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Evidence for an Alkaline-Basaltic Volcanism at the Northern Margin of Gondwana Within the Austroalpine Basement Complex of the Eastern Alps (Austrian/Italian Border)

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13 Text-Figures and 3 Tables

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Osttirol
Schobergruppe
Lasörlinggruppe
Austroalpine Nappe Complex
Metabasites
Geochemistry
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Inhalt

Hinweise auf einen alkalibasaltischen Vulkanismus am Gonwana-Nordrand innerhalb des oberostalpinen Grundgebirges der Ostalpen (Grenzregion Österreich/Italien)

Zusammenfassung

Der schmale Streifen des Austroalpinen Basements der Ostalpen zwischen dem zentralen Tauernfenster und den Südalpen ist durch das Auftreten einer Vielzahl von metabasischen Gesteinen charakterisiert. Die geochemische Analyse der Haupt- und Spurenelemente dieser Metabasite erlaubt die Formulierung einer plattentektonischen Situation für die Genese der magmatischen Edukte der Metabasite.

Zwei deutlich unterschiedliche Suiten können voneinander abgegrenzt werden. Gering fraktionierte Chondrit-normalisierte SEE-Muster ($(La/Yb)_N$ = 3,8) und Nb/Y-Verhältnisse <0,66 sind typisch für metatholeiitische Gesteine, deren Vorkommen auf die östliche Lasörling-Gruppe beschränkt ist. Die metaalkaline Suite zeigt stark fraktionierte SEE-Muster, wobei der Grad der Fraktionierung von $(La/Yb)_N$ = 10 innerhalb der Lasörling-Gruppe auf bis zu $(La/Yb)_N$ = 26 in einigen Proben der Schwarzen Wand ansteigt. Ihre geotektonische Position ist damit an ein sich öffnendes Intraplatten-Rift gebunden. Eine auffällige Verarmung und dabei gleichzeitig starke Fraktionierung der Elemente Zr und Hf (Zr/Hf bis zu 78) wird in allen Proben der metaalkalinen Suite beobachtet. Es wird angenommen, dass es sich dabei um eine primäre Signatur handelt, verursacht durch die Metasomatose CO_2-reicher Fluide im oberen Erdmantel infolge der Subduktion ozeanischer Sedimente.

Es wird weiterhin postuliert, dass die Anreicherung der Mantelquelle für die Generation metaalkaliner Schmelzen im Zusammenhang mit dem subduktionsgebundenen Vulkanismus steht, der für metabasische Gesteine im Norden der Lasörling-Gruppe und im Prijakt-Gebiet nachgewiesen werden konnte. Ein Übergang von Gesteinen der Alkalin-Serie hin zu MOR-Tholeiiten ist in Übereinstimmung mit der rezenten Entwicklung in kontinentalen Riftsituationen.

Abstract

Metabasic rocks are a common constituent in the Austroalpine basement of the Eastern Alps between the central Tauern Window and the “Southern Alps”. Different metabasic rocks were taken and analysed for major and trace elements in order to establish a plate tectonic setting for the generation of the magmatic rocks.

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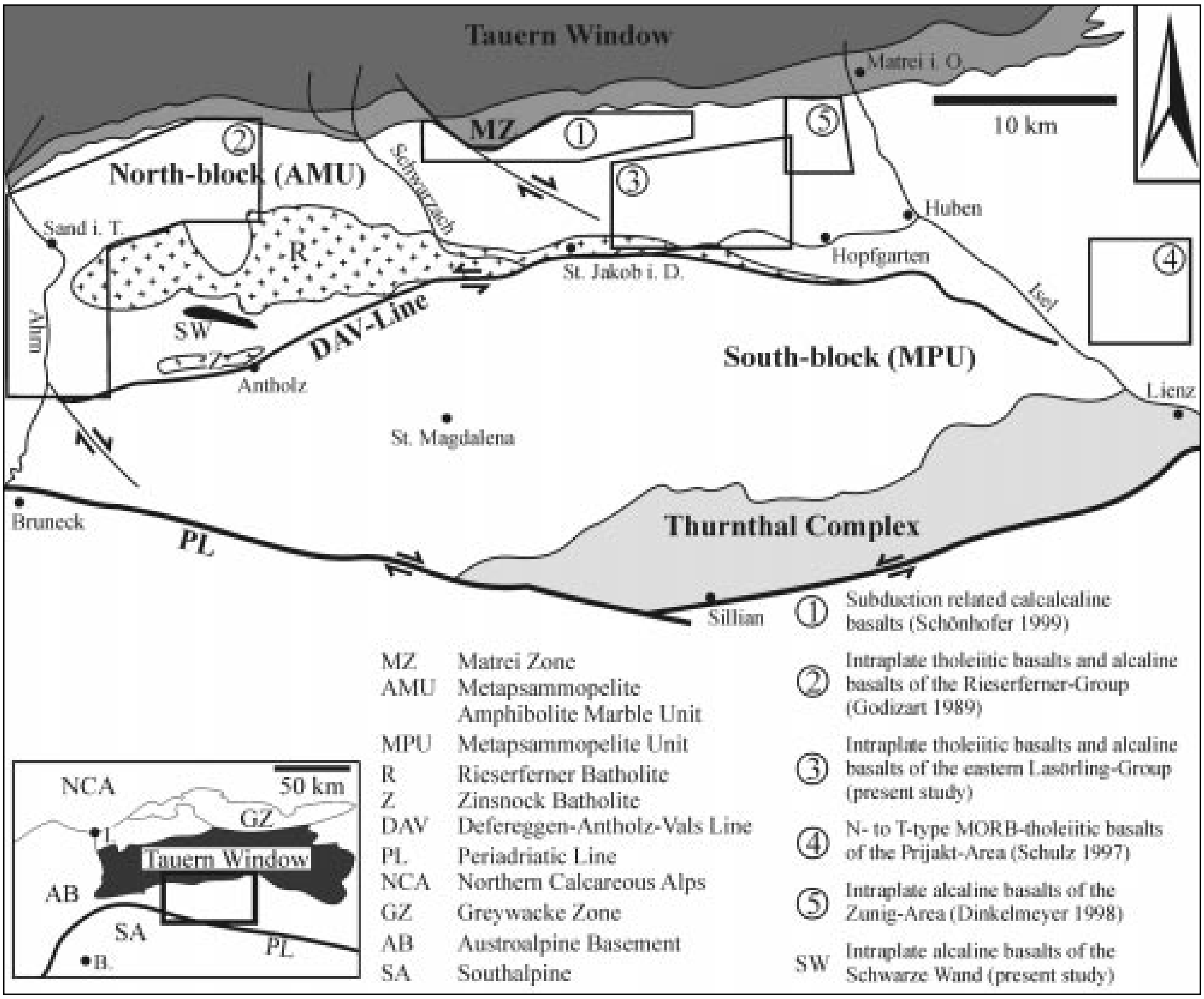
Two major groups could be distinguished. A metatholeiitic suite is characterised by little fractionated chondrite-normalised REE-patterns ($(La/Yb)_N$ = 3.8) and Nb/Y-ratios <0.66. It occurs only in the eastern Lasörling Group. Metaalkaline series are identified by strongly fractionated REE. $(La/Yb)_N$ = 10 within the eastern Lasörling Group and $(La/Yb)_N$ up to 26 within the samples of the Schwarze Wand fix their position to an intraplate rift setting. A depletion and fractionation of Zr and Hf (Zr/Hf up to 78) was found in all samples. It may be attributed to a CO_2-mantle metasomatism caused by the former subduction of oceanic sediments.

It is assumed, that the enrichment of the mantle source is produced by a subduction related volcanism within the northern part of the Lasörling Group and the Prijakt Area. A transition from alkaline rock series to MOR-tholeiites is in agreement with the development of recent continental rift setting.

1. Introduction

Basic metavolcanic rocks are an important part of the lithological record in orogenic belts. Their major and trace element compositions can often be used in detecting the primary tectonic environments. Recently the results of several geochemical investigations on the Austroalpine basement between the Tauern Window and the Periadriatic Line were reported (GODIZART, 1989; KREUTZER, 1992; SCHULZ, 1993; DINKELMEYER, 1998; SCHÖNHOFER, 1999).

This paper presents geochemical data from the metabasic rocks of the Lasörling Group (Deferegger Alps), and the Schwarze Wand (Croda Nera) (Text-Fig. 1). The metabasic rocks are predominantly composed of amphibolites with minor occurrences of pyroxenites within the suite of the Schwarze Wand. For the latter MAGER (1985) proposed a magmatic origin based on zircon typology. The extrusion ages are unconstrained. Deformed amphibolitic xenoliths within the common Upper Ordovician orthogneisses may point to a pre Upper Ordovician age for the metabasic rocks. From field studies all metabasic rocks were deformed during variscan amphibolite facies metamorphism, followed by an eoalpine greenschist facies metamorphism partly overprinting the former structures and mineral associations. The overprint is most penetrative within the samples of the Lasörling Group (STÖCKHERT, 1982, 1985; SCHÖNHOFER, 1999).



Text-Fig. 1.
Line drawing of the major units within in the Austroalpine basement between the central Tauern Window and the Southern Alps.
Boxes show the areas of former and the present geochemical investigations on metabasic rocks. Note also the situation of the metabasic rocks of the Schwarze Wand (SW).

The subject of this paper is to reveal the tectonic environment of the basic metavolcanic rocks in the eastern Lasörling-Group and in the Schwarze Wand based on their geochemical signatures. Since the investigated metabasic rocks suffer two metamorphic events interpretations are based on elements which are regarded to be largely immobile during metamorphism. A comparison with the data of former publications (GODIZART, 1989; SCHULZ, 1993; SCHÖNHOFER, 1999) should enable modelling the early Paleozoic geodynamic evolution in the Austroalpine basement assuming similar emplacement ages for the diverse mafic rocks.

2. Geological Setting

All investigated rock samples were collected from the Austroalpine Basement (AB) Complex located between the South Alpine (SA) and the central Tauern Window (Text-Fig. 1). Its tectonic relation to the upper-Austroalpine nappes was established by BÖGEL et al. (1976). TOLLMANN (1977) suggested a relation to the mid-Austroalpine nappes.

In the south the Puster-Valley faultzone (PL) separates the Austroalpine basement from the South Alpine basement. To the south-east it is the Markinkele Line (ML) which is the border to the Thurnthaler Complex (TC) (HEINISCH et al., 1984). The Matrei Zone (MZ) in the north divides between the palaeozoic Austroalpine basement series and the metapelitic and metavolcanic rocks of the upper "Schieferhülle" which is part of the penninic Tauern Window.

The most remarkable fault within this part of the Austroalpine Basement is the steep, east–west-trending Defereggen-Antholz-Vals (DAV) Line, which separates the basement into a north and south-block (STÖCKHERT, 1982, 1985; SCHULZ, 1988).

The preservation of Variscan amphibolite facies mineral associations and deformation structures in the south-block is caused by sinistral strike slip faulting with a substantial dip slip component along the DAV-Line (STÖCKHERT, 1982, 1985; KLEINSCHRODT, 1987). In the north-block the Variscan metamorphism and deformation are partly obliterated by the eoalpine greenschist facies metamorphism. In this respect the DAV-Line takes the role of the Periadriatic Line.

A pre-alpine tectonostratigraphic relation of the mid-Austroalpine to the Gondwana derived "Celtic Terrane" is suggested by FRISCH et al. (1989). The different lithological associations of the metamorphic rocks within the basement lead to a division in lithological subunits which possibly represent former palaeogeographic sedimentary facies areas (SCHULZ, 1997). To the south of the DAV fline monotonous paragneisses predominate with occurrences of fine-grained amphibolites, marbles and calc-silicates being rare. These rock series are summarised as the metapsammopelitic unit (MPU) (SCHULZ, 1994). The Thurntaler Complex to the south of the MPU is mainly composed of phyllitic sequences which are regarded to be deposited on the passive margin of the "Celitic Terrane" (FRISCH et al., 1989). To the north of the DAV-Line the paraseries are characterised as metapsammopelitic-amphibolite-marble unit (AMU) (SCHULZ, 1994). Within the widespread light garnet-mica-schists (SENARCLENS-GRANCY, 1965) and biotite-paragneisses are several intercalations of marbles and amphibolites, the latter partly as "garbengneisses" or garnet-amphibolites. The metabasic series of the Schwarze Wand is also part of the AMU. It is situated in the centre of a syncline between the batholites of Rieserferner (Verdrette di Ries) and Zinsnock (Cima di Villa) (Text-Fig. 1).

Intrusions with granitic to tonalitic composition occur on both sides along the DAV-Line. Two groups of different age could be distinguished. The Tertiary granodioritic to tonalitic intrusions of the Rieserferner and Zinsnock are situated in the north-block, whereas the caledonian intrusions are situated to both sides of the DAV-Line. Among others they are represented by ortho-augengneisses "type Sand in Taufers" (Rb-Sr wholerock-isochrone 445 ±24 Ma [HAMMERSCHMIDT, 1981]) and by mica-orthogneisses "type Gsies" (Rb-Sr wholerock-isochrone 434 ±4 Ma [BORSI et al., 1973]). Their generation is caused by an anatectic event within the pre-Upper Ordovician sediment pile (PECERILLO et al., 1979; MAGER, 1985).

3. Petrographic Description and Metamorphic Overprint of the Samples

The amphibolites occur as layers from centimeters to several meters within the metasedimentary series. In case of the Schwarze Wand the metabasics constitute a 200 m thick sequence in the AMU. With respect to the penetrative alpidic foliation the contact to the surrounding paraseries is concordant and sharp. Compositional transition between the amphibolites and the paraseries was never observed. Considering the mineral-associations and fabrics of the amphibolites two different groups could be distinguished.

1) Within the samples from the Schwarze Wand the Variscan structures are preserved. Remarkable is the occurrence of garnet-pyroxenites. The coexistence of clinopyroxene and garnet is the product of the amphibolite facies "Barrow-Type" metamorphism (T = 650°C, P = 7.5 kbar after STÖCKHERT [1982]; MAGER [1985]). Clinopyroxene-bearing garnet-amphibolites and epidote-amphibolites with clinopyroxene-calcite-layers form transitions to amphibolites, garnet-amphibolites and "garbengneisses", reflecting the decreasing P-T-conditions during prograde Variscan metamorphism.
2) The observed mineral association of blue-greenish amphibole + plagioclase + Ti-phase (in general titanite) accompanied by varying quantities of garnet and epidote/clinozoisite reflect the conditions of the Variscan amphibolite facies metamorphism (T_{max} = 670°C, P_{max} = 7.5 kbar after SCHÖNHOFER [1999]). Against the former view of a penetrative eoalpine "almandine low grade" metamorphism within the Austroalpine Basement to the north of the DAV-Line (STÖCKHERT, 1982), recent P-T-estimations within the garnet bearing metapelites and amphibolites of the Lasörling-Group indicate only a weak alpine metamorphic overprint (T_{max} = 420°C, P_{max} = 3.0 kbar after SCHÖNHOFER [1999]), with minor or no recrystallisation of former Variscan minerals.

A further alteration in the amphibolites may be the result of an Alpine metamorphism. This is marked by the decomposition of plagioclase to albite and epidote/clinozoisite. This reaction is partly complete. Moreover, the replacement of amphibole by biotite and also chlorite occurs. These reactions can not be explained isochemical, so the influx of K^+ by hydrothermal fluids is necessary. The sporadic observation of patchy replacement of blue-greenish porphyroblastic amphiboles by actinolite is connected with the formation of calcite. This calcite appears as inclusions measuring a few µm in size within the amphibole. The replacement of garnet by epidote/clinozoisite is initiated in the garnet-cores, whereas the substitution by decussate biotite and chlorite is proceeding from the grain boundaries and fractures.

The set of the alpine mineral association consisting of actinolite + albite + chlorite + biotite ± epidote/clinozoisite ± quartz fixes conditions of the lower greenschist facies (SCHÖNHOFER, 1999).

4. Analytical Methods

Representative amphibolite and pyroxenite samples that were unweathered were chosen for analyses. Sample material weighed, depending on the grain size, between 1 kg and 10 kg per sample. The major and some of the trace elements of bulk rock powders from 37 samples were analysed by X-ray fluorescence (Li-borate glass and powder pellets in a Philips PW 1480© sequential spectrometer). 23 samples were prepared for ICP-MS Trace element analyses carried out with a Fisions Plasmaquad II©. The accuracy of the measurement was established using an international reference sample

Table 1.
Petrography of the metabasic rocks.

Eastern Lasörling-Group	
△	Amphibolites containing blue greenish amphibole + plagioclase ± epidote/clinozoisite ± titanite
⬠	Garnet-amphibolites containing blue greenish amphibole + plagioclase + garnet + epidote/clinozoisite ± titanite
Schwarze Wand	
◇	Amphibolite containing blue greenish amphibole + plagioclase ± epidote/clinozoisite ± titanite
	Pyroxenites containing clinopyroxen + garnet + epidote/clinozoisite + titanite
	Garnet-pyroxen-amphibolites containing blue greenish amphibole + plagioclase + garnet + clinopyroxen + epidote/clinozoisite
	Garnet-amphibolite containing blue greenish amphibole + plagioclase + garnet ± epidote/clinozoisite ± titanite
	Layered amphibolite containing blue greenish amphibole + plagioclase + epidote/clinozoisite + clinopyroxene
	Layered amphibolites containig blue greenish amphibole + plagiclase + epidote/clinozoisite + clinopyroxene + calcite

Table 2.
Major and trace element analyses of selected tholeiitic rock samples from the eastern Lasörling-Group.

	△ AN 39.1	△ Hi 46.1.95	△ Hi 18.7.95
Mg-number	64.4	62.4	59.4
SiO_2	45.00	42.60	48.50
TiO_2	1.53	1.19	1.81
Al_2O_3	14.95	11.98	15.60
$Fe_2O_{3\,(tot)}$	10.57	10.07	10.77
FeO	7.45	6.98	7.87
Fe_2O_3	2.29	2.31	2.02
MnO	0.16	0.16	0.16
MgO	7.57	6.50	6.45
CaO	7.18	9.60	9.87
Na_2O	2.60	1.73	3.51
K_2O	0.82	0.33	0.53
P_2O_5	0.13	0.14	0.26
ΣH_2O	3.46	2.77	2.22
CO_2	2.88	5.93	1.05
S	0.016	0.018	0.018
Total (Fe as Fe^{2+}+Fe^{3+})	96.04	92.22	99.86
Li	57	24	45
Be	0.60	0.48	1.83
Sc	32	44	30
V	206	242	253
Cr	531	131	131
Co	47	31	42
Ni	190	31	76
Cu	17	37	30
Zn	95	79	132
Rb	21	8	14
Sr	292	376	198
Y	17	24	27
Zr	83	73	122
Nb	6	4	15
Mo	0.31	0.22	0.28
Cd	0.16	0.29	0.14
Sn	1.26	0.74	1.41
Sb	0.41	0.24	0.20
Cs	6.51	0.19	1.16
Ba	81	91	67
La	7	4	16
Ce	21	12	37
Pr	2.8	1.9	4.7
Nd	14	12	21
Sm	3.7	3.5	5.5
Eu	1.27	1.22	1.71
Gd	3.8	3.8	5.1
Tb	0.60	0.70	0.86
Dy	3.6	5.0	5.3
Ho	0.72	0.97	1.02
Er	2.00	2.84	3.01
Tm	0.30	0.43	0.42
Yb	1.80	2.47	2.82
Lu	0.27	0.37	0.39
Hf	2.16	1.85	2.69
Ta	0.44	0.24	1.44
W	0.48	0.54	0.05
Tl	0.429	0.041	0.082
Pb	5.15	7.3	9.6
Bi	0.03	0.14	0.42
Th	0.67	0.5	1.9
U	0.28	0.16	0.46

JA-2 (Andesite, Japan) and the standard sample BB (Basalt, Bramburg, Germany). The analytical results of the standard and reference sample differ less than 5 %rel. from the expected values. A determination of the Fe^{2+}/Fe^{3+}-ratio as well as the H_2O content was done via titrimetric wet chemical analysis, while sulphur and CO_2 content was determined by photometry. The primary mineralogical composition of the sample material is given in Table 1 and a compilation of the analytical results is given in Tables 2 to 4.

Table 3.
Major and trace element analyses of selected alkaline rock samples from the eastern Lasörling-Group.

	⬠	△	△	⬠	⬠	⬠	⬠	⬠	⬠	⬠
	56.1.96	**38.X.96**	**33.5a.96**	**39.3.96**	**31.4.96**	**AN 159**	**36.6.96**	**AN 83.3**	**Hi 48.2.95**	**52.O.K.96**
Mg-number	66.9	68.0	70.5	53.0	52.1	51.1	49.2	47.1	44.6	51.5
SiO_2	47.36	47.47	46.95	44.50	44.04	50.70	51.52	46.30	49.80	46.35
TiO_2	1.84	2.12	1.75	3.06	2.75	3.31	3.24	3.79	2.97	2.64
Al_2O_3	15.38	12.46	12.14	15.63	16.19	14.55	14.22	13.84	16.63	14.44
$Fe_2O_{3\,(tot)}$	10.20	11.58	11.23	13.68	14.52	12.80	12.30	15.20	12.60	12.59
FeO	7.57	8.26	8.45	10.34	10.81	9.60	8.07	10.43	9.13	9.24
Fe_2O_3	1.79	2.39	1.84	2.19	2.51	2.13	3.33	3.61	2.45	2.32
MnO	0.16	0.17	0.13	0.19	0.18	0.20	0.19	0.20	0.22	0.19
MgO	8.57	9.86	11.32	6.53	6.60	5.63	4.39	5.21	4.13	5.51
CaO	11.41	10.28	9.87	9.51	6.53	8.12	6.22	11.84	7.39	4.01
Na_2O	2.82	2.49	2.17	2.46	2.29	2.06	4.72	0.99	3.13	3.37
K_2O	0.26	0.43	0.38	0.34	0.61	0.48	0.35	0.31	0.39	1.28
P_2O_5	0.21	0.27	0.24	0.49	0.41	0.55	0.64	0.58	0.76	0.44
$\Sigma\,H_2O$	2.35	3.01	3.84	2.87	3.25	2.11	2.40	2.36	2.47	2.51
CO_2	0.08	0.51	0.08	0.63	1.50	0.41	0.12	0.13	0.06	2.84
S	0.004	0.019	0.004	0.312	0.010	0.019	0.017	0.046	0.072	0.010
total (Fe as $Fe^{2+}+Fe^{3+}$)	99.80	99.74	99.16	98.74	97.67	99.85	99.41	99.59	99.53	95.14
Li	41	34	34	39	63	38	30	35	47	37
Be	0.85	1.45	2.28	2.45	5.12	2.80	2.14	1.11	2.93	1.32
Sc	31	34	39	26	25	22	15	30	14	24
V	223	283	239	351	446	264	282	415	263	337
Cr	271	400	571	36	64	151	10	27	23	110
Co	39	45	51	45	40	36	32	34	30	38
Ni	125	183	213	38	61	62	9	11	8	74
Cu	8	15	7	90	7	38	114	101	76	20
Zn	105	126	150	162	282	155	131	136	149	107
Rb	6	15	28	10	35	15	19	8	19	56
Sr	466	330	187	254	403	182	232	447	199	306
Y	18	18	19	32	28	34	38	30	37	30
Zr	91	133	146	282	235	379	369	218	399	269
Nb	22	20	21	42	107	43	44	29	87	46
Mo	0.48	0.56	0.79	2.28	0.29	2.92	1.69	1.51	0.80	0.11
Cd	0.20	0.16	0.16	0.15	0.39	0.20	0.16	0.18	0.19	0.12
Sn	1.34	1.56	1.87	3.41	5.19	3.92	1.97	2.14	3.76	2.01
Sb	0.42	0.70	0.56	0.66	0.38	0.25	0.25	0.55	0.53	0.12
Cs	0.21	0.62	1.15	1.95	2.11	1.40	1.83	0.29	1.72	2.25
Ba	25	124	62	71	98	54	27	12	47	243
La	13	19	19	35	30	49	50	28	71	40
Ce	30	45	42	85	73	117	118	71	163	91
Pr	4.0	5.5	5.0	9.9	9.0	13.8	14.0	9.0	18.0	10.4
Nd	20	23	20	40	39	57	57	38	72	42
Sm	4.5	5.4	4.8	9.4	8.7	11.8	12.1	8.8	13.2	8.8
Eu	1.62	1.75	1.49	2.93	2.68	3.66	3.77	3.14	4.02	2.76
Gd	4.5	4.6	4.1	7.8	7.3	9.5	9.4	7.3	10.6	7.1
Tb	0.70	0.65	0.61	1.19	1.09	1.43	1.40	1.07	1.44	1.08
Dy	4.0	3.6	3.3	6.3	6.0	7.7	7.7	5.8	7.9	6.0
Ho	0.71	0.66	0.61	1.14	1.12	1.32	1.38	1.04	1.41	1.08
Er	1.91	1.72	1.61	2.99	2.90	3.45	3.43	2.78	3.71	2.84
Tm	0.24	0.23	0.21	0.39	0.39	0.46	0.47	0.37	0.48	0.41
Yb	1.42	1.41	1.38	2.49	2.41	3.00	3.02	2.31	3.12	2.57
Lu	0.21	0.19	0.18	0.31	0.32	0.40	0.41	0.31	0.39	0.34
Hf	2.36	2.87	3.08	5.35	5.03	7.70	6.90	4.24	8.10	5.40
Ta	1.26	1.45	1.44	3.91	6.18	3.22	3.87	1.96	6.03	3.37
W	1.86	0.24	1.11	0.90	2.49	4.18	0.56	0.37	0.86	0.23
Tl	0.025	0.050	0.098	0.052	0.176	0.083	0.098	0.043	0.123	0.167
Pb	15.8	8.5	10.2	15.6	13.9	9.3	11.4	14.5	21.9	4.7
Bi	0.81	0.09	0.52	1.07	0.30	0.46	0.49	1.00	1.12	0.03
Th	1.3	1.5	1.7	3.1	3.0	5.9	4.5	1.9	8.1	4.0
U	0.40	0.35	0.40	0.78	0.89	1.65	1.25	0.56	2.32	0.86

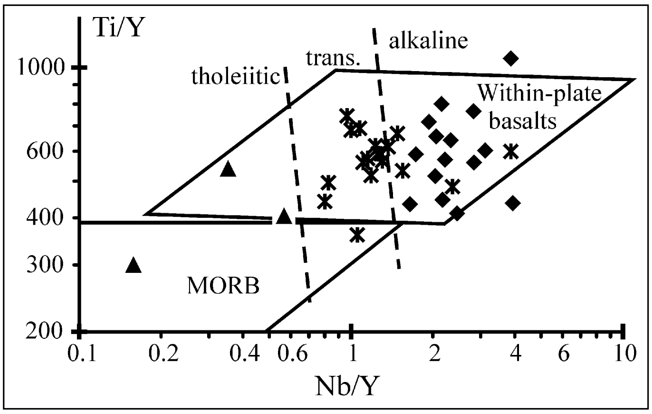
Table 4.
Major and trace element analyses of selected alkaline rock samples from the Schwarze Wand.

	SW 45.3.96	SW 47.2.96	SW 45.5.96	SW 45.2.96	SW 45.1.96	SW 52.2.96	SW 44.3.96	SW 47.1.96	SW 51.1.96	SW 52.3.96
Mg-number	65.3	64.32	38.5	60	59.3	54.5	42.2	60.1	56.3	63.7
SiO_2	47.27	46.73	42.80	46.82	45.51	40.95	40.26	42.18	39.70	39.63
TiO_2	1.48	0.98	2.97	2.00	1.90	2.81	2.88	2.76	4.41	2.84
Al_2O_3	15.94	7.02	9.79	12.48	12.54	9.21	11.38	10.36	11.97	13.39
$Fe_2O_{3\,(tot)}$	10.88	11.63	18.45	12.33	13.10	12.51	17.50	12.32	17.38	11.93
FeO	8.13	8.41	14.90	8.20	8.86	8.55	13.11	7.94	12.72	8.79
Fe_2O_3	1.84	2.33	1.89	3.22	3.26	3.01	2.93	3.49	3.25	2.16
MnO	0.19	0.96	0.83	0.21	0.22	0.20	0.58	0.20	0.36	0.26
MgO	8.59	8.51	5.23	6.89	7.24	5.74	5.37	6.70	9.17	8.65
CaO	11.00	22.19	18.50	12.91	12.44	15.85	14.88	21.73	10.49	12.83
Na_2O	2.60	0.58	0.13	1.77	1.64	2.03	0.43	0.44	0.83	1.22
K_2O	0.81	0.04	0.17	0.87	1.13	0.29	0.57	0.75	2.58	1.14
P_2O_5	0.46	0.32	0.69	0.44	0.74	1.14	1.18	1.00	0.74	1.30
ΣH_2O	1.96	0.54	1.01	2.06	1.82	1.07	1.11	2.50	2.57	1.53
CO_2	0.24	0.68	0.77	0.73	1.50	3.84	1.45	0.62	0.08	2.16
S	0.009	0.008	0.198	0.058	0.021	0.009	0.010	0.012	0.013	0.011
total (Fe as $Fe^{2+}+Fe^{3+}$)	100.52	99.30	99.68	98.59	98.79	94.69	96.13	100.68	98.86	95.91
Li	56	26	12	27	20	7	13	25	136	115
Be	1.03	10.20	3.91	2.52	1.69	2.25	3.40	3.83	2.67	5.37
Sc	33	16	16	19	18	16	15	15	17	23
V	224	144	195	182	173	228	183	207	224	232
Cr	194	384	261	338	324	232	280	476	201	274
Co	39	31	31	47	51	57	44	44	45	40
Ni	142	110	204	223	208	189	244	281	122	158
Cu	95	5	50	44	19	5	4	8	47	32
Zn	122	223	86	101	147	132	112	131	157	141
Rb	30	6	3	27	28	2	8	22	108	55
Sr	1038	473	77	793	834	289	703	750	193	690
Y	20	14	22	23	26	30	31	28	25	39
Zr	132	76*	131*	285*	227	290	265*	333*	363	521*
Nb	34	35	48	48	56	66	87	86	95	154
Mo	1.20	0.35	0.79	1.40	0.90	0.27	0.42	0.33	0.63	0.65
Cd	0.11	0.76	0.92	0.15	0.14	0.19	0.63	0.31	0.37	0.23
Sn	1.39	10.88	26.57	3.18	2.05	3.04	22.92	6.88	8.83	3.34
Sb	0.26	0.29	0.20	0.37	0.27	0.74	0.35	0.09	0.07	0.43
Cs	7.84	0.34	0.21	1.92	2.09	0.04	0.61	2.20	16.00	10.44
Ba	152	63	24	461	372	86	67	221	483	417
La	38	22	48	55	69	83	109	107	58	173
Ce	85	43	106	108	150	182	221	216	132	337
Pr	9.1	4.9	12.1	11.2	16.0	19.6	22.4	22.3	15.2	31.9
Nd	35	18	48	42	64	78	86	85	63	112
Sm	7.0	3.9	9.0	8.2	11.9	14.1	15.1	14.2	12.6	18.4
Eu	2.10	1.52	3.34	2.67	3.52	3.97	5.66	4.09	4.27	5.33
Gd	5.5	3.1	7.0	6.8	8.7	10.5	11.0	10.3	9.6	14.6
Tb	0.78	0.47	1.01	0.97	1.18	1.34	1.43	1.27	1.22	1.57
Dy	3.9	2.5	5.0	5.1	6.0	7.0	7.2	6.3	6.2	7.5
Ho	0.69	0.46	0.86	0.89	0.97	1.10	1.17	1.02	1.03	1.35
Er	1.84	1.24	2.08	2.26	2.43	2.81	2.88	2.50	2.35	3.65
Tm	0.23	0.17	0.24	0.29	0.32	0.33	0.34	0.29	0.28	0.45
Yb	1.37	1.14	1.50	1.87	1.90	2.02	2.31	1.83	1.62	2.75
Lu	0.18	0.15	0.18	0.24	0.24	0.25	0.26	0.23	0.20	0.37
Hf	2.40	1.20	2.91	4.21	4.20	5.47	4.88	4.39	8.19	7.29
Ta	1.93	33.78	3.28	3.55	3.85	4.18	5.63	5.32	6.48	8.81
W	0.73	0.54	2.11	1.04	1.80	0.81	1.87	0.92	1.65	0.67
Tl	0.097	0.020	0.033	0.102	0.100	0.012	0.034	0.087	0.404	0.170
Pb	11.2	11.0	2.9	8.2	10.3	10.3	10.7	11.1	6.2	10.4
Bi	0.18	0.25	0.49	0.31	0.42	0.34	1.97	0.43	2.35	0.12
Th	3.2	1.8	3.8	9.0	4.5	5.4	11.6	10.3	5.5	21.2
U	0.74	0.94	0.84	2.30	1.72	1.88	2.37	2.80	1.58	6.70

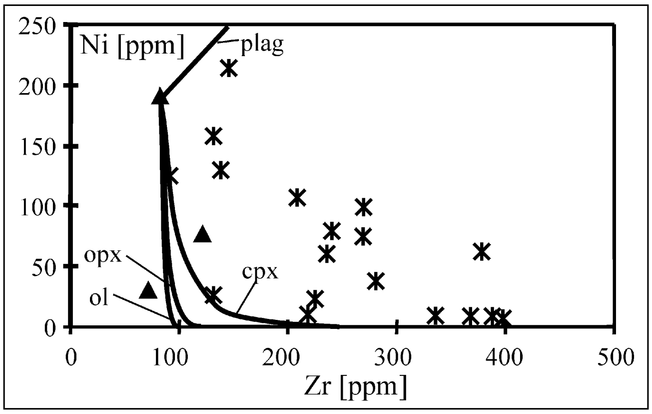
5. Results and Discussion

5.1. Distinction Between the Different Rock Series

The Mg-number of the samples all lie within the range 71 to 39 with a bias towards basaltic compositions. Since K_2O and Na_2O are highly mobile during metamorphism the presentation of the total alkali versus the silica content (TAS-diagram) is impossible. Immobile trace elements as Nb, Y, and Ti allow to discriminate into an alkaline suite and a tholeiitic suite. The element ratios of Nb/Y versus Ti/Y (PEARCE, 1982), give evidence that the majority of all samples belong to the transitional and alkaline series of a within plate setting (Text-Fig. 2). Besides, Nb/Y ratios are



Text-Fig. 2.
Nb/Y versus Ti/Y discrimination diagram for basaltic compositions (PEARCE, 1982) showing the fields of alcaline, transitional and tholeiitic basalts.
Most of the samples plot above the Nb/Y discrimination ratio of 0.66, the limit between alkaline and tholeiitic composition series (WINCHESTER & FLOYD, 1977).
Filled squares = metaalcaline suite of the Schwarze Wand; asterisks = metaalcaline suite of the eastern Lasörling-Group; triangles = metatholeiitic suite of the eastern Lasörling-Group.



Text-Fig. 3.
Variation diagram of Ni vs. Zr shows the metatholeiitic samples (triangles) and metaalcaline samples (asterisks) of the eastern Lasörling Group.
Trend lines show the development of the magma during fractionation of olivine, clinopyroxene, orthopyroxene and plagioclase. A flat fractionation trend within the metaalcaline samples is due to the influence of plagioclase fractionation.

above 0.66, the discrimination ratio between alkaline and tholeiitic series (WINCHESTER & FLOYD, 1977). Only a few samples are of tholeiitic composition with Nb/Y ratios below 0.66 (Text-Fig. 2). Furthermore, the tholeiitic samples are identified by Chondrite normalised (BOYNTON, 1984) flat REE-patterns with $(La/Yb)_N$ = 3.8 and a slightly enriched La-content of up to 50 times above the chondritic value. These are characteristics known from recent P- to T-type MORB (Text-Fig. 4a).

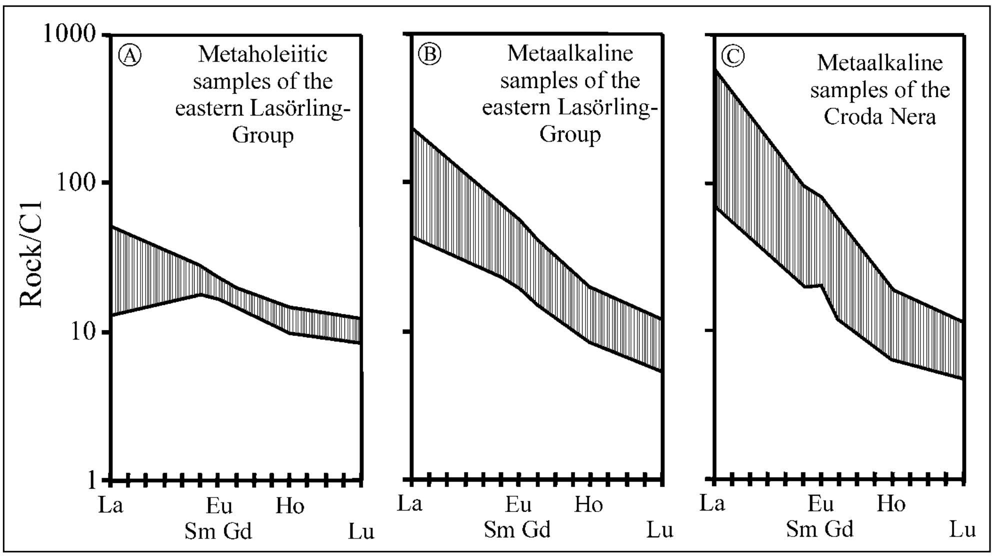
The metabasic rocks are mainly represented by the predominant alkaline basaltic suite with strong fractionated REE-patterns and high contents of incompatible HFSE. However, two subgroups can be defined: The eastern Lasörling-Group with moderate and the Schwarze Wand with strong fractionated REE $(La/Yb)_N$ = 10 and 26 while the La-content is above 230 and 560 times the chondritic value, respectively (Text-Fig. 4b,c). Zr/Y ratios between 5 and 15 support a generation in an intraplate rift-setting (PEARCE et al., 1979).

5.2. Geochemical Characteristics

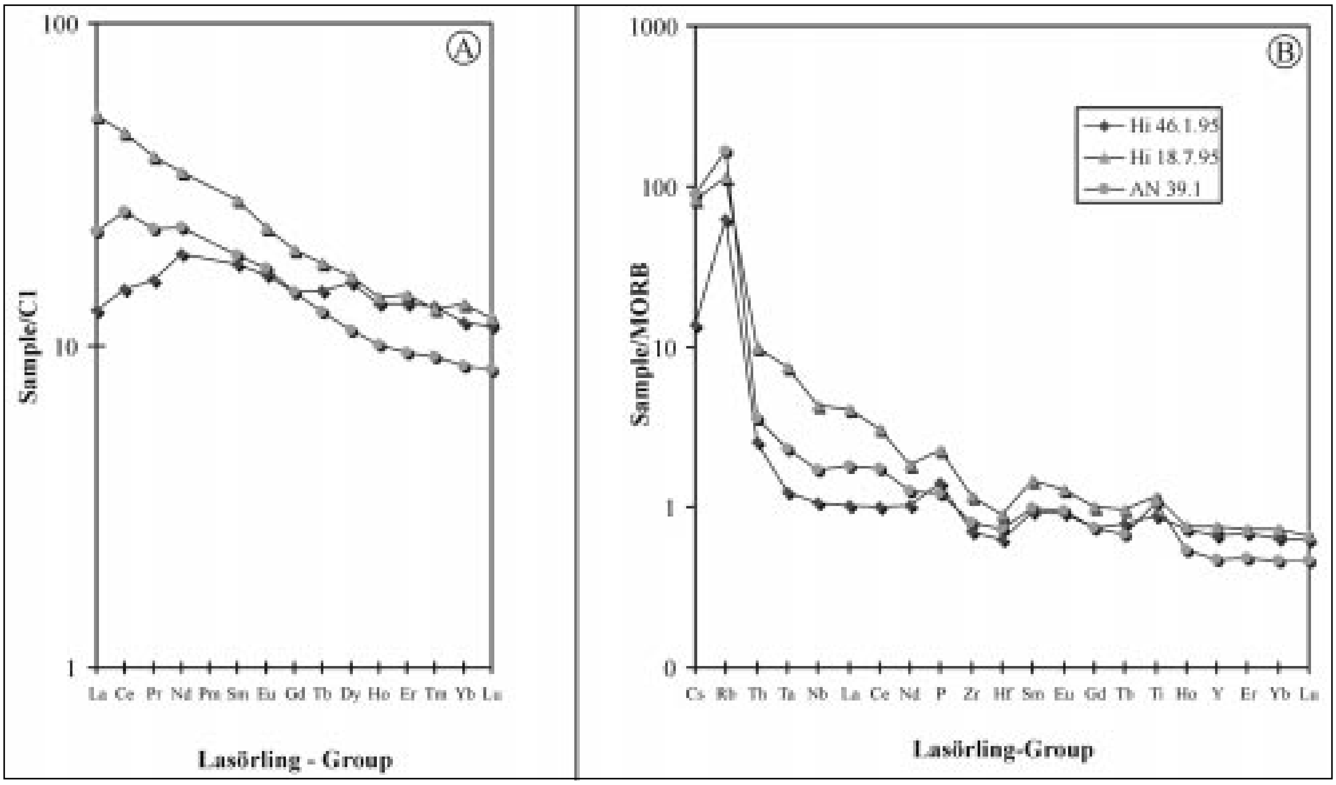
Within the metatholeiitic suite a strong decrease of the compatible elements like Cr, Ni and Co is observed, that may be caused by the fractionation of olivine and pyroxene during the magma ascent (Text-Fig. 3). Moreover, the increasing REE content correspond also with an increasing Zr-value and a decreasing Mg-number. On the other hand, non parallel REE-patterns could not be explained by simple fractional crystallisation but rather has to be related to a change of the magma source region (Text-Fig. 5a). This observation is even more striking at the transition to the alkaline suite, which is documented by more steeply fractionated REE-patterns (Text-Fig. 4) with a simultaneous depletion of the HREE-values.

Subparallel REE-patterns within the alkaline suite of the eastern Lasörling-Group clearly indicate the control of the element contents by fractional crystallisation (Text-Fig. 6) except the sample "31.4.96". This sample exhibits a conspicuous positive Nb-Ta-anomaly. A selective enrichment of Nb and Ta and a strong fractionated Nb/U-ratio (Nb/U = 120) may point to an enriched mantle source as a result of recycled oceanic crust from a former subduction process (Text-Fig. 7). This sample is therefore similar to the HIMU basalts of HOFMANN (1997). Since we have no isotopic data further investigations should be carried out in order to manifest the thesis of an enriched source area.

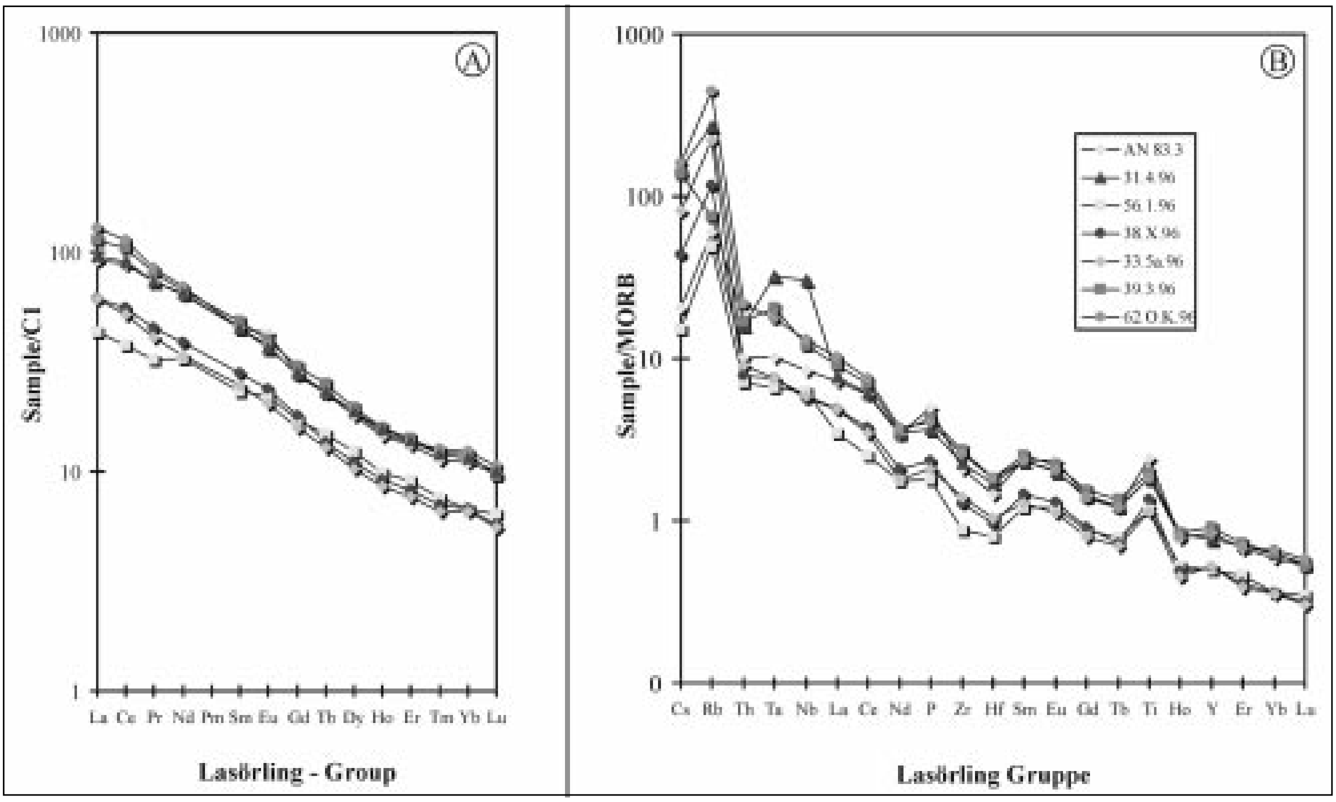
A more complex genesis for the metaalkaline basalts of the Schwarze Wand is suggested by its widely varying element concentrations (Text-Fig. 8). Non parallel fractionation trends of the REE could be due to different compositions of the magma source. Considerable fractionation of the HREE $((Ho/Yb)_N$ = 2.3) is a good indication of residual



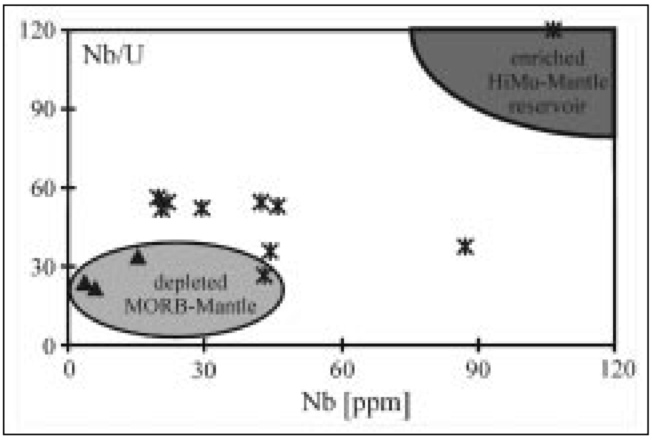
Text-Fig. 4.
Chondrit normalised (BOYNTON, 1984) REE-patterns of the sampled metabasic rocks.
A strong enrichment of the LREE with simultaneous depletion of the HREE with increasing alcalinity is obvious.



Text-Fig. 5.
Spidergrams of the metatholeiitic samples with a relation to T-type to P-type-MORB.
A) Chondrit normalised REE-diagram (Chondrit-values after BOYNTON, 1984).
B) MORB-normalised Spiderdiagram (MORB-values after HOFMANN, 1988).
Mg-numbers of the samples: AN 39.1 = 62; Hi 18.7.95 = 57.7; Hi 46.1.95 = 59.5.



Text-Fig. 6.
Spidergrams of selected alcaline basaltic samples of the eastern Lasörling-Group.
For explanation see Text-Fig. 5.
Mg-numbers of the samples: >60 = 56.1.96, 38.X.96, 33.5a.96; 50–60 = 39.3.96, AN 159, 31.4.96; <50 = AN 83.3, 36.6.96, 62.O.K.96, Hi 48.2.95.



Text-Fig. 7.
Variation diagram of Nb/U vs. Nb.
Recycled oceanic crust with a selective enrichment of Nb and Ta and a depletion in U, caused a positive Nb-Ta anomaly of sample 31.4.96 in a MORB-normalised spidergram and a strong fractionation of the Nb/U-ratio. This sample is therefore similar to HIMU basaltic composition (s. a. HOFMANN, 1997). Symbols see Text-Fig. 3.

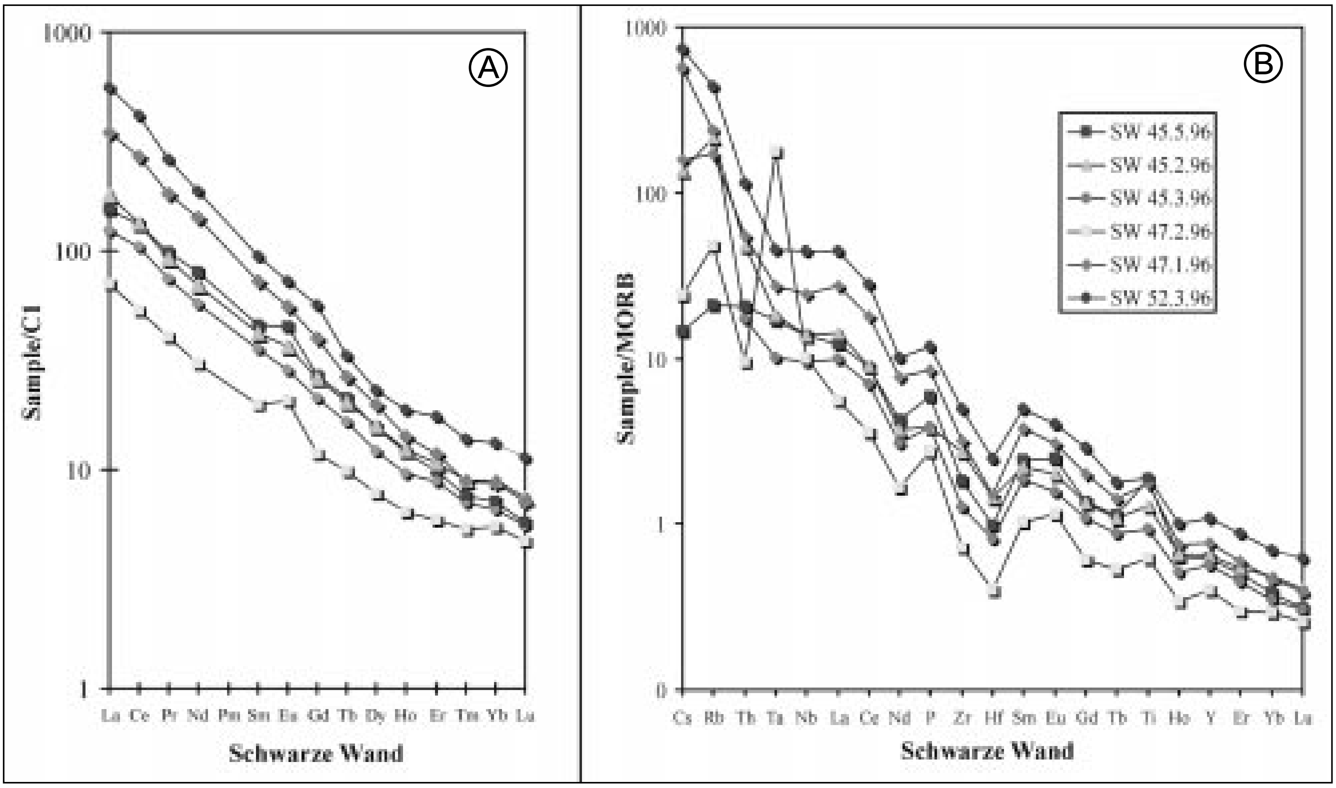
garnet in the lherzolitic source. Compared to this, a lower $(Ho/Yb)_N$-ratio of 1.7 in the metaalkaline basalts is most likely caused by residual spinell (Text-Fig. 9). Some samples of the Schwarze Wand show a slight positive Eu anomaly with $(Eu/Eu^*)_N$ up to 1.35. A lower positive Eu anomaly could also be observed in the samples of the eastern Lasörling Group. This is probably due to the accumulation of plagioclase. In Text-Fig. 10 two different trends are obvious: one follows the enrichment of plagioclase and the other the enrichment of pyroxene in the melt.

In all three samples suites a considerable fractionation of Zr and Hf is evident reflected by a depletion in these elements. Both elements are immobile and so this feature should be of primary origin. A slight deviation from the typical ratio in the mantle lherzolite of Zr/Hf = 36 up to Zr/Hf = 48 occasioned by residual clinopyroxene is shown by JOHNSON et al. (1989, in DUPUY et al. [1992]). The latter found that a strong fractionation of Zr and Hf depends on the degree of CO_2-mantle metasomatism. Also the element ratios of Zr/Sm versus Hf/Sm and also La/Sm versus Zr/Hf exhibit a positive correlation, which could not be explained by residual clinopyroxene or garnet. Distribution coefficients of the minerals for the named elements would lead to a negative correlation of these element ratios, while the positive correlation support the hypothesis of a CO_2-mantle metasomatism (Text-Fig. 11).

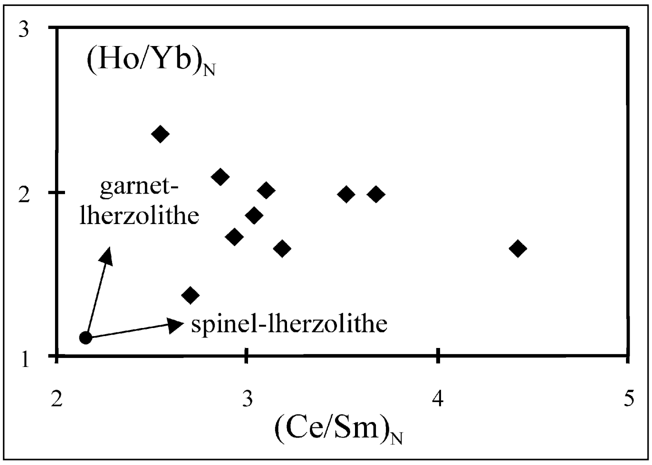
In the variation diagram Th/Yb versus Ta/Yb (PEARCE, 1983) all samples plot along a mixing-line between a depleted MORB-source and an enriched WPB-source. An influence by subduction of an oceanic crust or crustal contamination is not indicated (Text-Fig. 12). As it turns out the shift from an alkaline towards a more tholeiitic magmatism in the investigated area is the most simple explanation.

The very high LREE contents from the Schwarze Wand (La content is up to 560 times the chondritic value) is given by a low degree of partial melting of a garnet-lherzolite. These samples are similar to ultrabasic rocks like lamproites or kimberlites which occur in the margins of recent continental rift settings (Text-Fig. 13, see WILSON [1989] for discussion).

Probably a secondary feature is an enrichment in MnO in some of the samples of the Schwarze Wand together with FeO and CaO contents. A possible reason could be the hydrothermal alteration by manganese-rich fluids, generated at a spreading axis. This may be explained by

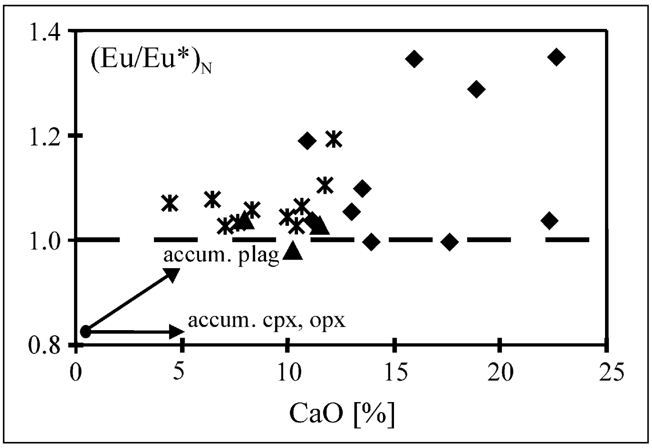


Text-Fig. 8.
Spidergrams of selected alcaline basaltic samples of the Schwarze Wand.
For explanation see Text-Fig. 5.
Mg-numbers of the samples: >60 = SW 45.3.96, SW 47.2.96, SW 52.3.96; <60 = SW 45.2.96, SW 45.5.96, SW 47.1.96



Text-Fig. 9.
Variation diagram of $(Ho/Yb)_N$ vs. $(Ce/Sm)_N$ for the alcaline basaltic samples of the Schwarze Wand.
Trend lines show the fractionation of LREE and HREE in different magma source compositions. Residual garnet will cause a steep fractionation of the HREE whereas residual spinel causes a more slightly HREE fractionation.

the temporal transgression of seawater within a developing rift setting and furthermore to the effusive nature of the basaltic rocks.



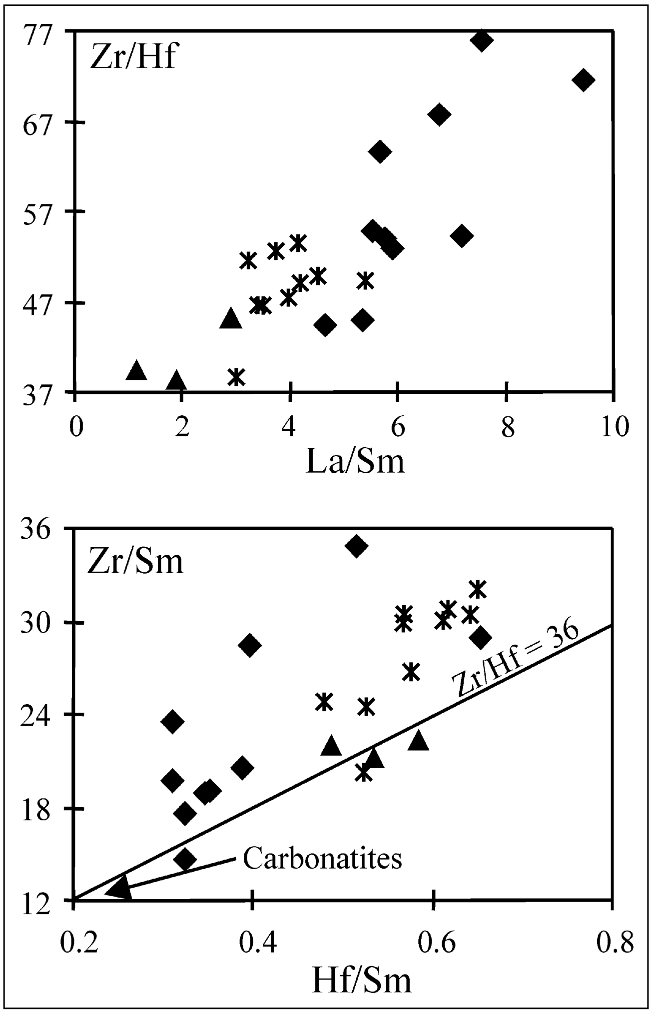
Text-Fig. 10.
Variation diagram $(Eu/Eu^*)_N$ vs. CaO for all samples.
Trend lines show the development of accumulations of plagioclase or clinopyroxene and orthopyroxene.
Symbols see Text-Fig. 2.

6. Conclusion

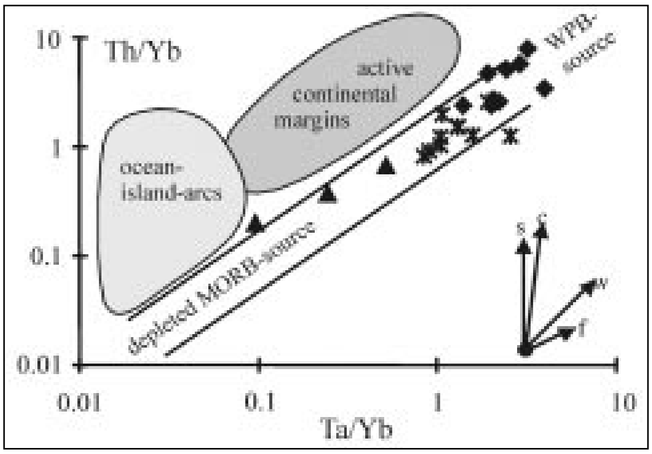
A preliminary model for the early Paleozoic evolution of the Austroalpine Basement to the south of the central Tauern Window has to be based on structural and geochemical observations due to the lack of geochronological data.

Within the south eastern Bohemian Massif a comparable sequence of metabasic rocks ranging geochemically from "within plate basalts" to MORB type, altough some data suggest a local influx from a subduction modified mantle source, was characterised by FINGER et al. (1995). They proposed a passive rifting in the back arc realm of the northern Gondwana margin in the Early Paleozoic for this sequence.

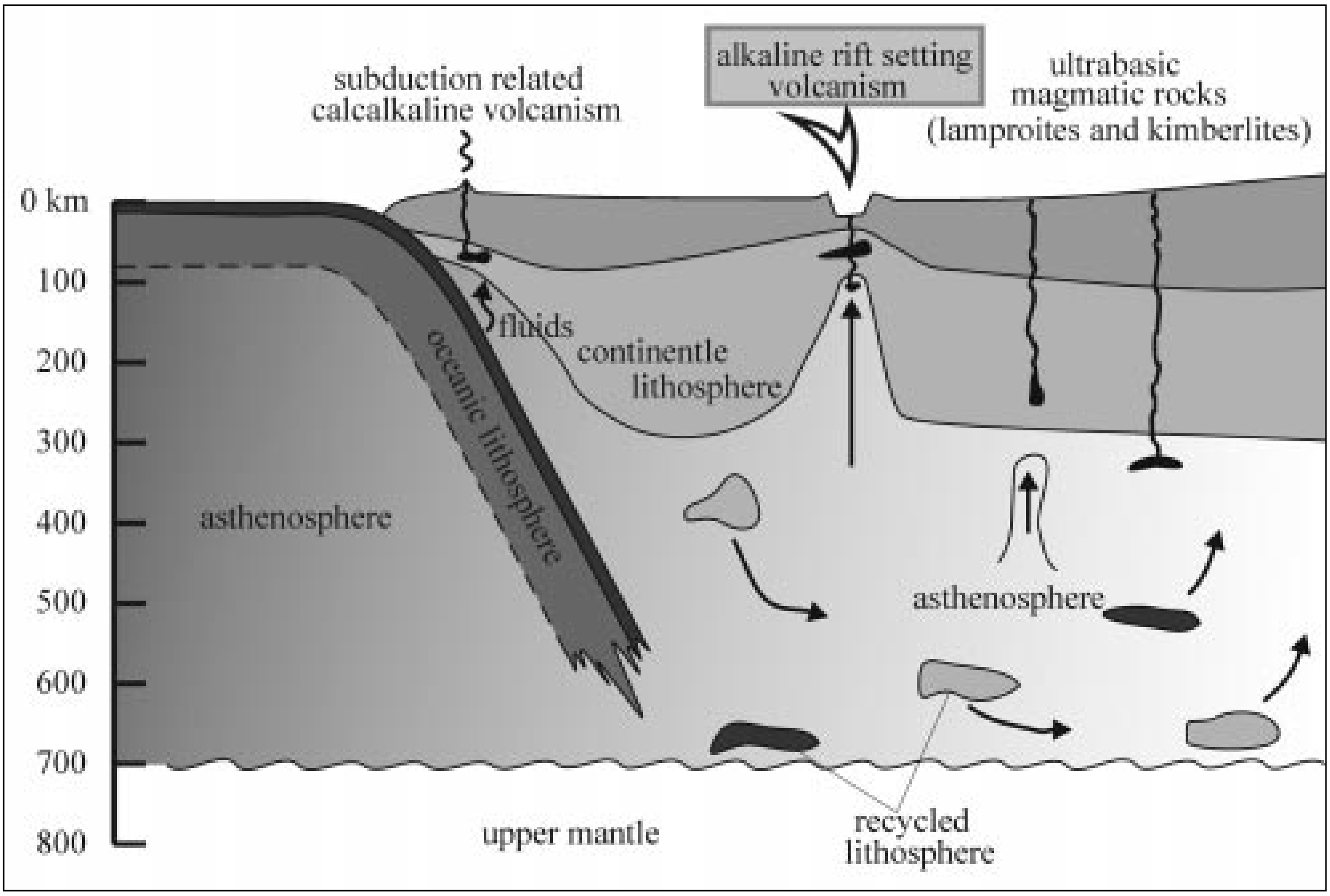
In the southern part of the eastern Lasörling Group metaalkaline and tholeiitic rocks occur alternating within the pre-Upperordovician paragneisses and micaschists of the Austroalpine Basement. Therefore, a spatial and temporal relationship between the different magmatic



Text-Fig. 11.
Variation diagrams of Zr/Hf vs. La/Sm and Zr/Sm vs. Hf/Sm.
CO_2-rich fluids within the upper mantle cause a fractionation of Zr and Hf (for explanation see text).
Symbols see Text-Fig. 2.



Text-Fig. 12.
In the variation diagram Ta/Yb vs. Th/Yb (PEARCE, 1983) all samples lie along a mixing line between a depleted MORB-source and an enriched WPB-source.
Uncontaminated intracontinental plate basalts should plot in the enriched mantle source region. Trend lines shown indicate the influence of subduction components (s), crustal contamination (c), within-plate enrichment (w) and fractional crystallisation (f).
Symbols like Text-Fig. 2.



Text-Fig. 13.
Cartoon of the supposed pre-upperordovizian plate tectonic setting for the different kinds of magma composition between the central Tauern Window and the southern Alps.
The transition from alcaline basalts to tholeiitic basalts is due to the proceeding development of a rift setting. A common feature of alcaline rift volcanism is the association with ultrabasic magmatic rocks like lamproites and kimberlites in the hinterland. Their extreme enrichment in LILE and incompatible HFSE is a good explanation for the observed enrichment in these elements within the Schwarze Wand.

rocks is evident. The lower age limit is given by amphibolitic xenoliths within the Upper Ordovician acid plutons (BORSI et al., 1973). Rb-Sr whole rock data of 430–440 Ma for the orthogneisses are interpreted as intrusion ages.

The magmatic origin of the amphibolites within the AMU (including the Schwarze Wand) and the amphibolitized eclogites from the Prijakt-Area (Schober Group) was demonstrated by several authors (GODIZART, 1989; SCHULZ, 1993; DINKELMEYER, 1998; SCHÖNHOFER, 1999) (Text-Fig. 1). A lithostratigraphic and therefore temporal relationship with the amphibolites investigated in this study is given for the metabasic rocks of the Rieserferner Group between the Ahrn-Valley and the Italian border (GODIZART, 1989) as well as for the amphibolites from the far east of the Lasörling Group (Zunig-Area [DINKELMEYER, 1998]). GODIZART (1989) determined compositions for the amphibolites which range from N-type MORB to alkaline basalts highly enriched in incompatible elements. There is also no indication for a calcalkaline subduction-related magmatism which agrees quite well with our findings. Also DINKELMEYER (1998) described predominantly metaalkaline geochemical signatures of the amphibolites.

Nevertheless the geochemical data is still contradictory with a Cambrian island-arc-situation observed in other areas of the mid-Austroalpine units, which are expected to be Gondwana derived crustal blocks (Celtic Terrane [FRISCH et al., ,1989; VON RAUMER 1998, and references herein]). The occurrence of magmatic rocks generated in an island-arc-situation within the referred area is restricted to the northern part of the Lasörling Group next to the Matrei Zone and the Prijakt-Area. Trace element signatures of amphibolitized eclogites from the Prijakt-Area show an affinity to recent N-type MORB. A slight enrichment of LILE and REE point also to an influence by subducted oceanic crust during magma generation (SCHULZ, 1993). The rocks appear to document a “back-arc-basin” spreading. Moreover, amphibole plagioclase gneisses from the northern part of the Lasörling Group along the Matrei Zone range from basaltic to andesitic composition. A calcalkaline fractionation trend, as well as typical fractionated element ratios of a subduction related magmatism suggest a position at an active continental margin (SCHÖNHOFER, 1999).

With respect to the metasedimentary sequences the primary tectonic environment based on conventional tectono-geochemical discrimination models for the generation of our different basaltic rocks can be reconstructed. Up to now, any geochemical data on the composition of the paragenic country rocks is lacking. However in comparison with gneiss-amphibolite-associations occurring in other areas within the Austroalpine Basement (FRISCH et al., 1984) the metasediments could be former greywackes. In such cases their occurrence together with metabasic rocks is another link for a generation in an intraplate setting with a beginning ocean formation. A temporal influence of oceanic water is also documented by the partial enrichment of Mn, Ca and Fe within some samples of the Schwarze Wand.

A simple lithostratigraphic correlation between the calcalkaline basaltic rocks in the northern Lasörling Group and the MORB-like "back-arc-basin" basalts from the Prijakt-Area seems to be highly speculative from field evidences. The first group is situated next to the Matrei Zone whereas field observations imply a late alpine facoid-like emplacement of these rocks. Also the relationship of the Prijakt Area to the Lasörling and Rieserferner Group up to now is almost impossible to reconstruct due to inadequate structural observations concerning the continuation of the DAV-Line to the east of the Isel-Valley. However, both sequences occur together with microcline bearing orthogneisses while the Lasörling Group do not show any evidence from a high pressure overprint. Together with the Prijakt eclogites they are probably generated in a "back-arc-basin" setting with a somewhat different position with respect to the subduction front. During this subduction oceanic crust and sediments would be recycled with the effect of an enriched mantle source and CO_2-mantle metasomatism. The latter may be caused by subducted oceanic sediments. Ascending mantle material in a following rifting process will be accompanied by an alkaline volcanism which changes with the proceeding evolution to a tholeiitic volcanism (Text-Fig. 13). Such development is observed in almost every recent rift environment (see WILSON [1989] for a review). A similar setting for the change of alkaline to tholeiitic volcanism with the beginning ocean formation was proposed by MAGGETTI et al. (1988) for the metabasic rocks of the Silvretta nappe.

FRISCH et al. (1984, 1987) supposed that associated paragneisses and amphibolites are the typical rock series in a former "back-arc-basin". Hence the expected calcalkaline metabasic rocks should occur frequently within the Austroalpine Basement (Text-Fig. 13). Investigations on basalts from rift zones next to active continental margins show that a typical depletion of specific HFSE-elements could be absent. Instead the occurrence of enriched alkaline basalts were observed (NW Philippine Sea [KLEIN et al., 1981]). This is in good agreement with the development of a "back-arc-basin" (Prijakt-Area, SCHULZ [1993]), where metabasic rocks indicate the influence of subducted oceanic crust.

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