

**Zeitschrift:** Schweizerische mineralogische und petrographische Mitteilungen =  
Bulletin suisse de minéralogie et pétrographie

**Band:** 66 (1986)

**Heft:** 3

**Artikel:** Geochemistry of meta-lamprophyres from the Central Swiss Alps

**Autor:** Oberhänsli, Roland

**DOI:** <https://doi.org/10.5169/seals-50898>

#### Nutzungsbedingungen

Die ETH-Bibliothek ist die Anbieterin der digitalisierten Zeitschriften auf E-Periodica. Sie besitzt keine Urheberrechte an den Zeitschriften und ist nicht verantwortlich für deren Inhalte. Die Rechte liegen in der Regel bei den Herausgebern beziehungsweise den externen Rechteinhabern. Das Veröffentlichen von Bildern in Print- und Online-Publikationen sowie auf Social Media-Kanälen oder Webseiten ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. [Mehr erfahren](#)

#### Conditions d'utilisation

L'ETH Library est le fournisseur des revues numérisées. Elle ne détient aucun droit d'auteur sur les revues et n'est pas responsable de leur contenu. En règle générale, les droits sont détenus par les éditeurs ou les détenteurs de droits externes. La reproduction d'images dans des publications imprimées ou en ligne ainsi que sur des canaux de médias sociaux ou des sites web n'est autorisée qu'avec l'accord préalable des détenteurs des droits. [En savoir plus](#)

#### Terms of use

The ETH Library is the provider of the digitised journals. It does not own any copyrights to the journals and is not responsible for their content. The rights usually lie with the publishers or the external rights holders. Publishing images in print and online publications, as well as on social media channels or websites, is only permitted with the prior consent of the rights holders. [Find out more](#)

**Download PDF:** 21.07.2025

**ETH-Bibliothek Zürich, E-Periodica, <https://www.e-periodica.ch>**

## **Geochemistry of meta-lamprophyres from the Central Swiss Alps**

by *Roland Oberhänsli*<sup>1</sup>

### **Abstract**

Geochemical investigations show that lamprophyres behave as nearly closed chemical systems under metamorphic conditions; except for volatiles, uranium and trace elements concentrated in feldspars (Sr, Ba). Trace element analyses show an enrichment of mobile elements (Sr, K, Rb, Ba) compared to a primitive basaltic composition. Cr and Ni distribution compared to Mg and Fe distribution indicates that the evolution of lamprophyric magmas starts from evolved basaltic melts. On the one hand REE patterns indicate that lamprophyric and calc-alkalic granitic magmas cannot be cogenetic. On the other hand, the REE patterns do not reflect primitive mantle compositions.

A mantle origin is proposed for the lamprophyres of the Swiss Alps. Due to dehydration of a subducted slab of oceanic crust, the overlying lithospheric mantle wedge was metasomatized. At deeper levels, melting of the subducted oceanic crust occurred combined with partial melting of the upper mantle. Mixing of melts of the metasomatized mantle with partial melts from the down-going plate could have produced lamprophyric magmas. Stagnation of such magmas at different levels below and within the crust yields diverse lamprophyre magmas, e.g. minettes, vosesites, etc. Later tectonic activity, a change from compressional to tensional stress fields (probably due to isostatic uplift of the orogenic calc-alkalic batholiths and thrusting) allowed the emplacement of the lamprophyric dikes.

**Keywords:** Geochemistry, lamprophyres, Central Alps, Switzerland.

### **Introduction**

The origin of lamprophyric dikes is still very controversial. Extensive reviews of the vast literature on the genesis of lamprophyres are presented by WIMMENAUER (1973) and ROCK (1984). Among the many current genetic ideas and models three major opinions emerge:

1. Models involving magmatic processes, such as differentiation, fractional crystallization and/or partial melting:

---

<sup>1</sup> Mineralogisch-petrographisches Institut der Universität, Baltzerstr. 1, CH-3012 Bern.

Lamprophyres represent remobilized mafic residuals of granitic, anatectic or tholeiitic melts without participation of new primitive basaltic magma.

2. Models considering complete or selective contamination, assimilation or hybridization with or without volatile enrichment at different crustal levels:  
Lamprophyres represent reaction products of a basaltic magma with K-rich material in the crust.
3. Models preferring partial melts of unaffected parents from deeper levels as well as metasomatically enriched lithospheric mantle: Lamprophyres are products of more or less primitive partial melts.

BEGER (1923) presented a world-wide compilation of lamprophyres with 382 analyses, of which 52 were from the Central Swiss Alps. At that time Beger referred to the Gotthard region as one of the best known and best investigated areas with respect to lamprophyric dike rocks. This statement was mainly based on the classical studies of WEBER (1904), GRUBENMANN (1919) and SONDER (1921). Beger's assessment stands in remarkable contrast to the extensive recent compilation by ROCK (1984) in which not a single reference to lamprophyres of the Central Swiss Alps is to be found. Whether this shift in emphasis is due solely to the fact that modern research on the rocks has been largely confined to unpublished theses (KÜPFER, 1977; SCHALTEGGER, 1984; STEINER, 1984), or whether the metamorphic overprint has deterred those interested in the petrogenesis of lamprophyres is not clear. However, the extent of alteration and the geochemical consequences of the Alpine metamorphism on these rocks have been poorly documented until very recently. An extensive data collection by OBERHÄNSLI (1985) and the aforementioned theses provide the basis for a reassessment. The aim of this paper is to discuss these geochemical data on metamorphosed lamprophyres, especially from the area of the Central Swiss Alps belonging on the Hercynian orogenic cycle which escaped earlier Hercynian metamorphism. It is suggested here that the limited degree of bulk chemical change during metamorphism of lamprophyres does permit the use of geochemical data in tracing the primary origin of these rocks, even in metamorphic terrains. Such a model is developed for the suite of meta-lamprophyres from the Central Swiss Alps.

#### Material and methods

Mafic dikes and lamprophyres occur throughout the Swiss Alps in the crystalline massifs and their gneissic envelopes as well as in the crystalline Penninic and Austroalpine nappe systems. With few Tertiary exceptions they mark the latest (or last) magmatic event of the Hercynian orogenic cycle. A compilation of lamprophyre occurrences from the Swiss Alps is given in figure 1 and table 1.

Lamprophyres were investigated along a N-S profile from the Schwarzwald to the Ticino. Lamprophyres were sampled in the unmetamorphosed massifs e.g. in the Vogesen (Vosges) and the Schwarzwald (Black Forest) and were examined together with meta-lamprophyres from the increasingly overprinted external (Aarmassif) and internal (Gotthardmassif) massifs and the crystalline Penninic nappes (Ticino) from the Alps. Chemical analyses from lamprophyres of the Punteglias area (samples A 16-26) are taken from the unpublished Ph. D. thesis of T. KÜPFER (1977).

For comparison the distribution of meta-lamprophyres along an E-W traverse from the Mont Blanc to the lower Engadine window was also studied.

Sample locations are given in a tectonic sketch map (Fig. 2) showing Vogesen, Schwarzwald, Aar- and Gotthardmassif, as well as the Penninic realm of the Ticino. Short petrographic descriptions are compiled in table 2.

Mineralogical and metamorphic aspects of the meta-lamprophyres from the Central Swiss Alps shall be discussed elsewhere (OBERHÄNSLI, in prep.).

#### USE OF NOMENCLATURE

In the Vogesen and the Schwarzwald the terms lamprophyre, semilamprophyre and anchibasalt as defined by WIMMENAUER (1973), as well as the terms minette, vogesite, spessartite and kersantite will be used. Where recognition is still possible in the Alps, the terms (minette, vogesite, etc.) are used despite of weak metamorphic overprinting (terms like meta-minette will not be introduced) and these rocks will also be referred to as lamprophyric dikes. With increasing deformation and metamorphic recrystallization, the distinction between the rock-types such as minette and vogesite is no longer possible. For such rocks the term meta-lamprophyres will be used. From a petrographical point of view, these meta-lamprophyres are chlorite-sericite schists or biotite gneisses.

#### ANALYTICAL METHODS

Bulk rock, major and trace elements were determined by X-ray fluorescence as described by DIETRICH et al. (1976) and NISBET et al. (1979).

The XRF analyses were performed with automatic Philips sequential spectrometers (PW 1450) at the Eidgenössische Landwirtschaftliche Versuchsanstalt Liebefeld, Köniz and at the Mineralogical Institute of the University of Fribourg. Trace elements were analysed on pressed powder pills by XRF at the Centre d'Analyse of the Geological Institute of the University of Lausanne.

Rare earth elements (REE) were analysed in collaboration with the Institute of Radiochemistry of the University of Bern, by radiochemical neutron activation analysis at the Federal Institute of Reactor Research, Würenlingen.

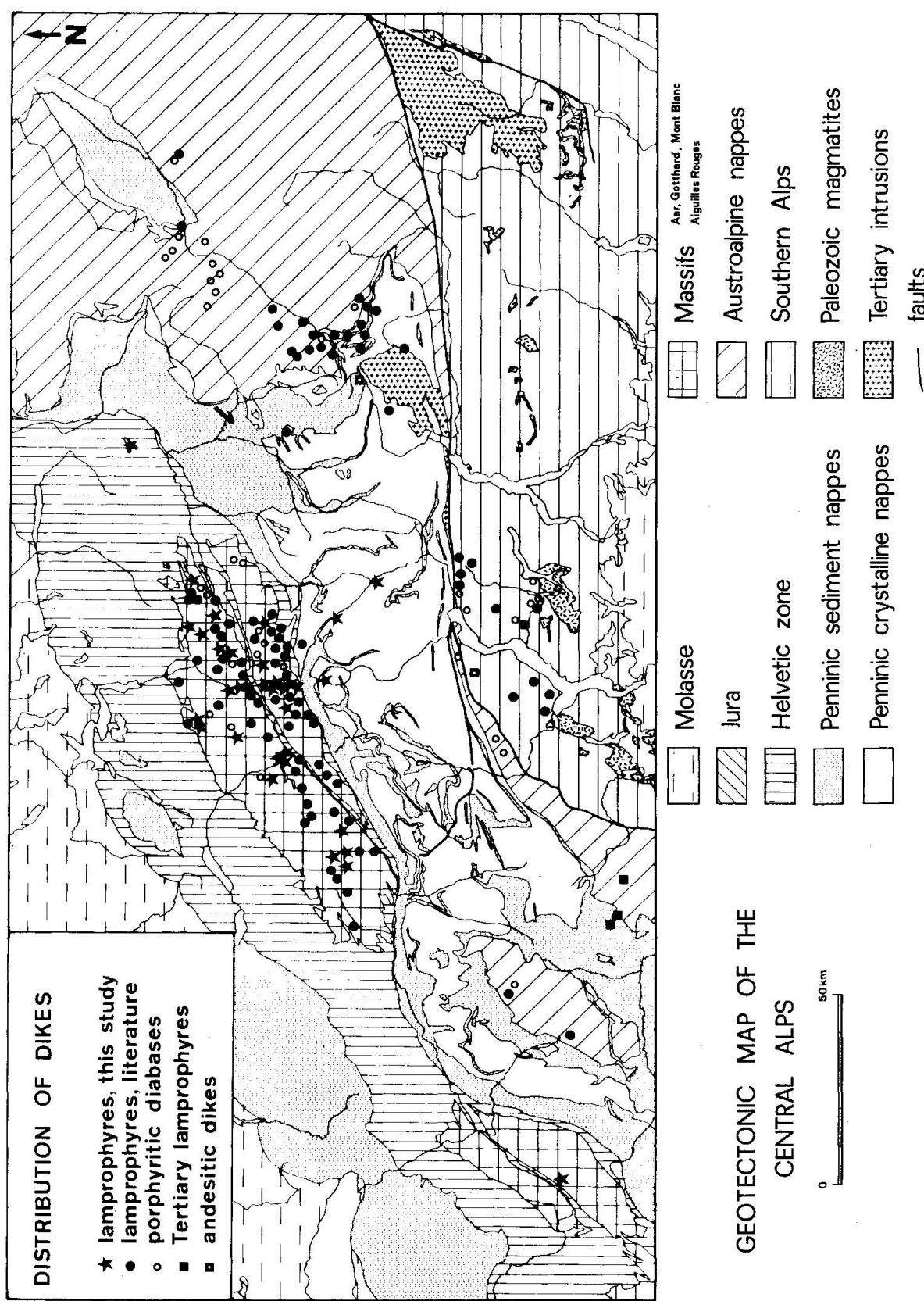


Fig. 1 Distribution of mafic dikes, lamprophyres and porphyritic diabases in the Central Alps. Data from literature and this study.

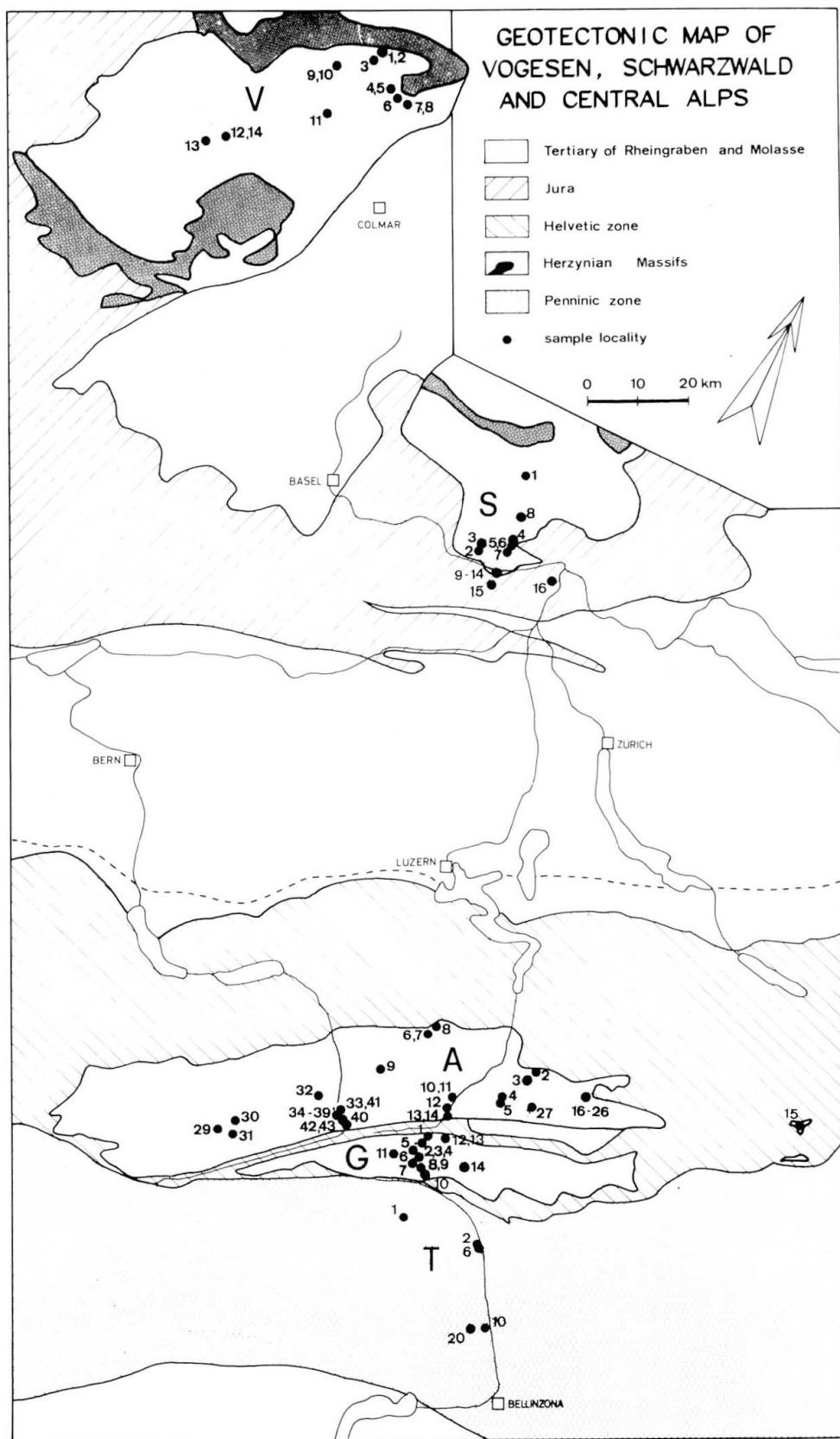


Fig. 2 Sample locality index map covering the Vogesen (V), the Schwarzwald (S), the Aar- (A) and Gotthard-massif (G) and the Ticino (T).

*Tab. 1* Lamprophyre occurrences in the Swiss Alps, compiled from the literature. Detailed references can be obtained from the author by request.

						* chemical analysis BI magmatic mineral bi metamorphic mineral
<b>Schwarzwald</b> *****						
lamprophyre	Laufenburg Kaisen Leuggern	bi-gneiss granite	Niggli P., 1912 Suter H., 1924 * Büchi et al., 1984 * Müller W.H., 1984 Nagra, 1984 *	Laufenburg Nagra drill holes	BI PLG KFSP AP ab ser mu chl cc ep/czo sph mgt	
=====						
<b>Aarmassif</b> *****						
minette (malchite)	Lauchernalp	banded amphibolites, biotite gneisses,	Zgraggen P., 1975	Lötschental	KFSP BI DI -> ACT bi ser ep czo sph	
spessartite	Schafberg Kleines Nesthorn Distelberg Beichpass	northern gneisses of central Aargranite	Ledermann H., 1946 * Hügi et al., 1985		PLG HBL ZO EP CHL ->ACT	
lamprophyre	Oberaletsch Aletschhorn	amphibolites	Niggli et al., 1930 *	Aletschhorn		
lamprophyre kersantite spessartite vogesite	SE Blatten Massaschlucht S Sparrhorn Grisighorn (lake)	augen gneisses central Aargranite, qtz dioritic gneisses	Labhard T., 1965 Steck A., 1966	Massa valley, N Naters Belalp, Grisighorn, N Naters	BI PLG HBL EP ab bi ep sph cc act gr	
kersantite	N Bettmeralp	granitic gneisses	Zbinden P., 1950	Bettmeralp, Goms		
lamprophyre	Märjelensee	central Aargranite	Niggli et al., 1930 *	Aletsch glacier		
kersantite	Grünhörligrat Finsteraarhorn Oberaarhorn Löffelhorn	northern Aargranite central Aargranite	Wyss R., 1932	Finsteraarhorn	BI KFSP AB-OLIG QZ EP ZO AP ZIR SPH ser	
spessartite kersantite	S Steinlauihorn	central Aargranite, gneisses	Abrecht J., 1975	Oberhasli valley	PLG KFSP BI -> hbl ser	
kersantit	Kalter Kehr	southern gneisses	Niggli C., 1965 Velde D. *	Obergoms, SW Cletsch	bi ep ab qz	
lamprophyre	Trübtenbach Grimselsee Nollen (Grimsel) N Todtseeli Nägelisgrätli Belvedere (Furka) Furkahorn S Lochstock (Ross- mettlen) Schälichen	central Aargranite, gneisses S central Aargranite	Fehr W., 1923, 22, 26 Hugi E., 1907 Huber M., 1922 Minder W., 1932 Niggli P., 1924 * Stalder A., 1964 (*) Nagra, 1981	between Grimsel and Andermatt	BI -> mu chl ep sph cc	
	Trübtensee Trübtenjoch	southern Grimseigranite	Fehr W., 1926 Wyss R., 1932		BI KFSP AB-OLIG QZ EP/ZO AP ZIR SPH ser	
	Urnerloch Teufelsboden	gneisses S of Grimsel- granite				
lamprophyre	Dammastock E Flanke	central Aargranite	Liechti H., 1933 *	Göscherernalp valley		
lamprophyre	Sustenpass	Silberbergserie	Schaltegger U., 1984 *	Sustenpass	DI BI SP (OL) KFSP PLG CC AP EP act ser chl mu cc ep ilm	
hornblende- minette	Winterberg W Flanke	central Aargranite	Fischer O., 1905 *	Voralp valley, Göschenen	BI HBL AP MGT mica ep ab sph	
minette	Erstfeldertal	Blocks !!	Sauer A., 1905 Lotze R., 1914	Erstfeld valley	BI PYX KFSP KFSP BI DI -> chl	
lamprophyre	SBB Kraftwerkstollen Amsteg	central Aargranite	Hugi E., 1923	Amsteg		

(1) Rock type

(2) Locality

(3) Country rock

(4) Authors

(5) Area

(6) Mineralogy

Tab. I (continued).

lamprophyre	Maderanertal	central Aargranite	Sigrist F., 1947	Maderaner valley	
kersantite	Klüsertal-Fellital	central Aargranite	Pflugshaupt P., 1927 *	W Bristenstock	BI HBL PLG sph ser ilm
lamprophyre	Stöckligrat	southern Aargranite	Weber F., 1904 *	Vorderrhein valley	HBL BI EP KFSP PLG
spessartite	S Wichenital	Giufsyenite	Niederer J., 1932		MGT act sph ep ab ser
kersantite	Crispalt	southern gneisses	Huber W., 1948		BI PLG HBL QZ ep ser sph
	Giufstöckli				
	Culmatsch				
	Val Mila				
	Piz Ault				
	Piz Gendusas				
	Val Calvaniev				
	Val Placi				
spessartite	Val Glims	granitic gneisses	Eugster H., 1951	Val Russein	PLG BI HBL QZ EP
kersantite	Cuolm Tgietschen		Böhm C., 1986		CHL ser act chl
	Piz Cambrialas		Weber F.		
	W Clavadi				
lamprophyre	Piz Posta Bialla	monzodiorite	Wehrli L., 1896	Val Punteglias	BI PLG KFSP DI QZ
	Crap Grond	Puntegliasgranite	Weber F., 1924		HBL PX ab ser bi
	Val Ufiern		Küpper T., 1974, 77 *		act ep/zo sph
kersantite	Kreuzbach	syenite	Hügi T., 1941	Vättis	BI PLG KF SPH EP CC chl ser mgt
<hr/>					
Gotthardmassif					
*****					
lamprophyre	Kummenhorntobel	Gotthard gneisses,	Oberholzer W., 1955	Obergoms	PLG HBL → bi act chl
	Stock SE Münster	2-mica-gneisses			
	Distelgrat				
	S Pizzo Gallina				
lamprophyre	Val Prosa, Nufenen	Bi-plg-gneisses	Schmidt & Preiswerk, 1908	E Nufenenpass, Bedretto valley	
lamprophyre	W Nufenenpass	Rotondogranite	Sonder R., 1921 *	N Bedretto valley,	bi ab ep/zo qz act sph mu
	Gross Mutthorn	Scoresciagneiss	Fischer E., 1923	W of Gotthard pass	BI PLG mu ep/zo bi sph act ab
	Gerental	Fibbia granitegneiss	Eichenberger R., 1924		BI KFSP MGT DI → HBL sph ser chl bi ab
	Pne di Manio	Prato series	Eichenberger R., 1926 *		
	Alpe di Manegorio	Gamsboden granitegneiss	Hafner S., 1958		
	Rotondohütte		Hafner S., 1975		
	Rottällihorn				
	Ronggergrat				
	Cavannapass				
	Passo Lucendro				
	Pizzo Lucendro				
	Fibbia				
lamprophyre	Winterhorn	aplitic granite	Waindziok P., 1906	Gotthard pass area	BI ab zo mgt mu bi hbl sph
spessartite	Mätteli	Gamsbodengneiss	Krieger L., 1916		BI bi hbl act gr ab mu ep
kersantite	Alpe di Rodont	bi-plg-gneiss	Grubenmann U., 1919 *		
	Monte Prosa		Sonder R., 1921 *		
	Gotthard Hospiz		Ambühl E., 1929		
	Fieud		Koenigsberger J., 1930		
			Hofmänner F., 1964 *		
lamprophyre	Passo Sella	micaceous gneisses	Fritsch K., 1873	Gotthard area,	BI act bi mu sph
kersantite	Unteralptal		Krieger L., 1916	E of the pass	
	Cadlimo		Ambühl E., 1929		
	Plauncacotschna		Zweifel H., 1954		
spessartite	Tgiern Toma	bi-gneisse, amphibolite	Huber H., 1943	Val Medel	BI PLG HBL zo mu
kersantite	Piz Miez	grandiorite			ser act chl cc
lamprophyre	Val Cristallina	Cristallina granite	Holst W., 1913	Lukmanier area	BI PLG KFSP MGT ep ser ab
intermediate dykes	Rossbodenstock	bi-plg-gneisses	Niggli E., 1944 *	Vorderrhein valley	HBL BI PLG QZ ep
	Piz Maler		Niggli E., 1948 *		act ab ser sph chl
	Vel Nalps				HBL PLG BI ab ?bi
	Piz Pazzola		Arnold A., 1970		

- (1) Rock type
- (2) Locality

Tab. 1 (continued).

## Penninic nappes

\*\*\*\*\*

lamprophyre TERTIARY	N Colle Pallasina	metasediments	Dal Piaz G.V., 1979	Combinzone Ayas valley, N Italy	HBL BI KFSP DI AP SPH OL
lamprophyre	Poncione dei Laghetti	granodiorite	Ramsey & Allison, 1979 Steiner H., 1984 *	Maggia nappe Mattorello, S Airolo	bi act kfsp qz cc ep
lamprophyre		bi-pig-gneiss	Krieger L., 1916 Bossard L., 1929	Lukmanier nappe, Lago Ritom, S Airolo	
minette	Alp Tobel	Rofneporphyre	Ruetschi G., 1903 *	Suretta nappe, Ausserferrera,	bi mu par or

## Austroalpine nappes

\*\*\*\*\*

lamprophyre	Mt. Morion	Arollagneiss	Stutz A., 1940 *	Dent Blanche nappe, Valpelline valley	PLG HBL BI ser zo
lamprophyre TERTIARY	Colle Pallasina	gneiss minuti	Dal Piaz G.V., 1979 *	Sesia zone, Ayas valley, N Italy	HBL BI KFSP DI AP SPH OL
lamprophyre	N Piz Crevasalvas N Piz Nalar Piz Calderas Piz d'Err Jenatsch area Piz Giemels S Val Alvra (Crasta Mora) N Piz Lagrev N & S Julier pass St. Moritz SE Piz Julier Piz Albana Piz Palaschin (Tscheppa)	granite diorite	Eugster & Frey, 1927 Cornelius H., 1935 Bühler C., 1983 *	Err nappe	PLG PYX BI AP ILM ab act HBL PYX act ab
lamprophyre	Mortel vogesite spessartite kersantite	granite granite porphyre	Grubenmann U Staub R., 1915 * Münger R., 1982 * Müller D., 1982 *	Bernina nappe	HBL BI ILM act ep ser chi ab ?bi Ilm -> sph mu ab ser act stilp chl
camptonite	Crasta Languard	Languardkristallin	Schuppli H., 1921 Scheidegger B., 1984 *	Languard nappe	?OL CPX HBL BI PLG ser bi Na-amph chl
vogesite	Aip Laret Belezza, Ardez-Fetan	Tasnagranite	Züst O., 1905 Grubenmann U., 1909 *	Tasna nappe	
Hbl vogesite	Griankopf	mica gneisses	Grubenmann U., 1909 *	Ötztaldecke	KFSP HBL AUG BI chl mgt ep cc

## Bergell Intrusion

\*\*\*\*\*

lamprophyre TERTIARY	Val Trubinasca Cima di Vazzeda	granodiorite marbles	Staub R. (Niggli et al., 1930 *) Wenk et al., 1977 *	NW Bergell	BI HBL EP AP SPH ILM
-------------------------	-----------------------------------	-------------------------	--	------------	-------------------------

## Southern Alps

\*\*\*\*\*

lamprophyre	Palianza Mergozzo	schisti dei Laghi bi-pig-gneisses	Boriani et al., 1977	SW Lago Maggiore	
lamprophyre	Quinto Contone Cadenazzo S. Cubiasca S. Indemini Astano SE Sessa	bi-pig-gneisses Ceneri zone	Kelterborn P., 1923 Bearth P., 1932 * Bächlin R., 1937 Spicher A., 1940 Grätzer P., 1951 Reinhard M., 1964 * Wenger C., 1983	Sotto Ceneri	PLG HBL AUG BI CC QZ AP SPH chl

(1) Rock type (2) Locality (3) Country rock (4) Authors (5) Area (6) Mineralogy

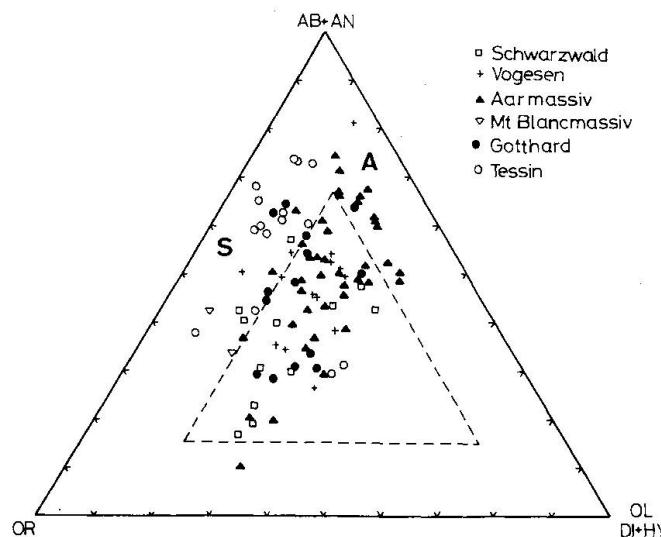
## Geochemistry

### IDENTIFICATION OF META-LAMPROPHYRES

Alpine deformation and metamorphism render recognition of lamprophyric dike rocks difficult. Especially difficult is the distinction of meta-lamprophyres from porphyritic and diabasic dikes. Therefore, geochemical methods have been additionally used to identify strongly overprinted meta-lamprophyres.

The geochemical and mineralogical criteria introduced by WIMMENAUER (1973) and ROCK (1984) were employed to identify and classify lamprophyric rocks. In addition to these two screens, MANSON's (1967) chemical criteria for basalt discrimination were applied. Because Wimmenauer's lamprophyre classification scheme is partly based on Manson's basalt discrimination criteria, there is generally a good correlation between both methods. Rock's modal, mineralogical, chemical and normative screens differ in many respects. For example, most samples from the highly metamorphosed region of the Ticino are not meta-lamprophyres according to the criteria of ROCK (1984), although they would be classified as semilamprophyres according to WIMMENAUER (1973). By contrast, the pyroxene spessartites from Punteglias (samples A 20 to A 26) do not violate Rock's criteria and would be classified as lamprophyres but they are basaltic after Manson's and anchibasaltic after Wimmenauer's classification.

Lamprophyres and meta-lamprophyres plotted in the triangle of normative Or-Pla-Maf (WIMMENAUER, 1973) show great variations (Fig. 3). Many samples fall into the fields of anchibasalts and diabases on the one hand, or into the fields of porphyrites and semilamprophyres on the other hand, instead of into the lamprophyre field.



*Fig. 3* Norm (CIPW) classification for lamprophyres after Wimmenauer (1973). OR: orthoclase, AB: albite, AN: anorthite, OL: olivine, DI: diopside, HY: hypersthene, S: semilamprophyres and porphyrites, A: anchibasalts and diabases.

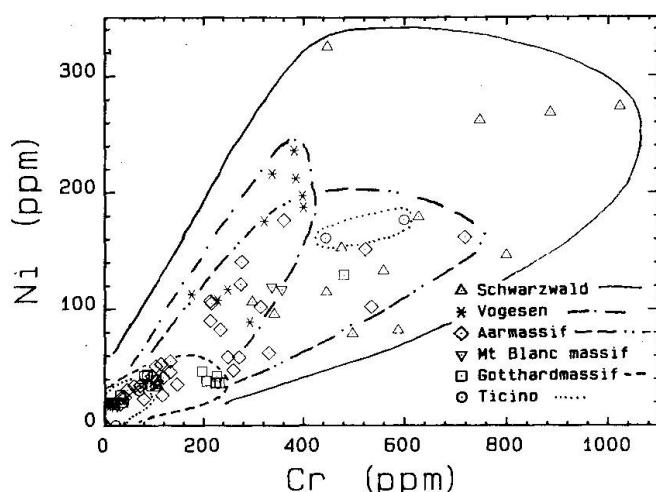


Fig. 4 Cr vs Ni distribution in lamprophyres and meta-lamprophyres. Different areas show varying compositional fields, reflecting the regional diversity of different magmatic suites.

None of the criteria used for different screens are conclusive for the identification of completely recrystallized meta-lamprophyric rocks. WIMMENAUER and HAHN-WEINHEIMER (1966) found that Cr and Ni contents of lamprophyres from the Schwarzwald and Vogesen are very high (Cr 440 ppm, Ni 100 ppm). Therefore, high concentrations of Cr and Ni were taken to identify meta-lamprophyres amongst the mafic dike rocks with high contents in alkalies from the Central Alps. The results are shown in figure 4. The mafic to lamprophyric dike rocks from different areas seem to have their particular Cr and Ni values, indicating a characteristic, slight to strong enrichment. For example samples from Schwarzwald are clearly higher in Cr than those from the Vogesen. The Aarmassif samples are intermediate and show two distinct populations: one with low Cr (< 3–180 ppm) and Ni (< 3–60 ppm) values representing anchibasaltic and semilamprophyric dikes (recognizable in part by their relic magmatic mineralogy) and another population enriched in Cr (200–700 ppm) and Ni (40–180 ppm), representing meta-lamprophyres. In the Gotthardmassif, dike rock samples have generally significantly lower Cr values compared to Vogesen, Schwarzwald and Aarmassif. Again, two populations representing lamprophyres (Cr ca. 200 ppm) and semilamprophyres (Cr ca. 40 ppm) can be observed. From this diagram one might conclude that every region (Vogesen, Schwarzwald, Aarmassif and Gotthardmassif) has its own characteristic pattern of Cr and Ni. These patterns might reflect the influence of igneous fractionation processes. However, in Alpine lamprophyric dikes and meta-lamprophyres it is not possible to assume Cr and Ni fingerprints for single intrusive complexes within one region, as has tentatively been done for restricted areas in the Schwarzwald (MÜLLER, 1982). In general, the high Cr concentrations (> 200 ppm) found in alkalic mafic dikes in the Alps are a strong indication for

the lamprophyric nature of dike rocks containing relics of magmatic biotite or hornblende.

Porphyritic, semilamprophyric or anchibasaltic dikes tend to show significantly lower Cr concentrations. This is also confirmed by data from the Austroalpine Bernina nappe (EIKENBERGER, 1984).

However, recognition and identification of the original character of meta-lamprophyres, e.g. minette, vogesite, kersantite and spessartite, on the basis of bulk rock analyses is rather difficult. Mean values of major elements for different minettes and kersantites were compiled by MÜLLER (1982). The most obvious difference between the two rock types is their  $\text{Na}_2\text{O}$  to  $\text{K}_2\text{O}$  ratio which is below 0.5 for minettes and above 0.5 for kersantites. In the metamorphic terraines of the Central Alps however, distinction between minettes, vogesites, kersantites, spessartites using this ratio is not reliable.

#### BULK CHEMICAL CONSEQUENCES OF METAMORPHISM

The discussion on recognition of meta-lamprophyres by geochemical methods showed that Cr is one of the elements almost unaffected by metamorphism.

As to uranium, recent investigations on lamprophyres from the Southern Schwarzwaldmassif report relatively high contents (BÜCHI et al., 1984). The U enrichment in lamprophyres from the Southern Schwarzwald with concentrations of 14–19 ppm U (BÜCHI et al., 1984), is confirmed in drill holes from northeastern Switzerland (Tab. 2). The U concentrations in other samples from the Schwarzwald as well as from the Vogesen, however, are lower and contain 5 to 10 ppm U. In the course of U-prospecting by routine scintillometer methods in the Alps, meta-lamprophyres have been found to have low U contents (HÜGI and LABHART, pers. comm.). In meta-lamprophyres from the Alps, U concentrations are below 5 ppm, with very few exceptions from the Aarmassif, whereas the Mont Blanc samples show a higher U content ( $> 13$  ppm). The distribution of U and its variation seems to be a very local phenomenon which can be attributed in part to metamorphic depletion.

Trace elements included in alkalifeldspars represent another class of mobile elements susceptible to metamorphic and/or metasomatic effects. The Ba-concentration, although variable in primary lamprophyres, is indeed higher in nonmetamorphic samples. Lamprophyres from the Vogesen and Schwarzwald, Mont Blanc and the Northern Aarmassif contain more than 1000 ppm of Ba, whereas the Ba concentration in meta-lamprophyres from the Southern Aarmassif, Gotthardmassif and the Ticino is below 1000 ppm (Tab. 2).

Similarly, the distribution of Sr shows a depletion of Sr due to metamorphism. Nonmetamorphic samples from Vogesen, Schwarzwald and the northern Aarmassif have Sr contents above 400 ppm (up to 660 ppm) whereas

samples from the Gotthardmassif and the Ticino show mean values of Sr of 200 ppm and 150 ppm respectively. Rb seems not to be redistributed, showing comparable concentrations (ca. 200–240 ppm) over the investigated areas. U, Sr and Ba are the only elements that show the effect of metamorphic overprinting; all others vary randomly (Tab. 2). STEINER (1984) discusses the geochemical small scale behavior near the margins of lamprophyric dikes under metamorphic conditions.

Keeping in mind that lamprophyres show considerable syn- to post-magmatic autohydrothermal alteration which results in great chemical variations, the overprint of regional metamorphism is not chemically discernable in meta-lamprophyres from the Central Alps. The regional metamorphism of lamprophyres may thus tentatively be considered a largely isochemical process.

#### MAJOR AND TRACE ELEMENTS

For reasons outlined above a specific discussion of each meta-lamprophyre type is not possible. Chemically semilamprophyres and anchibasaltic rocks do differ significantly from lamprophyres. Semilamprophyres are higher in  $\text{SiO}_2$  (Fig. 5), lower in  $\text{FeO}$ ,  $\text{MgO}$ ,  $\text{TiO}_2$ ,  $\text{MnO}$  and  $\text{CaO}$  (Tab. 2) compared to meta-

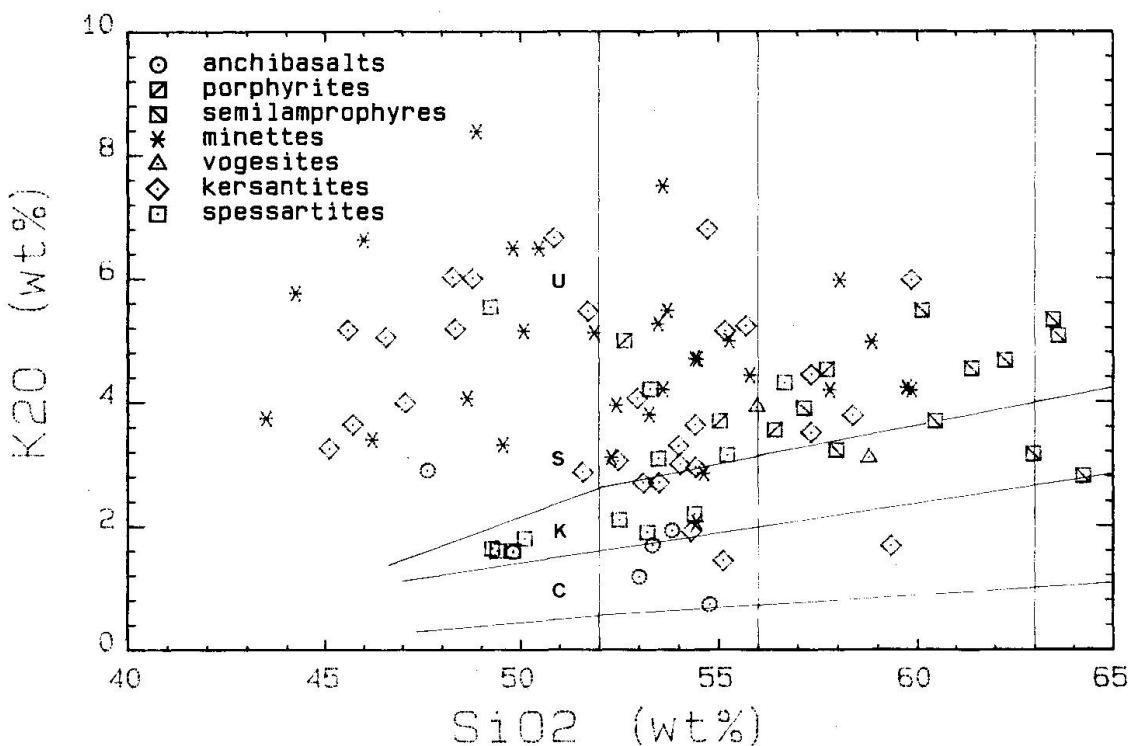


Fig. 5 Potassium silica diagram showing the separation of the semilamprophyres from lamprophyres and metlamprophyres. C: calc-alkalic, K: high-K calc-alkalic, S: shoshonitic, U: ultrapotassic.

lamprophyres. The main compatible trace elements Cr, Ni and Co, as well as most of the incompatible trace elements Zr, Sr and Ba, are also lower than in meta-lamprophyres. Whereas potassium values are comparable, sodium is enriched compared to the meta-lamprophyres. The anchibasaltic rock group is higher in CaO and Na<sub>2</sub>O and significantly lower in K<sub>2</sub>O concentration compared to the meta-lamprophyres. The porphyrite group does not plot as a separate rock type in the chemical discrimination diagrams. Distinction between meta-lamprophyres and porphyrite is made only on the basis of mineralogical aspects i.e. microscopically and/or macroscopically visible matrix feldspar. The meta-lamprophyres range from calc-alkaline to shoshonitic and ultrapotassic compositions. Similar to dike rocks from the northwestern Alps in Italy (VENTURELLI et al., 1984), these ultrapotassic rocks are lower in Al and higher in P, Zr, Rb, K, Th and U than the calc-alkaline and shoshonitic rocks.

Fig. 6 shows a high Ni/MgO ratio and indicates a distribution corresponding to a trend line of fractional crystallization of olivine from a primitive picritic

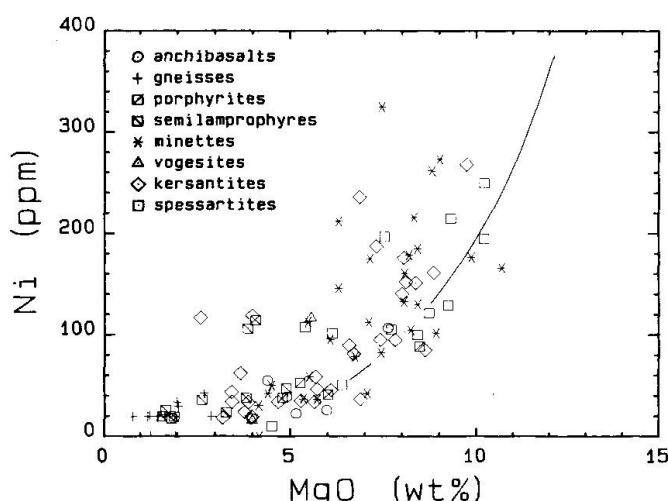


Fig. 6. Ni vs MgO diagram showing a line of olivine fractionation after HART and DAVIS (1978) starting from a primitive melt with 12% MgO. Ni/Mg ratios (Ni ppm/MgO %) vary between 5 and 35, they are generally higher in ultrapotassic rocks.

tic basalt with approximately 12 wt.% MgO (HART and DAVIS, 1978). These authors showed that it is possible to produce such picritic basalt melts by some 5% partial melting of a model mantle peridotite composed of some 79% ol, 20% opx and 10% cpx. The high Cr, Ni, MgO values of the meta-lamprophyres investigated here and their high mg-number also point to an origin by partial melting of a primitive mantle.

The Th/Nb values are generally high ( $> 0.5$ ) and are thus comparable to values of lavas from active margins (Th/Nb  $> 0.2$ ; BAILEY, 1981). The enrichment of LREE (Fig. 8) and Zr are comparable to within-plate patterns.

Normalization of calc-alkalic, shoshonitic as well as ultrapotassic meta-lamprophyres against a N-type MORB (WOOD et al., 1979; sample 409-2) show bossed patterns (Fig. 7) similar to those of calc-alkalic volcanic arc basalts, showing enrichment of Sr, K, Rb and Ba. The enrichment of Ce is typical for

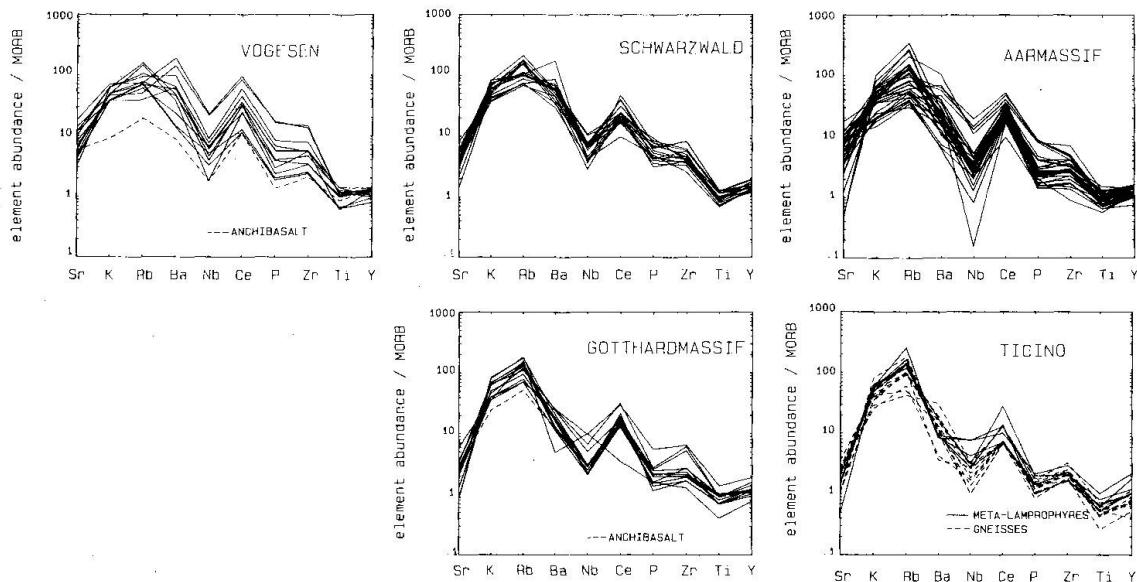


Fig. 7 Spider diagram for MORB normalized trace elements (MORB after WOOD et al., 1979). The patterns display an enrichment of mobile elements due to partial melt of primitive material as well as Nb, P, Ti anomalies indicating subduction processes. For explanation see text.

high-K calc-alkalic rocks (PEARCE, 1983). The weaker enrichment of Nb, P and Ti suggests an influence of subduction processes (PEARCE, op. cit.). In figure 7 patterns of lamprophyres and meta-lamprophyres are very similar and again no effect of metamorphism can be detected.

#### RARE EARTH ELEMENTS

Rare earth element (REE) contents are given in table 3. Chondrite-normalized REE distribution (SUN and NESBITT 1977, 1978) of lamprophyres and meta-lamprophyres show a pattern (Fig. 8) where light REE are enriched by factors of 60 to 300. No Eu anomaly can be detected. Heavy REE and to some extent also light REE produce gently inclined plateaus. The patterns follow a general alkali-basaltic trend (CHAUVEL and JAHN, 1984).  $(La/Yb)_N$  values are low and vary from 4 to 20.

For comparison, REE patterns of lamprophyres compiled by ROCK (1984) are plotted together with data from the Schwarzwald (MÜLLER, 1982, 1984) and the Alps (Fig. 9). These lamprophyres show steeper patterns with LEE enrichment varying from 300 to 1000 for La and HREE depletion compared to the lamprophyres from the Schwarzwald and the Alps.  $(La/Yb)_N$  values are higher and vary between 70 and 90. The higher HREE in lamprophyres from the Schwarzwald and meta-lamprophyres from the Alps may correlate with the very elevated amphibole content. Amphibole is the only mineral with high HREE concentrations occurring in these rocks. Garnet, another mineral with HREE enrichment is not a primary phase in lamprophyre.

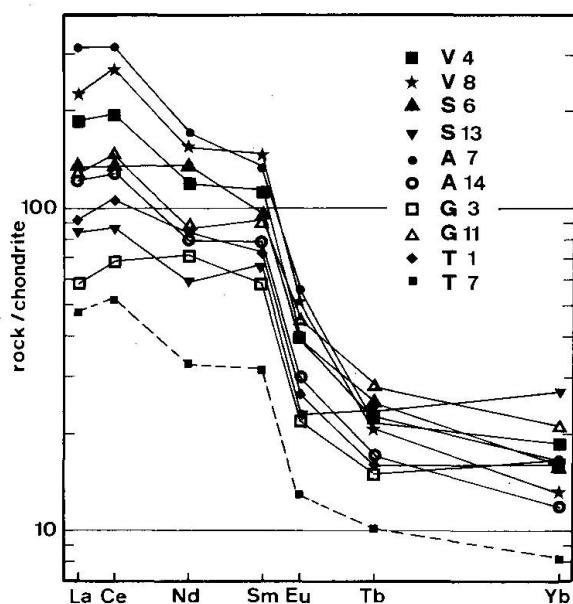


Fig. 8 Chondrite normalized REE distribution pattern showing an enrichment of LREE of 60 to 300 times. Two "plateaus" are visible for LREE and HREE. The HREE plateau possibly is a reflection of the very high amphibole content of Alpine lamprophyres and meta-lamprophyres.

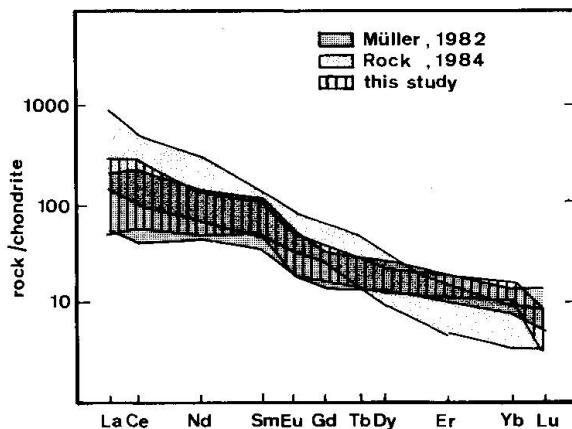


Fig. 9 Chondrite normalized REE distribution pattern of the Alps compared with data from the Schwarzwald (MÜLLER, 1982) and data given in a compilation by ROCK (1984). The Schwarzwald as well as the Alpine samples are less enriched in LREE and show higher HREE contents than lamprophyres from other localities.

### Magmatic evolution

Since REE data of lamprophyres from the Schwarzwald and the Central Swiss Alps differ considerably from published data of lamprophyres elsewhere (Fig. 9), some ideas on the genesis of these calc-alkalic lamprophyres from the Hercynian orogenic cycle are presented here.

Trace element distributions (Fig. 7) show that a considerable mantle component as well as variable portions of a second component, probably subduction-related, might be involved in the generation of lamprophyric magmas. The MgO content indicates a small amount of partial melt released from a peridotite (AHERN and TURCOTTE, 1979; THOMPSON et al., 1984) and the enrichment in Cr and Ni can be assigned to the portion of partial peridotite melt. The general trace element enrichment fits well with data reported from alkalic xenoliths with Cr-spinell and high Ni content in olivine. As pointed out by VENTURELLI et al. (1984), however partial melting of primordial mantle cannot account for all of the trace element ratios. Admixture of other source-material is required.

Petrological investigations of the meta-lamprophyres from the Central Swiss Alps allowed to deduce pressures of 20 to 30 kb and temperatures between 950 and 1150 °C from the magmatic relics (OBERHÄNSLI, 1985 and in prep.). These physical conditions represent a situation in the upper mantle at 60 to 100 km depth.

The model presented below is based on the following petrogenetic considerations:

- Below the site of production of calc-alkalic magmas partial melting of portions of the upper lithospheric mantle wedge due to a possible partial melt of deeply subducted ( $> 100$  km) oceanic crust seems possible (WYLLIE and SEKINE, 1982; SEKINE and WYLLIE, 1982; PEARCE, 1983).
- The composition of a melt produced from the subducted crust might be similar to that of a rhyodacite (NICHOLLS and RINGWOOD, 1973).
- Mixing of such a siliceous melt with the newly produced partial melts of an overlaying mantle peridotite can lead to local concentrations of potassium and separations of the resulting magma (SEKINE and WYLLIE, 1982).
- Portions of these alkalic melts could remain at the bottom of the continental lithosphere until they are activated by tectonic or thermal events (WYLLIE and SEKINE, 1982).

The geochemical data discussed here and further geological data presented elsewhere (OBERHÄNSLI, 1985 and in prep.) are consistent with the following genetic model of Hercynian lamprophyric magmas beneath the Central Alps.

Lamprophyres, according to this model, formed by complex processes of melting of oceanic crust at great depth ( $> 100$  km) and in different proportions, producing acid, rhyodacitic melts of variable compositions. These diverse products provoke partial melting in the overlying upper mantle. Variable percentages of melting of this earlier metasomatized mantle (metasomatized above the down going slab by fluids due the dehydration of the slab) produce partial mantle melts of varying compositions. Mixing of the two melts and the possibility that potassium enriched calc-alkalic melts could stagnate at the bottom of the continental lithosphere provides a clue to the diversity of lamprophyres e.g. minettes, vogesites, spessartites and kersantites.

The production and/or resorption of biotite and/or hornblende in lamprophyric magmas is controlled by fluid content, fluid and total pressure as well as temperature.

*Tectonic activity* rather than changes in the thermal pattern are thought to have led to the emplacement of lamprophyric dikes. Continued thrusting, isostatic uplift and/or volume reduction by cooling (shrinking) of the earlier intruded calc-alkalic batholiths had the potential to produce deep fault systems through which the lamprophyric magmas intruded. Thrustlike faults and compressional stresses at shallow crustal levels, due to concave upward flexures formed in response to denudation and isostatic uplift, while at the same time deeper crustal levels, according to SPENCER (1985), lay in a large scale extensional stress field.

**Tab. 2** Bulk rock analyses of lamprophyres, meta-lamprophyres, semilamprophyres, porphyrites, anchibasalts and gneisses from Vogesen (V), Schwarzwald (S), Aar-A., Mont Blanc-(M) and Gotthardmassifs (G) and Ticino (T) and petrographic sample descriptions.

Sample Nr.	V 1	V 2	V 3	V 4	V 5	V 6	V 7	V 8	V 9	V 10	V 11	V 12	V 13	V 14
Weight %														
SiO <sub>2</sub>	45.31	44.48	52.31	55.98	58.78	53.74	47.06	48.64	53.49	52.63	52.63	45.59	57.80	57.80
TiO <sub>2</sub>	1.29	1.27	1.40	1.15	0.78	0.98	1.64	1.65	1.22	0.78	1.47	1.36	0.71	1.15
Al <sub>2</sub> O <sub>3</sub>	12.61	12.02	14.16	16.99	15.26	18.76	13.71	13.89	14.52	15.16	15.35	13.63	14.48	17.54
Fe <sub>2</sub> O <sub>3</sub>	2.79	2.60	2.77	2.23	1.51	4.60	3.42	5.13	3.54	1.75	2.19	4.28	2.20	2.12
FeO <sub>3</sub>	3.63	3.85	3.77	4.16	3.75	4.06	3.54	2.67	3.36	3.67	5.19	2.67	1.82	3.58
MnO	0.17	0.21	0.16	0.10	0.12	0.19	0.17	0.16	0.11	0.12	0.09	0.33	0.06	0.08
MgO	7.30	8.50	5.46	3.98	5.54	3.89	6.84	6.29	7.52	5.64	8.45	7.30	2.64	4.17
CaO	7.94	8.44	6.16	3.84	4.92	5.69	6.74	7.16	6.13	5.25	2.04	6.83	2.84	1.94
Na <sub>2</sub> O	1.70	2.08	3.82	3.08	3.16	5.03	2.65	2.63	2.86	3.23	1.51	2.18	3.22	3.52
K <sub>2</sub> O	5.90	3.82	3.11	3.92	3.10	0.71	3.99	4.06	3.09	3.31	4.99	5.17	5.07	4.19
P <sub>2</sub> O <sub>5</sub>	2.32	2.42	0.94	0.33	0.28	0.19	0.78	0.80	0.54	0.26	0.56	1.16	0.41	0.33
H <sub>3</sub> O <sup>+</sup>	1.35	2.10	2.29	2.18	2.39	1.90	2.78	3.04	2.50	2.55	3.51	1.75	0.88	3.14
C <sub>6</sub> H <sub>6</sub>	7.43	7.93	3.10	0.08	0.16	0.14	4.35	4.54	0.26	0.13	1.09	7.66	0.08	0.04
Total	99.57	99.72	99.16	98.02	99.75	99.88	98.57	100.66	99.14	99.83	99.07	99.91	98.02	99.60
Total	11770	9518	4884	4884	3035	3036	1463	1463	4574	4291	3099	1857	3744	4686

Tab. 2 (continued).

Sample Nr.	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S 10	S 11	S 12	S 13	S 14	S 15	S 16
Weight #																
SiO <sub>2</sub>	45.99	53.25	54.43	52.47	59.85	58.05	54.47	58.85	60.21	53.48	49.80	60.13	62.25	52.42	49.72	
TiO <sub>2</sub>	1.32	0.98	0.84	1.11	1.45	1.48	1.16	1.03	0.97	1.33	1.40	1.04	1.44	1.09	1.03	0.79
Al <sub>2</sub> O <sub>3</sub>	15.74	14.26	13.66	14.50	13.78	13.75	13.97	13.98	15.04	13.64	14.20	16.34	15.10	13.20	14.99	12.61
Fe <sub>2</sub> O <sub>3</sub>	8.72	2.08	2.31	1.39	2.59	2.89	1.67	2.54	1.82	2.67	2.92	3.61	2.37	1.80	2.41	
FeO	2.34	4.35	4.64	5.43	3.49	3.75	4.25	2.91	3.19	3.73	2.82	2.35	2.32	4.35	3.77	4.67
MnO	0.08	0.12	0.12	0.12	0.06	0.07	0.10	0.09	0.11	0.10	0.42	0.08	0.06	0.13	0.10	0.13
MgO	7.45	8.17	9.72	8.09	6.68	6.72	8.79	6.05	3.61	8.04	6.28	3.86	4.07	9.00	4.50	10.68
CaO	3.33	4.29	6.16	5.71	1.58	1.55	3.62	3.07	4.28	3.07	5.76	2.41	1.58	5.23	2.37	5.30
Na <sub>2</sub> O	0.22	2.30	1.96	2.91	1.51	1.22	1.05	2.51	3.17	1.75	1.36	2.70	2.44	1.58	1.79	1.71
K <sub>2</sub> O	6.63	3.80	2.95	3.06	5.98	5.97	4.69	4.97	3.68	5.27	6.49	5.48	4.67	3.95	4.23	3.31
P <sub>2</sub> O <sub>5</sub>	1.07	0.62	0.49	0.55	0.88	0.91	0.73	0.97	0.45	1.08	1.16	0.59	0.60	0.80	1.29	0.67
H <sub>2</sub> O <sub>4</sub>	3.82	2.58	1.67	3.24	2.47	2.82	4.17	2.77	1.35	2.56	2.15	1.63	1.87	2.77	3.05	4.86
C <sub>6</sub> H <sub>2</sub>	1.32	1.58	0.18	0.75	0.11	0.11	2.15	0.15	1.06	1.07	2.91	0.05	0.05	2.18	0.40	2.20
Total	98.03	98.38	99.13	99.33	100.43	99.29	100.82	99.29	99.84	97.81	97.42	99.58	100.06	99.07	99.39	
ppm :																
Ba	5982	2126	1562	1002	2491	1927	2224	2139	1247	1911	1553	1171	1716	1339	3040	
Rb	197	165	128	141	187	204	212	187	136	341	401	295	289	325	1377	
Sr	247	357	391	304	506	481	282	374	690	284	359	443	177	316	447	
Pb	43	18	15	11	23	20	9	32	12	19	27	15	97	13	24	
Th	6	15	7	16	24	23	10	14	11	41	30	19	41	36	27	
U	<1	7	4	8	7	7	11	9	4	9	20	14	9	20	21	
Nb	13	17	14	16	29	27	22	29	11	39	41	25	24	28	16	
La	220	66	19	40	161	131	93	90	69	72	92	100	99	73	51	
Ce	282	125	106	115	189	147	141	102	145	110	144	242	100	239	129	
Nd	68	34	33	47	56	51	42	28	49	39	51	98	28	109	31	
Y	37	36	35	33	40	39	48	32	44	51	39	52	40	41	36	
Zr	311	251	229	264	576	569	283	350	273	406	428	326	401	293	274	
V	223	176	169	144	280	196	173	177	136	219	227	145	198	194	183	
Cr	447	626	883	474	586	496	745	340	105	557	798	296	444	1021	123	
Ni	325	179	268	152	81	78	262	95	34	133	146	106	114	273	50	
Co	39	46	43	31	42	18	47	35	24	46	39	30	40	49	36	
Cu	27	33	35	23	16	47	25	41	25	21	33	30	52	79	13	
Zn	448	83	104	78	125	113	200	84	108	189	121	83	138	236	105	
Ga	25	18	17	16	19	19	18	18	17	18	20	20	19	19	13	
Sc	29	29	28	22	32	31	28	26	19	34	36	24	35	36	33	
Total	8369	4407	4088	2949	5473	4594	4988	4202	3163	4536	5028	3929	3403	5150	3058	5661

Tab. 2 (continued).

Sample Nr.	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 9	A 10	A 11	A 12	A 13	A 14	A 15	A 16	A 17	A 18
SiO <sub>2</sub>	53.28	49.27	57.97	55.12	45.71	46.57	47.63	53.34	56.42	57.72	57.33	54.41	51.72	48.33	53.60	53.50	
TiO <sub>2</sub>	1.09	1.73	0.75	1.46	1.20	1.48	1.16	1.13	0.92	0.91	0.81	1.39	0.99	1.00	1.10		
Al <sub>2</sub> O <sub>3</sub>	15.35	15.97	17.48	17.08	15.29	14.66	14.99	17.02	16.19	16.17	17.36	16.82	15.47	12.48	12.80	14.10	
Fe <sub>2</sub> O <sub>3</sub>	2.97	2.89	2.54	4.64	2.80	2.84	1.00	3.24	3.16	1.79	3.27	4.31	2.81	1.91	1.20	1.30	
MnO	0.12	0.17	0.11	0.15	0.14	0.12	0.16	0.13	0.12	0.13	0.13	0.14	0.25	0.13	0.11	0.18	
Cr <sub>2</sub> O <sub>3</sub>	8.71	6.38	3.28	3.19	6.56	7.98	7.61	5.14	4.78	6.00	3.87	5.27	8.03	8.84	8.40	7.40	
ZnO	3.55	7.67	5.88	7.12	8.20	8.27	8.46	7.46	5.55	3.35	5.86	7.36	4.57	6.59	7.20	8.40	
Al <sub>2</sub> O <sub>2</sub>	2.59	3.64	2.80	3.23	2.31	1.66	2.85	3.11	2.93	3.35	1.19	1.98	2.16	1.46	3.10	2.90	
Fe <sub>2</sub> O <sub>2</sub>	4.21	1.64	3.22	1.44	3.64	5.05	2.90	1.69	3.55	4.52	4.44	3.63	5.47	5.18	4.20	2.70	
Cr <sub>2</sub> O <sub>2</sub>	0.34	0.58	0.20	0.34	1.22	1.11	1.17	0.30	0.38	0.36	0.23	0.19	0.56	1.10	1.40		
Zn <sub>2</sub> O <sub>2</sub>	3.44	2.91	1.95	2.54	3.61	2.79	3.40	2.84	1.55	1.84	1.92	1.67	1.45	2.48	1.00	2.00	
Al <sub>2</sub> O <sub>4</sub>	0.13	0.55	0.17	0.13	0.13	2.23	1.94	0.06	0.03	0.07	0.03	0.05	0.82	3.64	0.10	0.65	
Total	99.87	100.54	98.97	100.22	98.95	98.70	99.57	99.99	98.40	100.30	100.03	99.37	99.53	98.48	99.31	100.13	
ppm :																	
SiO <sub>2</sub>	608	826	2030	2222	1653	437	898	737	1029	807	517	3610	5000	3000			
TiO <sub>2</sub>	93	100	253	71	159	185	83	85	152	238	296	522	394	150	70		
Al <sub>2</sub> O <sub>3</sub>	680	642	470	887	646	1068	743	747	457	491	764	454	983	850	1475		
Fe <sub>2</sub> O <sub>3</sub>	9	<6	11	22	12	9	25	<6	7	22	25	37	42	18	36		
Cr <sub>2</sub> O <sub>3</sub>	<5	<5	<5	10	22	<5	<5	5	<5	<5	11	16	-	-	-		
ZnO	<1	3	<1	4	4	3	5	<1	2	3	3	10	2	-	-		
Al <sub>2</sub> O <sub>4</sub>	9	15	<3	13	55	74	49	8	10	12	12	6	20	42	-		
Cr <sub>2</sub> O <sub>4</sub>	47	66	<15	33	128	163	118	<15	42	19	<15	43	128	-	-		
Zn <sub>2</sub> O <sub>4</sub>	123	103	159	287	312	241	147	108	113	149	131	151	215	-	-		
Al <sub>2</sub> O <sub>5</sub>	68	73	53	84	110	123	97	73	34	71	78	75	-	-	-		
Cr <sub>2</sub> O <sub>5</sub>	29	37	20	36	39	33	32	28	31	33	27	30	41	-	-		
ZnO <sub>2</sub>	204	223	94	185	343	482	315	155	186	188	156	116	219	281	395		
Al <sub>2</sub> O <sub>6</sub>	124	146	110	223	168	152	161	184	107	131	139	142	82	191	-		
Cr <sub>2</sub> O <sub>6</sub>	273	102	32	31	212	275	212	78	104	118	58	145	359	717	470		
ZnO <sub>3</sub>	121	51	24	18	90	141	107	23	38	41	34	35	176	161	130		
Al <sub>2</sub> O <sub>7</sub>	28	39	17	14	25	34	37	17	15	26	26	27	42	21	35		
Cr <sub>2</sub> O <sub>7</sub>	32	36	17	35	58	51	53	25	8	14	17	16	55	42	39		
ZnO <sub>4</sub>	87	107	100	117	95	82	78	105	88	120	66	128	219	108	80		
Al <sub>2</sub> O <sub>8</sub>	17	15	19	20	16	17	15	19	17	20	19	23	17	35	-		
Cr <sub>2</sub> O <sub>8</sub>	22	23	13	26	27	21	20	28	10	12	16	19	17	-	-		
Total	2200	2543	2236	4755	5038	4375	2185	2539	2339	2777	3011	2596	2777	7155	7116	5815	

Tab. 2 (continued).

Sample Nr.	A 18	A 19	A 20	A 21	A 22	A 23	A 24	A 25	A 26	A 27	A 29	A 30	A 31	A 32	A 33	A 34
<b>Weight %</b>																
SiO <sub>2</sub>	54.00	53.60	53.10	52.50	53.20	54.40	49.40	50.10	49.80	53.00	49.80	51.88	58.37	56.67	59.85	55.03
TiO <sub>2</sub>	0.88	1.50	0.92	0.71	0.62	1.40	1.80	0.33	1.80	1.11	1.24	1.00	0.84	1.01	0.86	1.21
Al <sub>2</sub> O <sub>3</sub>	16.50	12.60	16.20	15.30	14.70	17.70	16.50	14.80	16.20	17.34	16.17	15.94	16.21	14.99	17.58	
Fe <sub>2</sub> O <sub>3</sub>	1.70	2.00	1.30	2.10	2.10	1.80	2.60	2.00	5.10	4.75	3.49	1.96	2.53	2.27	1.89	
FeO	5.00	4.80	5.50	6.00	5.10	5.00	7.40	5.90	7.40	2.95	2.40	3.41	3.99	4.95	4.21	5.84
MnO	0.09	0.08	0.14	0.12	0.13	0.13	0.19	0.20	0.22	0.13	0.14	0.14	0.15	0.14	0.15	0.16
MgO	7.80	8.40	8.60	10.20	9.30	4.50	8.40	10.20	7.70	5.96	4.39	8.90	5.67	6.11	5.50	5.25
CaO	5.20	5.60	5.50	5.10	7.80	5.40	5.30	7.90	5.80	8.89	6.72	6.54	3.55	4.33	3.09	6.19
Na <sub>2</sub> O	1.90	2.00	2.60	3.00	2.00	4.40	3.50	2.60	3.80	2.74	5.38	0.79	3.94	1.58	2.75	2.27
K <sub>2</sub> O	3.30	7.50	2.70	2.10	1.90	2.20	1.60	1.80	1.60	1.18	1.58	5.12	3.78	4.31	4.19	3.69
P <sub>2</sub> O <sub>5</sub>	0.24	0.92	0.24	0.22	0.20	0.32	0.50	0.23	0.49	0.22	0.65	0.24	0.32	0.27	0.35	0.30
H <sub>2</sub> O <sub>4</sub>	2.90	1.60	2.80	3.50	3.30	1.80	3.60	2.80	2.70	2.71	2.22	3.24	2.02	3.03	1.73	1.45
Ca <sub>2</sub>	0.11	0.30	0.15	0.30	0.66	0.66	0.10	0.10	0.76	0.10	0.12	3.65	0.41	0.07	0.04	0.06
Total	99.62	100.40	100.45	100.35	101.01	99.45	100.09	100.82	99.61	101.45	99.09	101.10	99.92	101.18	100.40	100.92
<b>ppm :</b>																
Ba	2575	1700	1025	370	240	550	950	360	560	231	240	1348	378	1211	375	568
Rb	190	270	175	165	110	150	100	135	105	65	76	249	264	202	299	214
Sr	780	620	600	320	340	680	710	360	809	312	279	99	205	322	388	
Pb	16	19	15	12	10	38	8	12	22	9	<6	6	6	7	7	18
Th	-	41	-	-	-	-	-	-	-	<5	<5	<5	<5	5	5	
U	-	-	-	-	-	-	-	-	4	1	5	<1	1	4	5	
Nb	-	-	-	-	-	-	-	-	-	8	14	9	12	16	17	13
La	-	-	-	-	-	-	-	-	-	<15	<15	15	27	56	39	39
Ce	-	-	220	-	-	-	-	-	-	58	181	163	145	165	99	162
Nd	-	-	-	-	-	-	-	-	-	28	99	75	74	77	89	
Y	-	-	-	-	-	-	-	-	-	30	37	26	30	34	33	41
Zr	190	580	170	105	110	200	240	110	200	102	212	82	115	137	192	185
V	-	-	-	-	-	-	-	-	-	-	212	82	115	122	181	191
Cr	300	360	350	640	550	85	190	710	180	115	131	533	247	313	270	113
Ni	95	185	85	250	215	10	100	195	105	26	55	102	59	102	59	53
Co	46	38	48	63	52	39	70	64	72	28	29	36	28	27	23	30
Cu	35	40	24	37	31	22	27	62	20	24	36	19	9	49	8	16
Zn	70	80	85	95	95	240	70	140	77	77	87	95	197	104	154	
Ga	-	-	-	-	-	-	-	-	-	20	18	22	20	25	22	
Sc	-	25	-	-	-	-	-	-	-	27	16	23	20	27	22	24
Total	4297	4294	2577	2057	1713	1869	2635	2078	1764	1873	1646	3234	1819	3084	2111	2325

Tab. 2 (continued).

Sample Nr.	A 35	A 36	A 37	A 38	A 39	A 40	A 41	A 42	A 43	A 44	Weight %	Weight %	Sample Nr.	M 1	M 2
SiO <sub>2</sub>	54.03	46.21	54.31	45.11	48.88	54.63	54.45	59.33	63.48	50.85	SiO <sub>2</sub>	48.77	48.26		
TiO <sub>2</sub>	1.29	1.18	1.05	1.43	1.50	1.07	1.23	0.65	0.82	0.74	TiO <sub>2</sub>	1.33	1.18		
Al <sub>2</sub> O <sub>3</sub>	16.84	14.86	17.17	18.66	18.29	17.51	17.20	15.80	14.17	21.57	Al <sub>2</sub> O <sub>3</sub>	18.96	16.98		
Fe <sub>2</sub> O <sub>3</sub>	2.44	2.39	4.15	2.75	2.04	3.58	3.30	3.87	1.65	1.59	Fe <sub>2</sub> O <sub>3</sub>	8.10	7.71		
FeO	5.43	5.38	3.49	7.99	7.12	3.88	4.78	3.26	3.46	3.46	FeO	2.99	5.91		
MnO	0.16	0.16	0.15	0.21	0.26	0.14	0.17	0.46	0.10	0.14	MnO	0.13	0.15		
MgO	3.77	8.22	4.67	8.35	7.42	4.15	4.40	3.67	4.89	6.08	MgO	2.60	3.98		
CaO	6.93	8.64	7.58	7.60	1.67	7.39	5.86	5.14	0.82	2.77	CaO	7.08	5.33		
Na <sub>2</sub> O	3.36	1.89	3.04	2.23	0.29	2.90	3.52	4.40	1.07	2.22	Na <sub>2</sub> O	0.46	0.60		
K <sub>2</sub> O	3.00	3.40	1.92	3.26	8.38	2.85	2.07	1.68	5.33	6.66	K <sub>2</sub> O	6.00	6.02		
P <sub>2</sub> O <sub>5</sub>	0.56	1.19	0.36	0.40	0.44	0.37	0.43	0.28	0.33	0.21	P <sub>2</sub> O <sub>5</sub>	1.26	1.15		
H <sub>2</sub> O <sup>+</sup>	1.48	3.62	2.00	3.03	2.87	1.78	2.41	1.64	2.26	2.89	H <sub>2</sub> O <sup>+</sup>	2.71	2.71		
CO <sub>2</sub>	0.56	2.53	0.04	0.04	0.21	0.00	0.04	0.05	0.03	0.38	CO <sub>2</sub>	0.05	0.06		
Total	99.85	99.67	99.93	101.06	99.37	100.25	99.86	100.23	98.41	99.56	Total	100.44	100.04		
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====		=====	=====	=====	=====
	ppm :												ppm :		
Ba	869	2473	558	1400	948	540	734	227	681	561	Ba	2801	2093		
Rb	117	116	57	136	660	104	108	74	282	490	Rb	237	301		
Sr	601	1483	692	382	39	767	464	299	40	201	Sr	623	475		
Pb	9	9	17	27	12	18	38	17	<6	<6	Pb	44	39		
Th	6	18	<5	<5	<5	<5	<5	<5	<5	<5	Th	47	42		
U	1	5	4	4	<1	4	2	<1	<1	<1	U	19	13		
Nb	11	49	11	20	18	11	20	3	11	5	Nb	69	69		
La	73	116	16	76	118	28	61	<15	54	22	La	101	100		
Ce	124	244	179	216	175	197	207	108	149	116	Ce	211	197		
Nd	50	98	94	117	96	97	101	59	67	59	Nd	65	72		
Y	38	34	37	43	39	39	44	31	29	27	Y	52	59		
Zr	289	334	184	245	229	193	286	61	176	120	Zr	680	611		
V	137	150	181	212	209	188	165	145	135	107	V	153	173		
Cr	39	215	70	521	233	44	95	329	259	131	Cr	355	335		
Ni	24	105	34	151	82	30	42	62	47	46	Ni	117	119		
Co	29	35	24	46	30	26	32	9	24	31	Co	14	<8		
Cu	43	56	23	21	17	23	17	54	8	9	Cu	18	23		
Zn	85	79	110	182	250	110	123	70	70	95	Zn	65	100		
Ga	16	15	21	27	24	21	22	14	24	23	Ga	32	32		
Sc	14	20	15	25	37	15	19	27	24	20	Sc	17	15		
Total	2575	5654	2327	3851	3216	2455	2580	1589	2080	2063	Total	5720	4868		
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====		=====	=====	=====	=====

Tab. 2 (continued).

Tab. 2 (continued).

Sample Nr.	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	T 11	T 12	T 13	T 14	T 15	T 16	T 17
Weight %																	
S10 <sub>2</sub>	50.08	61.40	62.21	61.81	64.55	57.16	65.04	65.37	67.14	55.79	68.21	64.77	70.97	63.83	71.12	54.40	
T10 <sub>2</sub>	0.96	0.60	0.63	0.63	0.53	0.72	0.53	0.50	0.71	0.78	0.84	0.52	0.31	0.65	0.75	1.20	
A1 <sub>2</sub> O <sub>3</sub>	14.29	18.20	18.23	18.00	16.33	19.93	16.47	16.33	15.13	15.47	14.95	15.62	15.17	16.87	17.00	13.27	
FeO <sub>2</sub> 3	2.87	0.56	0.87	0.30	0.96	1.62	1.22	1.31	1.07	0.62	0.87	1.61	0.68	0.98	1.18	4.83	
FeO <sub>3</sub>	5.28	3.63	3.01	3.51	2.43	4.04	2.38	2.18	3.77	7.06	3.88	1.81	1.01	3.14	2.97	0.00	
MnO	0.17	0.10	0.08	0.08	0.07	0.11	0.08	0.08	0.10	0.20	0.18	0.10	0.12	0.10	0.07	0.10	
MgO	9.85	1.57	1.23	1.18	1.48	1.90	1.44	1.65	2.01	8.06	1.98	2.88	0.78	1.94	1.26	7.10	
CaO	6.85	2.88	1.85	1.81	3.28	3.37	3.84	2.55	1.60	4.78	2.13	2.28	1.24	3.94	4.11	1.93	
Na <sub>2</sub> O	0.50	4.44	6.81	6.86	3.67	4.44	3.11	1.71	2.29	0.32	2.90	6.70	5.06	3.09	3.14	3.29	
K <sub>2</sub> O	5.15	4.54	2.77	2.76	4.10	3.90	4.28	6.51	4.17	4.43	2.31	2.03	3.39	3.51	3.17	4.70	
P <sub>2</sub> O <sub>5</sub>	0.28	0.20	0.22	0.21	0.19	0.20	0.18	0.17	0.17	0.24	0.14	0.25	0.19	0.12	0.15	0.30	
H <sub>2</sub> O <sub>4</sub>	2.04	0.73	0.82	0.85	0.80	1.26	0.79	1.09	1.38	1.56	1.25	0.84	0.58	0.88	0.87	0.00	
Cl <sub>2</sub>	1.52	0.19	0.32	0.15	0.48	0.24	0.36	0.16	0.09	0.05	0.09	1.01	0.08	0.05	0.06	0.10	
Total	99.84	99.04	99.05	99.15	98.87	98.89	99.72	99.61	99.70	99.26	99.84	100.36	99.51	99.52	99.49	99.45	
ppm :																	
Ba	610	300	136	411	330	327	376	666	324	1103	155	452	456	554	-	307	
Rb	224	311	199	329	234	257	266	344	185	273	80	115	96	180	174	-	
Sr	131	125	94	91	218	178	119	86	166	128	206	202	187	207	296	-	
Pb	14	13	9	9	13	10	9	9	9	16	9	9	11	<6	-	12	
Th	<5	6	<5	<5	6	<5	6	<5	7	<5	9	<5	<5	<5	<5	-	
U	2	<1	<1	<1	3	1	<1	<1	<1	3	1	1	1	<1	<1	13	
Nb	12	16	11	4	7	29	8	5	11	10	13	7	4	10	11	-	
La	36	30	27	20	17	41	<15	26	42	44	50	<15	21	15	-	57	
Ce	168	43	41	43	80	44	45	78	83	77	41	42	44	43	-	61	
Nd	90	26	25	<10	26	26	<10	27	26	27	46	25	<10	26	-	<10	
Y	33	29	32	11	20	49	24	21	27	28	27	19	14	19	18	-	
Zr	147	160	168	112	146	159	143	147	176	119	228	146	129	114	118	-	
V	158	69	36	63	54	75	44	61	92	171	97	38	21	69	88	-	
Cr	598	16	11	16	11	16	12	<10	12	68	444	89	11	<10	16	-	
Ni	176	20	20	20	20	20	20	20	20	30	161	34	20	20	23	-	
Co	39	12	8	14	12	15	12	19	23	44	22	13	13	21	-	35	
Cu	13	60	19	11	21	50	14	9	33	9	109	15	18	13	23	-	
Zn	151	238	97	130	88	171	95	58	85	135	104	93	28	99	91	-	
Ga	19	28	30	27	23	37	24	20	19	21	24	18	20	22	-	20	
Sc	17	11	9	10	7	14	6	8	13	26	14	8	5	11	14	-	
Total	2638	1513	972	1273	1371	1566	1168	1288	1750	2054	2348	942	1057	1357	1535	0	

Tab. 2 (continued).

Description of samples and localities			
Nr.	Locality	sample description	
V 1	Wackenbach	minette, massive compact dark grey mac: bi qz	S 12 Laufenburg T 646.80/268.20
V 2	Wackenbach	minette, massive compact grey brown mac: bi qz-oicelli kfsp-insets	S 13 Laufenburg T 646.80/268.20
V 3	S Rothau	minette, finegrained massive dark grey with salmon red points mac: qz-oicelli	S 14 Laufenburg T 646.80/268.20
V 4	Sperberbüchle	volcanite, dark massive compact grey mac:	S 15 Kasten D 64h.64/265.62
V 5	Sperberhächle	vogesite with fine margin, very compact massive grey-green mac: pig resorbed px few bl spessartite, compact massive grey mac: plg	S 16 Leuggern D 657.63/271.21
V 6	Eitermatten Lilsbach	kersanitite finegrained, reddish grey mac: qz-oicelli bi resorbed px/ol minette, reddish grey compact mac: bi px	A 2 Madrainer Tal 703.85/183.75
V 7	Andlau	kersanitite massive compact grey green mac: bi px or-oicelli lamprophyre, massive compact, grey green mac: bi px qz-oicelli	A 3 Tscharren 700.45/173.25
V 8	Andlau	kersanitite, feldspar rich medium mac: kfsp bi plg	A 4 Etzlöhütte 794.90/174.85
V 9	Tannenberg bei Saales	lamprophyre, massive compact grey-green mac: bi px	A 5 Kleiner Mutsch 697.80/174.20
V 10	Tannenberg bei Saales	lamprophyre, massive compact, grey green mac: bi px qz-oicelli	A 6 Sustenpass 677.25/175.75
V 11	Hensumont ob Markirch	kersanitite, feldspar rich medium mac: kfsp bi plg lamprophyre, fine-grained dark grey mac: kfsp bi	A 7 Sustenpass T 677.25/176.00
V 12	Col de la Grosse Pierre	lamprophyre, finegrained dark grey mac: kfsp bi	A 8 E Sustenpasshöhe 677.80/177.05
V 13	Petites Alpes	lamprophyre with gneiss insets, massive compact grey brown to reddish mac: bi qz ksp py (appamph?) minette, dark grey homogeneous mac: bi pyx	A 9 Trift 672.18/170.17
V 14	Col de la Grosse Pierre	minette, fine to medium grained mac: bi resorbed px/ol lamprophyre, fine to medium grained mac: bi pig kfsp (porphyrite) mac: bi qz-oicelli	A 10 Gösschenen 688.20/170.65
S 1	Todtnoos	kersantite, compact massive brownish grey mac: bi pig	A 11 Gösschenen 688.20/170.65
S 2	Lochmühle	lamprophyre, fine to medium grained mac: bi pig kfsp (porphyrite)	A 12 Schöllenen 678.75/167.25
S 3	Murgtal	lamprophyre, massive grey mac: bi qz-oicelli	A 13 Urnerloch 688.25/166.60
S 4	Tiefenstein	kersantite, compact massive brownish grey mac: bi pig	A 14 Urnerloch 688.25/166.60
S 5	Albtal	1. tunnel lamprophyre, fine to medium grained grey, compact mac: bi kfsp resorbed cpx/ol	A 15 Vättis, Kreuzbach 752.50/198.10
S 6	Albtal	1. tunnel lamprophyre, black finegrained compact massive matrix, dark red brown spherulitic parts, bi overgrowths, spherulites mac: bi, kfsp cpx/ol pseudomorphs lamprophyre compact, greenish grey mac:	A 16 Punteglas 716.06/162.80
S 7	Albtal	lamprophyre, massive compact reddish grey, many xenoliths of greenstones mac: bi kfsp	A 17 Punteglas 716.03/182.76
S 8	Bantlisboden	Bantlisloch lamprophyre, massive compact dark grey, fluidal textures mac: qz-oicelli	A 18 Punteglas 715.26/160.97
S 9	Laufenburg	lamprophyre, massive compact dark grey, matrix, dark red brown spherulitic parts, bi overgrowths, spherulites mac: bi overgrowths, spherulites	A 19 Punteglas 715.35/182.35
S 10	Laufenburg	lamprophyre, compact massive reddish spherulitic groundmass devitrified, bi overgrowths, spherulites mac: bi, totally resorbed cpx/ol	A 20 Punteglas 715.31/182.51
S 11	Laufenburg	lamprophyre, compact massive reddish mac: bi	A 21 Punteglas 715.06/182.58
			A 22 Punteglas 715.22/182.61

Tab. 2 (continued).

:REE(ppm)	: La	: Ce	: Nd	: Sm	: Eu	: Tb	: Yb	: Lu
: V 4	: 43.36	: 133.12	: 63.69	: 14.61	: 2.26	: .935	: 3.23	: .28
: V 8	: 53.6	: 185.9	: 83.2	: 16.98	: 2.9	: .91	: 2.2	: .11
: S 6	: 31.48	: 78.24	: 74.4	: 11.2	: 2.28	: 1.02	: 2.77	: .31
: S 13	: 17.2	: 61.1	: 31.8	: 7.8	: 1.29	: .99	: 5.2	: .38
: A 7	: 74.6	: 218.9	: 90.8	: 16.9	: 3.2	: .93	: 2.4	: .26
: A 13	: 28.9	: 83.7	: 42.9	: 11.	: 1.7	: .69	: 1.9	: .34
: A 19	: 116.	: 220.	: -	: -	: 4.7	: -	: 2.7	: .3
: G 3	: 13.7	: 49.4	: 88.2	: 7.9	: 1.29	: .61	: 2.63	: .21
: G 11	: 30.25	: 105.7	: 46.8	: 11.3	: 2.6	: 1.2	: 3.9	: .4
: T 1	: 21.4	: 78.2	: 46.5	: 9.6	: 1.5	: .67	: 2.7	: .55
: T 11	: 11.3	: 35.7	: 18.2	: 3.6	: .75	: .41	: 1.6	: .2

Tab. 3 Rare earth element analyses from lamprophyres and meta-lamprophyres from Vogesen, Schwarzwald and Central Swiss Alps.

### Acknowledgements

I am thankful to Prof. E. Niggli who has guided my interest to these complex and, in many aspects, intriguing rocks. It is a pleasure to acknowledge the help of Martin Engi, Ivan Mercolli, Urs Raz and Franz Schenker whose contributions to fruitful discussions, cohabitation during field-work and assistance in work is invaluable to me. Prof. Tj. Peters and J. Meyer provided data on the NAGRA drillholes from northeastern Switzerland. Further, I thank E. Reusser, P. Ulmer and R. Vocke for discussions, H. R. Pfeifer for trace element analyses and U. Krähenbühl for REE analyses. I especially thank Lisa Dietrich and Jill Engi who corrected the English.

### References

- AHERN, J. L. and TURCOTTE, D. L. (1979): Magma migration beneath an ocean ridge. *Earth and Planet. Sci. Lett.* 45, 115–122.
- BAILEY, J. C. (1981): Geochemical criteria for a refined discrimination of orogenic andesites. *Chem. Geol.* 32, 139–154.
- BEGER, P. J. (1923): Der Chemismus der Lamprophyre. In: P. Niggli (ed.), *Gesteins- und Mineralprovinzen* Vol. 1, Einführung, 217–577. Borntraeger, Berlin.
- BÜCHI, E., BULETTI, M. und NIGGLI, E. (1984): Neue Aufschlüsse im schweizerischen Anteil des Schwarzwälder Grundgebirges. *Schweiz. mineral. petrogr. Mitt.* 64, 49–66.
- CHAUVEL, C. and JAHN, B. M. (1984): Nd-Sr isotope and REE geochemistry of alkali basalts from the Massif Central, France. *Geochem. Cosmochim. Acta* 48, 93–110.
- DIETRICH, V., OBERHÄNSLI, R. and WALPEN, P. (1976): Röntgenfluoreszenzanalyse der Silikatsteine. Report Inst. Krist. Petr. ETH-Zürich.
- EIKENBERG, J. (1984): Geologie und Petrographie der Bernina. Teil VIII: Val da Fain. Diploma ETH-Zürich, unpubl.

- GRUBENMANN, U. (1919): Lamprophyrische Gesteine im zentralen Gotthardgranitgneis aus der Umgebung des St.-Gotthard-Hospizes. *Vrtljsschr. natf. Ges. Zürich* 64, 418–433.
- HART, S. R. and DAVIS, K. E. (1978): Nickel partitioning between olivine and silica melt. *Earth and Planet. Sci. Lett.* 40, 203–219.
- KÜPFER, TH. (1977): Mineralogisch-petrographische und geochemische Untersuchung der Syenodiorite und der Ganggesteine im Puntagliasgebiet. Ph.D. thesis Univ. Bern, unpubl.
- MANSON, V. (1967): Geochemistry of basaltic rocks: Major elements. In: Basalts, eds. H. H. HESS and A. POLDERVERAART, 215–270.
- MÜLLER, H. (1982): Petrographie und Geochemie von Lamprophyren des Schwarzwaldes. Diploma Univ. Freiburg i. Br., unpubl.
- MÜLLER, H. (1984): Die Lamprophyre des Schwarzwaldes. *Fortschr. Miner.* 62, 106–111.
- NICHOLS, I. A. and RINGWOOD, A. E. (1973): Effect of water on olivine stability in tholeiites and production of silica-saturated magmas in the island arc environment. *J. Geol.* 81, 285–300.
- NISBET, E. B., DIETRICH, V. and ESENWEIN, A. (1979): Routine trace element determination in silicate minerals and rocks by X-ray fluorescence. *Fortschr. Mineral.* 57, 264–279.
- OBERHÄNSLI, R. (1985): Mineralogy and geochemistry of meta-lamprophyres from the Central Swiss Alps. Habilitationsschrift Univ. Bern, unpubl.
- PEARCE, J. A. (1983): Role of the sub-continental lithosphere in magma genesis at active continental margins. In: Continental Basalts and Mantle Xenoliths, eds.: Hawkesworth and Norr; Shiva Geology Series, Shiva, Nantwich, 230–249.
- ROCK, N. M. S. (1984): Nature and origin of calc-alkaline lamprophyres: minettes, vogesites, kersantites and spessartites. *Trans. R. Soc. Edinburgh: Earth Sci.* 74, 193–227.
- SCHALTEGGER, U. (1984): Geologie und Petrographie der Gneiszone von Erstfeld in der Umgebung des Sustenpasses, Aarmassiv. Diploma Univ. Bern, unpubl.
- SEKINE, T. and WYLLIE, P. J. (1982): Phase relationships in the system  $KAlSiO_4-Mg_2SiO_4-SiO_2-H_2O$  as a model for hybridization between hydrous siliceous melts and peridotite. *Contr. Mineral. Petrol.* 79, 368–374.
- SONDER, R. (1921): Untersuchungen über den Differentiationsverlauf der spät-paläozoischen Granitinusionen im zentralen und westlichen Gotthardmassiv. *Schweiz. mineral. petrogr. Mitt.* 1, 5–71.
- SPENCER, J. E. (1985): Pliocene low-angle normal faulting and dike emplacement, Homer Mountain and surrounding areas, southeastern California and southernmost Nevada. *Bull. Geol. Soc. Amer.* 96, 1140–1155.
- STEINER, H. (1984): Mineralogisch-petrographische, geochemische und isotopengeologische Untersuchungen an einem Meta-Lamprophyr und seinem grano-dioritischen Nebengestein (Matorello-Gneis) aus der Maggia-Decke. *Schweiz. mineral. petrogr. Mitt.* 64, 261–272.
- SUN, S. S. and NESBITT, R. W. (1977): Chemical heterogeneity of Archean mantle, composition of the earth and mantle evolution. *Earth and Planet. Sci. Lett.* 35, 429–448.
- SUN, S. S. and NESBITT, R. W. (1978): Petrogenesis of Archean ultrabasic and basic volcanics: evidence from rare-earth elements. *Contr. Mineral. Petrol.* 65, 301–325.
- THOMPSON, R. N., MORRISON, M. A., HENDRY, G. L. and PARRY, S. J. (1984): An assessment of the relative roles of crust and mantle in magma genesis: an elemental approach. *Phil. Trans. R. Soc. London A* 310, 549–590.
- VENTURELLI, G., THROPE, R. S., DAL PIAZ, G. V., DEL MORO, A. and POTTS, P. J. (1984): Petrogenesis of calc-alkaline, shoshonitic and associated ultrapotassic Oligocene volcanic rocks from the Northwestern Alps, Italy. *Contrib. Mineral. Petrol.* 86, 209–220.
- WEBER, FR. (1904): Über den Kali-Syenit des Piz Giuf und Umgebung. *Beitr. geol. Karte Schweiz NF* 14.
- WIMMENAUER, W. (1973): Lamprophyre, Semilamprophyre und anchibasaltische Ganggesteine. *Fortschr. Mineral.* 51, 3–67.

- WIMMENAUER, W. and HAHN-WEINHEIMER, P. (1966): Geochemische und petrographische Kriterien für die Herkunft von Kersantiten und Minetten. *N. Jb. Mineral. Mh.* 7, 201-220.
- WOOD, D. A., TARNEY, J., VAREL, J., SAUNDERS, A. D., BOUGAULT, H., JORON, J. L., TREUIL, M. and CANN, J. R. (1979): Geochemistry of Basalts drilled in the North Atlantic by IPOD Leg 49; Implications for mantle heterogeneity. *Earth and Planet. Sci. Lett.* 42, 77-97.
- WYLLIE, P. J. and SEKINE, T. (1982): The formation of mantle phlogopite in subduction zone hybridization. *Contr. Mineral. Petrol.* 79, 375-380.

Manuscript received March 2, 1987; revised manuscript accepted March 25, 1987.