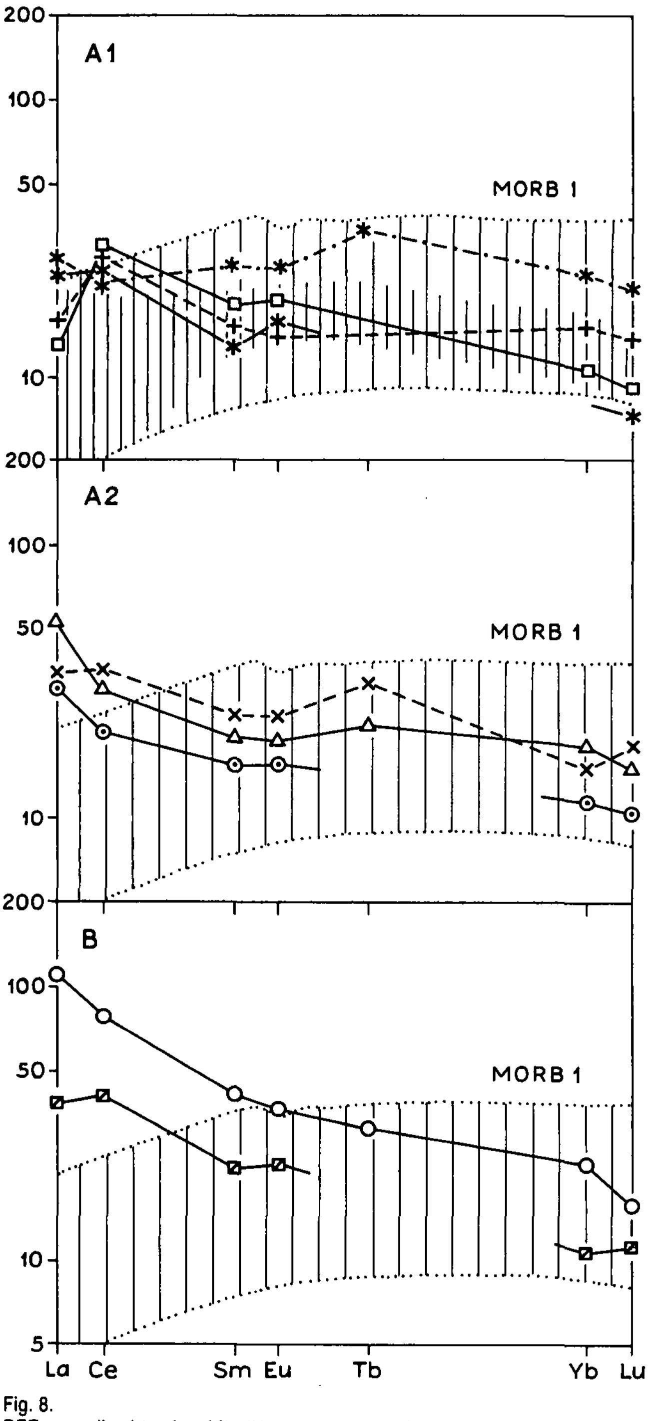

Fig. 8.
REE normalized to chondrite (HASKIN et al., 1986) diagrams for the amphibolites from the SE margin of the Bohemian Massif compared with REE patterns for MORB 1 (N-type MORB).
Data taken from Volcanism Study Project (1981) in COISH et al. (1986). The finer vertically hatched region corresponds to the field of REE patterns of eclogites associated with the studied amphibolites (FEDIUKOVÁ-DUDEKJ, 1974).
A_1 = samples 1,4,7,7a; A_2 = samples 2,3,6; B = samples 5 and 8 (Moravicum). Symbols as in fig. 6.

4. Discussion

Although the determination of the geotectonic provenance of the metamorphosed rocks is very difficult, some facts do follow from these considerations. The distribution patterns of the trace elements and REE for the studied amphibolites mostly exhibit a similarity with MORB, and the multielement plots exhibit a certain tendency to approach to the T-type (transite Type) of MORB. In addition, the tectonic discriminant diagrams (fig. 9, 10) reveal some relationships between the studied metabasalts and the T-type ocean floor

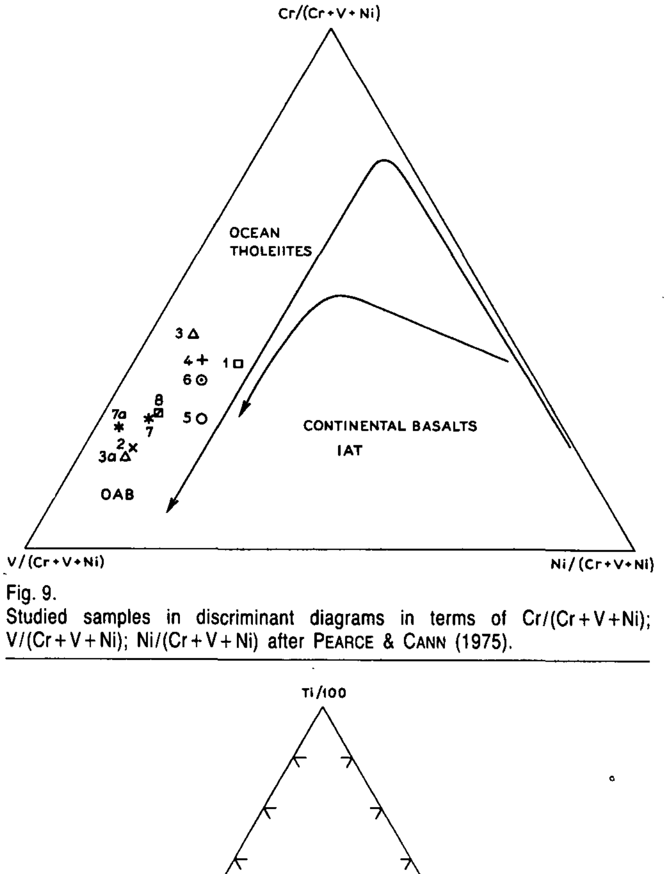

Fig. 9.
Studied samples in discriminant diagrams in terms of Cr/(Cr+V+Ni); V/(Cr+V+Ni); Ni/(Cr+V+Ni) after PEARCE & CANN (1975).

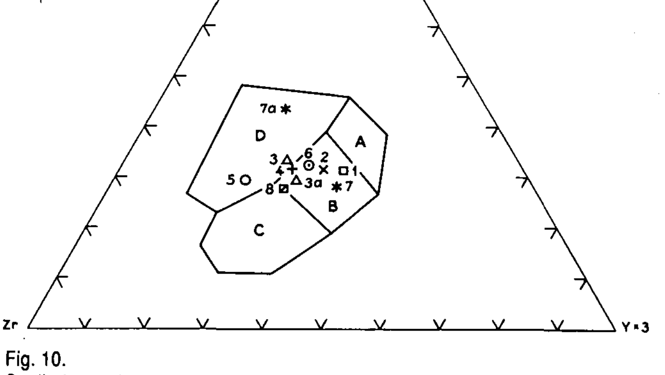

Fig. 10.
Studied samples in tectonic discriminant diagram in terms of Zr–Ti/100–Yx3 after PEARCE & CANN (1973).

tholeiites (MILLWARD et al., 1984). The higher LIL concentrations indicate a certain similarity with the basalts familiar from the environments of the marginal basins. This type of origin is also supported by the field relationships of present-day amphibolites, which form lens-shaped stripes several hundred metres in size, alternating with multiple paragneisses, quartzites and carbonate rocks, similarly to the submarine basalt flows near the ocean margin, while MORB form bodies with a large size and a huge thickness. The presence of the original argillaceous and arenaceous metasediments in the surroundings of the amphibolites indicates their sedimentation not too far from the actively eroded continent.

The typical feature of the studied area is the common occurrence of the amphibolites together with the acid granulites (with negative Eu anomaly), which are considered as metarhyolites, and are comparable with the rhyolites from the orogenic areas (FIALA et al., 1987). The intermediate members – andesites, common in the typical volcanic orogenic associations are here absent (fig. 11). Geochemically contrasting volcanic associations are usually described for areas of immature island arcs, rifted tectonic environments, or collision zones, developed in the marginal parts of the continental crust. Also the character of the present metasediments, which are intimately associated with the amphibolites and granulites, indicates the origin in the sedimentary basin in the marginal zone of the continental crust.

5. Conclusions

The studied samples of amphibolites are basaltic in composition. The major and minor element contents place them among tholeiitic basalts. They are relatively depleted or have an only slightly light REE enriched distribution, with a flat pattern shape with $(La/Yb)_N = 1$ to 2.8 (in sample 5 and 8 $[La/Yb)_N = 3.5$ and 5.3). The character of the trace element distribution is mostly similar to that of T-type basalts (MILLWARD et al., 1984); in sample 5 (and 8) they exhibit LIL enrichment and higher Nb and Ta contents. The slight enrichment in alkali elements (Rb, Ba, K) is higher than in the Transite type of MORB, but is mostly lower than in island arc tholeiites.

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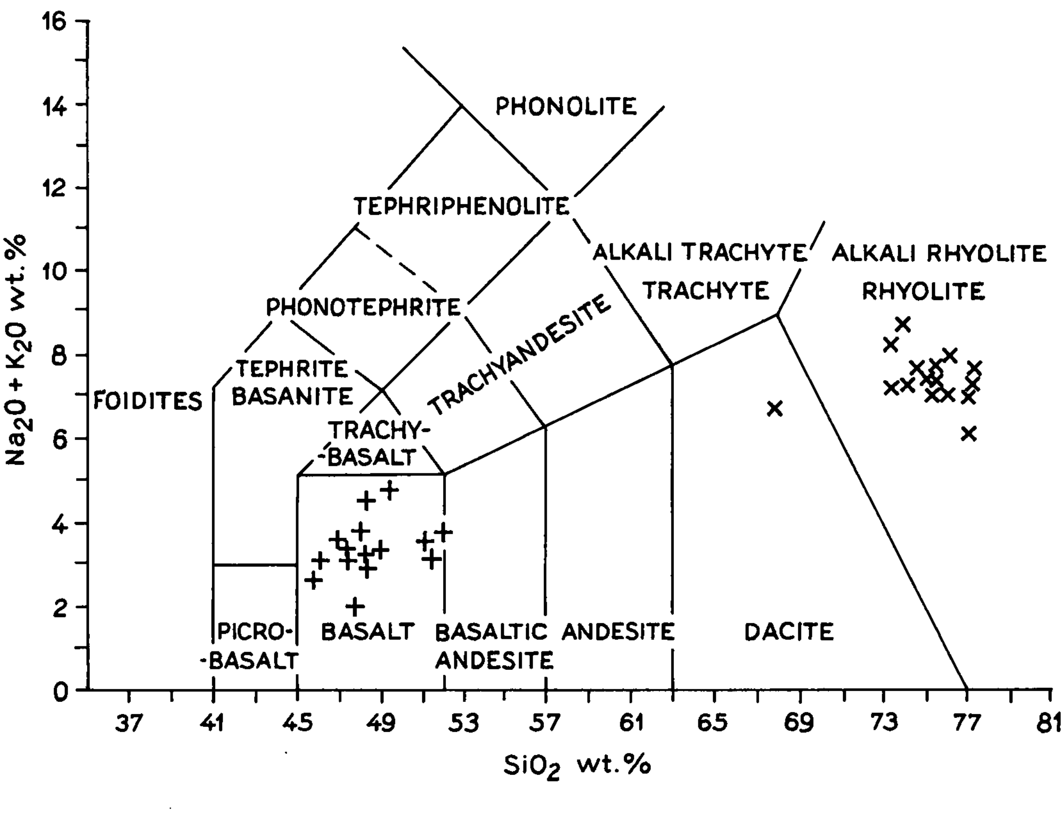

Fig. 11.
Studied amphibolites and the adjacent acid granulites in the total alkali silica (TAS) diagram after LE MAITRE (1984).
1 = amphibolites (studied samples); 2 = acid granulites from the SE margin of the Bohemian Massif (for chemical analyses see FIALA et al., in press).

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