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Geochemistry of Diabase Dikes of the Silvretta (Switzerland)*

by Barbara E. Hellermann¹

Abstract

In the Silvretta crystalline complex about 200 diabase dikes are known. The dikes intruded in post-Variscan time; they are not affected by Variscan metamorphism and tectonic movements. Primary mineral assemblages are commonly altered in response to Alpine very low grade metamorphism. Major and trace element geochemistry classify the dikes as tholeiitic basalts. Rare Earth element pattern reinforce the continental tholeiitic characteristics and suggest a crustal influence prior to magma intrusion.

Keywords: Diabase dikes, geochemistry, tholeiitic basalts, Silvretta nappe, Switzerland.

1. Introduction

In post-Variscan time about 200 diabase dikes intruded in the crystalline part of the Silvretta, a polymetamorphic complex of gneiss and amphibolite series.

The dikes have been mapped and described petrographically by BEARTH (1932). Beside the petrographic studies, no more than twelve chemical analyses were carried out by different authors (BEARTH, 1932; ESCHER, 1921; FLISCH, 1981; MICHAEL, 1985), which cannot give a complete picture of the mineralogical differences of the dikes, nor of their chemical affinities. The present study is based on 235 chemical analyses from 140 dikes (Fig. 1), including several vertical and horizontal profiles.

2. Field Relations and Petrography

In the Silvretta, mafic dikes intrude polymetamorphic gneisses and amphibolitic associations of the Variscan basement. The dikes are not affected by Variscan metamorphism and tectonic movements. They are not known from the triassic sedimentary cover of the Dukan- and Landwasser trough. From this geological setting, the dikes are assumed to have about Permian age. The dikes are widely metamorphosed with a maximum overprint by Alpine lower greenschist facies. Moreover many dikes display a weak foliation.

The dikes, which range in thickness from few centimeters to a maximum of 50 m, range from fine- to mediumgrained diabase with a sometimes well developed porphyritic texture. Primary magmatic minerals are plagioclase (An compositions from An_{40} to An_{70}) and clinopyroxene, in general augite or titanaugite. In some dikes orthopyroxene (enstatite-hyperstene) instead of augite is present. Both pyroxenes commonly show a subophititcal intergrowth with plagioclase laths. In few specimens talc is present, possibly as a pseudomorph after olivine. Dikes from the eastern part of the investigated area bear in some cases primary brown hornblende. In the interstices quartz, ilmenite, chlorite and biotite crystallized. Apatite is present as primary mineral in interstices or crystallized arbitrary in response to metamorphic events. The Alpine overprint is visible in the following alterations of magmatic phases: plagioclase crystals are variably replaced by epidote-clinozoisite, quartz, calcite and ore replacing it from the center. Secondary albite forms at the rims of the plagioclase crystals. Augite is altered in a first stage to green amphibole and later to chlorite. Veinlets filled with late stage chlorite, epidote, quartz and calcite cut some dikes. Petrographically five groups could have been distinguished which represent the increasing influence of Alpine metamorphism. If the groups are transferred to the geological map they scatter all over the area. No reconstruction of a zonation from the Alpine metamorphism overprint is possible.

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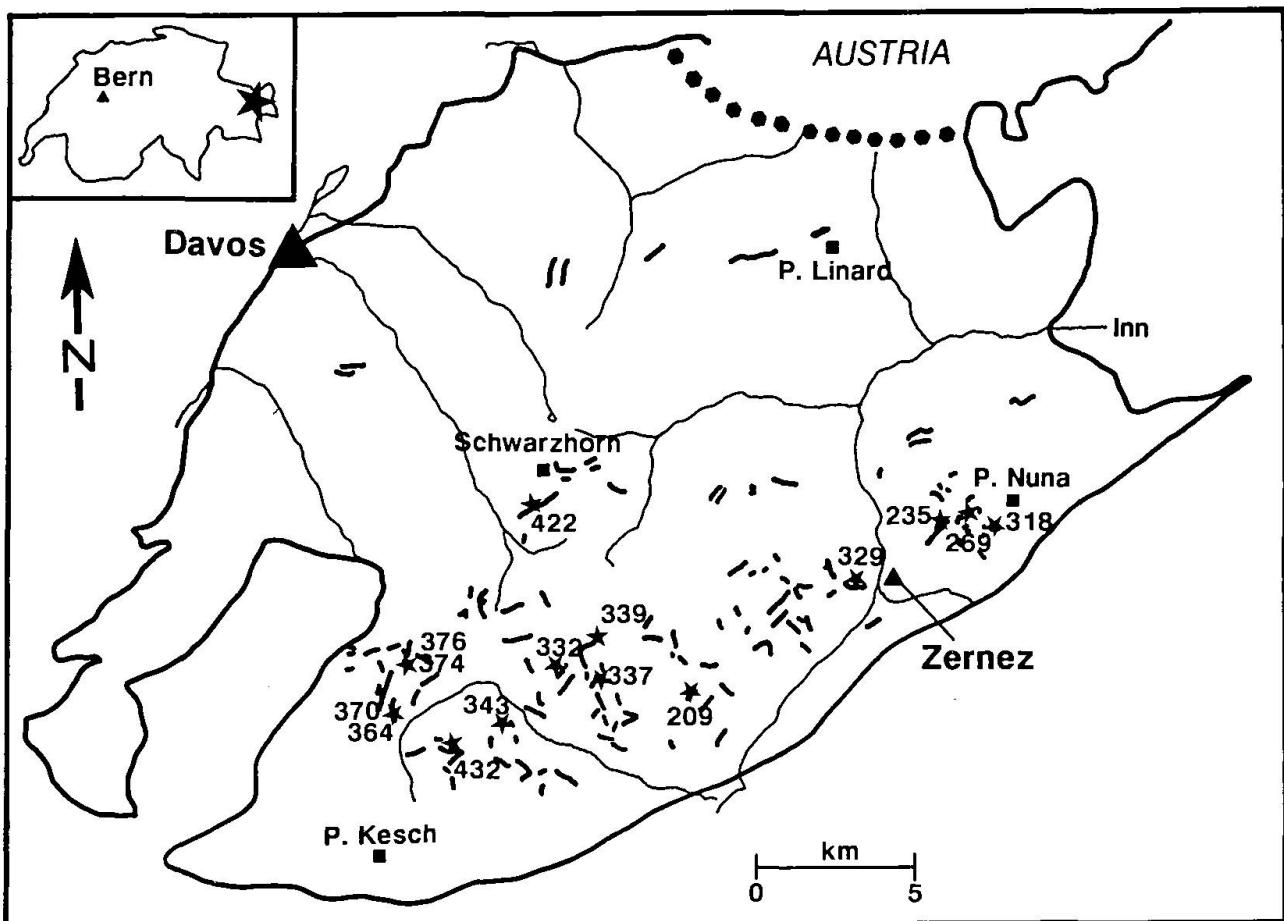


Fig. 1 Schematic map of the Swiss part of the Silvretta crystalline complex with the sampled diabase dikes in black (not to scale). Numbers refer to mentioned samples in the text. Map after BEARTH (1932).

Localities and sample coordinates:

| | | |
|--------|---------------|-------------------|
| BH 209 | Val Barlas-ch | 796 375 / 171 850 |
| BH 235 | Zernez | 804 675 / 177 550 |
| BH 269 | Munt Baseglia | 805 025 / 177 850 |
| BH 318 | Macun | 806 675 / 177 850 |
| BH 329 | Zernez | 802 075 / 175 450 |
| BH 332 | Vallorgia | 792 100 / 172 025 |
| BH 337 | Vallorgia | 793 075 / 172 625 |
| BH 339 | Vallorgia | 793 050 / 172 750 |
| BH 343 | Val Müsella | 790 600 / 169 625 |
| BH 364 | Platta Naira | 786 625 / 170 925 |
| BH 370 | Platta Naira | 786 550 / 171 150 |
| BH 374 | Sertigpass | 787 070 / 172 700 |
| BH 376 | Sertigpass | 787 000 / 172 755 |
| BH 422 | Rad. Rothorn | 791 275 / 177 900 |
| BH 432 | Passhöreli | 787 875 / 170 175 |

3. Major and trace element geochemistry

Major and trace element analyses of some representative diabase dikes are given in Table 1. Major and trace elements of 135 samples were measured with XRF in Fribourg, the rest of 100 specimens was analysed for major, trace and rare earth elements by INAA at Nancy/France.

The analysed specimens show varying degrees of alteration, from those retaining original mineralogy to those in which the primary minerals have been completely replaced. Therefore some mobility of certain elements can be suspected. Secondary mobility is indicated, if the element is plotted against a differentiation index $Mg' (Mg' = Mg/Mg + Fe) * 100$ and proves to show no more correlation (Fig. 2). This is especially evident for Si, Ca, Na, K, Ba, but also Ti, P and Zr reveal an influence of secondary processes, which might be of different origin as will be discussed later.

Overall major element compositions resemble broadly other continental tholeiitic basalts. SiO_2 contents vary between 48.9 and 60.64 wt% with Mg' -values between 30 and 68, indicating a magma suite from fairly primitive basalts to more differentiated derivates. A group of high P_2O_5 and TiO_2 contents is notable which might represent fractionation or variation in initial P_2O_5 (TiO_2 resp.) contents. They show no regional or metamorphic zonation and plot in the Zr/P_2O_5 vs. TiO_2 discrimination diagram from FLOYD and WINCHESTER (1975) in the field of alkali basalts.

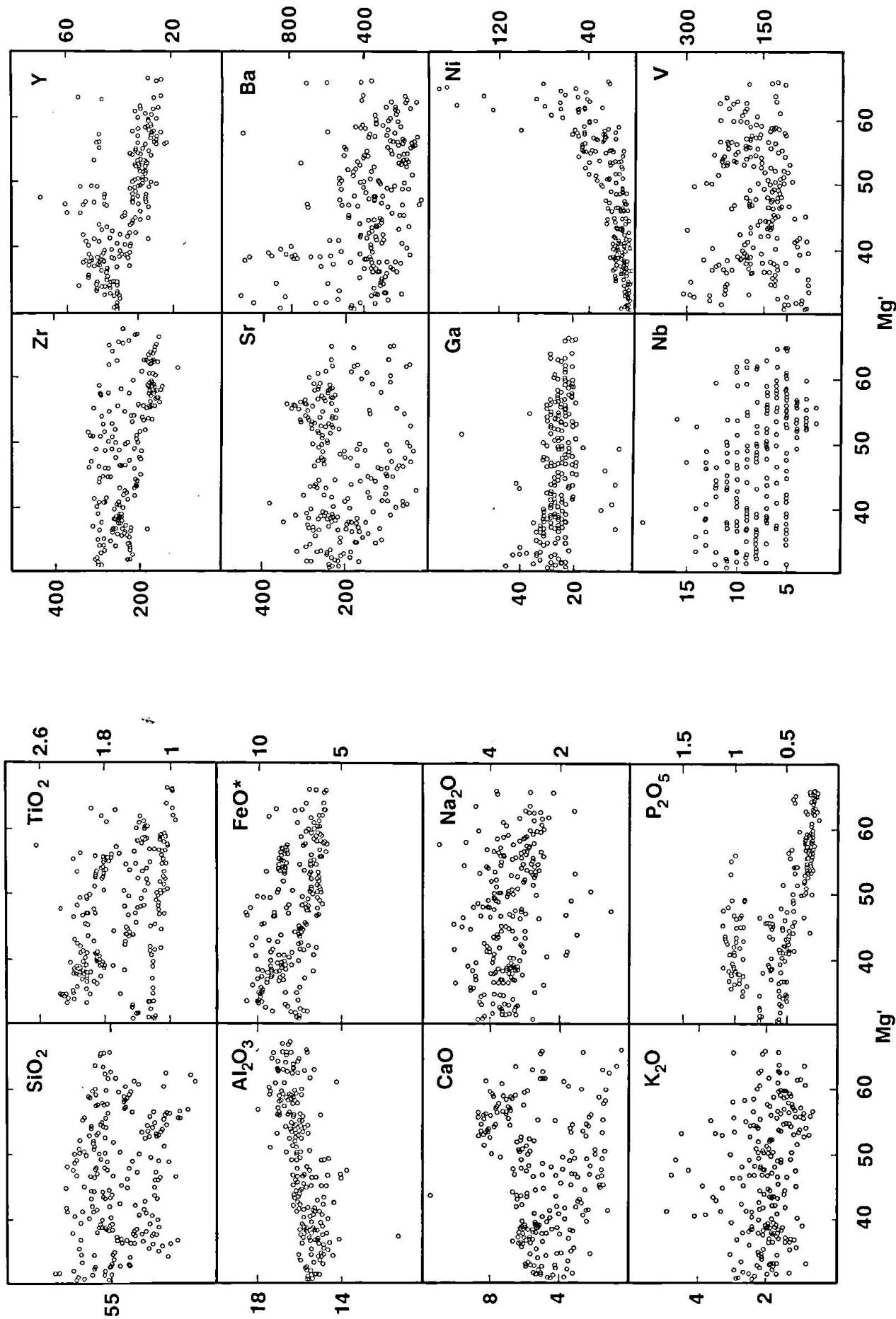


Fig. 2 Variation diagrams for selected major (wt%) and trace elements (ppm) for 235 diabases from the Silvretta. FeO^* = total Fe as FeO .

Tab. 1 XRF and INNA analyses of ten representative samples.

| Sample No. | BH318 | BH329 | BH332 | BH337 | BH343 | BH364 | BH374 | BH376 | BH422 | BH432 |
|--------------------------------|-------|-------|-------|-------|-------|-------|--------|-------|-------|-------|
| SiO ₂ (wt%) | 51.54 | 55.53 | 47.90 | 48.67 | 56.09 | 52.08 | 56.34 | 52.65 | 57.15 | 54.96 |
| TiO ₂ | 2.16 | 1.06 | 1.66 | 1.67 | 1.08 | 2.10 | 0.96 | 0.93 | 1.42 | 2.20 |
| Al ₂ O ₃ | 14.85 | 16.95 | 16.75 | 17.01 | 15.91 | 15.21 | 16.48 | 14.30 | 15.93 | 14.86 |
| Fe ₂ O ₃ | 3.45 | 0.61 | 2.01 | 1.94 | 0.91 | 2.26 | 1.71 | 1.26 | 1.98 | 3.28 |
| FeO | 9.15 | 5.99 | 8.21 | 7.74 | 7.23 | 8.14 | 4.90 | 6.38 | 6.33 | 8.37 |
| MnO | 0.20 | 0.11 | 0.14 | 0.19 | 0.13 | 0.16 | 0.08 | 0.13 | 0.10 | 0.20 |
| MgO | 3.29 | 4.44 | 6.39 | 6.44 | 4.69 | 2.94 | 6.44 | 5.69 | 5.98 | 2.94 |
| CaO | 6.30 | 7.16 | 7.74 | 6.93 | 4.37 | 5.87 | 2.75 | 3.89 | 1.45 | 4.10 |
| Na ₂ O | 4.49 | 3.72 | 3.69 | 4.08 | 3.64 | 4.41 | 3.77 | 3.59 | 4.32 | 3.87 |
| K ₂ O | 1.11 | 1.31 | 0.96 | 1.45 | 2.58 | 1.17 | 2.08 | 1.62 | 1.42 | 2.13 |
| P ₂ O ₅ | 1.04 | 0.28 | 0.30 | 0.32 | 0.32 | 1.06 | 0.96 | 0.28 | 0.39 | 0.49 |
| LOI* | 1.96 | 2.34 | 3.60 | 3.17 | 3.00 | 4.57 | 3.71 | 8.28 | 3.20 | 2.17 |
| Total | 99.54 | 99.50 | 99.35 | 99.61 | 99.95 | 99.97 | 100.06 | 99.00 | 99.67 | 99.57 |
| Mg | 35.50 | 56.20 | 56.90 | 56.70 | 54.80 | 36.70 | 65.20 | 60.80 | 59.50 | 34.60 |
| Ba (ppm) | 249 | 175 | 57 | 145 | 348 | 238 | 694 | 172 | 222 | 273 |
| Cr | 17 | 102 | 125 | 122 | 153 | 35 | 306 | 283 | 55 | 30 |
| Cu | 30 | 33 | 35 | 47 | 40 | 10 | 34 | 34 | 4 | 5 |
| Ga | 26 | 21 | 22 | 22 | 20 | 26 | 20 | 20 | 20 | 27 |
| Nb | 14 | 6 | 8 | 7 | 9 | 7 | 4 | 4 | 10 | 7 |
| Ni | 17 | 48 | 46 | 48 | 51 | 8 | 176 | 66 | 16 | 5 |
| Rb | 49 | 49 | 58 | 74 | 132 | 80 | 63 | 58 | 56 | 70 |
| Sc | 31 | 23 | 32 | 32 | 25 | n.d. | 23 | 25 | n.d. | n.d. |
| Sr | 270 | 324 | 295 | 306 | 137 | 183 | 178 | 86 | 133 | 174 |
| Th | 7 | 6 | <5 | <5 | 6 | <1 | 5 | 7 | 6 | 1 |
| V | 138 | 133 | 189 | 182 | 128 | 137 | 113 | 124 | 215 | 228 |
| Y | 56 | 26 | 48 | 30 | 30 | 46 | 27 | 26 | 33 | 42 |
| Zn | 106 | 89 | 76 | 119 | 93 | 116 | 56 | 18 | 71 | 111 |
| Zr | 290 | 154 | 159 | 162 | 237 | 252 | 237 | 195 | 214 | 229 |
| La | 28.74 | 12.80 | 21.11 | 10.62 | 17.75 | n.d. | 14.17 | 12.52 | n.d. | n.d. |
| Ce | 73.25 | 32.43 | 46.37 | 32.25 | 44.41 | n.d. | 32.44 | 36.35 | n.d. | n.d. |
| Nd | 39.05 | 15.44 | 18.47 | 17.00 | 20.46 | n.d. | 16.96 | 15.27 | n.d. | n.d. |
| Sm | 10.29 | 4.08 | 5.72 | 4.95 | 5.21 | n.d. | 4.26 | 4.29 | n.d. | n.d. |
| Eu | 3.63 | 1.58 | 2.13 | 1.64 | 1.76 | n.d. | 1.52 | 1.33 | n.d. | n.d. |
| Gd | 9.52 | 3.76 | 6.50 | 4.58 | 5.23 | n.d. | 4.64 | 4.11 | n.d. | n.d. |
| Dy | 8.32 | 3.62 | 5.58 | 5.24 | 4.82 | n.d. | 3.84 | 4.20 | n.d. | n.d. |
| Er | 4.17 | 1.96 | 3.06 | 2.85 | 2.64 | n.d. | 2.12 | 2.45 | n.d. | n.d. |
| Yb | 3.77 | 1.98 | 3.20 | 2.65 | 2.51 | n.d. | 2.00 | 2.34 | n.d. | n.d. |
| Lu | 0.64 | 0.31 | 1.21 | 0.42 | 0.48 | n.d. | 0.17 | 0.38 | n.d. | n.d. |
| (La/Lu)cn | 5.20 | 4.78 | 2.02 | 2.93 | 4.28 | n.d. | 9.66 | 3.82 | n.d. | n.d. |

LOI* = Loss on ignition

cn = chondrite normalized

n.d. = not determined

They therefore may be connected to the diabase dikes of the Ötztal massif being geologically related (time of emplacement) to the dikes of the Silvretta. The Ötztal dikes are classified as alkali basalts (PURTSCHELLER and RAMMELMAIR, 1982).

In the Silvretta case, a classification according to this diagram has been abandoned, because zirconium and phosphor are not well enough correlated with Mg' and an alkali chemistry has not been proofed. All diabase dikes of the Silvretta can be classified with the JENSEN (1982) triangle

diagram Al_2O_3 – MgO – FeO_{tot} as tholeiitic basalts. Element variations are moderately controlled by fractional crystallization processes of olivine, plagioclase and pyroxene, as shown by the positive correlations of Ni, Cr (not shown) and Al. Nickel and chrom contents are low for most samples, but increase steeply for primitive, high Mg' dikes. The high Mg, Cr and Ni-contents as typical for crystallization from primitive mantle derived magmas are however not attained.

Porphyritic varieties correlate frequently with the more acid compositions and correspondantly with lower Mg' values. No other relationship between texture and chemistry has been found.

Major element variations within a single dike are most obvious in higher Na_2O and K_2O contents at the center of the dike. Fe, Mg, Ca and Mn migrate into the more acid wall rocks. Where diabase dikes intruded basic series, these small scale differences in chemical compositions are neglectable. Flow-differentiation by plagioclase and pyroxene alignment at the center of a dike can cover the chemical differences mentioned above.

4. Rare earth element (REE) geochemistry

The chondrite-normalized REE pattern of 100 samples show typical trends of continental tholeiites (see Fig. 3). A characteristic feature of all dikes is the marked enrichment of light REE in respect to heavy REE with $(\text{La/Lu})_{\text{cn}}$ varying from 0.8 up to 25. For the samples with an increased $(\text{La/Lu})_{\text{cn}}$ ratio (> 4), a generation of the magma within the stability field of garnet is assumed. Dikes with lower REE abundances and flat pattern resemble p-type MORB (Fig. 3b, BH 337). In normalized spidergrams samples with high REE contents show peaks typical of continental crust (e.g. Lewisian gneiss, WEAVER and TARNEY, 1980) represented by negative anomalies for Th, Rb, Nb, Sr and Ti. It is therefore not ruled out that the non-linear behaviour of these elements in the variation diagrams could be the result of the influence of sialic material prior to dike emplacement.

Only few samples show a marked negative Eu-anomaly as would be expected from the late-stage plagioclase-rich differentiates. Dikes with a negative Eu-anomaly reinforce the conclusion of an olivine-, clinopyroxene and plagioclase dominated fractionation of these melts.

From the similarity of all REE patterns a common mantle source, i.e. a common parental magma is assumed. The tholeiitic diabase dikes

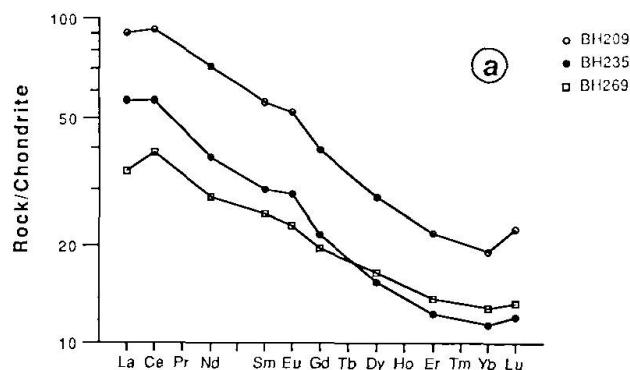


Fig. 3a Chondrite-normalized REE abundances for three selected samples. Normalization factors by NAKAMURA (1974).

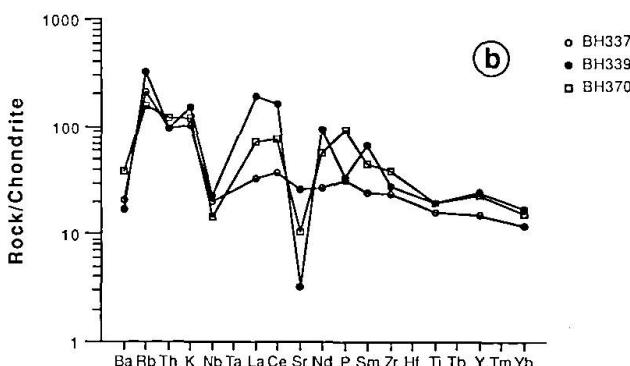


Fig. 3b Reduced trace element diagram for three selected samples. Normalizing factors as in Fig. 3a. Sample BH 337 resembles p-type MORB.

of the Silvretta are chemically similar to other continental, tholeiitic dikes, e.g. the quartz-dolerite from Mull (MORRISON et al., 1980), a dolerite from Morocco (BERTRAND et al., 1982) and the Great Cleveland dike in Great Britain (MACDONALD et al., 1988).

5. Conclusions

The diabase dikes of the Swiss part of the Silvretta can be described as continental, tholeiitic basalts. In chemical variation diagrams fresh and altered samples reflect influences of post-magmatic metamorphic overprints, as well as primary crustal contamination effects and/or mantle heterogeneities.

The dikes represent a magmatic suite, which evolved by fractional crystallization of olivine, clinopyroxene and plagioclase from a mantle derived magma.

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