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Contrasting REE characteristics in meta-lamprophyres from Variscan massifs of the Central Swiss Alps and REE patterns in lamprophyres from Variscan terranes of Western Europe

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Abstract

REE data of meta-lamprophyres from the Central Swiss Alps and lamprophyres from the Southern Black Forest are very similar, underlining the resemblance of these Variscan massifs. REE patterns from these lamprophyres do not match those reported from Western Europe (Armorican massif, Massif Central) in that the former are slightly depleted in lighter (LREE) and enriched in the heavier (HREE) elements. The REE data lend little support to the idea of magma mixing proposed on the basis of other trace elements and Nd and Hf isotopes. The significant difference in REE contents and $(La/Yb)_N$ is explained by differences in geotectonic setting and a second stage of magma differentiation. The mineral phases governing the change in REE are found to be zircon and possibly allanite. The site of differentiation lies within the stability field of amphibole, above the deep-seated source and site of magma mixing. This is also reflected by the age, geotectonic and magmatic situation during Permo-Carboniferous times in Central Europe.

Keywords: Lamprophyre, Central Swiss Alps, Black Forest, REE data, Nd and Hf isotopes.

Introduction

In the course of a more extensive geochemical and mineralogical study on 105 lamprophyric dikes along the Swiss Geotraverse in the Alps (Oberhänsli, 1986), 10 lamprophyre samples have been analyzed for rare earth elements (REE). The samples belong to different Variscan massifs in the Alps (e.g., Aar- and Gotthardmassifs as well as the Lepontine nappes). A striking similarity to REE contents of lamprophyres from the Southern Black Forest (Müller, 1982, 1984) was observed. Lamprophyres from the Northern Vosges show similar patterns.

In amphibolite facies zones, clear-cut dike country rock relations often are completely obliterated by intense deformation and recrystallization, rending recognition of meta-lamprophyres delicate. Rare earth elements were analyzed to test for isochemical behavior during Alpine metamorphism and to identify the lamprophyric character, shown in the enrichment of these elements (Bachinsky and Scott, 1979). For the metamorphic and deformed dikes a strict classification into minettes, vogesites, kersantites or spessartites is not rigorously applicable. However, in the Central Swiss Alps kersantites generally dominate with 72% over spessartites (18%), minettes (8%) and vogesites (2%).

Previous work showed a distinct difference between lamprophyres occurring in the Variscan basement of the Central Alps and the Southern Black Forest in respect to other areas (Oberhänsli, 1986), including Western Europe (Armorican massif, Massif Central). In earlier studies genetic models for these calcalkaline lamprophyre magmas have been postulated (Oberhänsli, 1986, Stille et al., 1989). This paper deals in

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more detail with the REE data and relates them to these hypotheses and the geotectonic evolution of the different realms.

Analysed samples and analytical methods

The identification of meta-lamprophyres in the field was based on the absence of macroscopically visible feldspars and on the occurrence of either biotite or hornblende. The definitive identification was based on mineralogy and on bulk rock chemistry, using several mineralogical and chemical screens (WIMMENAUER, 1973; ROCK, 1984; OBERHÄNSLI, 1986, 1987). Minettes from the Central Alps were selected for this paper (Fig. 1), so as to allow comparison with published data sets (ROCK, 1984; TURPIN et al., 1988).

Eight lamprophyres and meta-lamprophyres, all thought to represent minettes, from various Variscan massifs in the Alps (e.g., Aar-, Gotthardmassifs and the Lepontine nappes), Vosges and Southern Black Forest, have been analyzed for major and trace elements (Tab. 1) by X-ray fluorescence and for rare earth elements (Tab. 2) by instrumental neutron activation. Analytical details are given in OBERHÄNSLI (1986). Chemical data of one meta-lamprophyre sample was taken from KÜPFER (1977). One vogesite sample from the Vosges and one biotite-gneiss

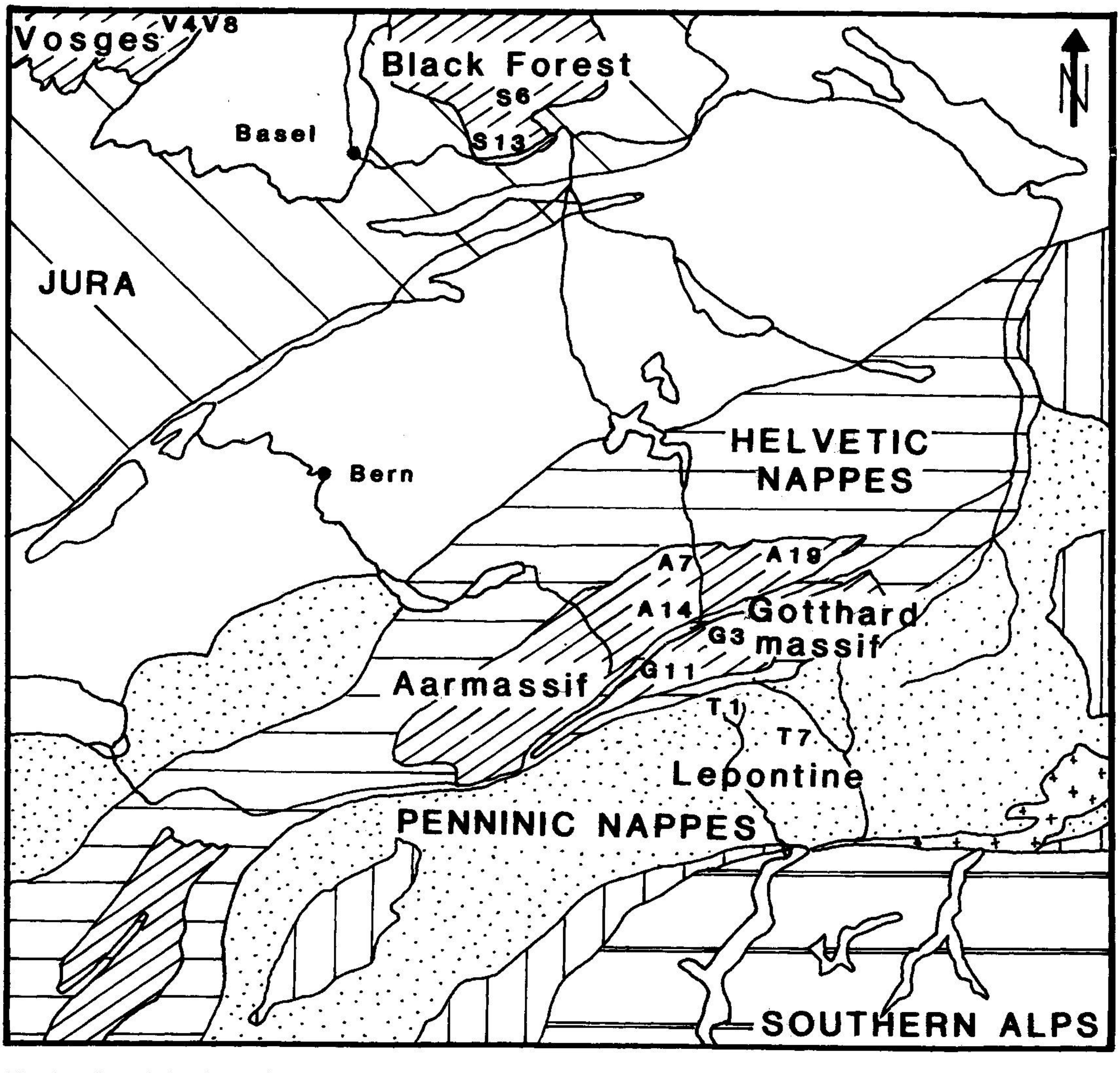

Fig. 1 Map of the Central Swiss Alps and southern Southern Black Forest with major tectonic units and sample locations.

Tab. 1 Major and trace element XRF analyses of meta-lamprophyres from the Central Alps.

sample	V 4	V 8	S 6	S 13	A 7	A 14	A 19	G 3	G 11	T 1	T 7	MIN
SiO_2	55.98	48.64	58.05	62.25	46.57	51.72	53.60	53.71	60.46	50.08	65.04	52.35
TiO_2	1.15	1.65	1.48	1.44	1.48	1.39	1.50	1.19	1.06	0.96	0.53	1.18
Al_2O_3	16.99	13.89	13.75	15.10	14.66	15.47	12.6	15.63	15.98	14.29	16.47	14.68
Fe_2O_3	2.23	5.13	2.89	3.61	2.84	2.81	1.50	2.76	2.89	2.87	1.22	2.77
FeO	4.16	2.67	3.75	2.32	3.84	4.83	4.80	7.88	2.80	5.28	2.38	4.47
MnO	0.10	0.16	0.07	0.06	0.12	0.25	0.08	0.16	0.11	0.17	0.08	0.15
MgO	3.98	6.29	6.72	4.07	7.98	8.03	8.40	5.7	1.67	9.85	1.44	7.05
CaO	3.84	7.16	1.55	1.58	8.37	4.57	5.60	2.38	4.99	6.85	3.84	5.00
Na_2O	3.08	2.63	1.22	2.44	1.66	2.16	2.00	1.86	3.66	0.50	3.11	1.84
K_2O	3.92	4.06	5.97	4.67	5.05	5.47	7.50	5.48	3.69	5.15	4.28	4.88
P_2O_5	0.33	0.80	0.91	0.60	1.11	0.56	0.92	0.29	0.38	0.28	0.18	0.70
H_2O^+	2.18	3.04	2.82	1.87	2.79	1.45	1.60	2.03	1.07	2.04	0.79	2.43
CO_2	0.08	4.54	0.11	0.05	2.23	0.82	0.30	0.67	0.65	1.52	0.36	1.74
Total	98.02	100.66	99.29	100.06	98.70	99.53	100.40	99.74	99.41	99.84	99.84	99.33
Ba	1287	1572	1927	1171	2222	517	1700	420	897	610	327	1918
Rb	279	148	204	289	185	522	270	278	225	224	266	233
Sr	571	511	481	177	646	454	620	174	303	131	119	478
Pb	29	29	20	15	12	37	19	11	19	14	9	23
Th	6	9	23	19	10	11	41	d.l.	d.l.	d.l.	d.l.	14
U	d.l.	6	7	9	3	10	n.d.	d.l.	d.l.	2	1	6
Nb	7	25	27	24	74	20	n.d.	11	25	12	8	27
La	76	149	131	99	163	43	116	71	42	36	d.l.	110
Ce	148	216	147	100	312	151	220	93	192	168	44	196
Nd	45	78	51	28	123	78	n.d.	49	97	90	d.l.	72
Y	35	37	40	52	33	30	n.d.	31	43	33	24	36
Zr	235	394	569	401	482	219	580	150	428	147	143	333
V	121	232	196	198	152	82	n.d.	182	110	158	44	180
Cr	19	383	496	444	275	359	360	223	30	598	12	406
Ni	16	212	78	114	141	176	185	36	26	176	20	134
Co	12	46	18	40	34	27	38	d.l.	d.l.	39	12	33
Cu	36	19	16	30	51	16	40	10	23	13	14	31
Zn	74	181	113	138	82	219	80	96	114	151	95	156
Ga	19	21	19	20	17	23	n.d.	27	23	19	24	20
Sc	20	23	31	35	21	17	25	35	14	17	6	26

Analysis A 19 from Küpfer 1977
Analysis MIN average minette composition (N=20)
n.d.: not determined
d.l.: below detection limit

Tab. 2 Rare earth elements in meta-lamprophyres (INAA analyses).

sample	V 4	V 8	S 6	S 13	A 7	A 14	A 19	G 3	G 11	T 1	T 7
La	43.36	53.6	31.48	17.2	74.6	30.0	116	13.7	30.25	21.4	11.8
Ce	33.12	185.9	78.24	61.1	218.9	83.1	220	49.4	105.7	78.2	34.0
Nd	63.69	83.2	74.4	31.8	90.8	38.9	n.d	88.2	46.8	46.5	16.1
Sm	14.61	16.98	11.2	7.8	16.9	12.0	n.d	7.9	11.3	9.6	4.9
Eu	2.26	2.9	2.28	1.29	3.2	1.75	4.7	1.29	2.6	1.5	0.80
Tb	0.935	0.91	1.02	0.99	0.93	0.64	n.d	0.61	1.2	0.67	0.38
Yb	3.23	2.2	2.77	5.2	2.4	2.0	2.7	2.63	3.9	2.7	1.4
Lu	.28	.11	.31	.38	.26	.34	.3	.21	.4	.55	.2
La/Yb	14.5	25.5	12.2	4.5	30.0	15.0	42.9	5.3	9.0	8.3	8.4

Analysis A 19 from Küpfer 1977
n.d.: not determined
All concentrations were calculated relative to those in USGS reference material BHVO-1. One sigma errors are 5 - 10 % for La,Ce, Nd, Eu, Tb and Yb and 10 -15 % for Sm.

(T7) of presumed meta-sedimentary origin from the Lepontine area were chosen for comparison.

Results

MINERALOGY OF META-LAMPROPHYRES

Non metamorphosed samples from the Black Forest and from the Vosges massifs often show significant autohydrothermal alteration.

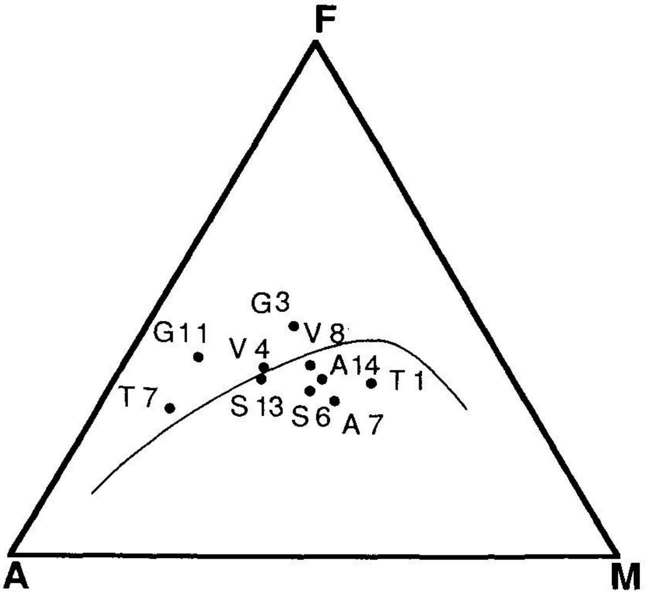

Fig. 2 Al_2O_3–FeO–MgO diagram showing the wide scatter of metamorphic and non-metamorphic lamprophyre samples along a calcalkaline trend.

In the weakly metamorphosed samples of the northern Aarmassif transformations are similar, since the Alpine metamorphic overprint did not change the hydrothermal assemblages. Increasing deformation leads to the overprint of the original textures and to the growth of chlorite and albite. From the southern Aar- to the Gotthardmassif, Alpine metamorphic overprint becomes more obvious. Newly formed biotite and occasionally garnet occur. In the Pennine nappes of the Ticino, lamprophyres have completely recrystallized to biotite-muscovite-actinolite gneisses with K-feldspar.

Accessory minerals such as apatite, picotite, ilmenite, sphene and zircon make up 5 vol.%. Allanite is sometimes present in very minor amounts.

MAJOR AND TRACE ELEMENTS

All samples show elevated SiO_2 contents and a general enrichment in Cr and Ni, typical of lamprophyres in granitic associations, specially in the Black Forest (WIMMENAUER, 1973; MÜLLER, 1982). The average chemical composition (N = 20) of metamorphic minettes from the Alps is in good agreement with data published by MÜLLER (1984) and by MÉTAIS and CHAYES (1963).

In an AFM diagram (Fig. 2) the samples scatter considerably throughout the field of calcalkaline rocks. Two samples fall off the trend: The high grade metamorphic biotite-gneiss from the

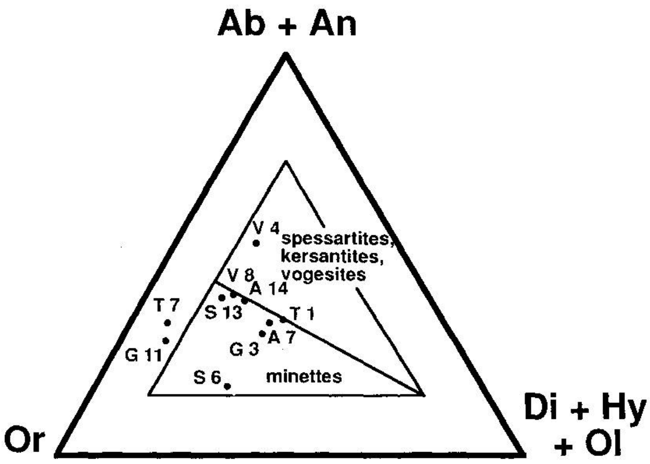

Fig. 3 Lamprophyre discrimination diagram based on the CIPW-norm after WIMMENAUER (1973). The gneiss (T7) and one meta-lamprophyre sample (G11) plot in the field of semi-lamprophyres. All other samples, except the vogesite (V4) lie within the minette field.

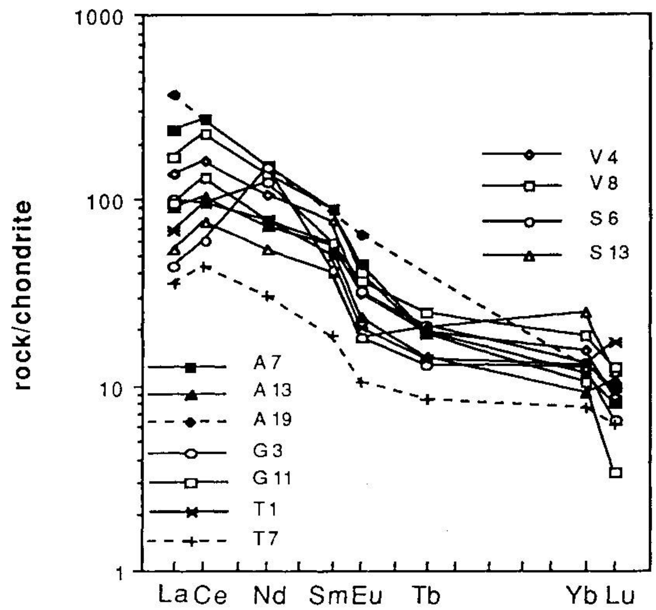

Fig. 4 Chondrite normalized (SUN and NESBITT, 1977) REE distribution of meta-lamprophyres and lamprophyres from the Vosges, Southern Black Forest and the Central Swiss Alps. Sample T7 is a biotite gneiss. Sample A19 from KÜPFER (1977).

Lepontine (T7) and a meta-lamprophyre from the southern Gotthardmassif (G11). Sample G11 shows clear-cut dike relations at the outcrop, with fine grained, possibly chilled margins and macroscopic biotites like in a minette. These two samples (T7, G11) show low Ni and Cr contents, as does the vogesite sample (V4). Zr, Ba and Sr show lower values in samples with higher metamorphic overprint.

WIMMENAUER (1973) proposed a classification diagram to discriminate lamprophyres from basic rocks and semi-lamprophyres using CIPW-norm calculations. In figure 3, the metamorphic gneiss (T7) and the meta-lamprophyre (G11) again plot outside the lamprophyre field. All other samples except one (V4, vogesite) are minettes.

RARE EARTH ELEMENTS

Meta-lamprophyres show an enrichment in light REE (Tab. 2; Fig. 4) by 60 to 300 times chondrite. Their normalized distribution patterns follow a general alkali basaltic trend (CHAUVEL and JAHN, 1984). No distinct Eu anomaly is visible. $(La/Yb)_N$ values are low; they scatter between 4 and 20. The patterns exhibit gently inclined plateaux, steeper for light REE and flat for heavy REE. Strongly metamorphosed samples seem to have slightly lower REE contents, however not enough data are available yet to support this observation. Compared to the meta-lamprophyres, the REE content of the biotite gneiss (T7) is clearly lower. Its REE pattern, however, is very similar to that of the lamprophyres.

The nineteen lamprophyres and semi-lamprophyres from the Southern Black Forest (MÜLLER, 1982) show exactly the same REE distribution, with rather low $(La/Yb)_N$ values and no Eu anomaly (Fig. 5). Again, slightly inclined plateaux on either side of Sm, Eu are manifest. Therefore, the striking similarity in mineralogical and geochemical composition between Southern Black Forest and Aarmassif is further emphasized.

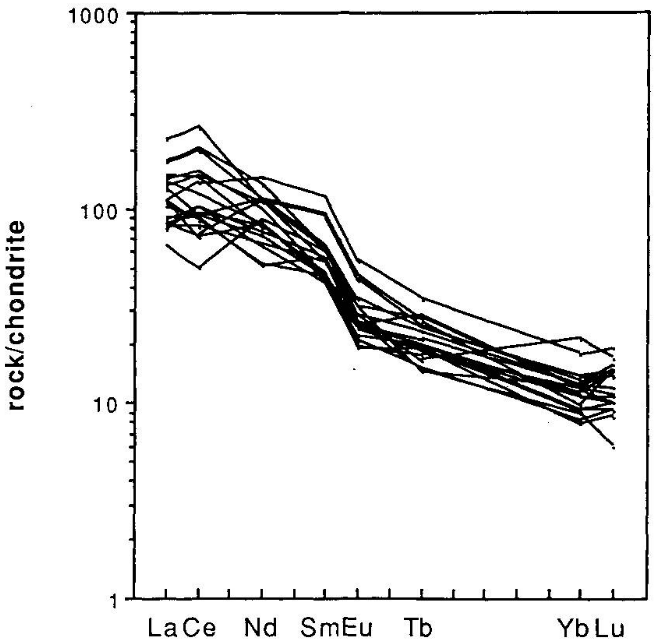

Fig. 5 REE distribution of lamprophyres from the Southern Black Forest (MÜLLER, 1982, 1984).

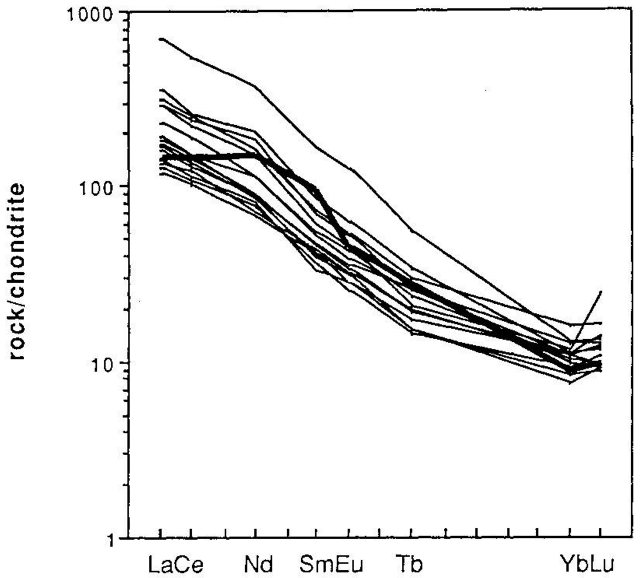

Fig. 6 REE distribution of lamprophyres from Western Europe (TURPIN et al., 1988). The heavy line represents a sample from the Vosges, with a pattern similar to those of this work (Fig. 4) and the Southern Black Forest (Fig. 5).

REE distribution patterns of lamprophyres from Western Europe, reported by TURPIN et al. (1988), differ significantly from those found in the Variscan massifs of Central Europe (Fig. 6). One exception is a lamprophyre from the Northern Vosges, which is comparable with those found in the studies of MÜLLER (1982) and OBERHÄNSLI (1986). Patterns of calcalkaline lamprophyres (CASK) of all continents compiled by ROCK (1984) are comparable to the data from Western Europe but differ from the Central Europe ones. They show steeper REE patterns with an enrichment of La varying from 300 to 1000 and a HREE depletion relative to the lamprophyres from the Alps and the Southern Black Forest. $(La/Yb)_N$ values are higher and range from 70 to 90 (Fig. 7).

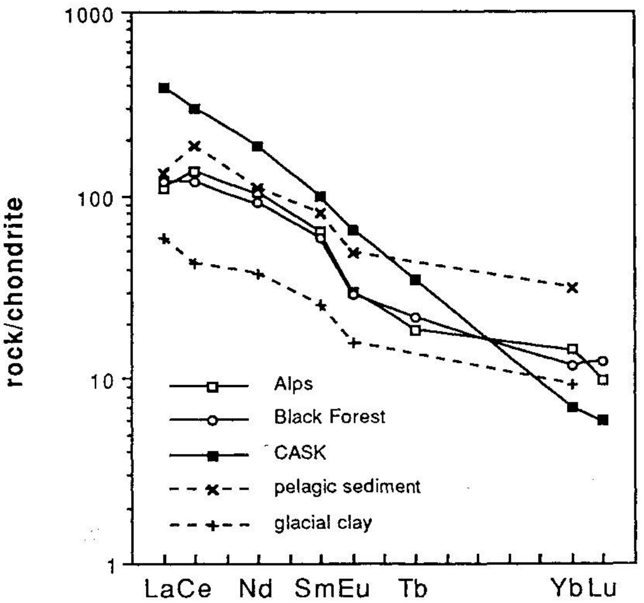

Fig. 7 REE distribution of average values from the Alps and the Southern Black Forest (MÜLLER, 1982, 1984). CASK: average value of calcalkaline lamprophyres compiled by ROCK (1984). Pelagic sediment and glacial clay composition taken from ELDERFIELD et al. (1981). The meta-lamprophyres and lamprophyres are not strictly the result of mixing of CASK with one or more of the sediments.

Discussion

HYPOTHESES ON LAMPROPHYRE MAGMA GENESIS

For the generation of calcalkaline lamprophyres several models have been put forward (c.f.: WIMMENAUER, 1973; ROCK, 1984), such as fractionation from a granitoid magmatic system, mantle origin and contamination of mantle melts by crustal material during ascent. It has been shown, that none of these explain the trace element and isotope characteristics of the meta-lamprophyres from the Alps (STILLE et al., 1989) and from the Southern Black Forest.

The lamprophyres from the Southern Black Forest cannot be derived from known granitoid magmatic systems for the following reasons: REE patterns of the mica-diorites associated with the lamprophyres are identical to the patterns observed for the lamprophyres (MÜLLER, 1982). Granites are depleted in Sm, Eu, Tb and Dy, whereas LREE (La, Ce, Nd) and HREE (Yb, Lu) are identical with respect to the enclosed lamprophyres (MÜLLER, 1984). Late Variscan granites from the Southern Black Forest show a general depletion in REE, especially LREE, with increasing SiO_2 content (EMMERMANN et al., 1975). Similar trends have been interpreted as a result of differentiation and fractional crystallisation of accessories, specifically monazite and allanite (MILLER and MITTLEFEHLDT, 1982).

Recently, a mantle origin and magma mixing processes were proposed for the genesis of calcalkaline lamprophyres from Variscan massifs:

For the calcalkaline meta-lamprophyres of the Central Swiss Alps a mantle origin and magma genesis related to subduction processes has been proposed on the base of bulk rock major and trace element geochemistry (OBERHÄNSLI, 1986).

In a similar model TURPIN et al. (1988), based on trace element an Pb–Sr–Nd isotope data, propose that the lamprophyric magmas formed in a subduction related environment by melting of mantle, enriched by recycling of crustal material.

STILLE et al. (1989) found correlations between ε_{Hf}–ε_{Nd} and trace elements and suggested that the lamprophyric magmas formed by mixing of sedimentary melts, strongly enriched in K, Rb, Zr, Hf, Y and Ba, and a metasomatically enriched mantle. It has been suggested that the sedimentary melts formed by partial melting of subducted oceanic sediments. It was concluded from isotope data that 5 to 15% of sedimentary material had to be assimilated by the enriched mantle melt to produce lamprophyric magmas. However, no correlation has been found between ε_{Hf}–ε_{Nd} and REE and thus it has been suggested that the original REE element abundances in the lamprophyric melts have been changed by fractional crystallization processes. This suggestion is supported by the present study.

The REE abundances and patterns of meta-lamprophyres and lamprophyres from the Central Alps and the Southern Black Forest significantly differ from those calcalkaline lamprophyres compiled by ROCK (1984), but they are very similar to those of sedimentary rocks (Fig. 7). This is in agreement with the above hypothesis and justifies a test. Mixing calculations among ehrwaldites (Cretaceous alkaline dikes in the Northern Calcareous Alps), which are considered to represent enriched mantle melts (TROMMSDORFF et al., 1990), and e.g. an average calcalkaline rhyolite (CAMERON and HANSON, 1982), pelagic sediments or glacial clays (ELDERFIELD et al., 1981), yielded 35, 50 and 45% of admixture of "crustal" material respectively to reproduce the REE patterns found in the investigated meta-lamprophyres. These values differ significantly from the 5–15% sediment admixture inferred from the previous isotope study (STILLE et al., 1989) on meta-lamprophyres from the Alps.

This divergence leads to the presumption that the REE patterns of meta-lamprophyres from the Alps cannot be explained by the magma/sediment mixing ratio calculated by STILLE et al. (1989). Granted that the Stille et al. calculations based on isotope investigations are valid, these rocks may represent the product of a later process. The LREE depletion and slight HREE enrichment, as compared to lamprophyres from other terranes, could be explained by differentiation in the upper mantle or at the base of the crust.

The depletion in Nb, Ti and P of these lamprophyres (OBERHÄNSLI, 1986) fits well with magmas related to subduction zones.

THE EFFECT OF MAJOR CONSTITUENTS

While trying to find a single mechanism for the generation of lamprophyric magmas, the diversity in their feldspar mineralogy, i.e. K-feldspar versus plagioclase, of calcalkaline lamprophyres has been attributed to different source compositions (TURPIN et al., 1988). The general regional separation of minette (K-feldspar) and kersantite (plagioclase) dominance further supports this view and might reflect changing composition of the hybrid mantle above a subduction zone. However, the diversity of mafic components (e.g., biotite and amphibole) within both feldspar groups is largely controlled by their stability fields. The stability of magmatic amphiboles is limited in the upper mantle (HOLLOWAY, 1973; SEMET and ERNST, 1981). Compared to phlogopite, amphibole is confined to lower pressure and temperature. The meta-lamprophyres from the Alps, classified as minettes, almost always show minor amounts of amphibole. Thus the fractionation of amphibole (instead of only phlogopite) in a lamprophyric magma could change the REE pattern of the melt. The REE patterns found for amphibole as well as biotite bearing lamprophyres (minettes and kersantites, Fig. 5; MÜLLER, 1982) and meta-lamprophyres cannot be distinguished, however. Yet a comparison of these patterns and of the mineralogy of the lamprophyres and meta-lamprophyres from the Black Forest and the Alps with data compiled by ROCK (1984) and TURPIN et al. (1988) for similar lamprophyres from elsewhere would indicate an additional stage of differentiation in the evolution of our lamprophyres. Since amphibole cannot be held responsible for these differences, other mineral phases (apatite, zircon, allanite) must be considered to form the observed REE patterns. Alternatively, the tectonic setting might be responsible.

Two possible hypotheses shall be forwarded to explain the observed differences.

THE EFFECT OF ACCESSORY MINERALS

Apatite is a common minor constituent in lamprophyres. Apatite REE patterns from lamprophyres of the Southern Black Forest (MÜLLER, 1982) parallel those of the whole rock (Fig. 8). They are slightly REE enriched compared to apatite from granodiorites (GROMET and SILVER, 1983) but depleted overall compared to apatites from granites. Addition to or removal from a melt would not significantly change the slope $(La/Yb)_N$ of the patterns. Therefore apatite alone cannot account for the observed changes in REE distribution between calcalkaline lamprophyres of different terrains.

Petrographic investigation of our samples show relatively abundant zircon in meta-lamprophyres. This is in line with the high zirconium

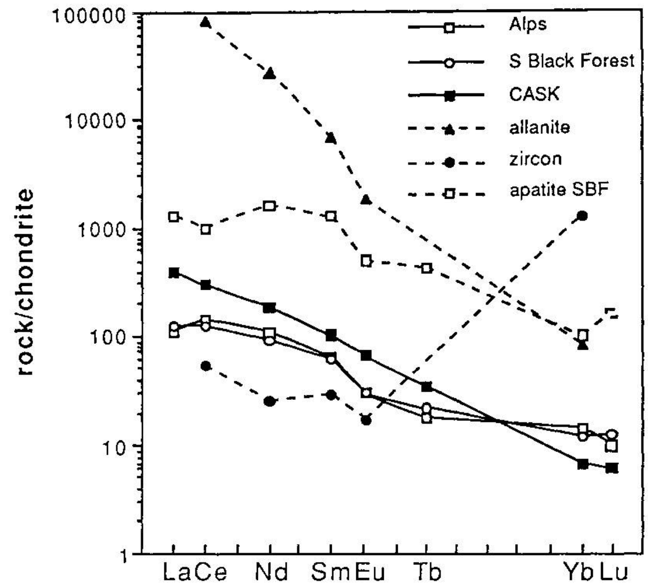

Fig. 8 Average REE values of meta-lamprophyres from the Alps, lamprophyres from the Southern Black Forest and calcalkaline lamprophyres (CASK, ROCK, 1984). Apatites from the Southern Black Forest (SBF) have patterns sub-parallel to the lamprophyre patterns. Removal of allanite from an initial CASK magma and a minor accumulation of zircon within the remaining melt could produce the lamprophyre patterns found in the Alps and the Southern Black Forest.

contents of these rocks compared to primitive basic melts. Zircon has a positive slope in the REE diagram (Fig. 8), depleting LREE in respect to HREE. Crystallization of this mineral in the lamprophyre magma could therefore lower the LREE and increase the HREE part of the lamprophyre pattern.

Another mineral strongly influencing the REE distribution is allanite. This phase shows high LREE concentrations. Removal of allanite from an alkaline melt would change the REE concentrations of a remaining magma and produce LREE depleted and HREE enriched patterns. Despite the fact that the MgO contents (6–8 wt%) in the meta-lamprophyres indicate high temperature liquidi, allanite is present. However, it is rare compared to other accessory minerals (e.g. apatite, zircon). TURPIN et al. (1988) found no allanite in minettes from Western Europe whose LREE contents is higher than in our samples. We conclude from this observation that allanite may not play a major role in the observed REE diversification but combined with the zircon it might contribute to the specific patterns found in the Central Alps and Southern Black Forest.

To our knowledge, no reliable REE partitioning coefficients for allanite from lamprophyres are published. Estimated coefficients given by PETERSEN (1980) may be used to evaluate allanite fractionation. Comparing an allanite-bearing granodiorite (GROMET and SILVER, 1983) to alkaline lamprophyres would necessitate the removal of 0.2–0.4 vol.% of allanite in order to explain the LREE depletion found in calcalkaline lamprophyres. This estimate is a maximum since allanite will not be the only phase being fractionated at a given stage of magma evolution. Such minor allanite fractionation could not account for the HREE enrichment, however; but zircon accumulation (Fig. 8) might explain these patterns. An accumulation of 0.6–0.8 vol.% of zircon is sufficient to produce the slight HREE enrichment. It may be impossible to detect such minute changes in accessory minerals by petrographic methods.

GEOTECTONIC SETTING

The conspicuous differences in REE composition of late magmatic dikes (lamprophyres) between distinct areas lead us to consider the geotectonic evolution and settings of the Variscan orogenies in Western and Central Europe. Variscan collision and orogeny affected the different European areas at different times; the subsequent tectonic history was also significantly different. The geotectonic evolutions of Western and Central Europe can be given as follows:

Western Europe

Following a subduction event (440–400 Ma; PIN and PEUCAT, 1986), the Western European terranes, the Armorican massif and Massif Central, underwent collision events spanning from 400 to 360 Ma with a paroxysm around 380 Ma (PIN and PEUCAT, 1986). Ongoing crustal shortening led to a hyper-collision stage with substantial thickening of the crust, followed by an orogen collapse leading to extension structures at the end of Carboniferous. Major magmatic activities and granite intrusions have been dated as Late Devonian (360 Ma) to Late Visean (330 Ma). Today the Western European terranes show a conspicuous seismically laminated lower crust and a well expressed low velocity zone.

Central Europe

In the Variscides of the Central Alps indications of subduction processes are given by magmatic activity, granite intrusions and volcanism, around 320 to 290 Ma. Upper Carboniferous compressive tectonics affected upper crustal levels (SCHENKER and ABRECHT, 1987; OBERHÄNSLI et al., 1988;

SCHALTEGGER, 1990). ZIEGLER (1986) and MERCOLLI and OBERHÄNSLI (1988) showed that, in the area of the Alps, terranes with successively younger magmatites collided with Pangea (e.g. in the Austroalpine and Southern Alpine realms, 280–265 Ma). This part of the orogen probably never underwent the hyper-collision stage recorded in the other terranes.

In the Southern Black Forest magmatic activity persisted up to 280–270 Ma (EMMERMANN and WOHLENBERG, 1989). Unlike the Western European areas and the Northern Black Forest, the lower crust shows a less typical seismic lamination and a low velocity zone is missing (GEHLEN et al., 1986). Under the Alps these structures have been obliterated by the later Alpine orogeny.

The processes that led to the diversity in seismic structure of the lower crust and the differences in tectonic evolution of the various terranes are the reason for changes in magmatic evolution thus might have lead to the observed differences in the REE patterns.

Conclusions

Compared to other lamprophyres, calcalkaline lamprophyres from the Swiss Alps and the Southern Black Forest differ in their REE pattern: they are slightly LREE depleted and HREE enriched. For their origin, models involving magma mixing in deep mantle-sources have been proposed. Contrary to Sm, Nd and Hf isotopes and some trace elements, the rare earth elements do not fully reflect these magma mixing trends. Instead, the REE data are here interpreted to trace a later stage of differentiation and fractionation in the uppermost mantle, possibly at the base of the continental lithosphere. Minor changes in the mode of allanite (0.2–0.4 vol.%) and zircon (0.6–0.8 vol.%) could account for the observed REE distribution. However, it is difficult to document a petrographic record of this stage of evolution.

The difference in calcalkaline lamprophyres from the Central Alps and southern Southern Black Forest compared to those in Western Europe can be correlated with regional magmatic and tectonic activity. Magmatic activity in the Western European realm had its paroxysm around 380 Ma. During Permo-Carboniferous times these terranes were cratonized and underwent basaltic intraplate volcanism (Armorican massif) or they lacked volcanic activity (Massif Central) (BÉBIEN and GAGNY, 1980). In the Central Alps the Variscan magmatism had its paroxysm around 330 to 280 Ma. Permo-Carboniferous volcanic activity was dominated by rhyolites produced in intramontaneous basins of an active continental margin (MERCOLLI and OBERHÄNSLI, 1988). This volcanism and the calcalkaline granitic magmatism predate the lamprophyre emplacement. The conspicuous differences in REE contents reflect the differences in the age as well as the type of the geotectonic evolution and the related magmatism. Paleozoic magmatism had its paroxysm about 50 Ma earlier in Western Europe compared to the Central Alps. The well documented stage of hyper-collision in Western Europe cannot be put in evidence in the Central Alps. For the latter, field evidence, magmatism and decreasing ages all indicate a tectonic setting in an active margin with accretion of terranes.

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