

# Geochemical Characteristics of Metabasites in Different Tectonic Units of the Northeast Bavarian Crystalline Basement <sup>z</sup>

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## ABSTRACT

Comprehensive geochemical investigations of metabasites yielded constraints for a correlation of, or discrimination between the different tectonic units within the northeast Bavarian crystalline basement.

The Münchberg nappe pile consists of at least five large tectonic units which exhibit differences in lithology, in part also in metamorphic grade and in metamorphic history. The metabasites in each of these nappes show their own, significant geochemical characteristics. The lowermost tectonic unit, the Bavarian lithofacies, includes the anchi-metamorphic Ordovician Randschieferserie which contains alkaline basalts. In their geochemistry, they are similar to the metabasites of the Fichtelgebirge crystalline complex in the autochthonous Saxo-thuringian. The next higher tectonic unit of the Münchberg nappe pile, the Prasinit-Phyllit-Serie contains metabasites which can be derived from subalkaline basalts with a clear calc-alkaline tendency. There is a striking geochemical resemblance to the metabasites of the Erbdorf Greenschist Zone (EGZ) underscoring the similar lithology of both allochthonous units which appear to be in a similar tectonic position. The Randamphibolit-Serie higher up in the Münchberg nappe pile consists of metabasites with tholeiitic characteristics and a pronounced differentiation trend. The next higher tectonic unit, the Liegendserie of the Münchberg gneiss complex s. str., contains metagabbros to metagabbro-norites with a high-Al basaltic composition. The amphibolites and banded hornblende gneisses of the overlying Hangendserie are of sub-alkaline basaltic character with calc-alkaline affinity.

The Zone Erbdorf-Vohenstrauss (ZEV) is currently regarded as an allochthonous unit equivalent to the higher crystalline nappes of the Münchberg pile. However, the geochemical character of the metabasites do not encourage such a correlation. Neither the schistose and striped amphibolites nor the flaseramphibolites of the ZEV with their N-MORB and E-MORB character respectively, find convincing counterparts in the crystalline nappes of the Münchberg pile. However, an interestingly close resemblance exists between the schistose and striped amphibolites in the ZEV, on the one hand, and in the autochthonous Zone Tirschenreuth-Mähring (ZTM) and the adjacent Moldanubian sensu strictu, on the other.

Owing to the absence of age criteria, our results cannot be used, so far, to reconstruct the paleogeographical position of the individual tectonic units, based on the geochemical characteristics of their respective metabasites.

## INTRODUCTION

During the pre-site studies for the German Continental Deep Drilling Program (KTB) our group investigated the geochemical characteristics of metabasites which form constituents of different tectonic units within the crystalline basement in northeast Bavaria. The aim of these studies was:

1. To evaluate constraints for a correlation and/or discrimination of these tectonic units.
2. To provide a data base for a sound recognition of metabasites and, consequently, their respective units in the future drill cores of KTB.

The geochemical characteristics of the various metabasites may serve as indications for the geotectonic positions of their respective protoliths, provided that the discriminating chemical elements and inter-element relationships were not affected seriously by post-magmatic alteration processes.

## GEOLOGICAL POSITION AND PETROGRAPHICAL CHARACTERISTICS

The new geotectonic concept developed during the KTB pre-site studies distinguishes two major nappe complexes in the northwestern part of the Bohemian massif:

1. The Münchberg nappe pile
2. The Zone of Erbdorf-Vohenstrauß (ZEV) with the underlying Erbdorf Greenschist Zone (EGZ).

In contrast, the Saxothuringian of the Frankenwald and the Fichtelgebirge, the Moldanubian and the transitional Zone Tirschenreuth-Mähring (ZTM) are regarded as autochthonous (Weber and Vollbrecht, 1986).

### The Münchberg Nappe Pile

The autochthonous Paleozoic of the *Thuringian lithofacies* in the southeastern Frankenwald is unconformably overlain by a stack of allochthonous units, the Münchberg nappe pile (Franke 1984).

The lowermost nappe unit consists of anchimetamorphic Paleozoic sediments with intercalations of alkaline basalts to trachyandesites (Wirth 1978) and minor keratophyres, designated as *Bavarian lithofacies* by Wurm (1961).

The next higher unit, the *Prasinit-Phyllit-Serie* (Kraus 1954) consists predominantly of prasinites and quartz phyllites in variable proportions. Locally, serpentinites are intercalated.

The prasinites show the assemblage  
actinolite + epidote + chlorite + albite + quartz + sphene + opaques  
typical of the greenschist facies.

Higher up in the nappe pile a tectonic unit of considerably higher metamorphic grade occurs, the *Randamphibolit-Serie*, which consists almost exclusively of amphibolites (briefly designated as "rand amphibolites") with the assemblage

hornblende + andesine + sphene ± grossular-rich almandine  
± epidote + opaques.

The randamphibolites exhibit a strong cataclastic deformation. They underwent a retrograde overprint documented by the formation of actinolitic hornblende, albite, chlorite and epidote (Oppermann 1985).

The next higher crystalline nappe unit is the so-called *Liegendserie* of the Münchberg Gneiss Complex s. str. Within a sequence of para- and orthogneisses subordinate metagabbros to metagabbroites (Matthes and Seidel 1977) are intercalated which exhibit distinct structural relics of the plutonic protolith as well as relics of the initial igneous An-rich plagioclase, hypersthene, clinopyroxene, brown hornblende, ilmenite and pyrrhotine. The regional metamorphic overprint led to the assemblage

oligoclase + hornblende ± garnet ± zoisite ± white mica + quartz  
+ rutile/sphene.

The uppermost unit of the Münchberg nappe pile, the *Hangendserie*, is characterized by a variegated lithology consisting predominantly of amphibolites and banded hornblende gneisses, and subordinate paragneisses, marbles and calc-silicate rocks. The metabasites contain the mineral assemblage

hornblende + oligoclase/andesine + quartz + rutile (partly  
replaced by sphene) ± almandine ± zoisite + opaques.

The banding is due to a variation in the hornblende vs feldspar + quartz ratio.

The famous *eclogites* of the Münchberg Gneiss Complex are concentrated in the border zone between the Hangend- and the Liegendserie. They can be interpreted either as constituents of the Hangendserie (Matthes et al. 1974) or as dislodged slices, tectonically intercalated between the two units (Stettner 1960). The eclogites testify to a high-pressure event which, according to Sm-Nd dating of Stosch (pers. comm., 1988), presumably took place 466 Ma ago. The main metamorphic event in the Hangend-, Liegend- and Randamphibolit-Serie is a medium-pressure metamorphism (Matthes et al. 1974; Blümel, in Weber and Vollbrecht 1986) which partly transformed the eclogites into eclogite-amphibolites. Recent K-Ar dating on hornblendes and micas from these units yielded ages around 380 Ma for the end of the amphibolite facies metamorphism, whereas the greenschist facies metamorphism of the underlying Prasinit-Phyllit-Serie seems to be slightly younger, i.e. about 365 Ma (Kreuzer et al. 1988).

#### The Erbdorf-Greenschist Zone (EGZ)

Situated between the autochthonous Fichtelgebirge in the north and the allochthonous Zone Erbdorf-Vohenstrauß in the south, the Erbdorf Greenschist Zone seems to be in a similar tectonic position as the Prasinit-Phyllit-Serie in the Münchberg nappe pile. The EGZ consists mainly of various metabasites, including metagabbros, and of serpentinites, but contains only minor metasediments. The main phase of regional metamorphism took place under conditions of the lowest amphibolite facies leading to the assemblage

oligoclase + plagioclase + epidote + opaques.

During a later retrogressive overprint, the mineral assemblages of this first metamorphic stage were partly replaced by albite, epidote, chlorite, carbonate and quartz. In the contact aureoles of the Steinwald and Falkenberg granites, the metamorphic sequences of the EGZ underwent a strong thermal overprint (Matthes 1951; Matthes and Olesch 1986).

### The Zone Erbdorf-Vohenstrauß (ZEV)

The ZEV consists predominantly of pelitic metasediments which contain intercalations of various metabasites, ultramafics, calc-silicate rocks, graphite quartzites, graphite schists and orthogneisses. The metabasites can be divided into three main types:

1. *Schistose and striped amphibolites* prevail in the southern part of the ZEV, but are also recorded in a few outcrops in the northern ZEV. The mineral assemblage is hornblende + andesine/labradore + sphene + ilmenite + sulphides. The banding is caused by a variation in the hornblende vs plagioclase ratio or by calc-silicate intercalations, mainly consisting of salite + plagioclase ± garnet.
2. *Flaseramphibolites* are predominant in the northern and central parts of the ZEV. The flaser structure is caused by ill-defined lenses or wavy bands rich in plagioclase or, rarely, salite. The mineral assemblage is hornblende + oligoclase/andesine ± garnet ± salite + sphene + ilmenite + sulphides. The garnets are frequently replaced by fine-grained aggregates of plagioclase and hornblendes. At the western margin of the Falkenberg granite, the flaseramphibolites underwent a thermal overprint.
3. *Metagabbros* are concentrated in the southwestern corner of the ZEV. They are characterized by a coarse-grained, massive structure testifying to a plutonic protolith (Voll 1960). The rocks consist of platy, heavily altered plagioclase and hornblende which is partly replaced by felty aggregates of secondary amphiboles (Schüssler 1987). Some metagabbros contain considerable amounts of biotite.

U-Pb dating of zircons and monazites (Teufel 1988), and K-Ar dating of hornblendes and micas (Kreuzer et al. 1988) from various rock types of the ZEV indicate that the medium-pressure, amphibolite facies metamorphism in the ZEV (Blümel, in Weber and Vollbrecht 1986) took place in the Early Devonian, about 380 Ma ago. Younger K-Ar ages around 325 Ma which prevail in the eastern ZEV are presumably a result of contact metamorphism.

### The Fichtelgebirge Crystalline Complex

Part of this zone is characterized by a variegated lithology with numerous intercalations of marbles, calc-silicate rocks and minor metabasites ("Bunte Gruppe" of Stettner 1975, 1980). There are, however, transitions to a more monotonous lithology with a predominance of pelitic to psammitic metasediments. The sequence underwent a low-pressure metamorphism ranging from the greenschist to the amphibolite facies (Mielke et al. 1979) dated at about 330 Ma by the K-Ar method (Kreuzer et al. 1988). Mineral relics of an older medium-pressure event

were recently recognized by Lenz et al. (in prep.). The regional metamorphic assemblages were partly overprinted by the intrusion of the Fichtelgebirge granites.

Most of the investigated metabasites are fine-grained, schistose amphibolites with the assemblage

hornblende + plagioclase ± biotite ± quartz + sphene + ilmenite + sulphides.

Two of the investigated metabasites exhibit relics of an ophitic texture testifying to a doleritic basalt as a protolith. Between the platy plagioclase crystals, there are relics of augite and aggregates of serpentine after primary olivine.

#### The Zone Tirschenreuth-Mähring (ZTM)

In its lithology the ZTM is less variegated than the Fichtelgebirge crystalline complex, but less monotonous than the Moldanubian gneisses (Richter and Stettner 1983). The rare amphibolites of the ZTM and the adjacent Moldanubian s. str. can be hardly distinguished from the schistose and striped amphibolites of the ZEV. The mineral assemblage is

hornblende + andesine ± salite + sphene + opaques.

One amphibolite lense contains garnet which is widely replaced by aggregates of hornblende and plagioclase.

The metamorphism in the ZTM which was dated at about 320 Ma (Teufel 1988; Kreuzer et al. 1988) took place under low-pressure conditions ranging from the greenschist to the high amphibolite facies (Schreyer 1966; Blümel and Wagener-Lohse, in Weber and Vollbrecht 1986).

## GEOCHEMISTRY

### Analytical Methods

The major elements Si, Ti, Al, Fe<sup>tot</sup>, Mn, Ca, K and the trace elements S, Sc, V, Cr, Co, Ni, Cu, Zn, As, Rb, Sr, Y, Zr, Nb, Ba, La, Ce, Nd were analyzed by standard XRF analysis using lithium tetraborate fusion discs and powder pellets respectively. Mg, Na and Li were determined by standard AAS methods after decomposing the samples in HF-H<sub>2</sub>SO<sub>4</sub> or HF-HClO<sub>4</sub>. P was determined by XRF or spectrophotometrically, Fe (II) by the vanadate method (Peters 1968) or spectrophotometrically; CO<sub>2</sub> was measured volumetrically, H<sub>2</sub>O<sup>+</sup> by the Penfield method. In part of the samples CO<sub>2</sub> and S were determined by IR spectrometric methods. W and Mo were analyzed by liquid-liquid extraction with Zn-dithiol (Richter 1984). Rare earth elements were measured by ICP-AES after decomposing the samples in HF-HClO<sub>4</sub> and separating the REE in chromatographic columns (Erzinger et al. 1984). Selected bulk rock analyses of metabasites from the Münchberg nappe pile, the Erbendorf Greenschist Zone, the Zone Erbendorf-Vohenstrauß, the Fichtelgebirge Crystalline Complex and the Zone Tirschenreuth-Mähring are presented in Tables 1 and 2. The REE data for the metabasites of the ZEV, EGZ and ZTM are given in Schüssler et al. (1988). A list of localities and the complete set of geochemical analyses can be obtained from the authors on request.

Table 1. Selected analyses of metabasites from different tectonic units of the Münchberg nappe pile

	Prasinit-Phyllit-Serie common samples				Hohenknoden				Randamphibolit-Serie				Hangendserie				
	P11	P22	P26	P35	P38	P40	RA16	RA17	RA42	RA44	RA23	S72/99	S72/100	S52	S72/108	H3	
(wt.%)																	
SiO <sub>2</sub>	48.2	47.4	48.0	50.1	47.2	46.2	48.5	47.7	47.4	47.4	50.0	50.8	48.4	52.0	50.6	51.9	
TiO <sub>2</sub>	0.67	0.68	1.17	0.66	2.28	1.89	1.10	1.91	1.71	1.06	0.53	0.69	0.67	0.64	0.70	0.56	
Al <sub>2</sub> O <sub>3</sub>	17.7	14.3	18.3	17.3	15.9	15.6	14.0	12.9	14.8	14.7	15.3	15.9	16.5	12.5	16.5	15.6	
Fe <sub>2</sub> O <sub>3</sub>	4.04	1.68	5.77	4.07	3.80	2.77	2.00	1.90	2.00	2.34	1.71	2.09	1.29	3.5	3.7	2.40	
FeO	3.11	5.54	4.11	3.38	5.83	7.06	9.11	13.4	9.15	6.16	6.25	6.23	7.33	7.85	7.96	8.28	
MnO	0.11	0.12	0.12	0.12	0.16	0.18	0.21	0.34	0.21	0.17	0.16	0.15	0.17	0.23	0.24	0.18	
MgO	6.13	13.9	5.27	6.52	6.99	8.74	8.48	6.69	7.28	10.4	8.70	7.92	9.03	9.91	6.11	6.79	
CaO	13.7	9.13	9.60	10.1	8.98	9.06	11.8	10.8	12.4	12.9	12.7	10.8	12.0	9.26	8.68	7.92	
Na <sub>2</sub> O	1.51	1.36	2.82	3.97	3.31	2.83	2.70	1.61	2.24	2.37	2.86	2.88	2.17	2.11	3.49	3.77	
K <sub>2</sub> O	0.49	1.44	0.85	0.22	0.96	0.55	0.34	0.16	0.29	0.29	0.24	1.00	0.28	0.21	0.24	0.24	
P <sub>2</sub> O <sub>5</sub>	0.14	0.28	0.22	0.14	0.36	0.33	0.10	0.15	0.18	0.12	0.05	0.05	0.05	0.10	0.13	0.08	
H <sub>2</sub> O <sup>+</sup>	3.0	3.5	3.2	2.8	3.4	3.7	1.9	1.8	1.9	2.1	1.6	1.8	1.7	1.4	1.2	1.6	
CO <sub>2</sub>	0.81	0.2	0.4	1.1	0.8	0.7	<0.05	<0.05	0.05	0.06	0.05	0.09	<0.05	<0.05	0.05	0.06	
S	<0.02	<0.02	0.02	0.17	<0.02	0.02	<0.02	<0.02	0.06	<0.02	<0.02	<0.02	0.11	<0.02	0.22	0.11	
Total (ppm)	99.61	99.53	99.85	100.65	99.97	99.63	100.24	99.36	99.67	100.07	100.15	100.40	99.70	99.71	99.82	99.49	
Cr	161	592	475	205	184	318	376	158	153	811	469	255	300	482	49	83	
Ni	66	319	137	89	87	152	95	45	71	253	89	148	212	83	30	30	
Cu	28	44	56	74	42	83	75	28	115	48	83	19	69	81	290	64	
Zn	64	54	99	64	80	90	88	129	93	73	62	95	73	92	118	83	
Rb	10	20	19	5	19	12	8	4	4	9	6	23	16	8	10	9	
Sr	241	412	383	220	351	323	160	58	261	250	168	125	130	93	130	170	
Y	20	21	31	23	40	36	25	53	28	18	17	-	-	20	22	15	
Zr	86	137	111	80	218	239	76	120	122	86	51	55	16	11	38	22	
Nb	3	4	3	3	7	8	5	5	13	8	2	-	-	<3	<3	4	
Ba	120	492	130	9	210	138	95	79	87	27	64	176	58	85	126	142	
Pb	2	4	5	<1	3	5	<1	<1	3	<1	1	4	4	5	4	<5	

Table 2. Selected analyses of metabasites from different tectonic units of the KTB target area

	Zone Erbdorf-Vohenstraus flaseramphibolites				schistose & striped amphibolites				metagabbros		Erbdorf Green- schist Zone			Fichtelgebirge		Zone Tirschen- reuth-Mähring	
	1-4	2-3	OP-84 -9	OP-84 -35	OP-84 -126	OP-84 -164	OP-84 -72	OP-84 -205	3-7	RBU-78 -66	RBU-78 -308	RBU-78 -342	Fil10a	Wa-1a	675	37	
(wt.%)																	
SiO <sub>2</sub>	46.2	47.2	47.9	46.6	46.8	48.8	50.8	51.6	48.4	51.2	48.6	46.5	51.5	51.0	47.9	47.4	
TiO <sub>2</sub>	1.94	2.12	2.40	1.01	1.29	1.04	1.77	1.85	0.72	0.71	0.58	0.85	3.26	3.92	1.18	1.36	
Al <sub>2</sub> O <sub>3</sub>	14.5	13.3	15.6	16.2	15.5	15.3	16.2	15.8	14.5	16.4	16.8	14.7	12.4	11.9	14.1	14.9	
Fe <sub>2</sub> O <sub>3</sub>	2.86	2.00	2.86	1.22	1.34	1.66	1.42	1.66	1.17	2.60	3.57	5.28	1.78	3.33	0.78	1.13	
FeO	8.82	9.70	8.41	8.62	7.88	7.60	8.35	8.22	6.60	5.21	2.43	1.55	10.3	10.9	9.73	8.78	
MnO	0.17	0.17	0.15	0.15	0.13	0.15	0.16	0.16	0.13	0.13	0.11	0.15	0.15	0.16	0.17	0.18	
MgO	7.80	6.70	4.98	9.65	8.37	8.54	7.13	6.38	12.9	3.65	9.90	9.80	6.90	7.80	7.94	7.8	
CaO	12.3	13.1	10.9	11.0	12.9	13.0	8.82	9.00	12.6	14.6	15.1	8.60	10.0	8.65	14.2	12.5	
Na <sub>2</sub> O	2.38	2.45	3.40	3.05	2.61	1.93	2.88	2.81	1.58	4.12	0.89	3.45	1.37	0.45	2.18	1.98	
K <sub>2</sub> O	0.48	0.58	0.98	0.20	0.15	0.13	0.65	0.72	0.22	0.27	0.23	0.38	1.02	0.10	0.16	0.13	
P <sub>2</sub> O <sub>5</sub>	0.42	0.46	0.29	0.06	0.08	0.07	0.17	0.18	0.07	0.23	0.19	0.14	0.48	0.50	0.15	0.19	
H <sub>2</sub> O <sup>+</sup>	1.6	1.6	1.3	1.5	1.5	1.2	1.5	2.0	1.2	1.2	2.1	3.9	0.8	2.1	1.0	1.9	
CO <sub>2</sub>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.24	<0.1	5.1	<0.1	<0.1	<0.1	<0.1	
S	0.04	<0.01	-	-	-	-	-	-	-	<0.01	0.02	<0.01	<0.01	0.13	0.27	0.66	
Total (ppm)	99.51	99.38	99.17	99.26	98.55	99.42	99.85	100.38	100.19	100.56	100.52	100.40	99.96	100.94	99.76	98.91	
Li	<10	<10	-	-	-	-	-	-	<10	<10	<10	33	50	<10	14	15	
Sc	38	38	-	-	-	-	-	-	41	30	38	37	33	32	46	47	
V	292	324	256	218	222	228	240	304	180	150	138	222	350	380	264	276	
Cr	410	180	152	329	378	333	158	156	1350	380	425	200	100	105	370	380	
Co	57	46	50	58	58	50	44	41	34	26	24	34	50	66	47	51	
Ni	205	78	117	246	220	97	75	37	250	211	236	192	78	84	135	180	
Cu	36	32	-	-	-	-	-	-	60	19	94	16	55	105	57	125	
Zn	109	101	-	-	-	-	-	-	56	74	45	62	129	141	116	115	
As	<2	8	<2	<2	3	6	-	-	-	<2	<2	<2	<2	4	<2	<2	
Rb	5	9	8	<4	<4	<4	37	16	5	7	7	11	53	5	<4	6	
Sr	385	385	366	231	266	227	301	282	150	412	345	283	790	470	154	144	
Y	28	28	28	25	26	22	32	24	18	20	16	24	29	27	22	28	
Zr	188	218	187	82	101	77	177	106	64	106	64	90	270	264	70	62	
Nb	20	19	16	<3	<3	4	8	6	<3	6	<3	5	32	32	5	8	
Mo	0.58	1.18	-	-	-	-	-	-	-	0.31	<0.10	<0.10	0.36	0.91	<0.10	0.25	
Ba	532	382	265	91	55	38	223	240	74	<5	<5	12	228	216	80	65	
La	17	17	-	-	-	-	-	-	<3	18	9	11	27	26	-	8	
Ce	28	35	21	<10	<10	<10	21	17	<10	36	26	18	55	54	<10	15	
Md	21	15	-	-	-	-	-	-	9	18	12	12	23	25	19	12	
V	0.36	0.31	-	-	-	-	-	-	-	0.65	0.34	<0.10	0.66	1.32	0.28	<0.10	

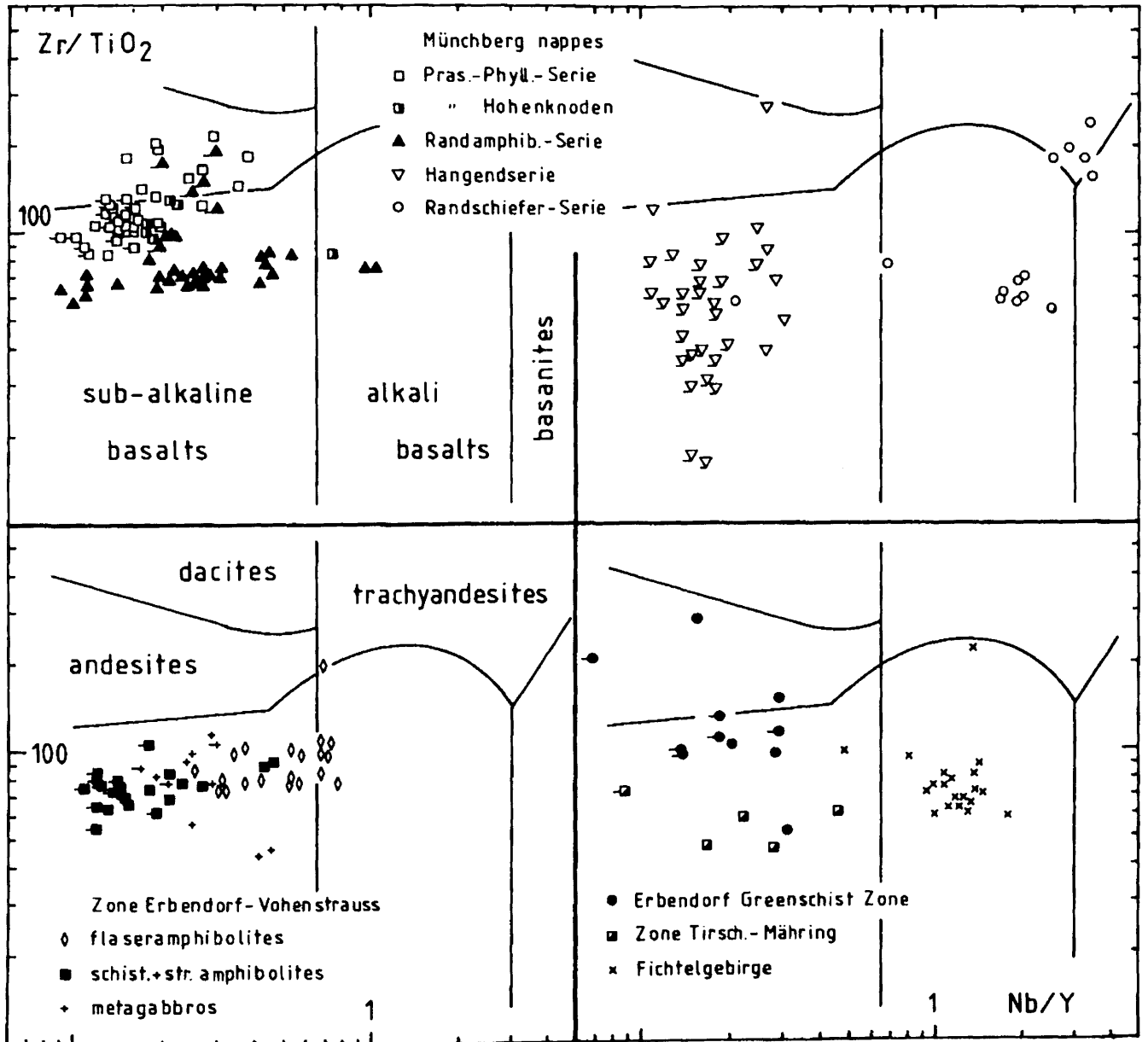


Fig. 1. Discrimination between subalkaline and alkaline series by Nb/Y vs Zr/TiO<sub>2</sub> (Floyd and Winchester 1978). Samples with Nb-contents below the detection limit of 3 ppm are indicated by bars. TiO<sub>2</sub> in wt.%, Nb, Zr, Y in ppm

### The Münchberg Nappe Pile

Because of significant chemical differences, the metabasites in the individual tectonic units of the Münchberg nappe pile cannot be derived from one common type of protolith. This finding clearly contradicts former assumptions according to which the metabasites in the Prasinit-Phyllit-Serie, in the Randamphibolit-Serie and in the Hangend-Serie are metamorphosed equivalents of the Ordovician alkaline basalts in the anchimetamorphic Randschiefer-Serie of the Bavarian lithofacies. According to their chemical composition (Wirth 1978), these Ordovician basalts form two different groups of alkaline basaltic and trachyandesitic character respectively (Figs. 1, 3).

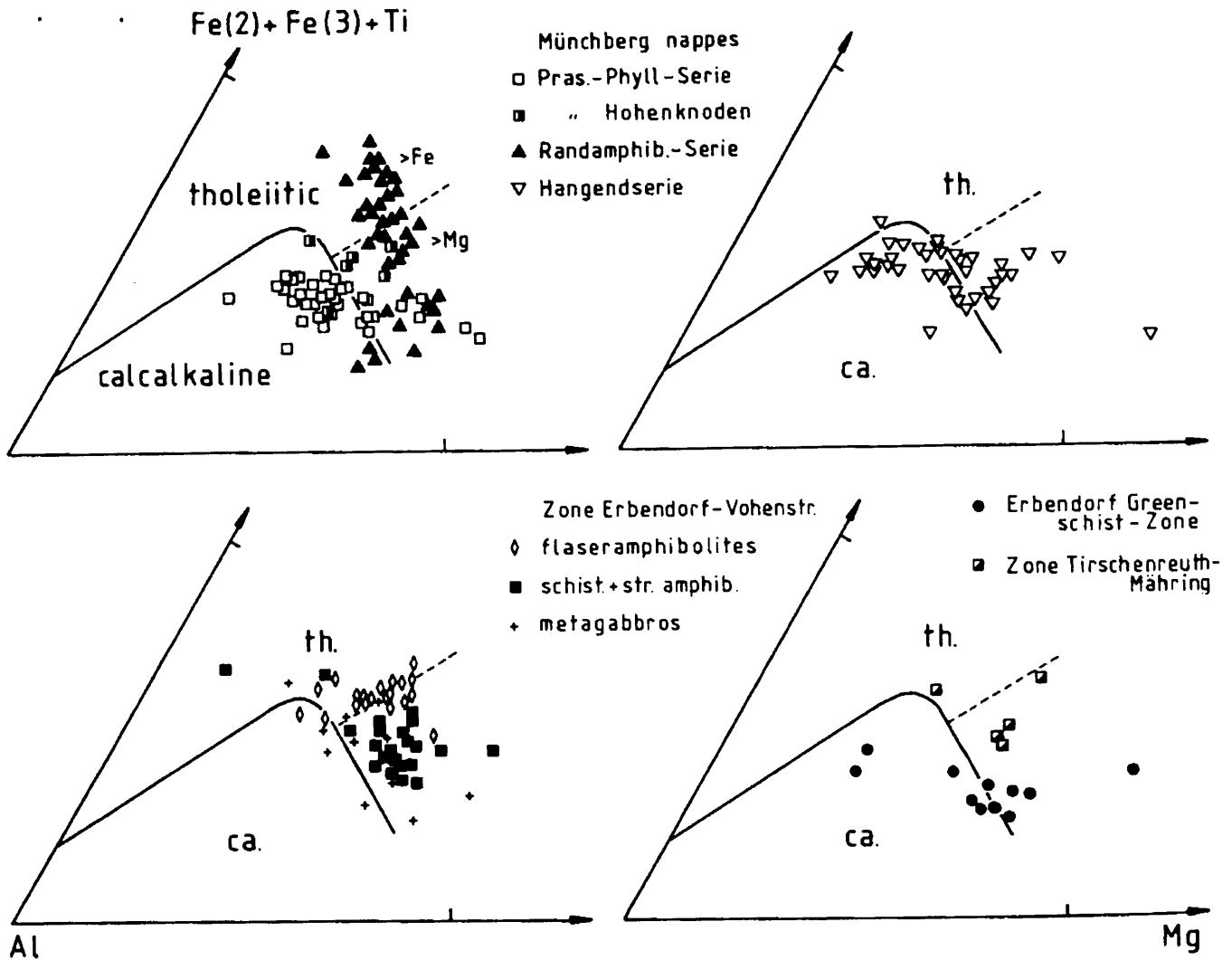


Fig. 2. Cationplot of Jensen (1976) used to subdivide subalkaline basalts into tholeiitic and calc-alkaline series respectively

Judging from their bulk rock chemistry as well as from structural and mineral relics, the metabasites of the *Prasinit-Phyllit-Serie* are clearly derived from a basaltic protolith including pyroclastics (Oppermann 1985). They are characterized by constantly low  $\text{TiO}_2$  contents (mean value  $0.9 \pm 0.2$  wt.%), but variable  $\text{P}_2\text{O}_5$  and Zr values (Fig. 3). The prasinites are clearly subalkaline in their geochemical character (Fig. 1) and show a calc-alkaline tendency (Figs. 2, 3).

Prasinites of the abandoned quarry north of *Hohenknoden*, situated at the tectonic contact between the *Prasinit-Phyllit-Serie* and the *Randamphibolit-Serie* have distinctly higher values of  $\text{TiO}_2$  and Zr than the bulk of the prasinites (Fig. 3). However, the  $\text{Zr}/\text{TiO}_2$  and  $\text{Nb}/\text{Y}$  ratios in the *Hohenknoden* prasinites are the same as in the other prasinites (Fig. 1). Mineralogically the *Hohenknoden* prasinites are distinguished from the other, sphene-bearing prasinites by the presence of rutile which is more or less replaced by sphene. From the metabasites of the overlying *Randamphibolit-Serie* the *Hohenknoden* prasinites are also distinguished chemically. As a consequence we assume that an additional tectonic slice is exposed in the *Hohenknoden* quarry.



The amphibolites of the *Randamphibolit-Serie* conform to subalkaline basalts in their chemical composition, with tholeiitic characteristics (Figs. 1, 2). In contrast to the fairly homogeneous group of the prasinites (disregarding the Hohenknoden samples), the randamphibolites show a pronounced differentiation trend from Mg-rich to Fe-rich compositions (Fig. 2). This trend is matched by a parallel enrichment of  $TiO_2$ , Zr (Fig. 3),  $P_2O_5$  and Y and by a depletion of Ni. The geochemical variation is expressed in the mineralogical composition, too: amphibolites with higher Mg/Fe ratios are free of garnet, whereas Fe-enriched amphibolites usually are garnet-bearing (Oppermann 1985).

In their bulk rock chemistry, the metagabbros to metagabbronorites of the *Liegendserie* conform to a high-Al basaltic composition, similar to that of the light eclogite type in the *Hangendserie*. However, judging from differences in e.g. the Zr and Ti contents, Matthes and Seidel (1977) deny a genetic relationship between these two rock types.

The amphibolites and banded hornblende gneisses of the *Hangendserie* are derived from a basaltic protolith (Pommerenke 1985) with consistently low  $TiO_2$  and Zr contents (Fig. 3). They belong to the subalkaline group (Fig. 1) with a calc-alkaline trend (Fig. 2). In the relevant correlation diagrams the metabasites of the *Hangendserie* show an affinity to those of the *Prasinit-Phyllit-Serie*, but have usually lower Zr contents. The chemical differences to the tholeiitic *Randamphibolites* and the alkaline basalts of the anchimetamorphic Ordovician *Randschieferserie* (Bavarian lithofacies) are obvious (Figs. 1, 2, 3).

The *eclogites* of the *Münchenberg Gneis Complex* can be divided into two principal groups: The dark eclogites have an N-MORB like composition, whereas the light, kyanite-bearing eclogites are high-Al basaltic in character (Matthes et al. 1974; Puchelt et al. 1978) and may be derived from plagioclase-rich, gabbroic cumulates (Stosch and Lugmair 1987). Despite some geochemical similarities, the light eclogites cannot be derived from the metagabbros and metagabbronorites of the *Liegendserie* (Matthes and Seidel 1977).

#### The Erbendorf Greenschist Zone (EGZ)

The predominant striped amphibolites and the subordinate metagabbros of the EGZ cannot be distinguished by their chemical compositions which conform to Mg-rich tholeiites to calc-alkaline basalts (Figs. 1, 2). In diagrams related to the tectonic setting of modern basalts the EGZ metabasites plot along the borderline between the midocean ridge and the island arc basalts or into the field of the island arc basalts (Fig. 3). The major and trace element contents of the metabasites in the EGZ and in the *Prasinit-Phyllit-Serie* of the *Münchenberg nappe pile* agree strikingly well. This fact underscores the similar lithological assemblages of both tectonic units.

#### The Zone Erbendorf-Vohenstrauß (ZEV)

The *schistose and striped amphibolites* of the ZEV conform in their chemical composition to basalts of the subalkaline series (Fig. 1). Their Mg-rich tholeiitic character is shown in the Jensen cationplot (Fig. 2). Trace elements including REE indicate similarities to modern N-MORB compositions (Fig. 3).

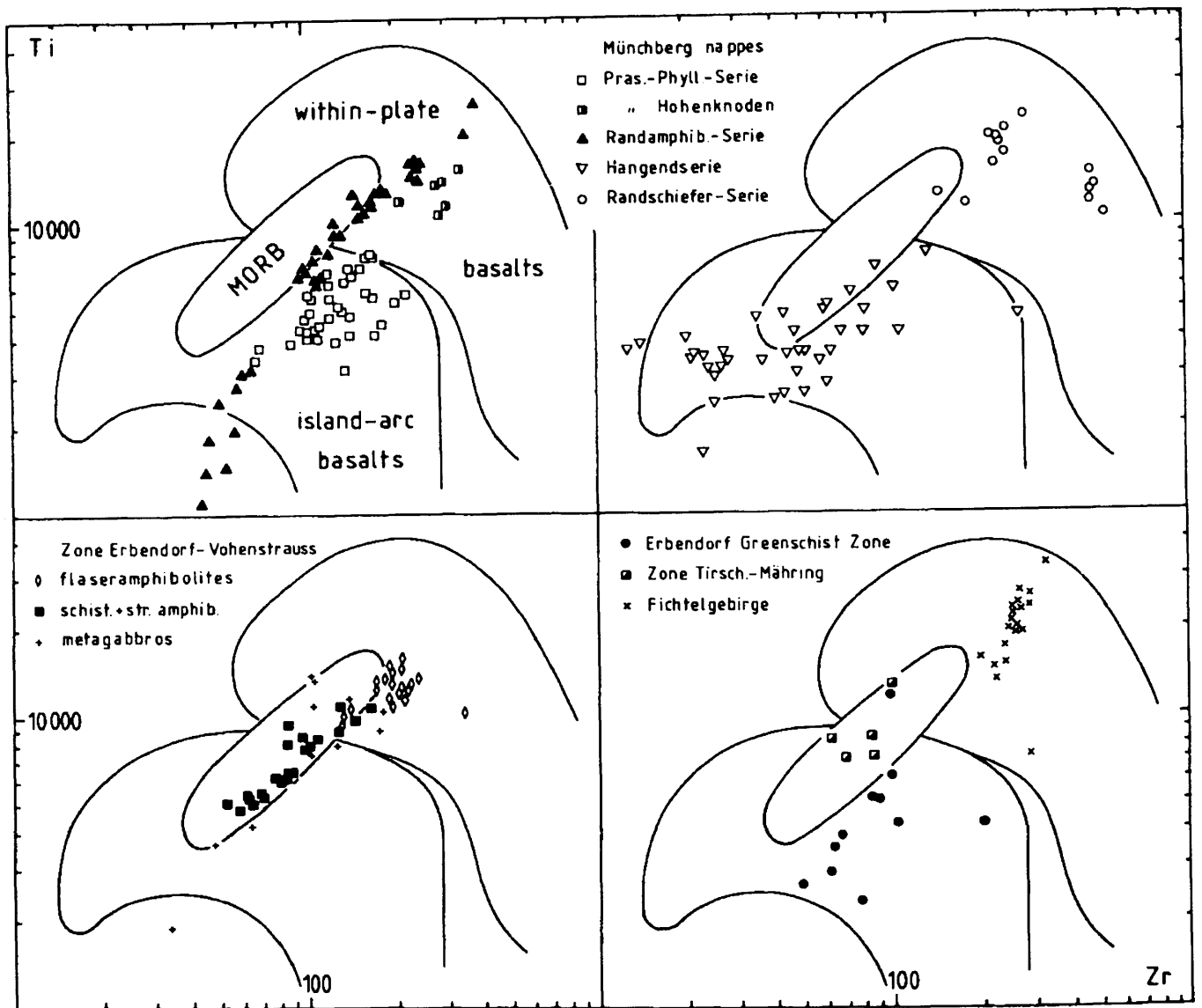


Fig. 3. Comparison of the investigated metabasites with modern basalts from various geotectonic positions in the Ti (ppm) vs Zr (ppm) diagramm (Pearce 1982)

In contrast, the *flaseramphibolites* of the ZEV are clearly enriched in the incompatible trace elements Nb, Ce, P, Zr, Ti and the LREE pointing to a tholeiitic protolith with an E-MORB or within-plate basalt character (Fig. 3). Compared to the schistose and striped amphibolites, the often garnet-bearing flaseramphibolites have generally a higher Fe/Mg ratio (Fig. 2). It should be noted that both amphibolite types show a relatively well-defined regional distribution within the ZEV. We, therefore, do not assume a differentiation relationship between the respective protoliths of the two types. This is in contrast to the situation supposed for the randamphibolites of the Münchberg nappe pile.

The *metagabbros* in the southwest corner of the ZEV are transitional in their geochemical character between the schistose and striped amphibolites and the flaseramphibolites. However, three of the investigated samples (e.g. 3-7 in Table 2) are clearly depleted in incompatible elements and, conformably, have lower Fe/Mg ratios and higher Cr contents (Figs. 2, 3), indicating a more primitive type of gabbroic protolith.

Some of the metabasites in the ZEV are chemically influenced by the intrusion of the Leuchtenberg and Falkenberg granites and/or altered by hydrothermal fluids (Schüssler et al. 1988, Schüssler 1989).

### The Fichtelgebirge Crystalline Complex

The metabasites of the Fichtelgebirge form a distinct group which is of alkaline basaltic character (Fig. 1). Modern basalts extruded within plates or at anomalous midocean ridges are similar in composition (Fig. 3). The enrichment of incompatible elements is still stronger than in the flaseramphibolites of the northern ZEV (Fig. 3). The Fichtelgebirge metabasites have no geochemical counterpart in the crystalline basement of northeast Bavaria. However, they agree quite well with the alkaline-basalts of the anchimetamorphic Randschieferserie (Bavarian lithofacies) in the Münchberg nappe pile.

### Zone Tirschenreuth-Mähring (ZTM)

The textural similarities between the schistose and striped amphibolites of the ZEV, on the one hand, and of the ZTM and the adjacent Moldanubian s. str., on the other, are matched by a nearly identical geochemical character, conforming to typical N-MORB compositions (Figs. 1, 2, 3).

### CONCLUSIONS

Metabasites in each of the individual tectonic units of the Münchberg nappe pile exhibit their own, significant geochemical characteristics. This fact indicates that the respective basaltic protoliths were initially emplaced in different paleogeographical environments. Owing to the absence of age criteria, the relative position of these environments in time and space, prior to the stacking of the Münchberg nappe pile, is so far unknown.

The close geochemical resemblance between the metabasites from the Prasinit-Phyllit-Serie of the Münchberg nappe pile and the Erbendorf Greenschist-Zone is a strong argument for a correlation of the two units which exhibit a similar lithological association and appear to be in an analogous tectonic position.

In contrast, a correlation between the higher, crystalline nappes in the Münchberg pile and the Zone Erbendorf-Vohenstrauß is not encouraged by our results. No geochemical relationship exists between the amphibolites and banded hornblende gneisses of the Hangendserie and the various metabasite types of the ZEV. The randomphibolites, too, find no convincing counterpart in the ZEV. As a consequence we must state that a connection between the higher units of the Münchberg nappe pile and the ZEV cannot be maintained in the straightforward way which has been postulated recently (Weber and Vollbrecht 1986, p. 26).

However; an interestingly close correlation exists between the schistose and striped amphibolites of the Zone Erbendorf-Vohenstrauß, on the one hand, and of the Zone Tirschenreuth-Mähring and the adjacent Moldanubian s. str., on the other. The interpretation of this finding is still open to discussion. Geochemical investigations on metabasites from the Zone Tepla-Domazlice and from the Moldanubian s. str. are in progress and hopefully will provide additional constraints.

The geochemical affinity between the metabasites of the Fichtelgebirge crystalline complex and the alkaline basalts of the anchimetamorphic Ordovician Randschieferserie (Bavarian lithofacies) in the lowermost position of the Münchberg nappe pile should be stressed. However, it would be daring to derive an age relationship from this fact alone.

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