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Geochemistry of meta-lamprophyres from the Central Swiss Alps

by *Roland Oberhänsli*[1]

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, vogesites, 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:

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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 terraines. 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 where 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.

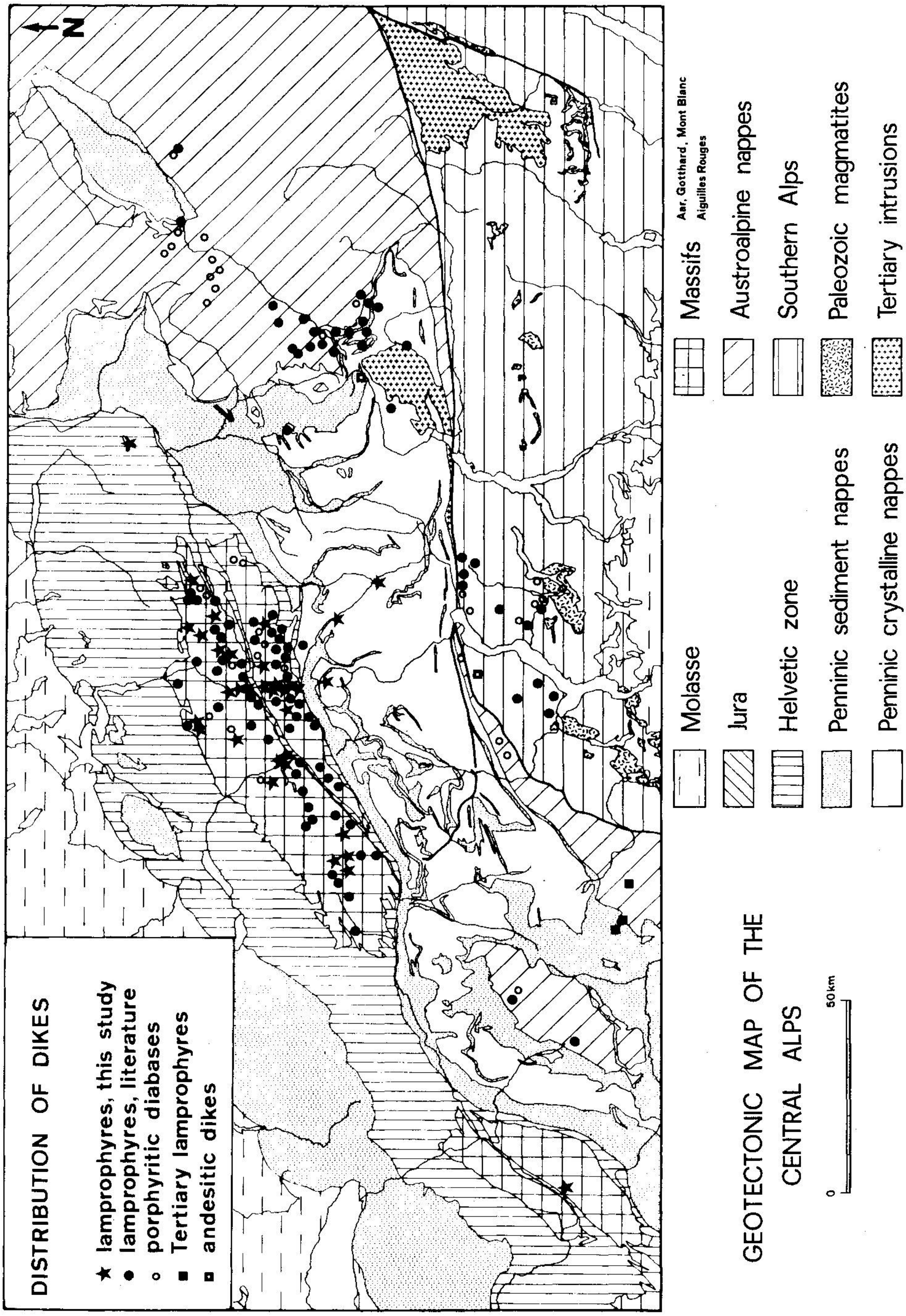

Fig. 1 Distribution of mafic dikes, lamprophyres and porphyritic diabases in the Central Alps. Data from literature and this study.

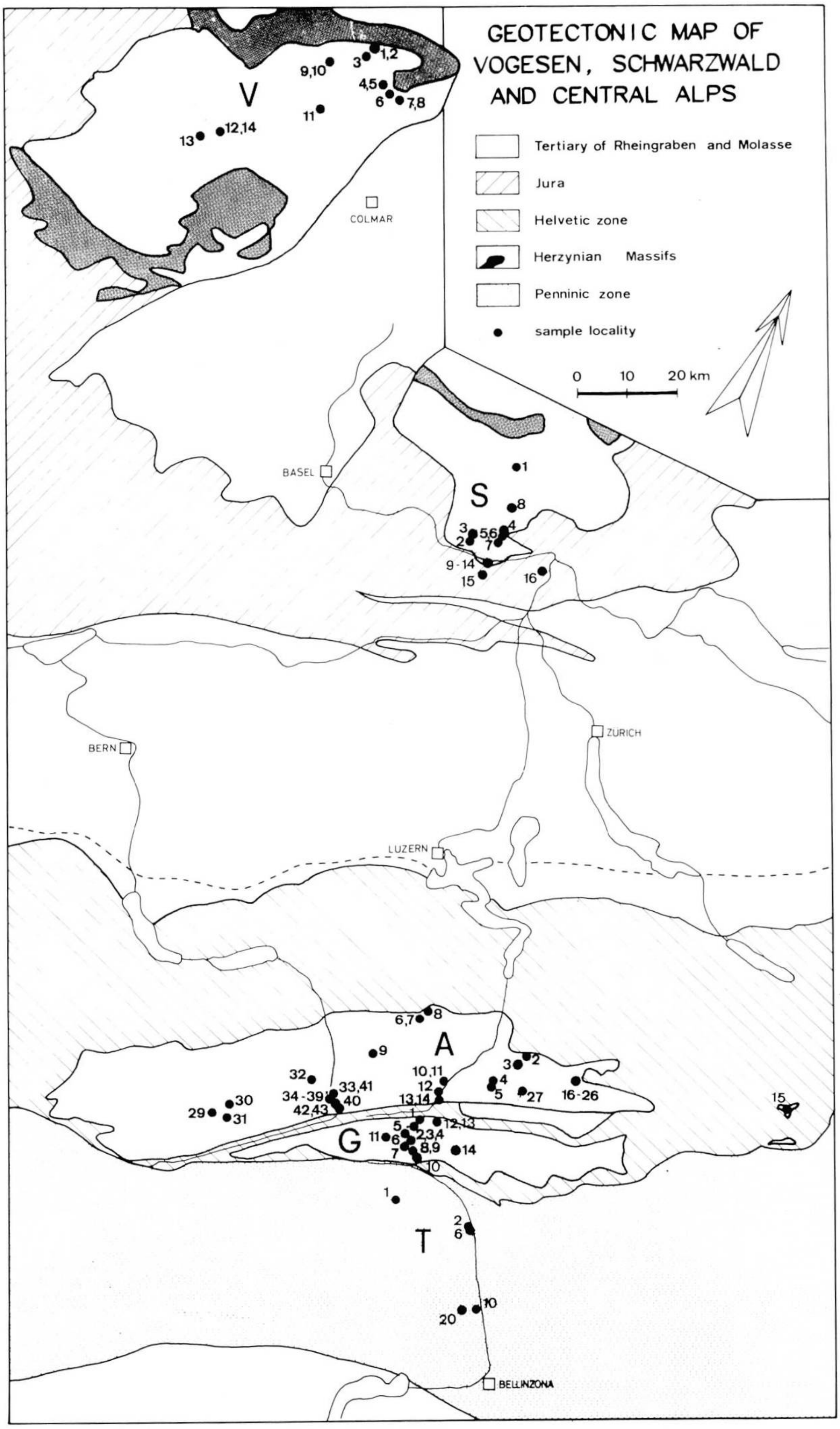

Fig. 2 Sample locality index map covering the Vogesen (V), the Schwarzwald (S), the Aar- (A) and Gotthard-massif (G) and the Ticino (T).

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

* chemical analyisis
BI magmatic mineral
bi metamorphic mineral

Schwarzwald
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lamprophyre	Laufenburg Kaisten 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

Aarmassif
****

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	Grünhörnligrat 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 Gletsch	bi ep ab qz
lamprophyre	Trübtenbach Grimselsee Nollen (Grimsel) N Todtseeli Nägelisgrätli Belvedere (Furka) Furkahorn S Lochstock (Ross- mettlen) Schöllenen	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 Grimselgranite	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 *	Göscherneralp 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)	(2)	(3)	(4)	(5)	(6)

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

Tab. 1 (continued).

(1)	(2)	(3)	(4)	(5)	(6)
lamprophyre	Maderanertal	central Aargranite	Sigrist F., 1947	Maderaner valley	
kersantit	Klüsertal-Fellital	central Aargranite	Pflugshaupt P., 1927 *	W Bristenstock	BI HBL PLG sph ser ilm
lamprophyre spessartite kersantite	Stöckligrat S Wicheltal Crispalt Giufstöckli Culmatsch Val Mila Piz Ault Piz Gendusas Val Calvaniev Val Placi	southern Aargranite Giufsyenite southern gneisses	Weber F., 1904 * Niederer J., 1932 Huber W., 1948	Vorderrhein valley	HBL BI EP KFSP PLG MGT act sph ep ab ser BI PLG HBL QZ ep ser sph
spessartite kersantite	Val Gliems Cuolm Tgietschen Piz Cambrialas W Clavadi	granitic gneisses	Eugster H., 1951 Böhm C., 1986 Weber F.	Val Russein	PLG BI HBL QZ EP CHL ser act chl
lamprophyre	Piz Posta Bialla Crap Grond Val Ufiern	monzodiorite Puntegliasgranite	Wehrli L., 1896 Weber F., 1924 Küpfer T., 1974, 77 *	Val Punteglias	BI PLG KFSP DI QZ HBL PX ab ser bi act ep/zo sph
kersantite	Kreuzbach	syenite	Hügi T., 1941	Vättis	BI PLG KF SPH EP CC chl ser mgt
Gotthardmassif **************					
lamprophyre	Kummenhorntobel Stock SE Münster Distelgrat S Pizzo Gallina	Gotthard gneisses, 2-mica-gneisses	Oberholzer W., 1955	Obergoms	PLG HBL -> bi act chl
lamprophyre	Val Prosa, Nufenen	Bi-plg-gneisses	Schmidt & Preiswerk, 1908	E Nufenenpass, Bedretto valley	
lamprophyre	W Nufenenpass Gross Mutthorn Gerental Pne di Manio Alpe di Manegorio Rotondohütte Rottällihorn Ronggergrat Cavannapass Passo Lucendro Pizzo Lucendro Fibbia	Rotondogranite Scoresciagneiss Fibbia granitegneiss Prato series Gamsboden granitegneiss	Sonder R., 1921 * Fischer E., 1923 Eichenberger R., 1924 Eichenberger R., 1926 * Hafner S., 1958 Hafner S., 1975	N Bedretto valley, W of Gotthard pass	bi ab ep/zo qz act sph mu BI PLG mu ep/zo bi sph act ab BI KFSP MGT DI -> HBL sph ser chl bi ab
lamprophyre spessartite kersantite	Winterhorn Mätteli Alpe di Rodont Monte Prosa Gotthard Hospiz Fieud	aplitic granite Gamsbodengneiss bi-plg-gneiss	Waindziok P., 1906 Kriege L., 1916 Grubenmann U., 1919 * Sonder R., 1921 * Ambühl E., 1929 Koenigsberger J., 1930 Hofmänner F., 1964 *	Gotthard pass area	BI ab zo mgt mu bi hbl sph BI bi hbl act gr ab mu ep
lamprophyre kersantite	Passo Sella Unteralptal Cadlimo Plauncacotschna	micaceous gneisses	Fritsch K., 1873 Kriege L., 1916 Ambühl E., 1929 Zweifel H., 1954	Gotthard area, E of the pass	BI act bi mu sph
spessartite kersantite	Tgiern Toma Piz Miez	bi-gneisse, amphibolite granodiorite	Huber H., 1943	Val Medel	BI PLG HBL zo mu ser act chl cc
lamprophyre	Val Cristallina	Cristallina granite	Holst W., 1913	Lukmanier area	BI PLG KFSP MGT ep ser ab
intermediate dykes	Rossbodenstock Piz Maler Val Nalps Piz Pazzola	bi-plg-gneisses	Niggli E., 1944 * Niggli E., 1948 * Arnold A., 1970	Vorderrhein valley	HBL BI PLG QZ ep act ab ser sph chl HBL PLG BI ab ?bi

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

Tab. 1 (continued).

Penninic nappes
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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-plg-gneiss	Kriege L., 1916 Bosshard L., 1929	Lukmanier nappe, Lago Ritom, S Airolo	
minette	Alp Tobel	Rofnaporphyre	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 Caldras Piz d'Err Jenatsch area Piz Giumels S Val Alvra (Crasta Mora) N Piz Lagrev N & S Julier pass St. Moritz SE Piz Julier Piz Albana Piz Palaschin (Tsheppa)	granite diorite	Eugster & Frey, 1927 Cornelius H., 1935 Bühler C., 1983 *	Err nappe Bernina nappe	PLG PYX BI AP ILM ab act HBL PYX act ab
lamprophyre vogesite spessartite kersantite	Mortel N Piz Corvatsch Corvatsch W grat S Mortelhütte Alp Ota Roseggletscher Piz Chalchagn Muottas di Pontresina Berninastrasse Bovalhüttenweg	granite granite porphyre	Grubenmann U Staub R., 1915 * Münger R., 1982 * Müller D., 1982 *	Bernina nappe	HBL BI ILM act ep ser chl 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	Alp 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	Pallanza Mergozzo	schisti dei Laghi bi-plg-gneisses	Boriani et al., 1977	SW Lago Maggiore	
lamprophyre	Quinto Contone Cadenazzo S Gubiasca S Indemini Astano SE Sessa	bi-plg-gneisses Ceneri zone	Kelterborn P., 1923 Bearth P., 1932 * Bächlin R., 1937 Spicher A., 1940 Gräter P., 1951 Reinhard M., 1964 * Wenger C., 1983	Sotto Ceneri	PLG HBL AUG BI CC QZ AP SPH chl
(1)	(2)	(3)	(4)	(5)	(6)

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

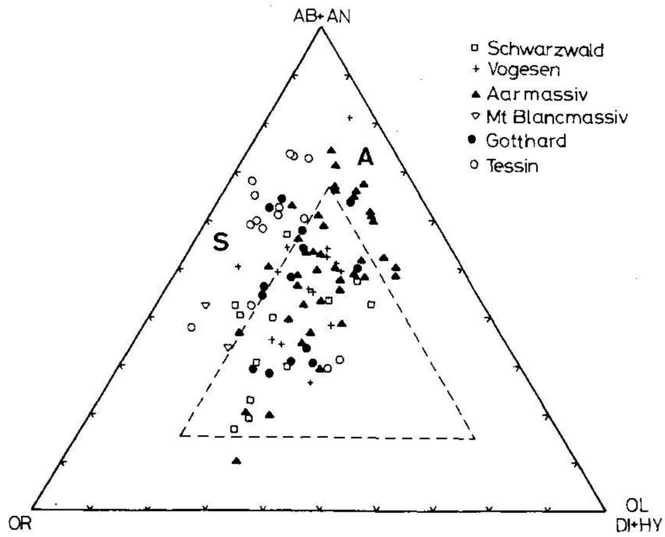

Fig. 3 Norm (CIPW) classification for lamprophyres after Wimmenauer (1973). OR: orthoclase, AB: albite, AN: anorthite, OL: olivine, DI: diopside, HY: hypersthene, S: semilamprophyres and porphyrites, A: anchybasalts and diabases.

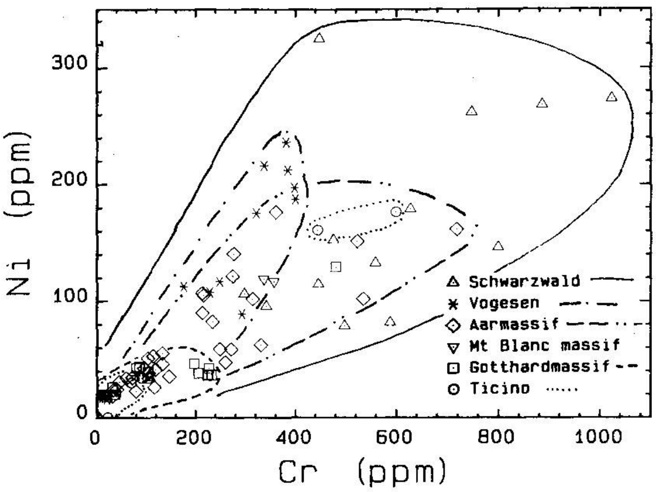

Fig. 4 Cr vs Ni distribution in lamprophyres and meta-lamprophyres. Different areas show variing compositional fields, reflecting the regional diversity of different magmatic suites.

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 Na_2O to K_2O 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 SiO_2 (Fig. 5), lower in FeO, MgO, TiO_2, MnO and CaO (Tab. 2) compared to meta-

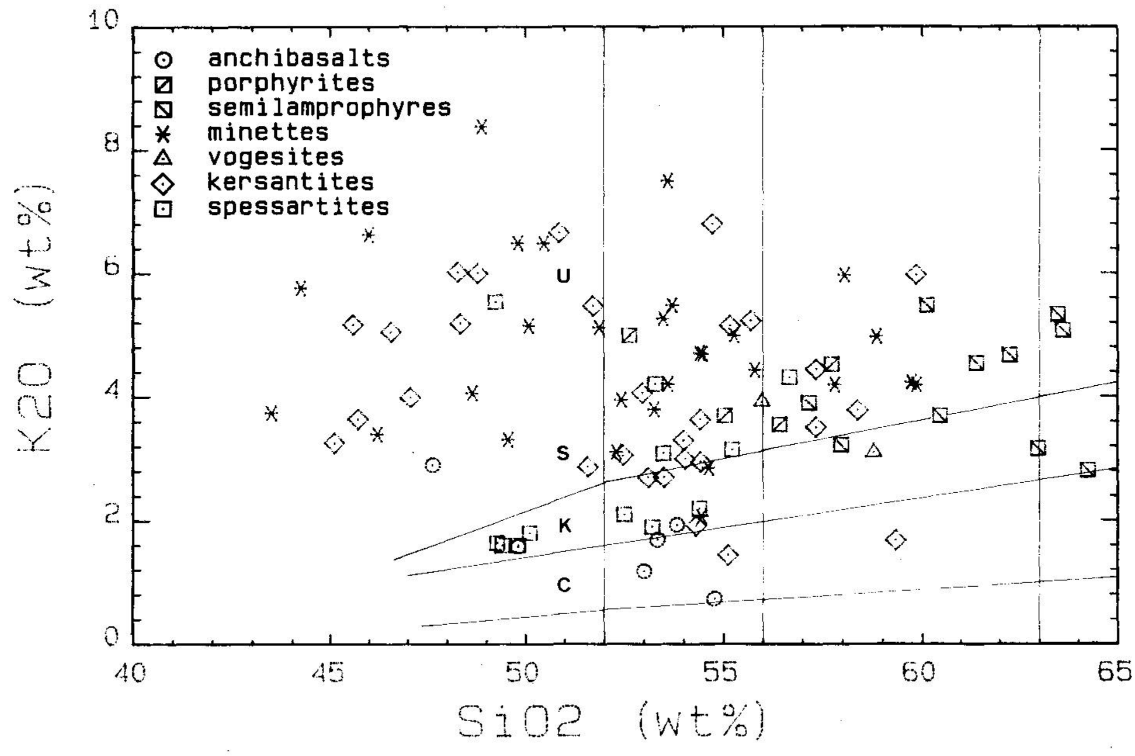

Fig. 5 Potassium silica diagram showing the separation of the semilamprophyres from lamprophyres and meta-lamprophyres. C: calc-alkalic, K: high-K calc-alkalic, S: shoshonitic, U: ultrapotassic.

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_2O and significantly lower in K_2O 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 calk-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 picri-

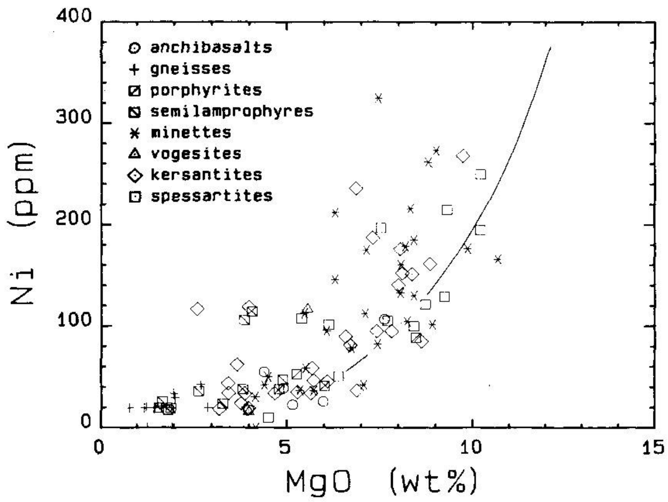

Fig. 6 Ni vs MgO diagram showing a line of olivine fractionation after HART and DAVIS (1978) starting from a primitive melt with 12% MgO. Ni/Mg ratios (Ni ppm/MgO %) vary between 5 and 35, they are generally higher in ultrapotassic rocks.

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

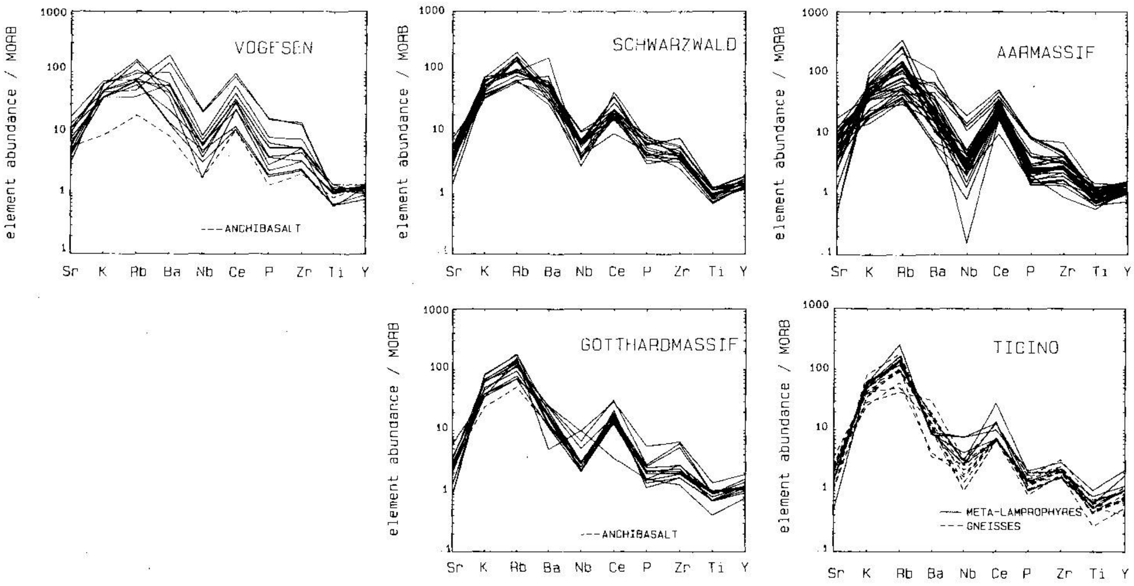

Fig. 7 Spider diagram for MORB normalized trace elements (MORB after WOOD et al., 1979). The patterns display an enrichment of mobile elements due to partial melt of primitive material as well as NB, P, Ti anomalies indicating subduction processes. For explanation see text.

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 alkalibasaltic 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.

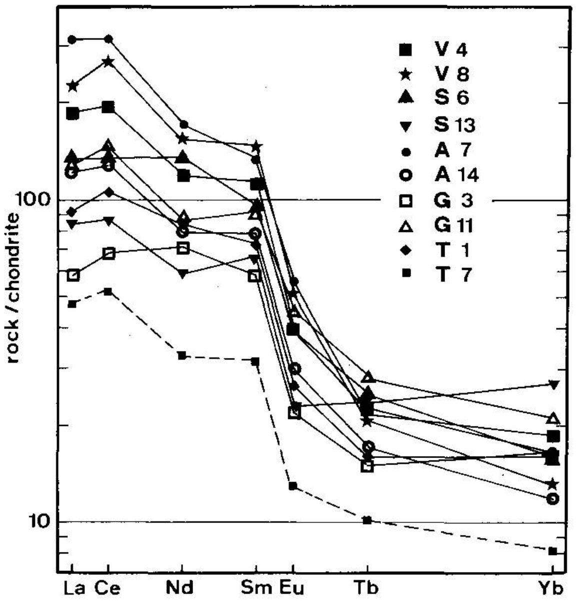

Fig. 8 Chondrite normalized REE distribution pattern showing an enrichment of LREE of 60 to 300 times. Two "plateaus" are visible for LREE and HREE. The HREE plateau possibly is a reflection of the very high amphibole content of Alpine lamprophyres and meta-lamprophyres.

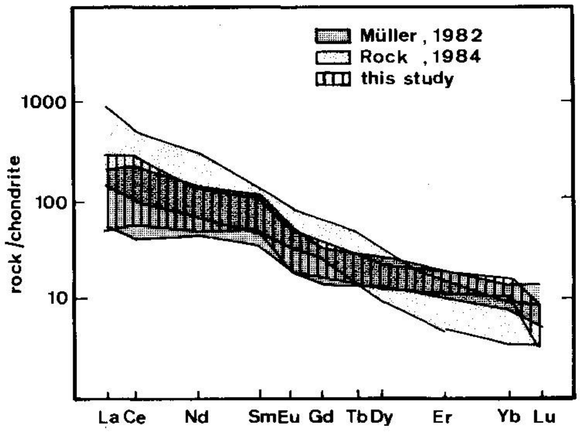

Fig. 9 Chondrite normalized REE distribution pattern of the Alps compared with data from the Schwarzwald (MÜLLER, 1982) and data given in a compilation by ROCK (1984). The Schwarzwald as well as the Alpine samples are less enriched in LREE and show higher HREE contents than lamprophyres from other localities.

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 biotitie 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_2	45.31	44.48	52.31	55.98	58.78	53.74	47.06	48.64	53.49	57.98	52.63	45.59	63.61	57.80
TiO_2	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_2O_3	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_2O_3	2.79	2.60	2.48	2.23	1.51	4.60	4.32	5.13	3.54	1.75	2.19	4.28	2.20	2.12
FeO	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_2O	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_2O	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_2O_5	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_2O+	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
CO_2	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
ppm :														
Ba	6621	4964	2167	1287	506	302	2025	1572	806	493	1634	3418	2227	-
Rb	140	96	75	279	139	37	132	148	116	133	302	179	201	-
Sr	1556	1204	998	571	389	493	426	511	691	365	269	850	996	-
Pb	62	18	7	29	8	21	24	29	<6	<6	9	64	71	-
Th	46	37	15	6	<5	<5	<5	9	7	<5	10	24	24	-
U	5	10	4	<1	3	6	<1	6	10	<1	4	6	9	-
Nb	86	82	29	7	19	7	23	25	25	12	15	34	17	-
La	413	330	173	76	18	<15	130	149	61	<15	161	265	108	-
Ce	579	507	271	148	77	67	216	216	143	69	199	364	190	-
Nd	146	146	85	45	27	19	74	78	47	15	74	122	44	-
Y	36	30	26	35	26	37	28	37	32	21	32	34	34	-
Zr	1016	937	382	235	176	147	387	394	238	166	325	543	392	-
V	166	148	151	121	102	119	210	232	150	84	136	197	96	-
Cr	320	336	174	19	247	11	380	383	396	227	292	398	78	-
Ni	175	216	113	16	117	18	236	212	197	107	89	187	36	-
Co	36	35	38	12	20	13	36	46	42	17	23	48	23	-
Cu	127	95	28	36	42	7	42	19	15	40	6	24	44	-
Zn	201	293	114	74	90	118	163	181	81	82	116	189	61	-
Ga	18	16	20	19	16	23	21	21	21	14	19	19	20	-
Sc	21	18	14	20	14	18	21	23	21	12	29	24	15	-
Total	11770	9518	4884	3035	2036	1463	4574	4291	3099	1857	3744	6989	4686	0

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_2	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	59.72	49.55
TiO_2	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_2O_3	15.74	14.26	13.66	14.50	13.78	13.75	13.97	13.98	15.94	13.64	14.20	16.34	15.10	13.20	14.99	12.61
Fe_2O_3	8.72	2.08	2.31	1.39	2.59	2.89	1.67	2.54	1.82	2.69	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	5.80
Na_2O	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_2O	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_2O_5	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_2O+	3.82	2.58	1.67	3.24	2.47	2.82	4.17	2.17	1.35	2.56	2.15	1.63	1.87	2.77	3.05	4.86
CO_2	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	99.04	99.39
ppm :																
Ba	5982	2126	1562	1002	2491	1927	2324	2139	1247	1911	1966	1553	1171	1716	1339	3040
Rb	197	165	128	141	187	204	212	187	136	341	401	295	289	298	325	137
Sr	247	357	391	304	506	481	282	374	690	284	359	443	177	316	116	447
Pb	43	18	15	11	23	20	9	32	12	19	27	27	15	97	13	24
Th	6	15	7	16	24	23	10	14	11	41	43	30	19	41	36	27
U	<1	7	4	8	7	7	11	9	4	9	20	14	9	20	21	10
Nb	13	17	14	16	29	27	22	29	11	39	41	25	24	28	25	16
La	220	66	19	40	161	131	93	90	69	72	92	100	99	73	73	51
Ce	282	125	106	115	189	147	141	102	145	110	144	242	100	239	129	59
Nd	68	34	33	47	56	51	42	28	49	39	51	98	28	109	31	31
Y	37	36	35	33	36	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	180
V	223	176	169	144	280	196	173	177	136	219	227	145	198	194	182	183
Cr	447	626	883	474	586	496	745	340	105	557	798	296	444	1021	123	890
Ni	325	179	268	152	81	78	262	95	34	133	146	106	114	273	50	166
Co	39	46	43	31	42	18	47	35	24	46	39	30	40	49	49	36
Cu	27	33	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	269
Ga	25	18	17	16	19	19	18	18	17	18	17	20	20	19	19	13
Sc	29	29	28	22	32	31	28	26	19	34	36	24	35	36	28	33
Total	8969	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
Weight %																
SiO_2	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_2	1.09	1.73	0.75	1.46	1.20	1.48	1.16	1.13	0.92	0.91	0.91	0.81	1.39	0.99	1.00	1.10
Al_2O_3	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_2O_3	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
FeO	4.09	7.14	2.62	3.78	4.46	3.84	6.30	4.53	2.82	4.09	3.49	2.73	4.83	5.35	5.20	4.50
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
MgO	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
CaO	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
Na_2O	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
K_2O	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
P_2O_5	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	1.40
H_2O+	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
CO_2	0.13	0.55	0.17	0.13	3.81	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 :																
Ba	608	390	826	686	2030	2222	1653	437	898	737	1029	807	517	3610	5000	3000
Rb	93	100	253	71	159	185	83	85	152	237	238	296	522	394	150	70
Sr	680	642	862	470	887	646	1068	743	747	457	491	764	454	983	850	1475
Pb	<6	9	<6	11	22	12	9	25	<6	7	22	25	37	42	18	36
Th	<5	<5	<5	<5	<5	10	22	<5	<5	5	<5	<5	11	16	-	-
U	<1	3	<1	4	4	3	5	<1	<1	2	3	3	10	2	-	-
Nb	9	15	<3	13	55	74	49	8	10	12	12	6	20	42	-	-
La	47	66	<15	33	128	163	118	<15	<15	42	19	<15	43	128	-	-
Ce	144	123	103	159	287	312	241	147	108	113	149	131	151	215	-	-
Nd	68	73	53	84	110	123	97	73	23	34	71	71	78	75	-	-
Y	29	37	20	36	39	33	32	33	28	31	33	27	30	41	-	-
Zr	204	223	94	185	343	482	315	155	186	188	156	116	219	281	355	495
V	124	146	110	223	168	152	161	184	107	131	139	142	82	191	-	-
Cr	273	102	32	31	212	275	212	78	104	118	58	145	359	717	470	480
Ni	121	51	24	18	90	141	107	23	38	41	34	35	176	161	130	95
Co	28	39	17	14	25	34	37	17	15	26	26	26	27	42	21	35
Cu	32	36	17	35	58	51	53	25	8	8	14	17	16	55	42	39
Zn	87	107	100	117	95	82	78	105	88	120	66	128	219	108	80	90
Ga	17	15	19	20	16	17	15	19	17	18	20	19	23	17	-	-
Sc	22	23	13	26	27	21	20	28	10	12	16	19	17	35	-	-
Total	2586	2200	2543	2236	4755	5038	4375	2185	2539	2339	2596	2777	3011	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
Weight %																
SiO_2	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_2	0.88	1.50	0.92	0.71	0.62	1.40	1.80	0.93	1.80	1.11	1.24	1.00	0.84	1.01	0.86	1.21
Al_2O_3	16.50	12.60	16.20	15.30	14.70	17.70	16.50	14.80	16.20	17.34	16.17	15.94	15.26	16.21	14.99	17.58
Fe_2O_3	1.70	1.50	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_2O	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_2O	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_2O_5	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_2O+	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
CO_2	0.11	0.30	0.15	0.30	0.66	0.10	0.10	0.76	0.10	0.12	3.65	0.41	0.07	0.04	0.46	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
ppm :																
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	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	<5
U	-	-	-	-	-	-	-	-	-	4	1	5	<1	1	4	5
Nb	-	-	-	-	-	-	-	-	-	8	14	9	12	16	17	13
La	-	116	-	-	-	-	-	-	-	<15	<15	<15	27	56	39	39
Ce	-	220	-	-	-	-	-	-	-	58	181	163	145	165	99	162
Nd	-	-	-	-	-	-	-	-	-	28	99	75	74	77	34	89
Y	-	-	-	-	-	-	-	-	-	30	37	26	30	34	33	41
Zr	190	580	170	105	110	200	240	110	200	102	242	137	192	194	195	185
V	-	-	-	-	-	-	-	-	-	212	82	115	122	181	171	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	55	95	240	70	140	77	77	87	95	197	104	154
Ga	-	-	-	-	-	-	-	-	-	20	18	22	18	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 %										
SiO_2	54.03	46.21	54.31	45.11	48.88	54.63	54.45	59.33	63.48	50.85
TiO_2	1.29	1.18	1.05	1.43	1.50	1.07	1.23	0.65	0.82	0.74
Al_2O_3	16.84	14.86	17.17	18.66	18.29	17.51	17.20	15.80	14.17	21.57
Fe_2O_3	2.44	2.39	4.15	2.75	2.04	3.58	3.30	3.87	1.65	1.59
FeO	5.43	5.38	3.49	7.99	7.12	3.88	4.78	3.26	3.46	3.46
MnO	0.16	0.16	0.15	0.21	0.26	0.14	0.17	0.46	0.10	0.14
MgO	3.77	8.22	4.67	8.35	7.42	4.15	4.40	3.67	4.89	6.08
CaO	6.93	8.64	7.58	7.60	1.67	7.39	5.86	5.14	0.82	2.77
Na_2O	3.36	1.89	3.04	2.23	0.29	2.90	3.52	4.40	1.07	2.22
K_2O	3.00	3.40	1.92	3.26	8.38	2.85	2.07	1.68	5.33	6.66
P_2O_5	0.56	1.19	0.36	0.40	0.44	0.37	0.43	0.28	0.33	0.21
H_2O+	1.48	3.62	2.00	3.03	2.87	1.78	2.41	1.64	2.26	2.89
CO_2	0.56	2.53	0.04	0.04	0.21	0.00	0.04	0.05	0.03	0.38
Total	99.85	99.67	99.93	101.06	99.37	100.25	99.86	100.23	98.41	99.56
ppm :										
Ba	869	2473	558	1400	948	540	734	227	681	561
Rb	117	116	57	136	660	104	108	74	282	490
Sr	601	1483	692	382	39	767	464	299	40	201
Pb	9	9	17	27	12	18	38	17	<6	<6
Th	6	18	<5	<5	<5	<5	<5	<5	<5	<5
U	1	5	4	4	<1	4	2	<1	<1	<1
Nb	11	49	11	20	18	11	20	3	11	5
La	73	116	16	76	118	28	61	<15	54	22
Ce	124	244	179	216	175	197	207	108	149	116
Nd	50	98	94	117	96	97	101	59	67	59
Y	38	34	37	43	39	39	44	31	29	27
Zr	289	334	184	245	229	193	286	61	176	120
V	137	150	181	212	209	188	165	145	135	107
Cr	39	215	70	521	233	44	95	329	259	131
Ni	24	105	34	151	82	30	42	62	47	46
Co	29	35	24	46	30	26	32	9	24	31
Cu	43	56	23	21	17	23	17	54	8	9
Zn	85	79	110	182	250	110	123	70	70	95
Ga	16	15	21	27	24	21	22	14	24	23
Sc	14	20	15	25	37	15	19	27	24	20
Total	2575	5654	2327	3851	3216	2455	2580	1589	2080	2063

Sample Nr.	M 1	M 2
Weight %		
SiO_2	48.77	48.26
TiO_2	1.33	1.18
Al_2O_3	18.96	16.98
Fe_2O_3	8.10	7.71
FeO	2.99	5.91
MnO	0.13	0.15
MgO	2.60	3.98
CaO	7.08	5.33
Na_2O	0.46	0.60
K_2O	6.00	6.02
P_2O_5	1.26	1.15
H_2O+	2.71	2.71
CO_2	0.05	0.06
Total	100.44	100.04
ppm :		
Ba	2801	2093
Rb	237	301
Sr	623	475
Pb	44	39
Th	47	42
U	19	13
Nb	69	69
La	101	100
Ce	211	197
Nd	65	72
Y	52	59
Zr	680	611
V	153	173
Cr	355	335
Ni	117	119
Co	14	<8
Cu	18	23
Zn	65	100
Ga	32	32
Sc	17	15
Total	5720	4868

Tab. 2 (continued).

Sample Nr.	G 1	G 2	G 3	G 4	G 5	G 6	G 7	G 8	G 9	G 10	G 11	G 12	G 13	G 14
Weight %														
SiO_2	65.78	51.59	53.71	62.98	55.27	54.72	52.95	55.70	53.82	50.46	60.46	55.17	49.23	
TiO_2	0.80	1.14	1.19	1.05	1.08	0.94	1.13	1.60	1.06	0.83	1.06	0.80	0.47	0.82
Al_2O_3	15.19	16.29	15.63	15.79	14.78	16.07	16.74	15.75	16.11	14.98	15.98	16.42	15.02	15.26
Fe_2O_3	1.10	1.95	2.76	2.08	1.80	3.03	2.50	1.98	2.44	3.56	2.89	2.30	1.71	2.42
FeO	4.58	6.48	7.88	3.70	8.21	4.32	5.55	5.20	4.47	3.19	2.80	3.79	2.55	5.59
MnO	0.09	0.16	0.16	0.10	0.17	0.15	0.14	0.12	0.12	0.15	0.11	0.13	0.12	0.15
MgO	2.70	6.87	5.70	1.83	5.34	5.71	5.63	3.43	4.90	7.06	1.67	3.97	3.82	9.22
CaO	1.91	7.28	2.38	3.26	2.90	6.35	4.21	4.86	6.32	6.10	4.99	4.70	2.88	7.26
Na_2O	2.45	2.40	1.86	4.15	1.76	0.18	3.72	2.30	4.09	0.55	3.66	2.13	3.09	0.22
K_2O	3.21	2.87	5.48	3.16	4.99	6.80	4.06	5.23	1.93	6.49	3.69	5.15	2.81	5.54
P_2O_5	0.22	0.27	0.29	0.36	0.27	0.21	0.34	0.76	0.34	0.19	0.38	0.30	0.22	0.16
H_2O+	1.90	1.72	2.03	1.00	1.95	1.50	1.55	2.03	1.10	2.36	1.07	2.31	1.74	3.06
CO_2	0.11	0.32	0.67	0.07	1.32	0.58	1.80	1.49	2.87	3.52	0.65	3.17	1.12	0.80
Total	100.04	99.34	99.74	99.53	99.84	100.56	100.32	100.45	99.57	99.44	99.41	100.34	99.79	99.73
ppm :														
Ba	647	405	420	848	467	735	578	891	430	450	897	643	190	570
Rb	148	133	278	134	254	331	179	209	98	341	225	240	297	268
Sr	242	509	174	217	177	73	109	283	245	70	303	182	177	73
Pb	14	6	11	<6	10	24	9	17	6	6	19	634	14	7
Th	12	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	9	<5	<5
U	<1	<1	<1	<1	<1	4	1	1	1	<1	<1	<1	10	<1
Nb	11	8	11	19	11	12	11	37	11	9	25	8	38	8
La	51	<15	71	25	86	20	66	119	<15	15	42	26	<15	<15
Ce	78	81	93	101	115	84	82	178	99	111	192	91	21	129
Nd	46	29	49	35	61	26	49	72	34	61	97	35	<10	75
Y	31	32	31	38	33	33	29	51	30	34	43	26	21	28
Zr	191	142	150	366	136	135	186	454	187	117	428	163	89	117
V	97	182	182	73	216	161	106	164	105	138	110	145	85	190
Cr	79	231	223	19	223	196	101	85	103	226	30	36	204	479
Ni	42	37	36	18	37	46	34	44	39	42	26	20	38	129
Co	26	33	<8	<8	8	31	28	25	17	12	<8	13	9	30
Cu	20	9	10	6	11	8	11	<4	9	15	23	11	19	15
Zn	108	92	96	60	94	107	122	116	104	100	114	111	69	95
Ga	20	20	27	18	28	17	19	21	19	18	23	19	19	18
Sc	15	20	35	11	38	16	16	19	13	27	14	18	12	33
Total	1878	1969	1897	1988	2005	2059	1736	2786	1550	1792	2611	2430	1312	2264

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 20
Weight %																	
SiO_2	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	64.25	63.83	71.12	54.40
TiO_2	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	0.65	0.75	1.20
Al_2O_3	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	16.60
Fe_2O_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	1.20
FeO	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	6.30
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	0.08	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	1.91	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	4.55
Na_2O	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	1.10
K_2O	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	2.67	4.70
P_2O_5	0.28	0.20	0.22	0.21	0.19	0.20	0.18	0.17	0.24	0.14	0.25	0.19	0.12	0.15	0.15	0.29	0.30
H_2O+	2.04	0.73	0.82	1.85	0.80	1.26	0.79	1.09	1.38	1.56	1.25	0.84	0.58	0.88	0.87	0.00	1.80
CO_2	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	0.00	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	99.14	99.49	99.45
ppm :																	
Ba	610	300	136	365	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	-	488
Sr	131	125	94	91	218	178	119	86	166	128	206	202	187	207	296	-	39
Pb	14	13	9	9	13	10	9	9	9	9	16	9	9	11	<6	-	12
Th	<5	6	<5	<5	<5	6	<5	7	<5	<5	9	<5	<5	<5	<5	-	21
U	2	<1	<1	<1	<1	3	1	<1	<1	<1	3	1	1	<1	<1	-	13
Nb	12	16	11	4	7	29	8	5	11	10	13	7	4	10	11	-	29
La	36	30	27	20	17	41	<15	26	42	44	50	<15	<15	21	15	-	57
Ce	168	43	41	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	26	-	<10
Y	33	29	32	11	20	49	24	21	27	28	27	19	14	19	18	-	60
Zr	147	160	168	112	146	159	143	147	176	119	228	146	129	114	118	-	207
V	158	69	36	63	54	75	44	61	92	171	97	38	21	69	88	-	333
Cr	598	16	11	16	11	16	12	<10	68	444	89	11	<10	16	21	-	268
Ni	176	20	20	20	20	20	20	20	30	161	34	20	20	20	<3	-	112
Co	39	12	8	14	12	15	12	19	23	44	22	13	13	21	21	-	35
Cu	13	60	19	11	21	50	14	9	33	9	109	15	18	13	23	-	<4
Zn	151	238	97	130	88	171	95	58	85	135	104	93	28	99	91	-	98
Ga	19	28	30	27	23	37	24	20	20	19	21	24	18	20	22	-	20
Sc	17	11	9	10	7	14	6	8	13	26	14	8	5	11	14	-	35
Total	2638	1513	972	1273	1371	1566	1168	1288	1750	2054	2348	942	1057	1357	1535	0	2195

Tab. 2 (continued).

Description of samples and localities

D: drillhole, T: tunnel
mac: macroscopically visible

Nr.	Locality		sample description
V 1	Wackenbach		minette, massy compact dark grey mac: bi qz
V 2	Wackenbach		minette, massy compact grey brown mac: bi qz-oicelli kfsp-insets
V 3	S Rothau		minette, finegrained massy dark grey with salmon red points mac: qz-oicelli
V 4	Sperberbächle		vogesite, dark massy compact grey mac:
V 5	Sperberbächle		vogesite with fine margin,very compact massy grey green mac: plg resorbed px few bi
V 6	Eftermatten Lilsbach		spessartite, compact massy grey mac: plg
V 7	Andlau		kersanitite finegrained, redish grey mac: qz-oicelli bi resorbed px/ol
V 8	Andlau		minette, redish grey compact mac: bi px
V 9	Tannenberg bei Saales		spessartite massy compact grey green mac: bi px qz-oicelli
V 10	Tannenberg bei Saales		lamprophyre, massy compact, grey green mac: bi px qz-oicelli
V 11	Henaumont ob Markirch		kersantite, feldspar rich medium grained greenish grey mac: kfsp bi plg
V 12	Col de la Grosse Pierre		lamprophyre, finegrained dark grey mac: kfsp bi
V 13	Petites Alpes		lamprophyre with gneiss insets, massy compact grey brown to redish mac: bi qz kfsp pyr (ep/amph?)
V 14	Col de la Grosse Pierre		minette, dark grey homogeneous mac: bi pyx
S 1	Todtmoos		minette, fine to medium grained mac: bi resorbed px/ol
S 2	Lochmühle		lamprophyre, fine to medium grained mac: bi plg kfsp (porphyrite)
S 3	Murgtal		lamprophyre, massy greenish grey mac: bi qz-oicelli
S 4	Tiefenstein		kersanite, compact massy brownish grey mac: bi plg
S 5	Albtal	1. tunnel	lamprophyre, fine to medium grained grey, compact mac: bi kfsp resorbed cpx/ol
S 6	Albtal	1. tunnel	lamprophyre, with chilled margin, black finegrained compact massy matrix, dark red brown spherulitic parts, bi overgrows, spherulites mac: bi, kfsp cpx/ol pseudomorphs
S 7	Albtal	Aibhalde	lamprophyre compact, greenish grey mac:
S 8	Bantlisboden	Bantlisloch	lamprophyre, dark grey compact redish grey, many xenolithes of greenstones mac: bi kfsp
S 9	Laufenburg		lamprophyre, massy compact dark grey, fliudal textures mac: qz-oicelli
S 10	Laufenburg	646.60/268.00	lamprophyre, compact massy redish spherulitic, groundmass devitrified, bi overgrows spherulites mac: bi, totally resorbed cpx/ol
S 11	Laufenburg	646.50/267.90	lamprophyre, compact massy redish spherulitic, groundmass devitrified, bi overgrows, spherulites mac: bi, totally resorbed cpx/ol
S 12	Laufenburg	T 646.80/268.20	lamprophyre, massy dark grey to brown redish spots mac: bi fsp
S 13	Laufenburg	T 646.80/268.20	lamprophyre, dark grey green with dark green spherulites mac: bi chl plg
S 14	Laufenburg	T 646.80/268.20	kersantite, compact greenish black mac: bi chl fsp
S 15	Kaisten	D 644.64/265.62	minette mac: bi px/ol pseudomorphs
S 16	Leuggern	D 657.63/271.21	minette mac: bi px/ol pseudom.s qz oicelli
A 2	Madraner Tal	703.85/183.75	chlorite schist, green mac: chl bi-pseudomorhsa
A 3	Tscharren	700.45/178.25	lamprophyric dike, finegrained green chl-bi-schist mac: chl ser bi pyr ep/fsp clods
A 4	Etzlihütte	794.90/174.85	lamprophyre, bi-chl-gneiss, grey white mac: bi fsp
A 5	Kleiner Mutsch	697.80/174.20	lamprophyre, ep-chl-bi-gneiss, green mac: ep fsp chl pyr
A 6	Sustenpass	677.25/175.75	lamprophyric dike, epidoite chlorite gneiss, compact grey gneiss mac: bi fsp
A 7	Sustenpass	T 677.25/176.00	lamprophyric dike, biotite gneiss, compact grey with ptygmatic fsp veins mac: bi
A 8	E Sustenpasshöhe	677.80/177.05	dike, chl-gneiss, granulous green grey mac: plg ep chl bi
A 9	Trift	672.18/170.17	chlorite gneiss, compact mac: chl ep fsp
A 10	Göschenen	688.20/170.65	chlorite biotite gneiss, brown grey mac: bi fsp qz insets
A 11	Göschenen	688.20/170.65	dike, silver grey dark sericite schist mac: bi fsp ep
A 12	Schöllenen	678.75/167.25	lamprophyric dike, clorite sericite schist, finegrained silver grey mac: chl ser bi fsp
A 13	Urnerloch	688.25/166.60	lamprophyric dike, bi-chl-ser-schist, grey silvery gneiss with fsp veins mac: bi chl ser
A 14	Urnerloch	688.25/166.60	lamprophyric dike, bi-chl-schist, silver grey mac: bi chl ser fsp-veins
A 15	Vättis, Kreuzbach	752.50/198.10	kersantite, compact grey dark gneisseous mac: bi chl? qz-inseets fsp?
A 16	Punteglias	716.06/182.80	pyroxene-minette, greenish grey compact to finegrained mac: bi px pseudomorphs
A 17	Punteglias	716.03/182.76	pyroxene-kersantite, grey green massy mac: bi pyx
A 18	Punteglias	715.26/180.97	amphibole-kersantite, grey green massy mac: bi amph
A 19	Punteglias	715.35/182.35	pyroxene-minette, greenish grey compact, finegrained mac: bi px pseudomorphs
A 20	Punteglias	715.31/182.51	amphibole-kersantite, grey green mac: bi amph
A 21	Punteglias	715.06/182.58	pyroxene-spessartite, grey green finegrained, compact mac: hbl px pseudomorphs
A 22	Punteglias	715.22/182.61	pyroxene-spessartite, grey green

Tab. 2 (continued).

			finegrained, compact mac: hbl px pseudomorphs
A 23	Punteglias	715.05/181.36	spessartite, grey green finegrained mac: hbl px pseudomorphs
A 24	Punteglias	715.38/181.71	spessartite, grey green finegrained mac: hbl px pseudomorphs
A 25	Punteglias	714.98/182.19	spessartite, grey green finegrained mac: hbl px pseudomorphs
A 26	Punteglias	712.13/180.54	spessartite, grey green finegrained mac: hbl px pseudomorphs
A 27	Lag Serein	705.05/176.10	dike, ep-bi-schist, green grey mac: ep fsp bi ?amph
A 29	Beichfirn	637.20/142.20	dike, bi-cc-gneiss, clear grey to greenish with qz insets mac: bi chl cc clods
A 30	Aletschhorn	642.70/146.00	lamprohyric dike, clear massy grey mac: chl ser bi fsp ep
A 31	Oberaletschhütte	641.10/141.70	lamprophyre, ser-chl-schist, phyllitic, grey, crenulated mac: bi fsp ser
A 32	Grubengletscher	663.00/162.80	lamprophyric dike, compact grey gneiss mac: qz-insets pyr
A 33	Grimsel	669.10/158.85	dike, chl-ser-schist, dark grey phyllitic mac: chl ser bi fsp-insets
A 34	Grimsel Egg	668.80/158.35	dike, brown grey bi-ser-genis mac: bi ser fsp qz-oicelli
A 35	Grimsel Erlen	668.68/157.80	dike, grey green chlorite schist mac: chl ser bi? pyr qz-oicelli
A 36	Grimsel Erlen	668.68/157.80	dike, bi-chl schist, greyish green mac: chl plg bi
A 37	Grimselhospiz	668.50/158.20	lamprophyric dike, bi-chl-gneiss, greenisch silver grey mac: bi chl plg ep
A 38	Grimselhospiz	668.50/158.20	lamprophyric dike, grey green schistose gneiss mac: bi chl ser
A 39	Zuleitungsstollen Grimsel	T 668 /158 (903m)	foliated lamprophyre, amph-bi-gneiss, very finegrained, strongly foliated mac: chl ser bi amph
A 40	E Grimselsee	668.70/157.70	lamprophyric dike, chl-bi-gneiss, greenish grey with spherulites mac: chl bi ep/fsp clods qz-oicelli
A 41	Verbindungsstollen Grimsel	T 668 /158 F III	lamprophyric dike, chl-bi-gneiss, dark greenish grey mac: chl bi pyr ep/fsp clods
A 42	N Grimselroad	669.50/157.30	lamprophyric dike, bi-chl-ser gneiss mac: chl ser bi
A 43	Grimselpass	669.05/157.60	lamprophyric dike, ser-bi-chl schist, dark grey black phyllitic mac: chl bi ser
A 44	Grimselpass	669.05/157.60	lamprophyric dike, ser-chl-bi-schist, silvery grey to greenish mac: chl bi ser
M 1	Station Glacier des Pelerins		lamprophyre, dark grey green schist mac: chl bi ser
M 2	Below Glacier des Pelerins		lamprophyre, dark grey gneiss mac: chl bi mgt qz-oicelli
G 1	Chämleten	686.50/163.20	biotite plagioclase gneiss mac: bi chl mu
G 2	Mätteli	686.15/161.25	lamprophyre or mafic inclusion, bi-ep-gneiss, grey black, ptygmatic folds mac: bi chl qz segregations
G 3	Mätteli	686.10/160.75	lamprophyric rimfacies of a quartz-porphyre, dark grey biotite gneiss with feldspar clods and veins mac: bi chl ser plg
G 4	Mätteli	686.05/160.60	dike, grey black biotite gneiss mac: bi plg qz
G 5	Gotthardroad	687.80/158.70	lamprophyric dike, grey to black biotite gneiss mac: bi mu fsp
G 6	Gotthardroad	685.70/157.60	dike, massy pseudodioritic biotite epidote gneiss, black and white dots mac: qz bi fsp ep
G 7	Gotthardroad	687.10/154.50	biotite gneiss, green to black mac: fsp bi chl ser
G 8	Gotthardroad	T 687.15/158.10 (5520m S)	biotite schist, silvery grey with white fsp insets, dark bi clods mac: bi mu plg
G 9	Tremolaroad	686.60/155.80	biotite amphibole gneiss, brown grey - mac: amph fsp ser
G 10	Gotthardroad	686.57/155.76	dike, pseudodioritic gneiss with black and white dots mac: bi qz fsp
G 11	Bedretto	T 679 /154 Window (5160m)	lamprophyric dike, compact massy grey mac: bi chl ser
G 12	Rossbodenstock	693.10/165.50	chlorite biotite schist, grey brown mac: chl bi ser
G 13	Rossbodenstock	693.10/165.50	dike, clear silver grey ser-chl-schist mac: chl ser
G 14	Lukmanierroad	707.29 /165.40	dike, clear grey green bi-amph-schist mac: chl ser bi plg
T 1	Laghetti	688.40/147.39	dike, coarse chl-bio-amph-gneiss mac: bi chl ep plg
T 2	Viadotto di Monte	D 702.75/149.25	biotite gneiss mac: bi plg qz
T 3	Viadotto di Monte	D 702.75/149.25	two mica gneiss mac: bi mu plg qz
T 4	Viadotto di Monte	D 702.75/149.25	biotite gneiss mac: bi plg qz
T 5	Viadotto di Monte	D 702.75/149.25	biotite gneiss mac: bi plg qz
T 6	Viadotto di Monte	D 702.75/149.25	two mica gneiss mac: bi mu plg qz
T 7	Viadotto di Monte	D 702.75/149.25	two mica gneiss mac: bi mu plg qz
T 8	W Faido	705.70/148.10	two mica gneiss mac: bi mu plg qz
T 9	Sta. Petronella Biasca	718.40/134.65	two mica gneiss mac: bi mu plg qz
T 10	Quarry Iragna	717.50/132.60	biotite gneiss, dark redish to black with black bi flakes mac: bi plg
T 11	Biascina Block	708.80/142.92	biotite gneiss mac: bi plg qz
T 12	Biascina	708.80/142.92	biotite amphibole gneiss mac: bi plg amph qz
T 13	Biascina	708.80/142.92	biotite gneiss mac: bi plg qz
T 14	Piotte di Bodio	713.40/137.72	biotite gneiss mac: bi plg qz
T 15	Piotte di Bodio	713.40/137.72	biotite gneiss mac: bi plg qz
T 16	Gremosina	711.10/138.65	biotite gneiss mac: bi plg qz
T 20	Val Ambra		biotite gneiss, dark redish with biotite flakes mac: bi plg

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.

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