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On Calcic Amphiboles and Amphibolites from the Lepontine Alps

By *E. Wenk*, *H. Schwander* and *W. Stern* (Basel) *)

With 24 figures in the text and 14 tables in appendix I

Summary

Spectrographic, XF- and microprobe-analyses of 56 calcic amphiboles from amphibolites and related rocks of the Central Alps, 15 coexisting biotites and 35 host rocks are presented. In the area considered mainly rocks in amphibolite facies are exposed; transitions to greenschist facies occur in the marginal parts. The metamorphic grade of amphibolites is judged in accordance with the anorthite content of the coexisting plagioclase. Fabric criteria and parageneses of amphibolite facies rocks indicate close approach to equilibrium conditions during the main phase of Tertiary regional metamorphism.

In amphibolite facies rocks common hornblende, rarely associated with actinolite, shows limited chemical variation, in spite of the considerable and regular compositional change of the coexisting plagioclase from high to low grade metamorphic zones. Mg increases in amphiboles as well as in amphibolites with higher grade and there is clear interdependence between the Mg/Fe ratios of hornblende, biotite and host rock. The mean values for Fe_2O_3, Na_2O and H_2O of the amphibole appear to decrease with higher grade, but the standard deviations are considerable. The bulk of common hornblendes is concentrated between Al^{tot} 1.75 and 2.4. Our data for amphibolite facies hornblendes indicate a compositional gap in the range Al^{tot} 1 to Al 1.75. In greenschist facies rocks, however, a miscibility gap is not evident. Tschermakitic hornblendes with $Al^{tot} > 2.5$ are of common occurrence in the schist-belt south of Gotthard and Lukmanier passes.

In amphibolite facies rocks the pronounced increase in anorthite content, reflecting progressive metamorphism, is performed mainly by modal variation. The quantities of Na, Ca, Si and Al remain fairly constant in the system (though not in greenschists). Plagioclase has to consume the major part of Na, hornblende the minor part. With rising anorthite content of plagioclase the balance can only be preserved by the formation of more feldspar, mainly at the expense of epidote-clinozoisite, chlorite and biotite, and in later stages also at the expense of hornblende. Modal analyses and calculations from rock and mineral analyses both show that andesine-amphibolites contain twice as much plagioclase as albite-amphibolites.

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1. Introduction

During the past twelve years many authors have investigated the regional distribution of rock-forming minerals, their physical and chemical properties and parageneses in the Central Alps, especially in the Canton Ticino and adjacent parts of Italy and in the Cantons Valais and Grisons. In this wide area of the Lepontine Alps, covering about 7500 km^2, rocks mainly in the amphibolite facies are exposed; transitions to greenschist facies occur in the marginal part of the area. The whole region is by now well subdivided by isograds of different types which form a concentric system, imprinted during various phases of Alpine regional progressive metamorphism, culminating in the Oligocene-Miocene.

Metamorphic carbonate-rocks, aluminous schists and ultramafic rocks have been studied extensively, and this highly rewarding research is still in progress. It appeared desirable to extend these investigations to the basic rocks after which the metamorphic facies are named: amphibolites and greenschists. These usually form extended zones of moderate thickness and, although minor in importance in comparison to gneisses and micaschists, they serve as geological key horizons. Amphibolites should be useful also as indicators of metamorphic grade. Often they are composed of only two main constituents and a few accessories, and they show a regular equidimensional fabric indicating close approach to equilibrium conditions.

Paragenetic studies require rich and representative collections. The first author started sampling in the Central Alps many years ago, and in 1969 E. Wenk and F. Keller reported on the results of modal anorthite determinations in 700 different amphibolites, listed in the appendix of the cited paper. These investigations outlined concentric zones of albite-, oligoclase-, andesine- and labradorite-amphibolites indicating progressive metamorphism. The highest grade rocks are confined to structural steep zones, especially to the so called root zone in the south and to the Maggia zone in the centre. The general pattern of these plagioclase isograds is in good agreement with the plagioclase isograds observed in silicate-marbles and calc-schists of the same area. The zones of highest and of lowest metamorphic grade coincide, only the absolute An-values differ. This indicates that there are no profound differences between the patterns of plagioclase isograds developed in CO_2-free rocks and those found in series strongly influenced by CO_2 partial pressure.

The present study is mainly concerned with questions of hornblende composition, modal and chemical variation of the host rock. It relies upon the collections described by Wenk and Keller (1969), augmented by further sampling (see sample maps Fig. 1). The responsibility for the extraction of mineral concentrates, for the chemical analyses and for parts 2 to 4.2 of the text rests with the second and third authors and their collaborators. The cell parameters of most of the analysed amphiboles, and a discussion of their variation with chemical composition, have been published by H. R. Wenk (1971).

A review of existing literature reveals little compositional variation of common hornblende in amphibolites of different grade, in spite of the given possibilities of complex crystallochemical substitution. The variation is controlled mainly by rock composition (especially Mg/Fe-ratio). Published evidence

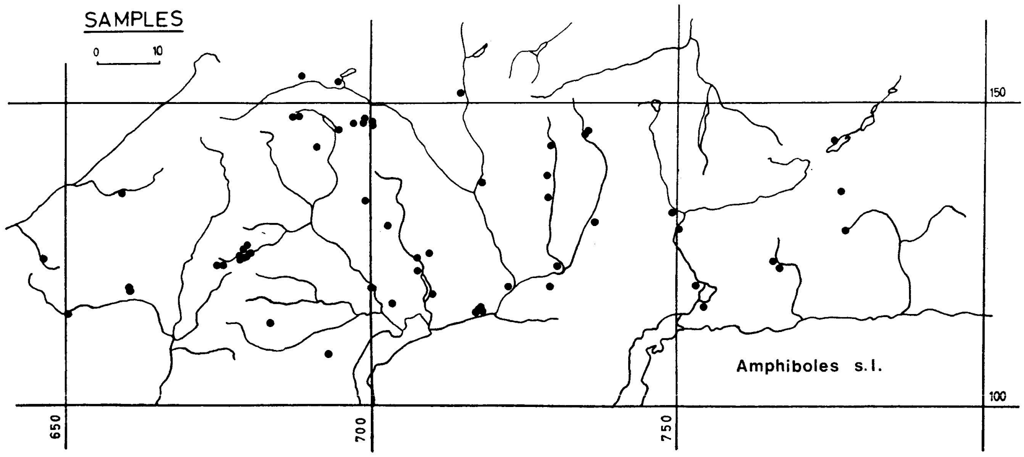


Fig. 1a. Samples, Amphiboles s. l.

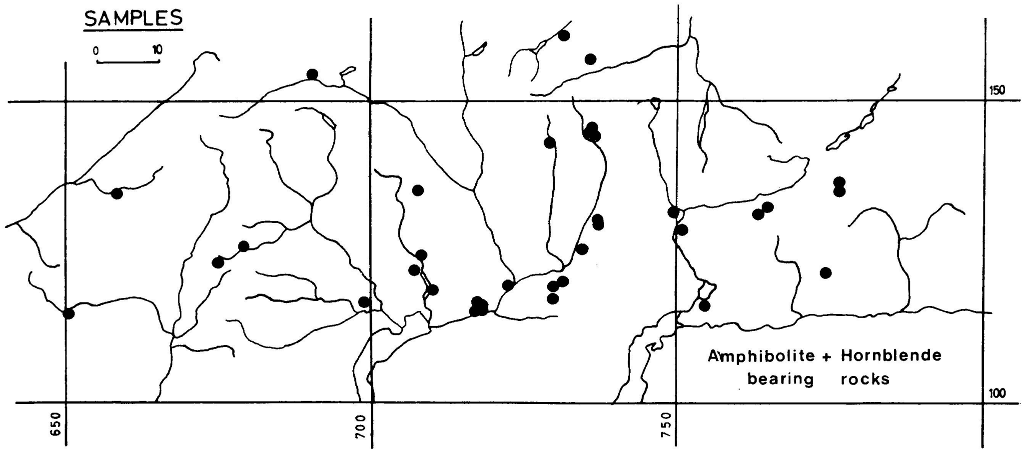


Fig. 1b. Samples, Amphibolite + Hornblende bearing rocks.

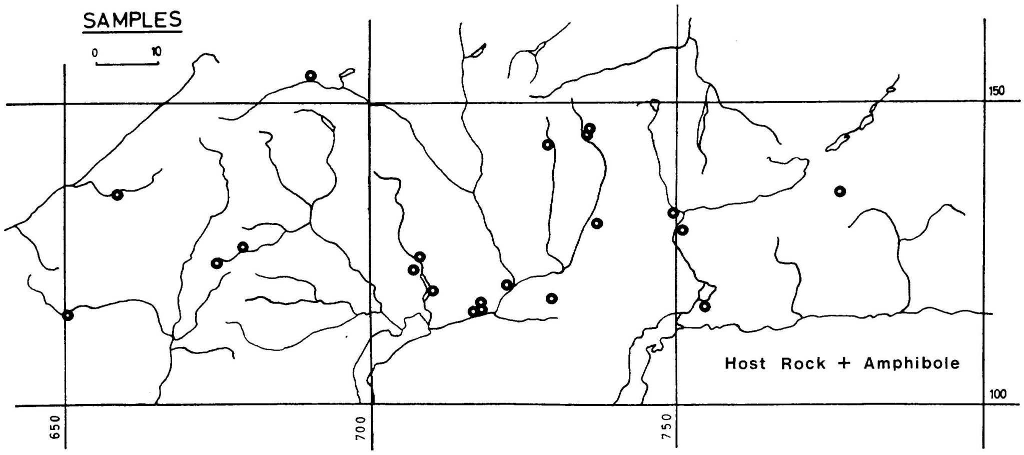


Fig. 1c. Samples, Host rock + Amphibole.

ascribing minor variations in hornblendes to metamorphic grade is in part consistent, in part conflicting. Also our contribution dealing with this complex subject leaves room for further discussion. We have the feeling that scientists often ask questions that nature does not pose, or to which our instrumental possibilities cannot reply. Obviously it seems more promising to concentrate upon those topics where clear statements can be made. Our discussion also deals with the arising difficult problem: How does plagioclase manage to change its anorthite content so well in response to metamorphic grade, even in rocks of similar bulk composition and without compensating change in hornblende composition?

Reference samples of the rocks and minerals described are in the collections of the Department of Mineralogy of the University of Basel (Switzerland). Research on these materials is still in progress by A. Steck (Lausanne, ore minerals), R. Steiger (Zürich, age determination of hornblendes) and H. Ulbrich (Basel, tschermakitic hornblendes of the Gotthard road-tunnel).

2. Methodological considerations

2.1. CHEMICAL INVESTIGATIONS

2.1.1. X-ray microprobe

Polished thin sections of amphibolites were investigated with a Jeol probe (for excitation conditions see table 1). Sample preparation was carried out with special care:

First grinding up to a gradation of emery-1000 and a slide thickness of 30 microns, subsequently polishing by hand on Metcloth 40-7158 support with one micron diamond paste, or on a Depiereux apparatus. Certain rocks had to be hardened prior to polishing with epoxy resins (araldite or Z 70 C).

After cleaning with brush and detergents, the thin section was coated first with a few angstroms of carbon, thereon with approximately 200 Å of gold (evaporation of a constant quantity of Au).

The use of different silicate minerals as reference samples causes generally different interelemental effects; working with low excitation conditions (as low as possible for an old type instrument) these elemental interactions may be reduced, and sample contamination as well. The lower limit of those excitation conditions is given by the counting statistics.

The overall reproducibility of our measurements has been checked by testing chemically homogeneous plagioclase and amphibole samples (e. g. Cal 21). The variation found corresponds reasonably well with the expected error of the probe. Thus, the quality of our thin sections seems to be sufficient.

2.1.2. Analysis of main constituents with X-ray fluorescence

Details of sample preparation and analyzing techniques have been described in a previous paper (Stern, 1972). Most of the analyses listed below have been executed according to these procedures, a few by means of light optical emission spectrometry (Schwander et al., 1968).

Mineral separation was performed mainly according to Stern (1966). Due to frequent intergrowths of amphiboles, especially from low grade amphibolites, minerals became separated out of small siftings (grain diameter 0.1 to 0.2 mm).

In certain cases, no pure hornblende concentrates could be obtained; these samples with 2 to 10% of inclusions and intergrowths were labelled as "concentrates".

2.1.3. Spectrographical trace element analysis

Some trace elements were analyzed by means of light optical emission spectrography according to Schwander et al. (1968).

2.2. PHYSICAL INVESTIGATIONS

2.2.1. Density

The density of the hornblende samples was determined using a 10 ml bottle, Gay-Lussac type, with a mixture of 10% alcohol in distilled water.

2.2.2. Index of refraction

The refractive indices of amphiboles have been determined on grains oriented with the aid of an Eulerian cradle. The microgoniometer/cuvette assemblage, developed and described by Steck and Glauser (1968), was used for the determinations listed in this paper.

2.2.3. Modal analyses

The mineral modes have been determined mainly with a point counter on the base of 2000 grains per thin section, step width 0.25 mm. Each slide was scanned in the two main directions; the accuracy of these determinations is approximatively $\pm 2\%$ rel.

The modes of some amphibolite samples were estimated; the accuracy may be assumed to reach $\pm 5\%$ rel.

3. Results

The bulk of analytical data is listed below, in tables 2–4, 6 and the evaluation follows in chapter 4.

Part of the analytical information had to be recalculated: structural formulae of minerals, QLM values of rocks, etc., have been computed by a Diehl Combitron calculator (program input with punch tape). Part of the programs had been obtained as software from Diehl Ltd. (regression calculations, student t test), another part has been set up by us.

3.1. CALCIC AMPHIBOLES (Tables 2, 6, Figures 2, 3)

With one exception (Bni 258) all analyses presented in tables 2 and 6 belong to the group of calcic amphiboles. Most of these monoclinic amphiboles from the Central Alps fit the conditions $(Na+K)_A < 0.5$ and $Ti < 0.5$, only in 13 cases is $(Na+K)_A > 0.5$. In fig. 21 the common hornblendes from amphibolites are concentrated in the field Al^{tot} 1.75–2.4, while actinolites and tremolites from silicate-marbles and mafic lenses found in the same area, occupy the corner $Al^{tot} < 1$. Accordingly our analyses have been grouped in the two tables 2a and 2b. Hornblendes with high alumina contents tending towards tschermakite, occur in a schist belt (garnet-hornblende-Garbenschiefer) which includes also some true amphibolites and which is localised in a zone south of the Gotthard massif (rock group III, Tremola, Frodalera). For these tschermakitic

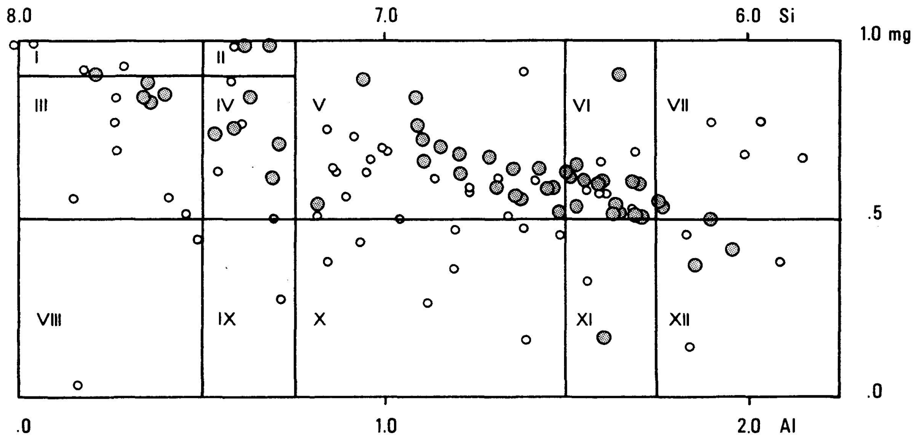


Fig. 2a. Calcic amphiboles, plotted after LEAKE (1968): $Ca+Na+K<2.50$; $Ti<0.50$. New data: big circles; literature: small circles.

I	Tremolite	II	Tremolitic hornblende
III	Actinolite	IV	Actinolitic hornblende
V	Mg-hornblende	VI	Tschermakitic hornblende
VII	Tschermakite	VIII	Ferro-actinolite
IX	Ferro-actinolitic hornblende	X	Ferro-hornblende
XI	Ferro-tschermakitic hornblende	XII	Ferro-tschermakite

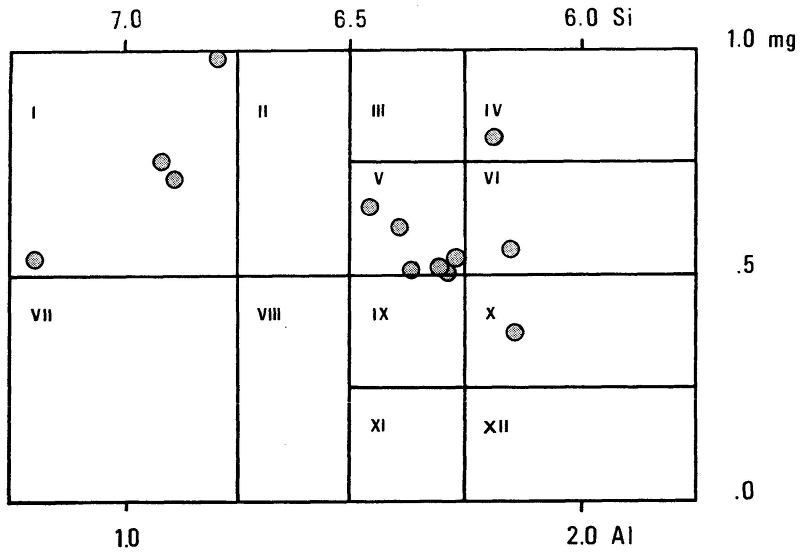


Fig. 2b. Calcic amphiboles, plotted after Leake (1968): Ca+Na+K>2.50; Ti<0.50.

I Edenite
II Edenitic hornblende
III Pargasitic hornblende
IV Pargasite
V Ferroan pargasitic hornblende
VI Ferroan pargasite
VII Ferro-edenite
VIII Ferro-edenitic hornblende
IX Mg-hastingsitic hornblende
X Magnesian hastingsite
XI Hastingsitic hornblende
XII Hastingsite

amphiboles which are included in tables 2a and 6, Angel (1967) proposed the name "gotthardite".

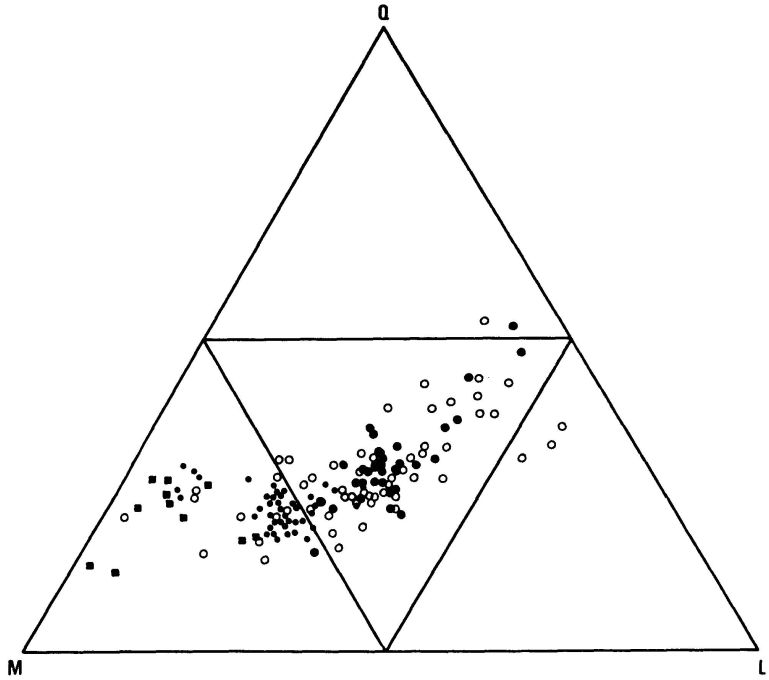


Fig. 3a. QLM-plot of calcic amphiboles and amphibolites. New data: small dots = calcic amphiboles; black rectangles = actinolitic/tremolitic hornblendes; big dots = amphibolites/hornblende bearing rocks. Literature: open circles = amphibolites/hornblende bearing rocks.

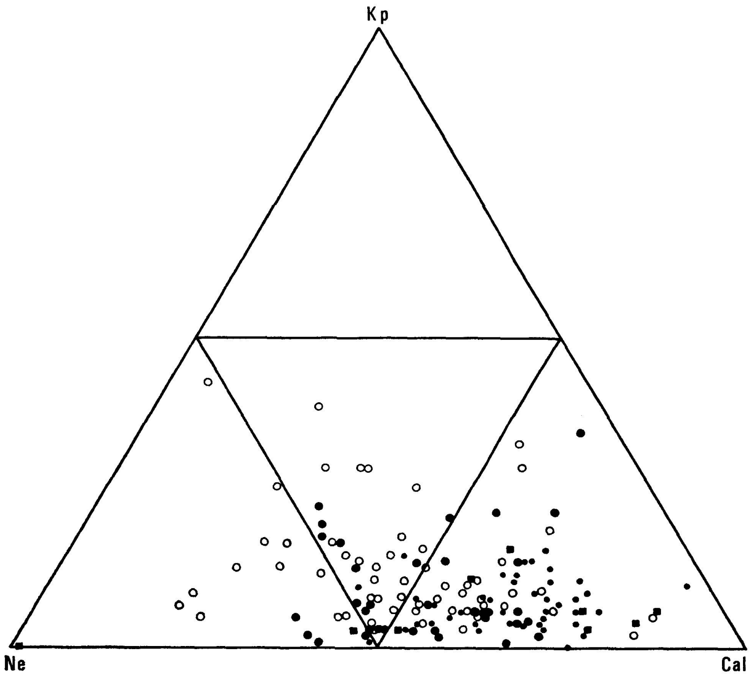


Fig. 3b. Kp-Ne-Cal plot; for explanation of symbols see fig. 3a.

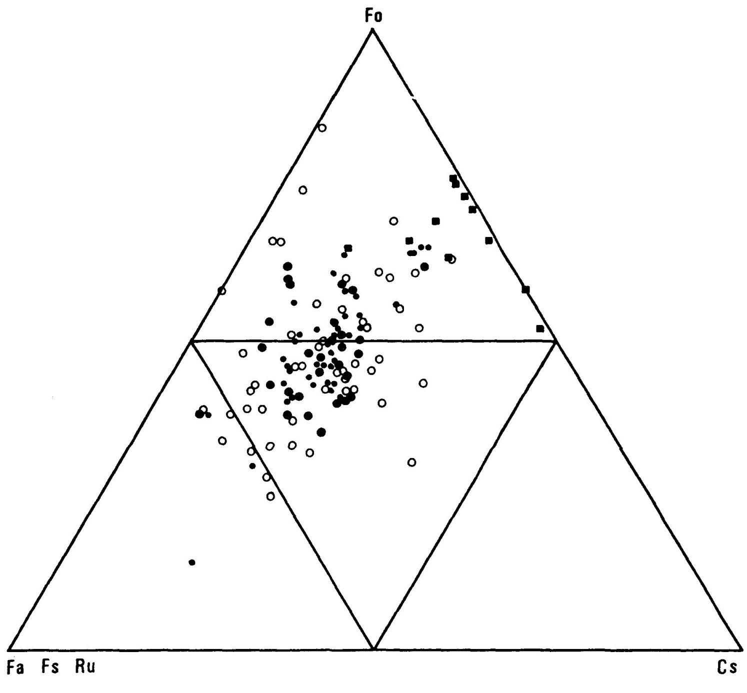


Fig. 3c. Fo-Fa-Cs plot; for explanation of symbols see fig. 3a.

While in the Ticino area proper, a clear miscibility gap exists between tremolite and common hornblende, the data presented by WETZEL et al. (1973) from lower grade metamorphic series adjacent to the W indicate miscibility (actinolitic hornblendes) and a trend toward edenitic and pargasitic compositions with $(Na+K)_A > 0.5$.

The analyzed calcic amphiboles are graphically presented on Figs. 2 and 3; some crystal chemical data are plotted on Figs. 4, 5 showing the distribution of octahedral sums (mean approximatively 5.00, probably more than one normal distribution) and of alkali sums (mean ±2.25, normal distribution).

The chemical homogeneity of the amphiboles was tested by microprobe. Spot analyses were taken along lines perpendicular and parallel to c of selected hornblende crystals; line scanning was not possible due to low sensitivity and

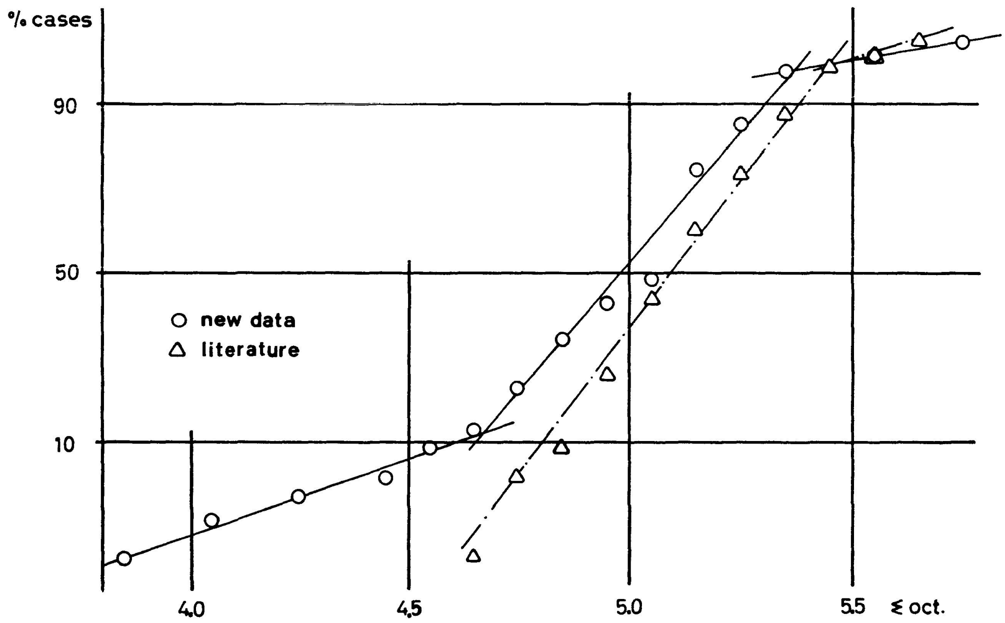


Fig. 4. Octahedral sum of calcic amphiboles; N = 60 new data, 90 from literature (triangles).

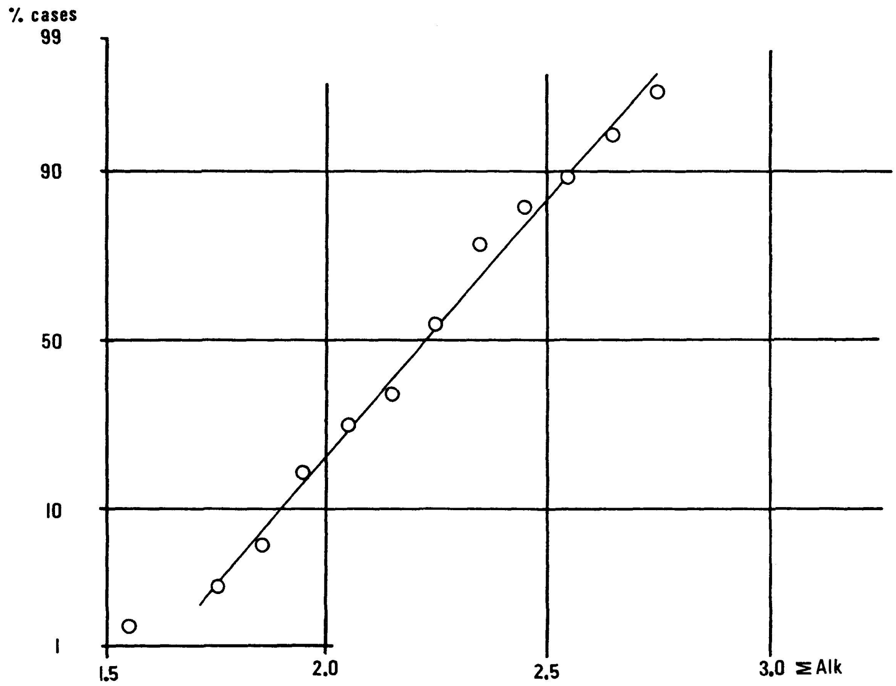


Fig. 5. Alkali sum of calcic amphiboles: normal distribution; N = 65.

the probable influence of topographical effects. Amphiboles from high grade amphibolites with well developed mosaic structure, showed a homogeneity corresponding with the relative error of the probe – point analyses along the mentioned lines showed the same variability as the respective averages of different mineral grains in the same slide:

1 to 2% rel. in case of SiO_2, 3 to 5% rel. in case of Al_2O_3, FeO_{tot}, MgO and CaO, 5 to 10% rel. in that of Na_2O, K_2O, see table 6. In these amphibolites it seems, that from the chemical standpoint, only one type of amphibole exists.

In the zone of low grade metamorphism however, especially in the marginal part of the Lepontine Alps, rather inhomogeneous hornblende patterns occur; spot analyses on one and the same crystal prove a better homogeneity – though being zoned – than the averages of different grains of the same thin section. Thus certain amphibolites of the lower metamorphic margin seem to contain at least two types of calcic amphiboles showing especially high variations of Si and Al and having high Si/Al-ratios. Whether the possible chemical variability of those amphiboles could even be greater or not, may not be decided on the base of the present data. If there exists furthermore an interdependence between chemical composition and casual zonality or domain texture should be tested with these chemically inhomogeneous amphiboles. This investigation should however be done by means of a new type microprobe with high geometrical resolution.

Microprobe analyses of calcic amphiboles and their structural formulae are listed on Table 6, the octahedral cations are plotted on Fig. 6.

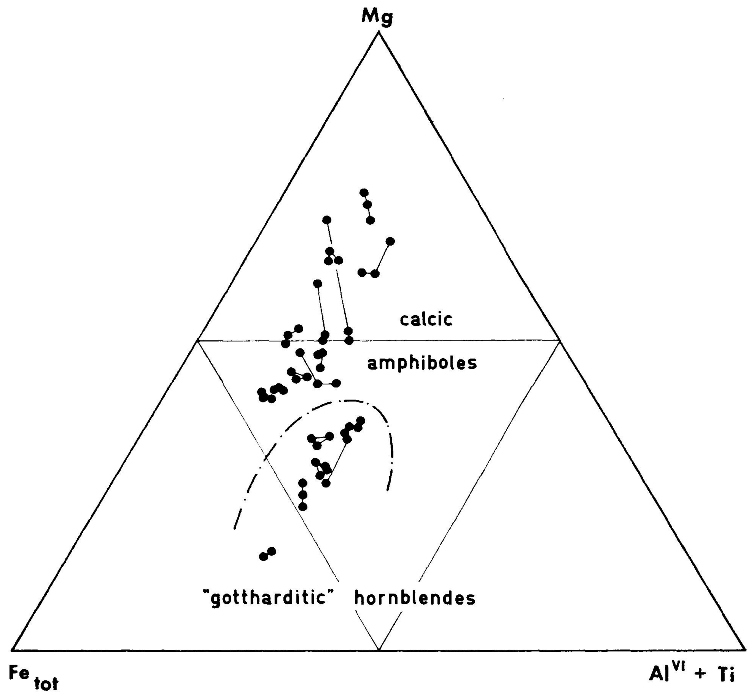


Fig. 6. Microprobe analyses of calcic amphiboles; tie lines between corresponding spot analyses on one crystal. Mg-Fe-Al^{VI} plot of octahedral cations.

The number of analyses being rather high – 106 amphibolites including literature values, and 86 calcic amphiboles of the Central Alps – a statistical evaluation of the data seemed to be of interest. The analyses were grouped according to petrographical criteria, i. e. to the optically determined An content of plagioclase in amphibolites (see Table 10), and the respective averages, standard deviations and variations of every main constituent were calculated (Table 11a, b).

From these data, student – t values were computed and the probabilities estimated for the chemical difference of the respective petrographical groups (see Fig. 7). It is obvious that the analyzed calcic amphiboles show clearer differences than the corresponding amphibolite groups: sodium, magnesium, aluminum, silicon (the latter in groups I, III only) in the case of calcic amphiboles, and calcium and H_2O^+ only in the case of amphibolites seem to have a certain diagnostic meaning in the Lepontine Alps, if any. Considering the often large variances in between these petrographical groups, one should not exaggerate the meaning of a single criterion.

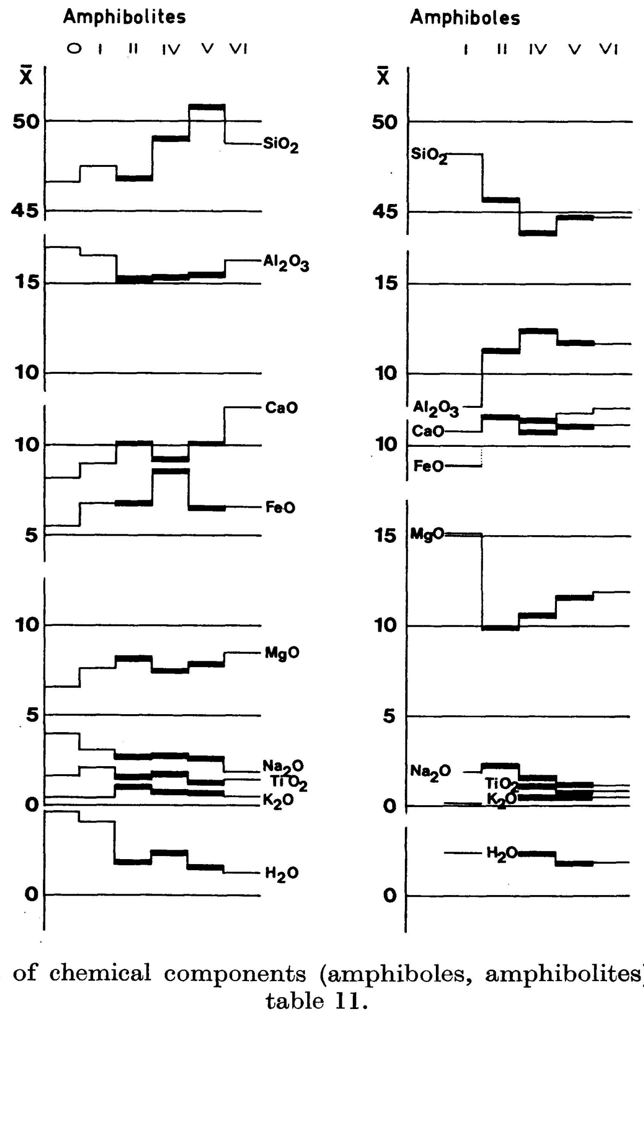


Fig. 7a. Mean values of chemical components (amphiboles, amphibolites), for comparison see table 11.

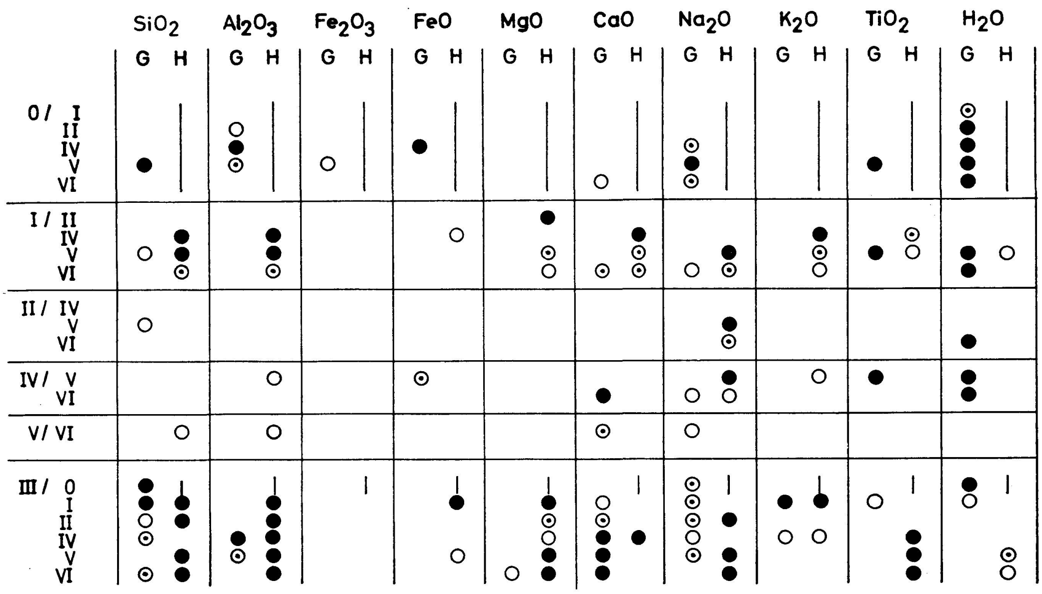


Fig. 7b. Probabilities estimating the chemical differences between petrographical groups.

● 99.6–99.99% probability G rocks
⊙ 98.5–99.5 H amphiboles s. l.
○ 95 –98

For roman ciphers see p. 144. Sources of chemical data: De Quervain et al. 1956, Leake 1968, Steiger 1961, Dietrich 1969, Weibel 1964; and analyses listed on tables.

3.2. TRIOCTAHEDRAL MICAS (Table 3, Fig. 8a–c)

From some amphibolites trioctahedral micas have been separated and analyzed as well. Moreover, published data (Wenk et al., 1963) have been added on micas coexisting with hornblendes discussed in this paper.

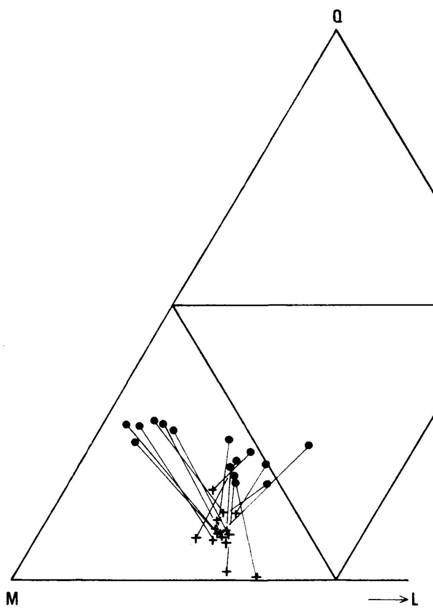


Fig. 8a. QLM plot hornblende-mica.

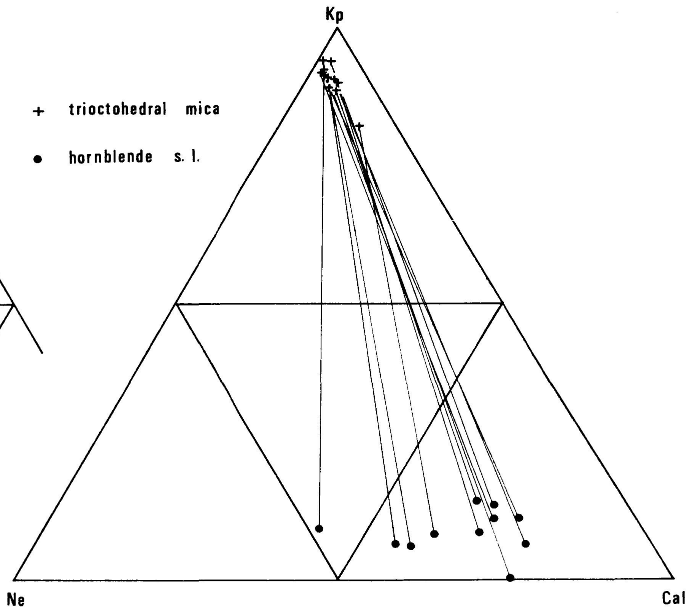


Fig. 8b. Kp-Ne-Cal hornblende-mica.

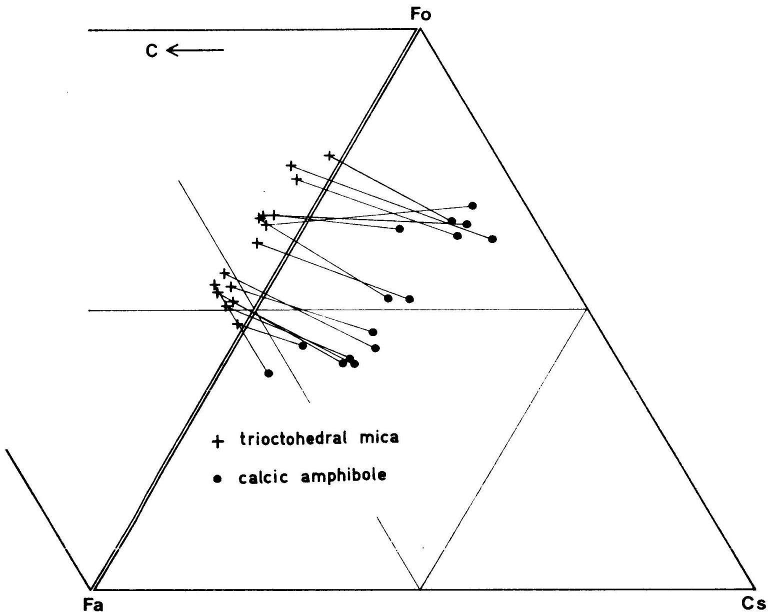


Fig. 8c. Fo-Fa-Cs/Fo-Fa-C plot of coexisting trioctohedral micas and calcic amphiboles.

3.3. HOST ROCKS; NEW AND LITERATURE DATA OF SOME LEPONTINE AMPHIBOLITES (Table 4, Figures 9a–c)

Only for 21 of the analyzed amphiboles can we present analytical data of the respective host rocks; on the other hand, we list a number of amphibolite analyses without corresponding data on hornblendes.

Recent published data on amphiboles and amphibolites from the Lepontine Alps are rather scarce. It seems moreover necessary to omit most of the early analyses collected and published by DE QUERVAIN et al. (1956), because of their questionable sodium values.

4. Discussion

4.1. CORRELATION BETWEEN CHEMICAL AND PHYSICAL DATA

The ratio Mg/Mg + Fe + Mn represents not only the basis of classification of the structural formulae (Table 5), but shows positive correlation with some physical parameters, such as density and refractive index (Fig. 10–12). Insofar as both specific weight and index of refraction are related to the chemical character of a calcic amphibole, density itself seems to be connected linearly with the optic parameters (see Fig. 13).

The optic parameters show a similar trend for n_α and n_γ, both rising parallelly, whereas $2V_x$ decreases at the same time. This phenomenon may be explained by the fact, that n_β–n_α increases generally with higher values, whereas n_γ–n_β diminishes (see Fig. 10).

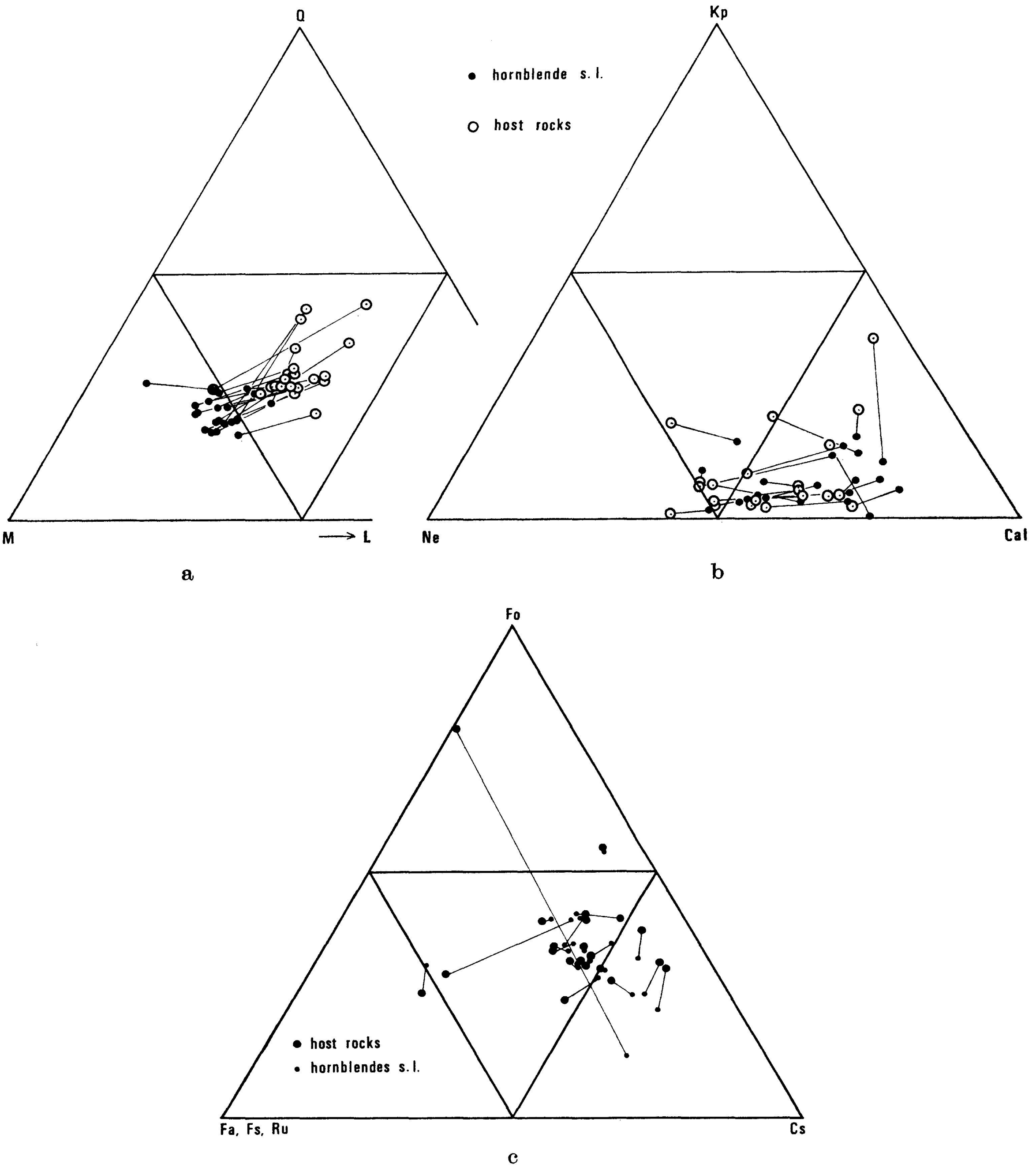


Fig. 9a/b/c. QLM plots of calcic amphiboles and host rocks. Small black dots = calcic amphiboles; big black dots = host rocks.

4.2. CHEMICAL RELATIONS BETWEEN COEXISTING MINERALS AND HOST ROCKS

From the two coexisting minerals hornblende s. l. and trioctahedral mica, only one main chemical constituent – magnesium – shows a clear interdependence between not only the two mineral phases (Fig. 14), but between horn-

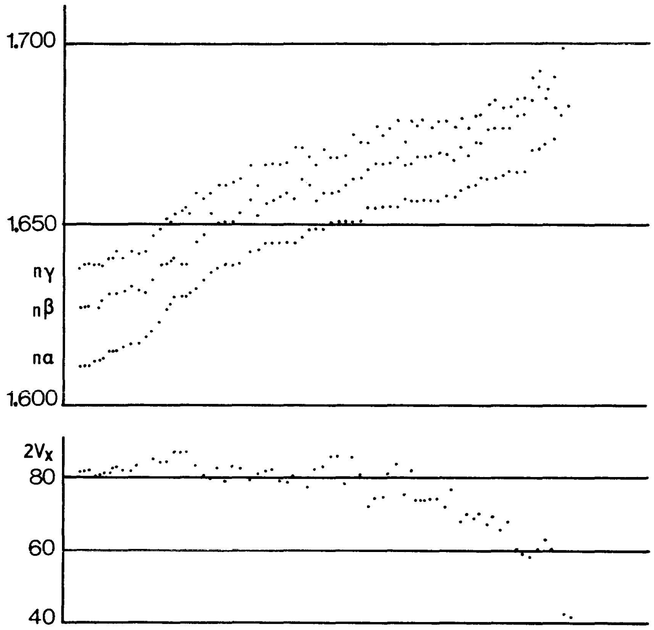


Fig. 10. Optical parameters of calcic amphiboles; grouping according to rising values of n_α.

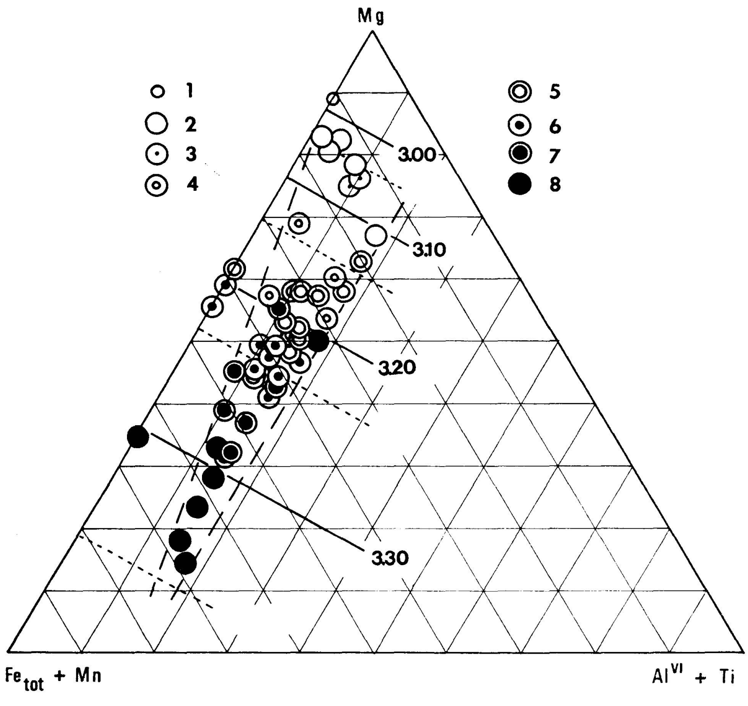


Fig. 12. Density of calcic amphiboles. Mg-Fe-Al^{VI} plot of octohedral cations.

1	D<3.00	2	3.01–3.05
3	3.06–3.10	4	3.11–3.15
5	3.16–3.20	6	3.21–3.25
7	3.26–3.30	8	>3.31

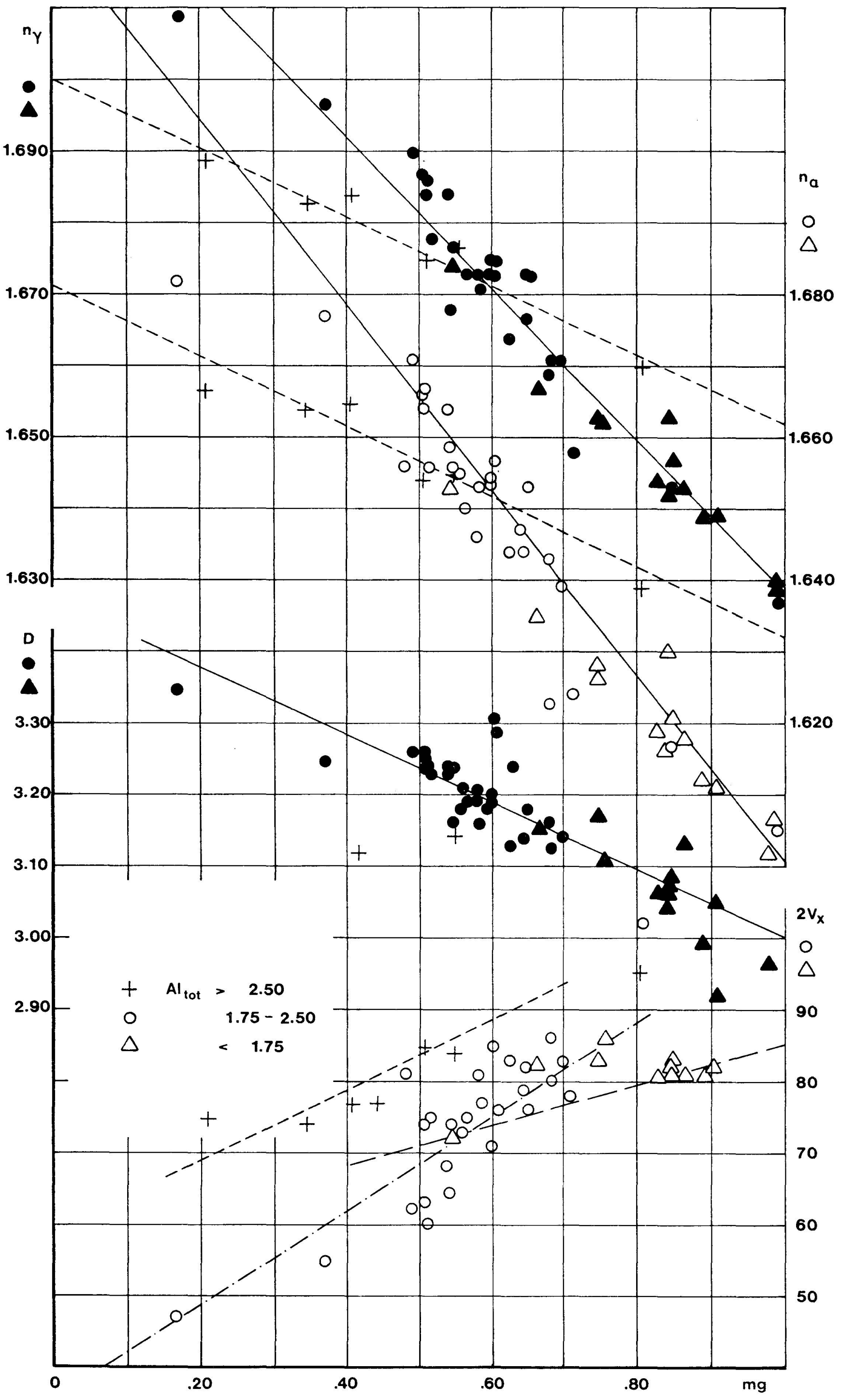


Fig. 11. Density, and optical parameters vs mg ($Mg/Mg+Fe_{tot}+Mn$) of calcic amphiboles. Triangles: tremolitic/actinolitic hornblendes; open circles: common hornblendes; crosses: "gottharditic" hornblendes. Calculated regressions: full lines for common and trem./act. hornblendes, broken lines for "gottharditic" hornblendes.

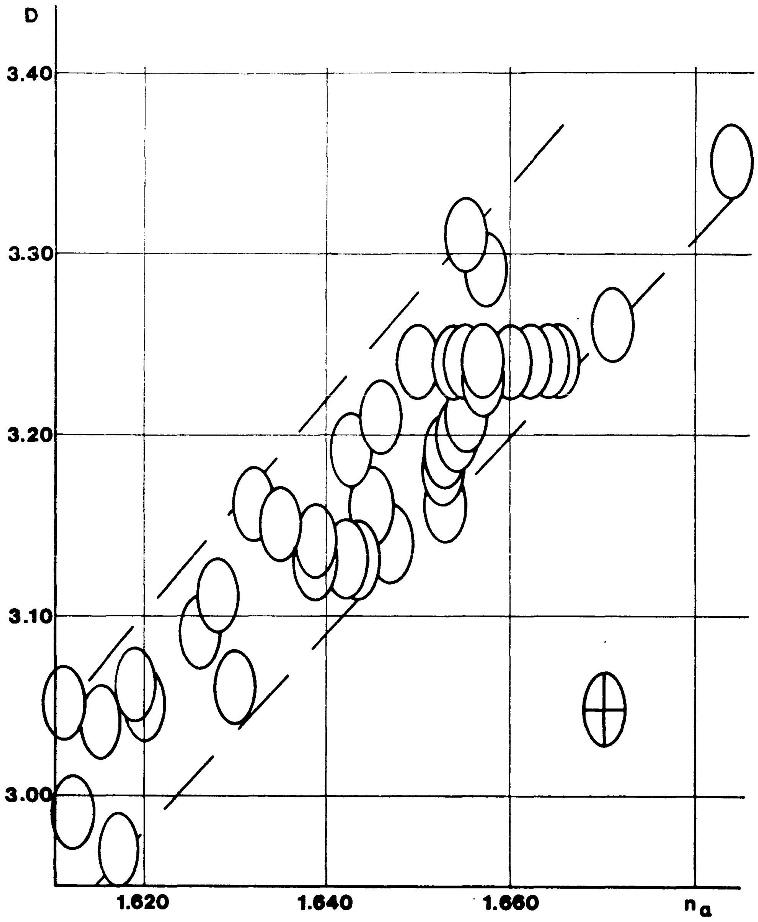


Fig. 13. Density vs n of calcic amphiboles.

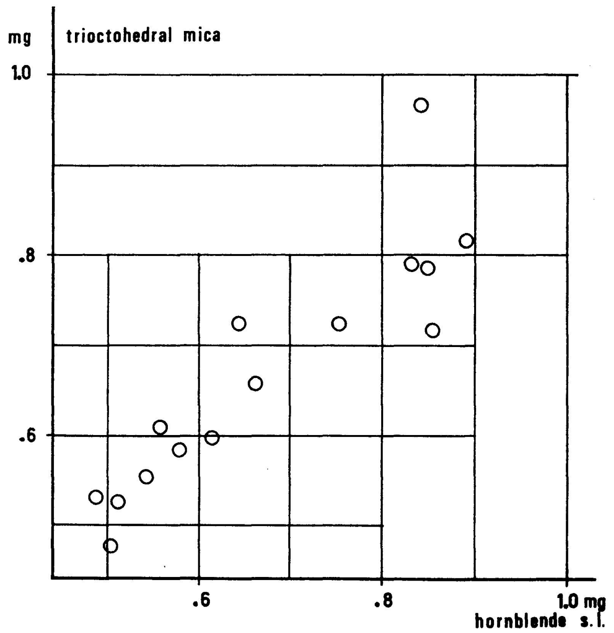


Fig. 14. mg (Mg/Mg+Fe‴+Fe″+Mn) of coexisting calcic amphiboles and trioctohedral micas.

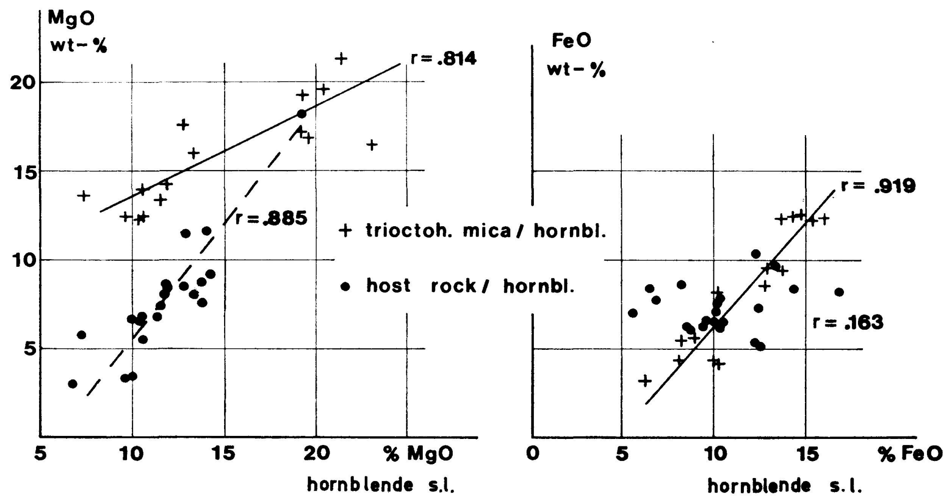


Fig. 15. MgO and FeO distribution (wt-%) between hornblende s. l. / host rock, and hornblende s. l. / coexisting mica. r = coefficient of correlation.

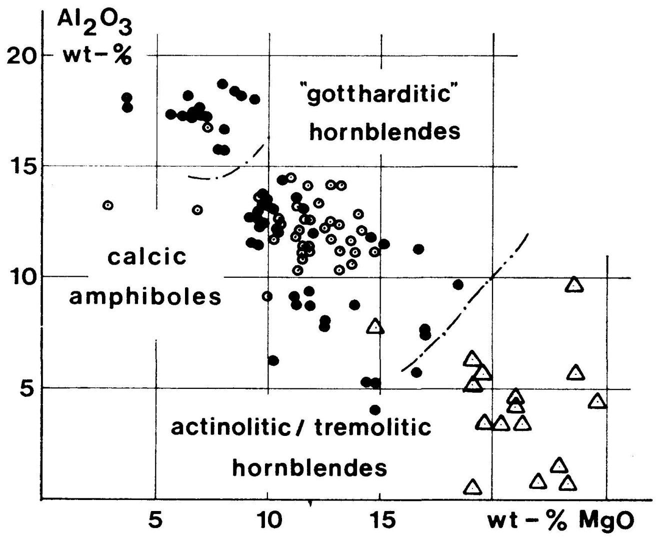


Fig. 16. Al_2O_3 and MgO (wt-%) of calcic amphiboles s. l. (new data). Black dots: microprobe analyses; circles and triangles: XFA.

blende and host rock as well (Fig. 15). All other elements participate in other mineral phases occurring in variable modes. Consequently, the chemical correlation of these hornblendes with their host rocks is rather poor, except for Mg. It may be noted, however, that the total of analyzed amphibole/host rock pairs is still fairly limited.

From Fig. 7 chemical differences between rock groups of different metamorphic grade can be estimated: calcic amphiboles of group III differ from all other groups especially with respect to Al and Mg. Fig. 16 with Al_2O_3 vs MgO

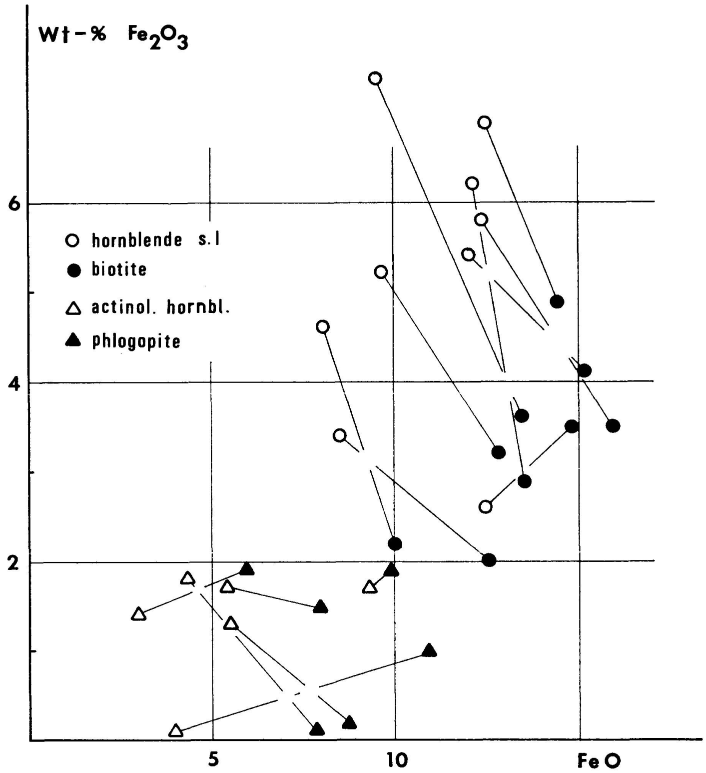


Fig. 17. Wt-% FeO vs Fe_2O_3 of coexisting calcic amphiboles and trioctohedral micas.

(wt-%) shows consequently a well defined group of "gottharditic" hornblende corresponding with group III, whereas common amphiboles and actinolitic/tremolitic hornblendes are not separated by a clear gap.

Fig. 17 informs about oxidation relations of calcic amphiboles and coexisting trioctahedral micas: the tie-lines between mineral pairs show two distinct trends: the ratio wt-% Fe_2O_3/wt-% FeO of hornblendes s. l. is in 70% of the cases higher than the one of coexisting trioctahedral micas. Note, however, that the vertical Fe_2O_3 scale is enlarged 2.5 times; thus, the analytical error of wet chemical FeO determinations appears enlarged as well.

The relations of coexisting micas and amphiboles are plotted on Fig. 8. Common and actinolitic/tremolitic hornblendes occupy distinct fields on the QLM plot, whereas most of the trioctahedral micas – biotites and phlogopites as well – are situated in a single, rather narrow field. Consequently, there are two different slopes of tie-lines between coexisting mineral pairs.

Obviously, trioctahedral micas can not be plotted on a Fo-Fa-Cs diagram (8c) because of their high aluminum and low calcium content. Their M relations were, therefore, calculated in a Fo-Fa-C triangle and connected – in a slightly unusual way – with their respective coexisting amphiboles.

4.3. RELATIONSHIP BETWEEN GRADE OF METAMORPHISM, FABRIC, MODE, An-CONTENT OF PLAGIOCLASE AND COMPOSITION OF AMPHIBOLITE AND CALCIC AMPHIBOLE

The following discussion concentrates upon common amphibolites with calcic hornblende and plagioclase as predominant constituents (75–95% vol), and with clinopyroxene, epidote-clinozoisite, biotite, chlorite or quartz as additional components. Sphene, rutile, iron ore, and rarely calcite are accessory minerals. Orthopyroxene is absent. Scapolite-, anthophyllite- and alkali-amphibole-bearing rocks are excluded. Also garnet-amphibolites and eclogites, both of which are rare in the Lepontine Alps, are not considered. This concentration upon the main rock types which form more than 95% of the total basic rocks occurring in the region investigated, infers that our conclusions pertain only to amphibolites, with a range of plagioclase from albite to labradorite.

Hornblende-rich rocks with plagioclases more calcic than An 60 are rare and our data insufficient. The transition zone from albite-amphibolites to hornblende-bearing greenschists (prasinites in the definition of KALKOWSKY 1886) is discussed by WETZEL (1973) and will be mentioned only occasionally.

At the western and northeastern margin of the area investigated (see Fig. 1) there is clear evidence that several zones of the Mesozoic ophiolitic suite in greenschist facies change into amphibolite facies rocks. However, in the higher grade central part of the Lepontine Alps few geological facts, e. g. the association of amphibolites with long stretched bands of silicate-marbles and calc-schists (Mesozoic Bündnerschiefer) indicate an ophiolitic parentage. The origin of all those amphibolites which are intercalated in the vast gneiss complexes is not known (Mesozoic ophiolites, older basic rocks, or restites in Alpine migmatites). The only proven fact is that all these Lepontine rocks recrystallized and were deformed during the Alpine orogenesis. Whatever the early history of these rocks of basaltic composition may be, they now form a correlated metamorphic series.

4.3.1. Fabric

With rising grade of metamorphism the fabric of the basic rocks becomes more regular with regard to grain size, shape and grain boundaries (compare Fig. 4 in WENK and KELLER 1969). Sieve-structured porphyroblasts and diablastic intergrowths disappear, and a mosaic results, made up of polygonal or interlocking crystals of hornblende and plagioclase of approximately equal size. In these advanced stages of progressive regional metamorphism the recrystallization is often accompanied by mineral sorting, producing compositional layering parallel to the foliation; but the individual layers show regular equidimensional structure. All amphibolites show distinct foliation and lineation parallel to the Alpine fold axes.

4.3.2. Number of mineral phases

From the zone of albite – to the zone of andesine – amphibolites the number of mineral phases decreases. Thus, often in the latter, only two main constituents, viz. a homogeneous hornblende and zoned andesine occur. With the appearance of clinopyroxene at higher metamorphic grade a new phase is added.

4.3.3. Mode and anorthite content of plagioclase

The results of modal analyses and of anorthite determinations in 85 plagioclase-amphibolites from the Central Alps (65 sets of data refer to our samples, 20 are taken from the literature) were plotted in a large scale diagram, with modal composition as the vertical and An-range as the horizontal axis. In this detailed master diagram each mineral component of the 85 rocks was represented by a straight line at the modal amount given, the length of the line indicating the An-variation of the feldspar. From this original diagram average

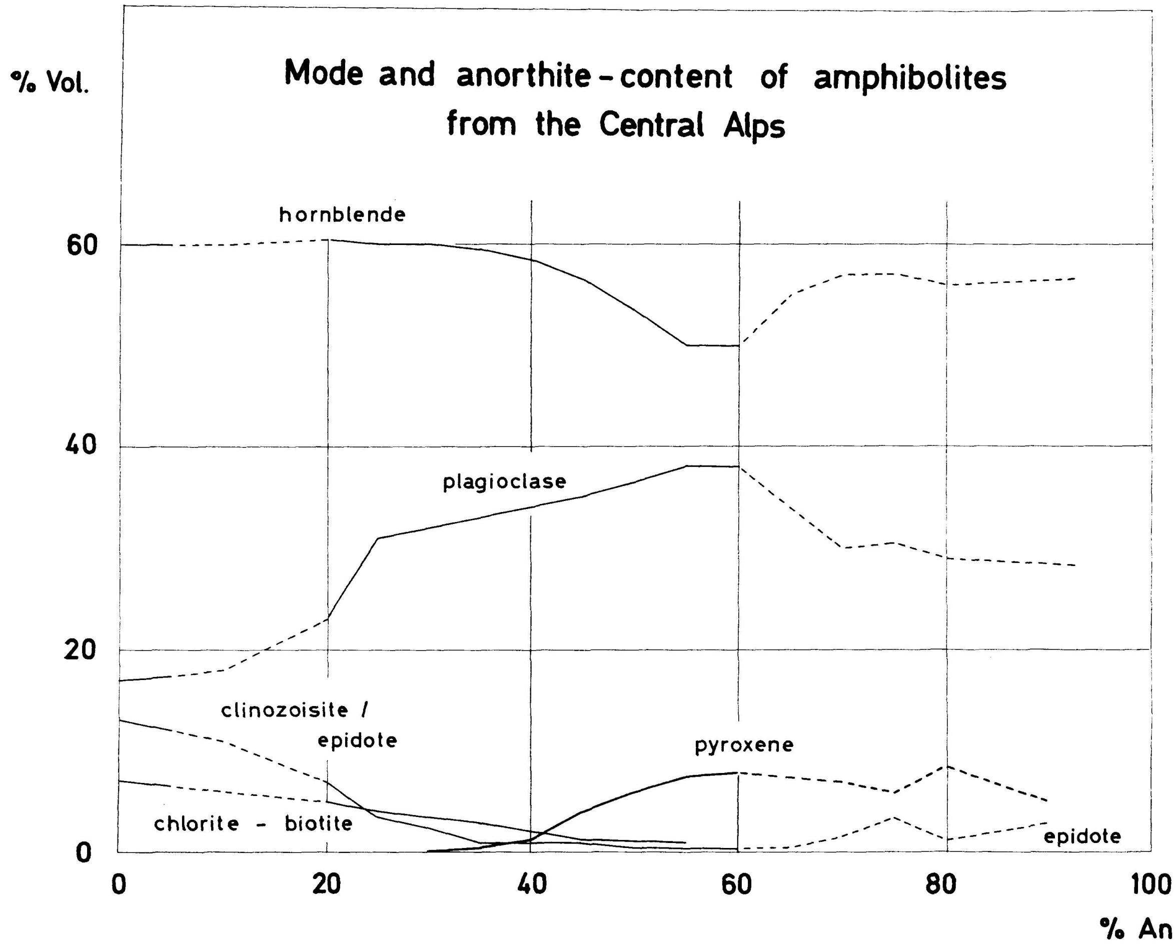


Fig. 18. Average modes of amphibolites with plagioclase ranging from An 0 to An 60. The diagram shows that the amount of plagioclase increases with rising anorthite content.

modes were derived for the An-intervals listed in Table 12, and represented in Fig. 18. The evidence offered in this diagram is well founded in the albite range and from An 20 to 60; it is less reliable within the peristerite gap and at An > 60 (dotted lines). The modal averages considered refer to rock-types of similar composition, and the mean values give rough information on the variable volumes of the mineral phases in relation to changing An-content of plagioclase.

Fig. 18 shows that from the peristerite gap on, the amount of plagioclase increases, concomitant with the rise in anorthite content, indicating higher metamorphic grade. Andesine-amphibolites carry on average twice as much feldspar as albite-amphibolites, mainly at the expense of clinozoisite-epidote. The quantity of hornblende remains almost constant in this range: from An 40 on it decreases in favour of pyroxene and plagioclase. At An-values higher than 60 our evidence is insufficient. Such calcic rocks have compositions different from common amphibolites. Our Fig. 18 agrees well with Fig. 2 in ENGEL et al. (1964) and includes additional information on lower-grade rocks.

The main result of the modal analyses is the *considerable increase of the volume of feldspar with rising anorthite content of the plagioclase.* This fact demands a critical discussion of possible variations in mode and mineral composition of isochemical rocks as a function of prograde metamorphism. Rapid checks on this topic are facilitated by P. NIGGLI'S (1936a) efficient method of equivalent norms. The equivalent weights of the main constituents of amphibolites closely agree: albite 52.4, anorthite 55.6, zoisite 56.8, tremolite 54.1, tschermakite 54.5 and diopside 54.1. Therefore, the calculated cation percentages of plagioclase, hornblende, clinopyroxene and clinozoisite do not differ much from the actual mode. Only minor components, such as sphene 65.3, rutile 79.9 or magnetite 77.2, show considerably higher equivalent weights (see also the compilation of BURRI, 1958). Table 13 shows the change in quantitative and qualitative mineral composition of three amphibolites with rising anorthite content of their plagioclase. Cation percentages were calculated from rock and hornblende analyses published in this paper. The amount of feldspar increases with rising anorthite content, and the results in Table 13 can be interpreted as representing approximate quantitative mineral reactions in a rock undergoing prograde metamorphism.

Increase of the amount of feldspar with rising anorthite content sheds also some light on the important Na balance of the host rock. In amphibolites plagioclase is the main, hornblende the minor consumer of sodium, so that in first approximation the sodium balance of hornblende can be disregarded.

Assuming that the total amount of Na present in the plagioclase of the rock remains constant and that Ca, Al and Si are freely available in the rock system, a calculation in cation percentages gives the data for An-content of plagioclase and for the total cation percentages of feldspar specified in Table 14 and

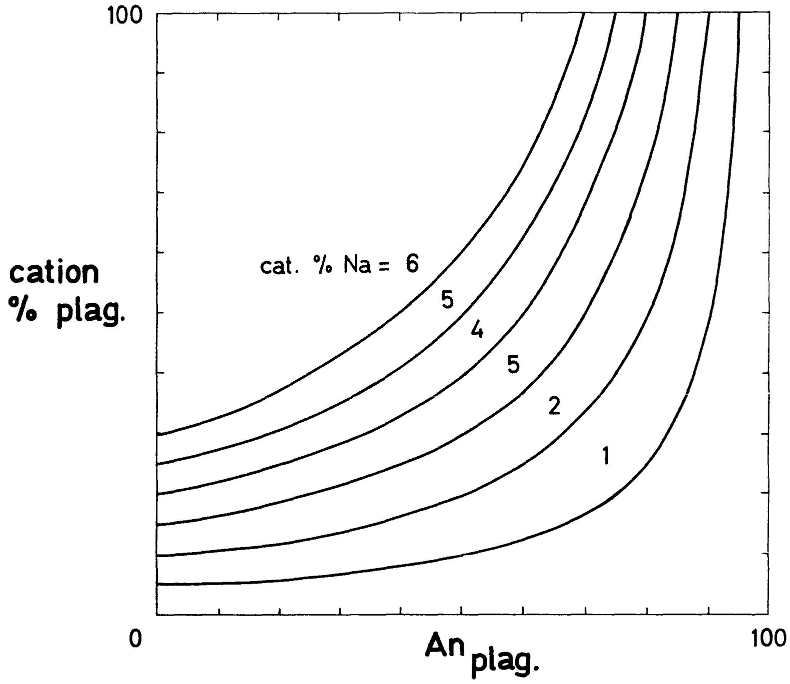


Fig. 19. Relations between total cation % plagioclase and anorthite content, assuming that Na remains constant and is equivalent to 1, 2, 3, 4, 5 or 6 cation %.

Fig. 19. This simplified model shows that under those conditions the volume of plagioclase doubles from albite to An 50. This is in good agreement with the observed facts. This theoretical approach which does not consider the role of the hornblende, makes also clear why bytownites and anorthites can only be formed in rocks very low in Na, if other mineral components consume appreciable amounts of Na[1]), or if sodium escapes.

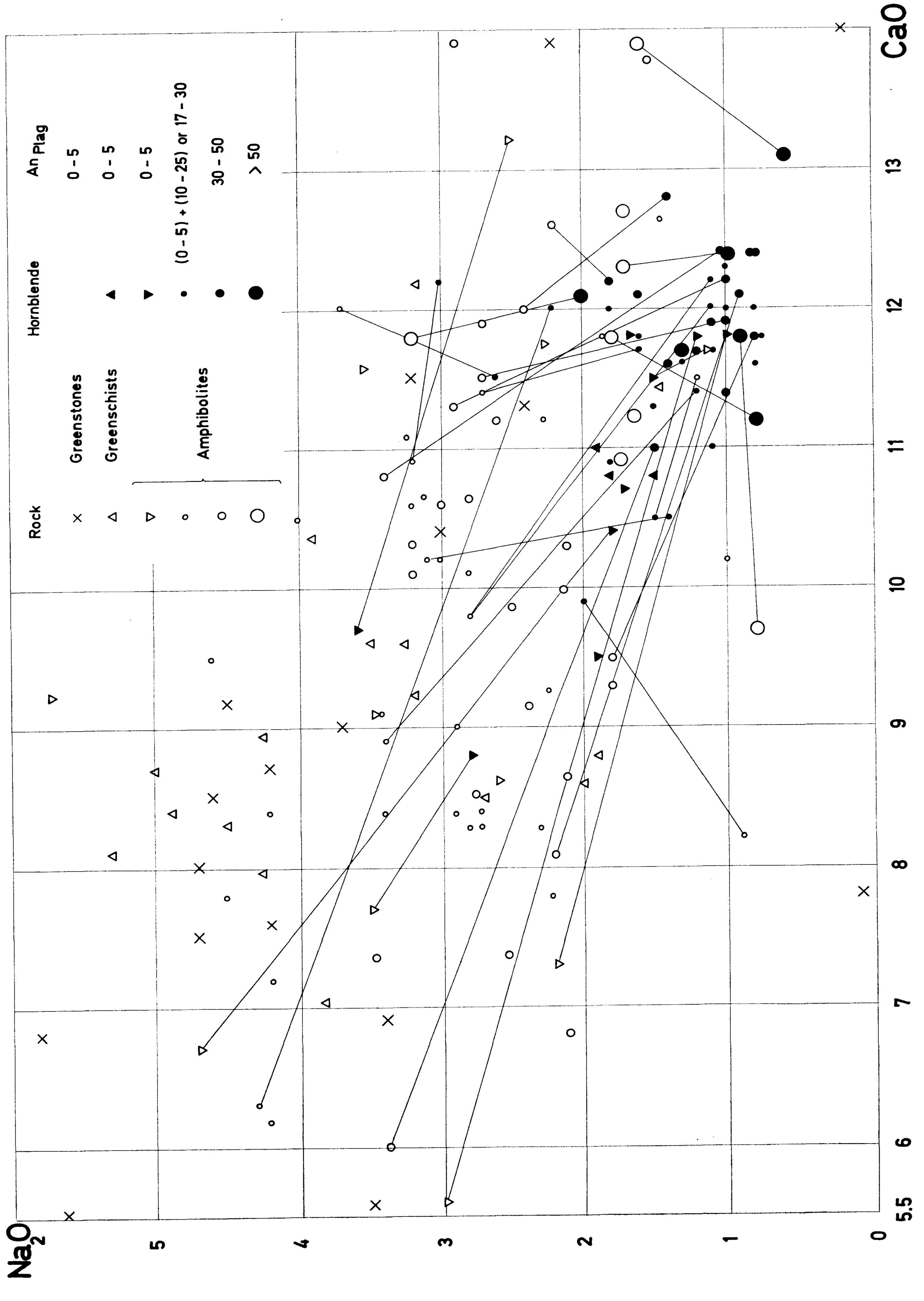
4.3.4. Rock composition

Table 11 b gives information on the average chemical composition of amphibolites of different metamorphic grade. Data from recent literature on Alpine greenstones (diabases etc.) and hornblende-bearing greenschists (prasinites) are added for comparison.

From albite- to andesine-amphibolites the mean values for SiO_2 increase distinctly, those for Al_2O_3 very slightly, while Fe_2O_3 and H_2O decrease. The

[1]) In this respect the joint occurrence of alkali-feldspar and anorthite in silicate-marbles of the Lepontine Alps may be mentioned.

Fig. 20. Na_2O-CaO diagram for greenstones (diabase etc.), hornblende-bearing greenschists (prasinites), amphibolites with different An content of plagioclase, and for hornblendes occurring in these rocks. Tielines connect hornblende and host rock of the same sample. The diagram shows the wide range of rock composition, contrasting with the limited chemical variation of hornblende.



Rock
Hornblende
An Plag
Greenstones
0 - 5
Greenschists
0 - 5
0 - 5
Amphibolites
(0 - 5) + (10 - 25) or 17 - 30
30 - 50
> 50
CaO
13
12
11
10
9
8
7
6
5.5
Na2O
5
4
3
2
1
0

other oxides show either no consistent trend or no significant variation. In particular, the average content in Na_2O remains almost constant in these amphibolite groups, a fact which is important for the discussion of the feldspar problem. The data for the small group of labradorite-bytownite-amphibolites have to be judged with reserve, as mentioned above; they show higher Al_2O_3, MgO, CaO, lower Fe_2O_3, Na_2O and H_2O than andesine-amphibolites. The basic rocks in low-grade greenschist facies differ considerably in composition from the amphibolites. Their mean values for SiO_2, FeO, MgO and CaO are lower, those for Al_2O_3, Fe_2O_3, Na_2O and H_2O distinctly higher.

Within the different groups of compared basic metamorphic rocks (see Table 11b), the individual members show wide compositional scatter. But, astonishingly, the mean values for albite-amphibolites, oligoclase-amphibolites and andesine-amphibolites agree fairly well. These amphibolites can be regarded as a rock-series of similar composition. Chemically they fit a gabbroic magma-type after P. NIGGLI (1936), and high-alumina basalt after KUNO (1968). The average values for ophiolitic rocks in greenschist facies, however, assemble in the field of alkali olivine basalt.

The differences between greenstones-greenschists (rocks with alkali-amphibole are excluded!) and amphibolites are well born out also by the Na_2O-CaO diagram of Fig. 20. Alpine ophiolitic rocks termed "diabase" in the literature show the highest Na_2O and lowest CaO contents. Sodium metasomatism may have played an important role in greenschist facies environment, not so in amphibolite facies series.

In the same diagram the projections for hornblendes are also entered and tie-lines connect corresponding rock and mineral analyses. Hornblendes contain generally more CaO and less Na_2O than their host rocks. The discussion will be continued in the next section (p. 125); but here we must emphasize the main impression given by the Na_2O-CaO diagram: *The wide range of individual rock composition contrasts with the limited chemical variation of hornblende,* concentrated near Na_2O 1.1, CaO 11.9 weight %. This compact field comprises the calcic amphiboles from low- and high-grade amphibolites. Only in some albite-epidote-amphibolite and in greenschist facies rocks do the amphiboles scatter in direction of higher Na_2O and lower CaO contents.

4.3.5. Composition of calcic amphibole

In metamorphic basic rocks in greenschist facies and in albite-epidote-amphibolites from the Alps a fairly broad range of amphibole composition is observed, leading from tremolite and actinolite to common hornblende and extending to pargasitic, edenitic and barroisitic types (WETZEL et al. 1973). In these low-grade rocks with strongly zoned amphiboles a miscibility gap between actinolite and magnesian hornblende is not evident, though it may be confined to a small part of the series; rather a concentration in the field of actinolitic hornblendes is found. In amphibolite facies rocks, with plagioclase > An 5, tremolites and actinolites still occur in rocks of appropriate composition, but there is a broad gap in the tremolite-tschermakite series between Al^{tot} 1.0 and 1.75 (Fig. 21). Not one analysis of a hornblende fits in this space. The bulk of common hornblendes is concentrated between Al^{tot} 1.75 and 2.4.

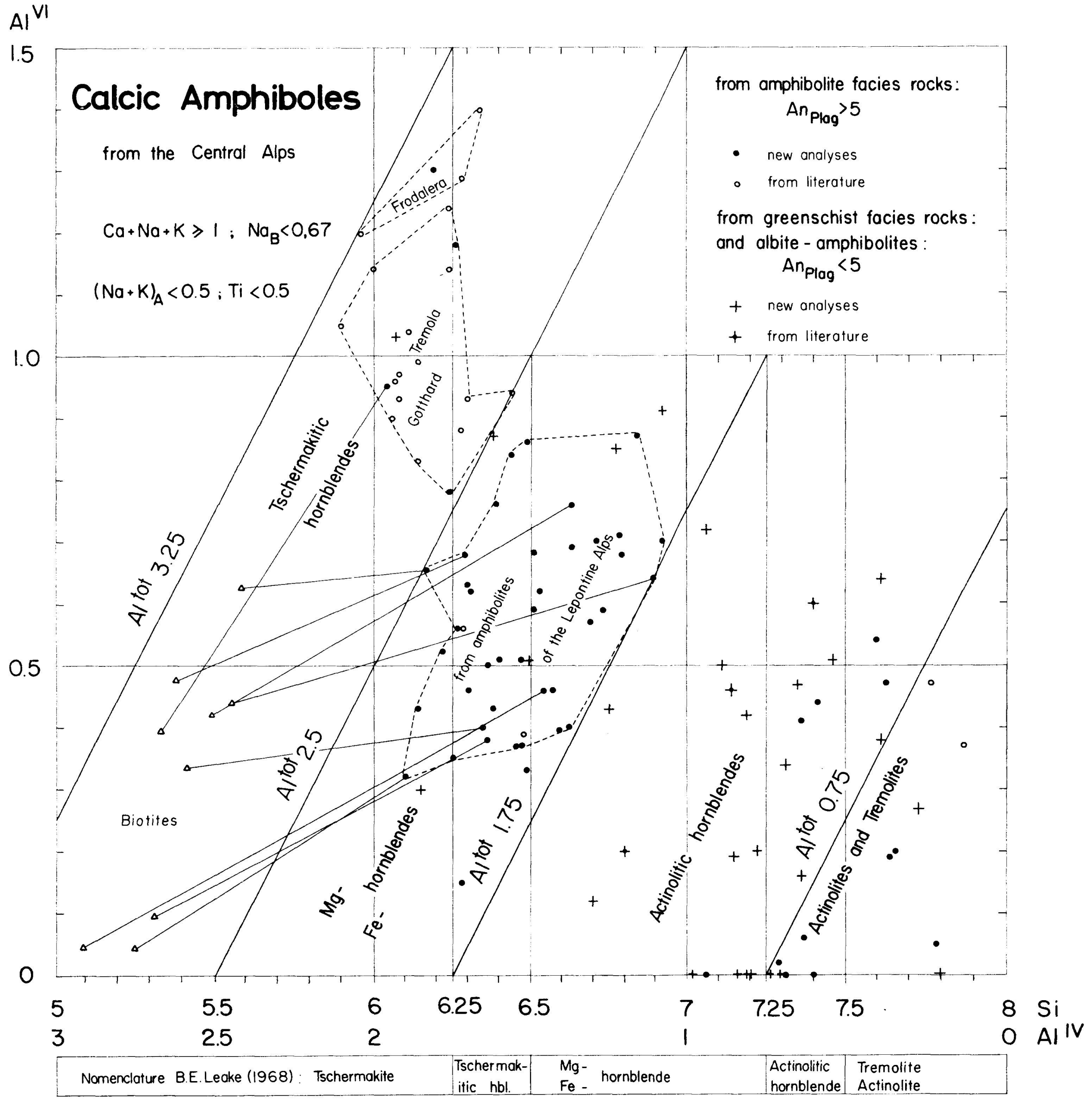


Fig. 21. Al^{VI}-Al^{IV} Si diagram for calcic hornblendes from the Central Alps, showing the fields of tschermakitic hornblendes from schists and amphibolites of the Gotthard-Tremola-Frodalera area, of Mg- and Fe-hornblendes from amphibolites of the Lepontine Alps, of actinolitic hornblendes and actinolites-tremolites. Circles and dots refer to amphibolite facies rocks, crosses to greenschist facies rocks.

In this compact field no distinction relative to metamorphic grade can be made, except for the fact, reported from rocks all over the world, that amphiboles from labradorite-pyroxene-amphibolites are arranged in the Al^{VI}-poor corner.

As mentioned above (p. 103), truly tschermakitic end members with $Al^{tot} > 2.5$ and $Al^{VI} > 0.9$ are confined to the meta-sedimentary belt south of the Gotthard massif (e. g. biotite-chlorite-garnet-oligoclase-hornblende-garben-schiefer of the Tremola series). The high Al^{VI} content is here hardly related to high pressure. Such tschermakitic hornblendes do not occur in the deeply eroded part of the Lepontine Alps and offer a special problem that needs further research.

The statistical data presented in Table 11a have been calculated from the new hornblende analyses contained in Table 2 of this paper and in the study of Wetzel et al. (1973); moreover the analyses of Alpine hornblendes included in the compilation of Leake (1968), and data published by Frey (1969) have been incorporated.

The studied section of the Central Alps is by now probably one of the regions best covered by hornblende analyses, though the number of analyses is still insufficient. The dominant first impression is the *great homogeneity of the hornblendes from amphibolites* (Gotthard-Tremola excluded). The mean values for Fe_2O_3, Na_2O and H_2O appear to decrease with rising anorthite content of the coexisting plagioclase, while MgO increases, but the standard deviations are considerable.

Other oxides vary little or inconsistently, unfortunately also TiO_2, which is only significantly lower in greenschist hornblendes. The hornblendes of greenschists differ irregularly from those of albite-amphibolites, but we are here in the poorly documented field of the strongly zoned actinolitic hornblendes, where the meaning of a chemical analysis of a mineral concentrate becomes uncertain.

Much more significant than the minor variability of hornblendes from amphibolites of different metamorphic grade is the clearly distinct chemical composition of the tschermakitic hornblendes of the Gotthard-Tremola-Frodalera group. Their mean value for Al_2O_3 is much higher, FeO higher and MgO much lower than the averages of all other hornblende groups. The rocks with tschermakitic hornblende occur in the zone of oligoclase-amphibolites and inside the kyanite and staurolite isograds. Most of the rocks from which these Al-rich amphiboles originated are aluminous schists or gneisses and a few are oligoclase-amphibolites proper. But as is now well displayed by the new outcrops in the Gotthard road tunnel, the hornblende-rich rocks are interlayered with a series of garnet-schists and gneisses. The significant differences between the hornblendes of the Tremola group and those of common oligoclase-amphibolites from other parts of the Lepontine Alps should make us cautious: rock composition and the environment within a layered series can influence the mineral composition more strongly than does changing metamorphic grade.

The Na_2O-CaO diagram (Fig. 20) supports graphically some conclusions, drawn from statistical data: the hornblendes of oligoclase-amphibolites (small dots), andesine-amphibolites (medium dots) and labradorite-bytownite-amphibolites (large dots) are crowded in a narrow field. Half of the hornblendes from albite-amphibolites occupy the same position; the other half scatter, as do the hornblendes of prasinites, as they approach higher Na_2O, lower CaO values (pargasitic and edenitic hornblendes). A significant change in hornblende composition is indicated only in these lower-grade rocks, not in the amphibolite facies series which forms the bulk of the material studied in this paper.

4.3.6. Distribution of Or Ab An between coexisting plagioclase and hornblende

In the examined amphibolite series of the Central Alps the proportion $\frac{An}{Or+Ab+An}$ of plagioclase increases with progressive regional metamorphism. This fact is well established (WENK and KELLER, 1969) and, in fact, is still the best indicator of metamorphic grade. The cations substituting in the plagioclase series are distributed between the following mineral components of the rocks:

Si	*Al*	*Ca*	*Na*
quartz	—	—	—
plagioclase	plagioclase	plagioclase	plagioclase
hornblende	hornblende	hornblende	hornblende
pyroxene	—	pyroxene	—
epidot-clinozoisite	epidote	epidote	—
chlorite	chlorite	—	—
biotite	biotite	—	(biotite)
muscovite	muscovite	—	(muscovite)
sphene	—	sphene	—
—	—	apatite	—
zircon	—	calcite	—
—	—	dolomite	—

This list shows that Si, Al and Ca can be apportioned to several major and minor mineral components, depending upon the paragenesis, but that Na occurs essentially only in the two main constituents plagioclase and hornblende. Thus the sodium balance is critical, but the role of the other cations should be considered as well. The balance Or Ab An in the rock system and the partitioning of these feldspar "molecules" among the mineral components are discussed with the aid of the feldspar triangle. This procedure is justified also by the fact that 1. in the analysed amphibolites the sum of normative feldspar components amounts to 55–68 cation percent, 2. in the hornblendes 35 to 45% and 3. in plagioclase 100%. Normal plagioclase-amphibolites are made up of $^2/_3$ hornblende and $^1/_3$ feldspar; therefore, commensurable amounts of feldspar components are present in these two main constituents.

Following the methods introduced by P. NIGGLI (1936) the weight percentages of the rock and hornblende analyses were transformed into cation percentages and then Or Ab and An were calculated. In our rocks which carry neither alkali hornblende nor jadeite, Al is always in excess after the formation of Or and Ab. However, there never remains enough Al to form anorthite from the total of Ca present. In all our amphibolites and hornblendes $(Na+K+2Ca) > Al$, and after the formation of normative feldspar Wo can

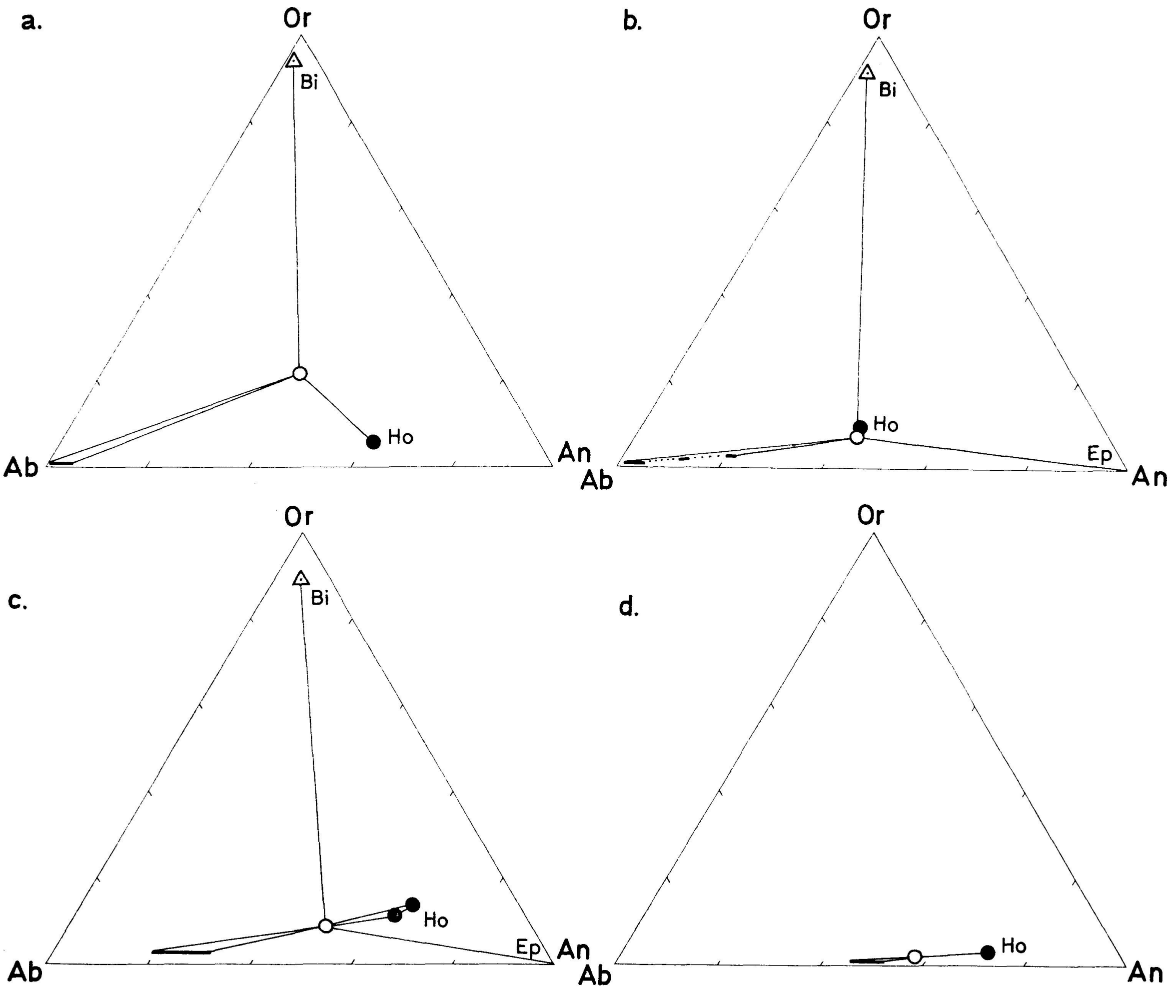


Fig. 22. Or Ab An diagrams for four different amphibolites:

a) Biotite-albite-hornblende-schist MF 147 (M. FREY, 1969), Val Casatscha.
b) Biotite-epidote-albite/oligoclase-amphibolite Cal. 25, Alpe Alögna, Calanca.
c) Epidote-biotite-oligoclase-amphibolite Hu 1170 a_3, Val di Campo.
d) Andesine/labradorite-amphibolite 20.7.69.01, Monti Laura.

Open circles represent the rock composition.

be calculated from the surplus Ca. The bottle-neck in these calculations is Al, not Si[2]).

Fig. 22 represents the projections of four different amphibolites with two or more of the components hornblende, plagioclase, biotite and epidote, ranging from albite- to andesine-amphibolite. It shows at first sight that – judged from the rock composition – none of these amphibolites should contain a plagioclase more acid than andesine. Furthermore, it demonstrates that with rising An-content the volumes of feldspar also increase (shorter distance between the projections of plagioclase and rock).

For technical reasons it proved impossible to assemble all the data for the studied rocks in one single diagram Or Ab An. Therefore, only the data for amphibolite and hornblende could be entered in Fig. 23. The rocks (open

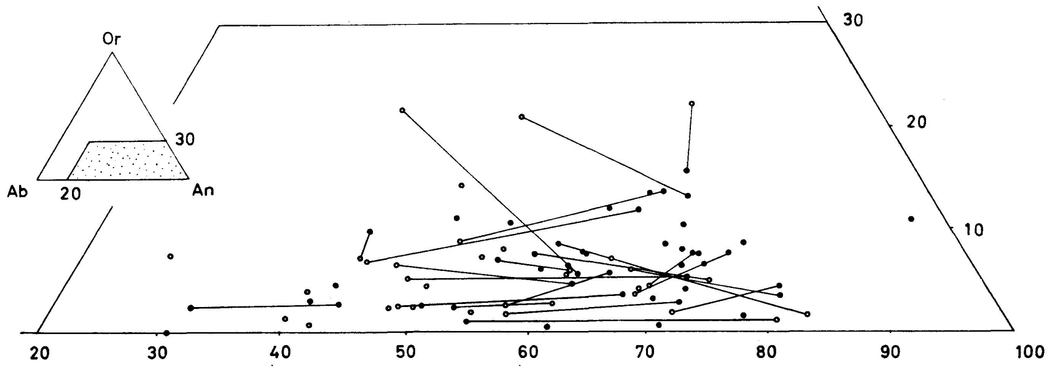


Fig. 23. Or Ab An diagram showing hornblende composition (dots) and rock composition (open circles).

circles) occupy the sector An 40 to 70, less than half of the range of the plagioclases found in these amphibolites. Except for biotite-bearing varieties the Or content of the rocks is low. The amphiboles (dots) group in a still narrower field, concentrated between An 60 and 80. If some epidote- and garnet-bearing varieties are disregarded, the amphiboles are always richer in An, poorer in Or and Ab than their host rocks.

In Fig. 24a the normative An content of the hornblende is related to the modal An of the coexisting plagioclase. In hornblende An varies much less than in plagioclase and, except for two cases, the normative An of the hornblende is higher than the modal anorthite content, but a positive correlation is indicated. Thus, in spite of the numerous ionic substitutions possible in amphibole structures, the variability Or Ab An is limited in our calcic hornblendes. Fig. 24b represents the relation between modal and normative anor-

[2]) In garnet-bearing hornblende rocks too high normative An values result from this calculation scheme.

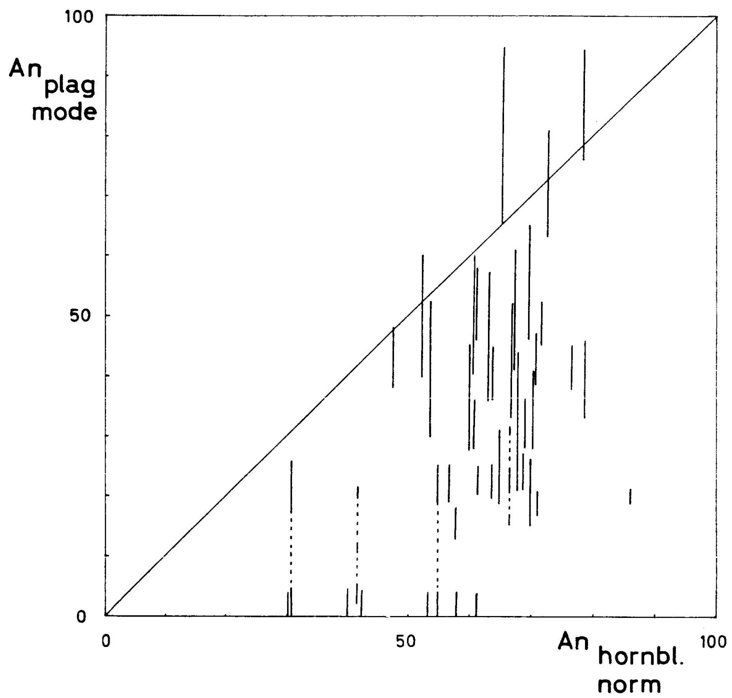


Fig. 24a. Relation between modal An content of plagioclase and normative An content of the coexisting hornblende.

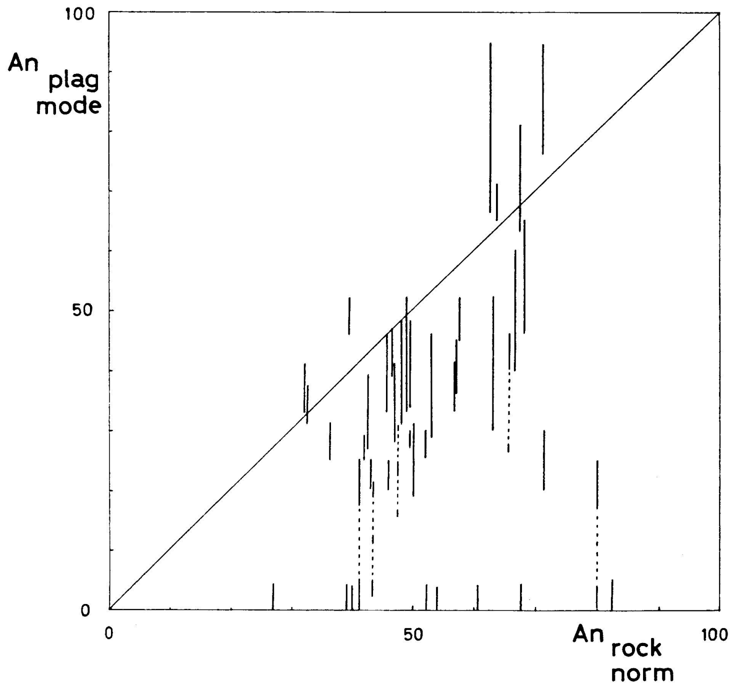


Fig. 24b. Relation between modal An content of plagioclase and normative An content of the host rock.

thite content in the rock-series. This diagram is instructive in showing that the modal An content is not dictated by rock composition. Albite and oligoclase are not confined to sodium-rich rocks. In Fig. 24b the rocks lowest and those highest in normative An both contain albite! Once the peristerite gap is passed, a vague positive correlation between An mode and norm may be read from the diagram. Bytownite, though, is restricted to calcic rocks.

4.3.7. Conclusions

In the studied plagioclase-amphibolite series the pronounced increase in modal anorthite content, reflecting progressive metamorphism, takes place without appreciable change in rock composition and without compensating substitution in the coexisting hornblende. It is performed mainly by modal variation. The quantities of Na, Ca, Si and Al remain fairly constant in the system (though not in greenschists and greenstones). Plagioclase has to consume the major part of Na, hornblende the minor part. With rising anorthite content of plagioclase the balance can only be preserved by the formation of more feldspar, mainly at the expense of epidote-clinozoisite, chlorite and biotite, and in later stages also at the expense of hornblende. Modal analyses and calculations from rock and mineral analyses both show that andesine-amphibolites contain twice as much plagioclase as albite-amphibolites.

This implies that for each rock-type of given normative Or Ab An ratio and of known paragenesis the maximum mean anorthite content of plagioclase and the maximum normative feldspar content, reached at high-grade metamorphism, can be deduced. In the high-grade metamorphic zone of the Lepontine Alps the highest modal An values observed in plagioclase amphibolites reach An 50 to 60, as can be calculated also from chemical analyses. The An content rarely exceeds An 60; bytownites occur only in hornblendic rock of more calcic composition.

In the same metamorphic zone bytownites/anorthites are common in silicate-marbles, while andesines occur in aluminous schists and oligoclase in the gneiss complexes. In alternating series of these rock-types irregularities in An-content, due to metasomatic processes may be observed, but they are usually confined to the cm-range.

The poor correlation between hornblende composition and metamorphic grade within the different groups of plagioclase-amphibolites confirms observations made in other parts of the world. Therefore, it is really surprising that plagioclase shows such strong compositional variation just in this range of metamorphism.

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Appendix I

Table 1. *Analyzing conditions*

Apparatus	Jeol JXA-3A	Analyzing crystals	Line
Excitation	Si, Al 10 kV, 0.14 μA	RAP, KAP	K α I
	Fe, Ca, K 15 kV, 0.09 μA	Quartz	K α I
	Mg, Na 10 kV, 0.09 μA	KAP	K α I
Beam	1 to 5 microns diameter		
Integration time	30 seconds.		
Counting technique	point analysis; at least 3 spots per crystal.		
Calibration	standardization with different silicate minerals of known composition e. g. hornblendes, pyroxenes, garnets.		

Table 2a. *XF Analyses: calcic amphiboles*

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	H_2O		D
AS 912	44.9	12.7	5.3	10.0	0.3	11.9	10.5	1.4	0.3	0.7		2.1	100.1	3.16
AS 941	42.7	12.2	4.7	13.3	0.4	10.4	11.7	1.6	0.3	1.0		1.8	100.1	3.25
Blen 48b	42.8	13.4	5.3	9.3	0.5	12.2	12.1	1.6	0.6	0.7		1.6	100.1	3.19
Brg 75 conc.	43.9	12.4	2.6	10.1	0.3	13.2	8.3	2.6	0.1	2.3	0.1	3.5	99.4	
Cal 25	42.1	12.7	5.2	9.7	0.3	10.5	11.5	2.6	0.8	1.7		2.9	100.0	3.21
Cal 29	41.8	13.1	5.4	12.1	0.3	11.3	11.7	1.1	0.6	1.1		1.6	100.1	3.24
Cal 30	44.6	11.1	2.6	12.6	0.4	11.9	11.6	1.4	0.4	1.5		2.0	100.1	3.21
FK 644	42.0	13.2	5.5	20.4	0.2	2.9	11.6	0.8	0.6	0.2		2.6	100.0	3.35
GdT S 580	41.2	16.8	6.2	12.2	0.4	7.3	9.9	1.4	0.0	0.9	0.0	2.9	99.2	3.21
Hu 1164d (Hu)	47.0	11.4	4.9	8.1	0.3	11.9	12.2	1.0	0.3	1.1		1.8	100.0	3.13
Hu 1170 (Hu)	47.7	11.3	5.6	5.7	0.3	13.2	12.0	1.1	0.7	0.4		2.2	100.2	3.13
Hu 1170a_3 (Hu)	42.4	13.7	7.7	9.4	0.5	9.6	12.2	1.1	1.1	0.8		1.6	100.1	3.28
Hu 1202a (Hy)	41.0	13.0	6.5	14.4	0.4	6.8	11.4	1.2	0.9	1.9		2.5	100.0	3.26
Luk 24	48.0	10.3	3.4	8.6	0.3	13.2	12.4	0.8	0.6	0.5		2.0	100.1	3.15
Mas 9z	43.7	10.9	5.5	11.7	0.3	11.3	11.7	1.3	0.5	1.5		1.7	100.1	3.24
Mas 19	42.9	11.8	5.4	12.1	0.5	10.3	11.4	1.0	0.9	1.3		2.3	99.9	3.24
Mera 33a	44.1	11.1	4.6	8.8	0.3	13.8	12.1	2.0	0.2	1.4		1.6	100.0	3.18
Mera 34	40.5	12.5	6.9	12.5	0.5	10.5	12.1	0.9	0.9	0.9		1.8	100.0	3.26
Mis 52b	49.5	12.9	1.1	6.9	0.1	14.0	9.2	2.1	0.3	1.1	0.1	2.4	99.7	
Mis 52c conc.	48.5	14.1	2.8	6.5	0.2	12.8	9.6	2.4	0.3	0.8	0.0	1.5	99.5	
Mto 798a	44.2	12.0	4.2	13.3	0.3	10.4	11.6	0.1	0.6	1.3		2.0	100.0	3.23
Mto 798b	42.8	11.5	4.8	12.4	0.4	11.5	11.8	1.6	0.4	0.9		1.9	100.0	3.24
Mto 823	43.6	12.2	4.8	10.1	0.4	12.5	12.3	1.0	0.5	0.7		1.9	100.0	3.20
Pior 9	42.2	14.6	4.0	12.2	0.2	11.0	11.3	1.5	0.3	1.1		1.6	100.0	3.24
PK 834	45.3	11.1	3.7	9.9	0.2	13.8	12.4	0.8	0.1	0.8		2.0	100.1	3.16
Riv 17	43.2	11.8	4.8	10.1	0.3	12.8	12.2	1.8	0.5	1.0		1.6	100.1	3.29
ShLz A 22	42.4	13.2	0.1	16.9	0.3	10.0	11.8	0.9	1.2	0.9		2.4	100.1	3.24
Spl 125	44.5	14.1	3.8	10.4	0.1	11.8	11.0	1.1	0.5	0.7		2.1	100.1	3.31
Splug IId conc.	49.5	9.2	2.6	12.2	0.3	10.0	11.0	1.5	0.9	0.6	0.0	2.1	99.9	
Vz 631	48.0	12.1	2.2	8.6	0.1	14.1	11.2	0.8	0.5	0.5		1.9	100.0	3.14
Vz 673	46.5	11.7	2.4	9.8	0.2	13.7	12.0	1.0	0.4	0.4		1.9	100.0	3.16
Wurz 138	45.9	12.5	4.6	8.1	0.2	12.7	11.9	1.1	0.6	0.8		1.7	100.1	3.14
Wurz 150	45.0	11.9	4.9	10.5	0.7	11.3	11.7	1.2	0.8	0.4		1.6	100.0	3.19
Wurz 175	46.0	11.0	3.6	10.5	0.3	11.5	12.4	1.0	0.3	0.9	0.2	2.1	99.8	3.18
Wurz 176	43.3	12.6	4.0	10.1	0.2	11.7	12.8	1.4	0.4	1.2	0.2	2.3	100.2	
Wurz 177b	44.6	12.1	3.2	11.3	0.3	11.3	12.4	1.0	0.5	0.9	0.2	2.0	99.8	3.19
Wurz 179	45.7	10.4	6.1	10.3	0.3	11.4	13.1	0.6	0.3	0.4	0.0	2.3	100.9	3.18
20.7.69.01	44.6	10.7	1.3	12.5	0.2	13.8	11.9	1.0	0.2	1.2	0.1	2.4	99.9	3.22
22.7.69.02	44.7	14.1	0.9	11.3	0.2	13.2	11.8	0.8	0.3	0.7	0.1	1.8	99.9	

Table 2b. *XF Analyses: actinolitic/tremolitic hornblendes*

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	H_2O		D
Brg 2	41.9	0.5	0.0	0.5	0.0	19.2	24.3	0.3	0.0	0.0	0.2	13.2	100.1	2.91
Cadonigo grau	53.8	4.5	0.9	n.b.	0.0	24.7	15.4	0.2	0.1	0.1	0.1	n.b.	99.8	
Cadonigo grün	48.5	5.7	0.3	0.4	0.0	23.5	14.1	0.4	0.1	0.1	0.1	7.4	100.6	
CT 19 «L»	48.5	9.7	0.4	0.0	0.0	23.5	14.1	2.1	0.2	0.1		1.4	100.0	3.04
CT 19 «S»	47.7	11.2	0.4	0.0	0.0	(23.1)	13.9	(2.1)	0.2	0.1		1.9	(100.6)	
Hu 1015 (Hu)	54.0	5.8	1.8	4.4	0.2	19.7	12.6	0.4	0.2	0.2		0.8	100.1	3.09
Hu 1026 I (Hu)	52.8	4.2	2.1	4.8	0.2	21.0	11.7	0.4	0.1	0.1		2.4	99.8	3.06
Hu 1026e I (Hu)	52.4	4.5	1.9	4.8	0.2	21.0	12.0	0.5	0.1	0.1		2.6	100.1	3.07
Hu 1026 II (Hu)	55.6	3.4	0.9	4.6	0.2	19.7	12.1	0.5	0.1	0.1		2.8	100.0	3.13
Hu 1026e II	52.7	7.9	2.1	6.9	0.2	14.9	12,0	1.3	0.4	0.3		1.4	100.1	3.17
Mera 40	53.8	0.9	0.0	0.4	0.0	23.4	16.1	0.9	0.3	0.0		4.2	100.0	2.96
TV 116e	44.6	0.8	0.0	0.3	0.0	22.0	20.9	1.4	0.1	0.0		9.8	99.9	
Varzo 6	54.8	3.3	1.7	5.5	0.2	21.4	11.2	0.1	0.1	0.1		1.6	100.0	3.04
Varzo 7	51.6	3.3	1.4	3.1	0.1	20.4	14.9	0.3	0.3	0.1		4.5	100.0	2.99
Vz 194	56.4	1.6	0.1	4.1	0.1	23.0	11.9	0.2	0.1	0.1		2.1	99.7	3.05
Vz 394	52.2	6.2	1.7	9.4	0.2	19.1	8.9	0.4	0.2	0.2		1.5	100.0	3.11
Vz 428	54.3	5.1	1.3	5.6	0.2	19.2	12.3	0.3	0.3	0.2		1.3	100.1	3.06

Table 2c. *XF Analyses: various amphiboles s. l.*

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	H_2O		D
Bni 258	53.4	3.4	10.9	7.8	1.1	10.5	1.2	7.9	0.8	0.5		2.7	100.2	3.19
HoVo	43.1	15.9	1.3	5.7	0.1	16.3	11.8	2.6	0.4	0.3	0.0	2.3	99.8	3.05
KAW 657	55.5	14.6	1.7	3.8	0.1	6.1	8.9	5.3	0.1	1.8	0.1	1.9	99.9	
KAW 658	50.7	6.1	2.9	12.0	0.3	13.4	10.1	1.7	0.1	0.2	0.0	2.4	99.9	

Table 3. *XF Analyses: trioctahedral micas*

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	H_2O	
Cal 25	37.8	18.0	3.2	12.9	0.1	14.0	0.2	0.4	8.2	2.1		3.2	100.1
Cal 30	35.5	16.0	3.5	14.8	0.2	14.3	0.4	0.4	7.6	3.1		4.3	100.1
GdT S 580	36.5	17.8	2.9	13.6	0.2	13.6	0.0	0.5	8.4	1.4		5.0	99.9
Hu 1015 (Hu)	41.3	17.8	0.1	8.0	0.1	16.9	0.9	0.3	8.4	1.3		4.9	100.0
Hu 1170a 3 (Hu)	36.2	17.6	3.6	13.6	0.3	13.3	0.6	0.4	8.4	1.9		3.8	99.7
Luk 24	37.6	16.6	2.0	12.7	0.2	16.0	0.2	0.4	9.0	1.6		3.6	99.9
Mas 19	35.9	16.4	4.1	15.2	0.6	12.2	1.4	0.4	8.0	2.4		3.4	100.0
Mera 34	33.2	15.9	4.9	14.4	0.4	12.3	0.3	0.4	11.7	2.4		4.1	100.0
Mto 798b	34.4	15.3	3.5	16.0	0.2	13.5	0.4	0.5	10.8	2.3		3.1	100.0
Varzo 6	39.6	14.3	1.5	8.1	0.07	21.3	0.1	0.3	9.6	0.9		4.0	99.77
Varzo 7	39.6	19.2	1.9	6.1	0.06	19.6	0.1	0.3	9.5	1.1		2.6	100.06
Vz 194	37.5	17.6	1.6	10.3	0.1	16.4	0.1	0.4	9.1	2.5		3.7	99.3
Vz 394	37.6	16.8	1.9	10.0	0.1	17.1	0.4	0.3	9.1	1.3		5.8	100.4
Vz 428	38.9	17.0	0.2	8.9	0.07	19.4	0.1	0.4	9.5	1.5		3.7	99.67
Wurz 138	38.1	17.3	2.2	10.1	0.1	17.7	0.4	0.4	7.8	2.0		4.0	100.1

Table 4. *XF Analyses: amphibolites and hornblende bearing rocks*

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	H_2O	
As 912	47.9	15.3	3.7	6.6	0.2	8.4	10.2	3.1	0.3	1.4		2.9	100.0
As 941	48.2	13.6	3.1	9.7	0.2	6.7	11.4	2.7	0.6	1.9		1.9	100.0
Brg 73	49.3	18.8	3.6	5.4	0.2	5.5	10.6	3.0	0.8	1.3	0.1	1.2	99.8
Brg 75	50.8	16.9	2.0	7.6	0.2	8.0	7.2	4.2	0.1	1.3	0.2	2.0	100.5
Cal 25	43.3	17.5	3.2	6.5	0.4	6.8	12.0	3.7	0.8	1.5	0.2	3.9	99.8
GdT S 580	49.6	14.5	3.5	10.3	0.3	5.8	7.6	1.3	1.2	2.4	0.3	2.9	99.7
Hu 1164d	50.6	14.9	0.2	8.6	0.2	8.5	11.3	2.9	0.5	1.3		1.9	100.9
Hu 1170a 3 (Hu)	54.0	16.9	3.8	6.2	0.2	3.2	9.8	2.8	0.9	1.1		1.3	100.2
Hu 1202a	53.0	16.1	2.4	8.32	0.21	3.0	8.9	3.4	0.7	2.3		2.1	100.43
Mera 33a	48.3	18.8	1.4	6.0	0.0	7.6	11.8	3.2	0.3	1.3	0.2	1.3	100.2
Mera 34	53.2	17.8	2.7	5.1	0.0	5.5	8.1	2.2	2.3	1.0		1.8	99.7
Mis 52	51.3	13.3	5.3	6.5	0.1	6.1	8.5	2.7	1.1	1.5		3.5	99.9
Mis 52b	47.4	15.7	1.9	7.9	0.0	11.7	8.6	2.0	0.5	1.2	0.0	2.9	99.8
Mis 52c	47.2	15.5	2.2	8.3	0.05	11.5	8.8	1.9	0.4	1.1	0.1	2.7	99.75
Riv 17	46.4	17.4	2.1	7.1	0.2	8.4	12.6	2.2	0.6	1.6	0.2	1.7	100.5
Sci 171	48.4	14.8	0.8	3.9	0.1	14.3	13.8	2.6	0.3	0.3		1.3	100.6
Sci 186	41.4	13.8	4.0	7.9	0.2	11.8	12.9	2.8	0.5	1.3		2.2	98.8
Sci 244	56.1	16.2	3.1	4.6	0.2	4.5	6.5	3.6	2.0	0.9		1.6	99.3
Sh Lz A 22a	52.4	14.3	2.6	8.1	0.2	6.6	9.7	0.8	1.8	2.0		1.6	100.1
Spluga 11d	61.7	15.3	0.2	5.4	0.1	3.4	6.0	3.4	2.1	0.6	0.1	1.4	99.7
Vz 428	47.3	14.6	1.6	7.0	0.1	18.1	5.7	0.3	3.0	0.5		2.2	100.4
Vz 631	50.1	16.9	2.1	6.1	0.2	9.1	11.8	1.8	0.4	1.2		1.6	101.3
Vz 703	50.5	16.3	1.5	7.9	0.2	7.1	10.3	3.2	0.3	1.2	0.1	1.4	100.0
Wurz 166	46.4	16.5	4.8	6.7	0.2	6.4	11.2	2.6	1.5	1.7		1.9	99.9
Wurz 175	49.5	16.6	1.9	6.6	0.2	7.4	10.8	3.4	0.3	1.6	0.2	1.5	100.0
Wurz 176	48.1	15.2	1.5	8.0	0.2	8.0	12.0	2.4	0.3	1.7	0.4	1.7	99.5
Wurz 177b	48.0	17.0	2.3	7.6	0.1	7.7	12.3	1.7	0.4	1.7	n.b.	1.3	100.1
Wurz 179	47.4	17.0	4.2	6.1	0.1	6.9	13.9	1.6	0.2	1.4	0.1	1.6	100.5
19.7.69.01	49.2	16.0	2.1	6.2	0.2	9.2	10.7	4.1	0.2	1.3		1.6	100.8
20.7.69.01	46.7	17.0	1.8	7.2	0.1	8.8	11.5	2.7	0.2	1.4		1.8	99.2
20.7.69.02	49.4	15.6	2.3	7.8	0.2	7.6	10.1	3.2	0.5	1.3	0.3	1.9	100.2
20.7.69.03	49.2	13.9	1.7	6.4	0.1	11.4	9.0	2.9	1.6	0.9		2.0	99.1
22.7.69.01	52.0	13.2	1.4	7.4	0.2	11.5	9.3	1.8	1.1	0.3	0.0	1.8	100.0
22.7.69.02	50.4	17.4	2.0	6.5		8.9	9.5	1.8	0.6	0.6		2.1	99.8
29.9.69.01	43.1	16.4	5.4	5.2	0.1	8.2	9.6	3.5	0.2	1.1		7.0	99.8

Table 5. *Structural formulae of analyzed amphiboles, 24 (O, OH)*

	Si	Al_{tot}	Al^{IV}	Al^{VI}	Fe^{3+}	Fe^{2+}	Mn	Mg	Ca	Na	K	Ti	P	OH	Okt.	Alk.	% R^{3+}	% R^{2+}	% Mg	$\frac{Mg \cdot 100}{Mg+Fe_{tot}+Mn}$
CT 19 «S»	6.59	1.82	1.41	0.42	0.04	—	—	4.76	2.06	0.56	0.04	0.01	—	1.75	5.23	2.66	9.0	—	91.0	99.2
TV 116e, corr.	7.40	0.16	0.16	—	—	0.05	—	4.82	2.69	0.46	0.02	—	—	2.33	4.87	3.17	—	1.0	99.0	99.2
Mera 40	7.31	0.14	0.14	—	—	0.05	—	4.73	2.34	0.24	0.05	—	—	3.80	4.78	2.63	—	1.0	99.0	99.0
CT 19 «L»	6.78	1.60	1.22	0.38	0.04	—	—	4.89	2.11	0.57	0.04	0.01	—	1.30	5.32	2.72	8.1	—	91.9	99.0
Vz 194	7.79	0.26	0.21	0.05	0.01	0.47	0.01	4.73	1.76	0.05	0.02	0.01	—	1.93	5.30	1.83	1.4	9.2	89.4	90.6
Brg 2 Trem. conc.	5.45	0.08	0.08	—	—	0.05	—	3.72	3.39	0.08	—	—	0.02	11.45	3.77	3.46	—	1.3	98.7	90.5
Cadonigo «grün»	6.35	0.88	0.88	—	0.03	0.04	—	4.58	1.98	0.10	0.02	0.01	0.01	6.46	4.66	2.09	0.9	0.9	98.3	90.2
Varzo 7 Strahlst.	7.07	0.53	0.53	—	0.14	0.35	0.01	4.16	2.18	0.08	0.05	0.01	—	4.11	4.68	2.32	3.6	7.8	88.8	89.1
Hu 1026 II	7.64	0.55	0.36	0.19	0.09	0.53	0.02	4.03	1.78	0.13	0.02	0.01	—	2.57	4.88	1.93	6.1	11.3	82.6	86.1
Hu 1015	7.60	0.96	0.40	0.56	0.19	0.52	0.02	4.13	1.90	0.11	0.04	0.02	—	0.75	5.45	2.04	14.3	9.9	75.8	85.0
Hu 1026e I Hu	6.93	1.77	1.07	0.70	0.34	0.93	0.04	3.16	1.77	0.39	0.04	0.07	—	1.43	5.25	2.19	21.3	18.5	60.2	84.8
Hu 1026 I	7.37	0.69	0.63	0.06	0.22	0.56	0.02	4.37	1.75	0.11	0.02	0.01	—	2.23	5.24	1.87	5.5	11.1	83.3	84.5
Varzo 6	7.66	0.54	0.34	0.20	0.18	0.64	0.02	4.46	1.68	0.03	0.02	0.01	—	1.49	5.52	1.72	7.2	12.1	80.7	84.2
Vz 428	7.63	0.84	0.37	0.47	0.14	0.66	0.02	4.02	1.85	0.08	0.05	0.02	—	1.22	5.33	1.99	11.9	12.8	75.4	83.1
Ho Vo	6.17	2.67	1.83	0.83	0.14	0.68	0.01	3.46	1.77	0.69	0.07	0.04	—	2.18	5.15	2.53	19.5	13.4	67.1	80.7
Mis 52b	6.91	2.12	1.09	1.03	0.12	0.81	0.01	2.91	1.38	0.57	0.05	0.13	0.01	2.23	5.01	2.00	25.5	16.3	58.1	75.6
Vz 394	7.41	1.04	0.59	0.44	0.18	1.12	0.02	4.04	1.35	0.11	0.04	0.02	—	1.42	5.83	1.50	11.1	19.6	69.3	75.4
Hu 1026e II	7.47	1.32	0.53	0.79	0.22	0.82	0.02	3.15	1.82	0.36	0.07	0.04	—	1.32	5.03	2.25	20.8	16.7	62.5	74.8
Mis 52c	6.89	2.36	1.11	1.25	0.30	0.77	0.02	2.71	1.46	0.66	0.05	0.10	—	1.42	5.15	2.18	32.0	15.5	52.6	71.3
Hu 1026e I Hy	7.29	0.74	0.71	0.02	0.20	0.56	0.02	4.35	1.79	0.13	0.02	0.01	—	2.41	5.17	1.94	4.5	11.3	84.2	70.5
Vz 631	6.84	2.03	1.16	0.87	0.24	1.02	0.01	2.99	1.71	0.22	0.09	0.06	—	1.81	5.20	2.02	22.5	19.9	57.6	70.0
Hu 1170	6.79	1.89	1.21	0.68	0.60	0.68	0.04	2.80	1.83	0.30	0.13	0.05	—	2.09	4.84	2.26	27.4	14.8	57.8	68.1
Vz 673	6.71	2.00	1.29	0.70	0.26	1.18	0.02	2.95	1.86	0.28	0.07	0.05	—	1.83	5.17	2.21	19.6	23.4	57.0	66.9
KAW 657	7.59	2.35	0.41	1.95	0.17	0.43	0.01	1.24	1.30	1.41	0.02	0.21	0.01	1.73	4.02	2.73	58.0	11.1	30.9	66.3
Luk 24	6.89	1.74	1.11	0.64	0.37	1.03	0.04	2.82	1.91	0.22	0.11	0.06	—	1.92	4.96	2.24	21.5	21.6	57.0	66.2
22.7.69.02	6.48	2.41	1.52	0.89	0.10	1.37	0.02	2.85	1.83	0.22	0.06	0.08	0.01	1.74	5.31	2.11	20.1	26.2	53.7	65.7
Mera 33a	6.46	1.92	1.54	0.37	0.51	1.08	0.04	3.01	1.90	0.57	0.04	0.17	—	1.56	5.18	2.50	20.3	21.5	58.1	65.0
Brg 75 conc.	6.26	2.08	1.74	0.35	0.28	1.20	0.04	2.80	1.27	0.72	0.02	0.28	0.01	3.33	4.95	2.00	18.2	25.1	56.7	64.8
PK 834	6.57	1.90	1.43	0.46	0.40	1.20	0.02	2.98	1.93	0.22	0.02	0.10	—	1.93	5.17	2.17	18.7	23.7	57.6	64.6
Wurz 138	6.63	2.13	1.37	0.76	0.50	0.98	0.02	2.73	1.84	0.31	0.11	0.10	—	1.64	5.09	2.26	26.6	19.7	53.7	64.5

20.7.69.01	6.49	1.84	1.51	0.33	0.14	1.52	0.02	3.00	1.86	0.28	0.04	0.15	0.01	2.33	5.16	2.17	12.0	30.0	58.0	63.9
Hu 1164d	6.78	1.94	1.22	0.71	0.53	0.98	0.04	2.56	1.88	0.28	0.05	0.13	—	1.73	4.94	2.22	27.8	20.5	51.7	62.4
KAW 658	7.31	1.04	0.69	0.34	0.31	1.45	0.04	2.88	1.56	0.47	0.02	0.02	—	2.31	5.04	2.05	13.5	29.4	57.1	61.7
Riv 17	6.38	2.05	1.62	0.43	0.53	1.25	0.04	2.81	1.93	0.51	0.09	0.13	—	1.57	5.19	2.54	21.0	24.8	54.3	60.7
Spl 125	6.44	2.40	1.56	0.84	0.41	1.26	0.01	2.54	1.70	0.31	0.09	0.09	—	2.03	5.15	2.10	26.0	24.6	49.4	60.1
Wurz 176	6.30	2.16	1.70	0.46	0.44	1.23	0.02	2.54	2.00	0.39	0.07	0.15	0.02	2.23	4.84	2.46	21.7	25.9	52.4	60.0
Blen 48b	6.30	2.32	1.70	0.63	0.59	1.14	0.06	2.68	1.91	0.46	0.11	0.09	—	1.57	5.18	2.48	25.1	23.3	51.6	60.0
Mto 823	6.40	2.11	1.60	0.51	0.53	1.24	0.05	2.73	1.93	0.28	0.09	0.09	—	1.86	5.14	2.31	21.8	25.0	53.1	60.0
Wurz 175	6.69	1.88	1.31	0.57	0.39	1.28	0.04	2.49	1.93	0.28	0.06	0.11	0.02	2.04	4.88	2.27	22.1	26.9	51.0	59.3
AS 912	6.51	2.17	1.49	0.68	0.58	1.21	0.04	2.57	1.63	0.39	0.06	0.09	—	2.03	5.16	2.08	26.0	24.2	49.8	58.4
Wurz 177b	6.53	2.09	1.47	0.62	0.35	1.38	0.04	2.46	1.94	0.28	0.09	0.11	0.02	1.95	4.97	2.32	21.8	28.6	49.6	58.0
Cal 30	6.54	1.92	1.46	0.46	0.29	1.55	0.05	2.60	1.82	0.40	0.07	0.19	—	1.96	5.13	2.29	18.2	31.1	50.7	58.0
Wurz 150	6.63	2.06	1.37	0.69	0.54	1.29	0.09	2.48	1.85	0.34	0.15	0.05	—	1.57	5.14	2.34	25.0	26.8	48.2	56.4
Cal 25	6.15	2.18	1.85	0.33	0.57	1.18	0.04	2.28	1.80	0.74	0.15	0.21	—	2.82	4.62	2.68	24.1	26.4	49.5	55.9
Wurz 179	6.62	1.78	1.38	0.40	0.66	1.25	0.04	2.46	2.03	0.17	0.06	0.05	—	2.22	4.85	2.26	22.9	26.5	50.7	55.8
Pior 9	6.24	2.54	1.76	0.78	0.44	1.51	0.03	2.42	1.79	0.43	0.06	1.14	—	1.58	5.31	2.27	25.6	28.8	45.6	55.0
Mto 798b	6.36	2.01	1.64	0.38	0.54	1.54	0.05	2.55	1.88	0.46	0.08	0.11	—	1.88	5.16	2.41	19.9	30.8	49.3	54.6
Splug 11d conc.	7.18	1.57	0.82	0.76	0.28	1.48	0.04	2.16	1.71	0.42	0.17	0.07	—	2.03	4.80	2.30	23.3	31.6	45.1	54.5
Mas 9z	6.47	1.90	1.53	0.37	0.61	1.45	0.04	2.49	1.86	0.37	0.09	0.19	—	1.68	5.15	2.32	22.8	28.8	48.4	54.2
Cal 29	6.22	2.30	1.78	0.52	0.60	1.51	0.04	2.51	1.87	0.32	0.11	0.14	—	1.59	5.31	2.29	23.8	29.1	47.2	53.9
Mto 798a	6.51	2.08	1.49	0.59	0.47	1.64	0.04	2.28	1.83	0.03	0.11	0.16	—	1.96	5.17	1.97	23.5	32.4	44.1	51.6
Mas 19	6.35	2.06	1.65	0.40	0.60	1.50	0.06	2.27	1.81	0.29	0.17	0.16	—	2.27	5.00	2.26	23.3	31.2	45.4	51.2
AS 941	6.36	2.14	1.64	0.50	0.53	1.66	0.05	2.31	1.87	0.46	0.06	0.13	—	1.79	5.16	2.38	22.3	33.0	44.7	50.9
Sh Lz A 22	6.31	2.31	1.69	0.62	0.01	2.10	0.04	2.22	1.88	0.26	0.23	0.11	—	2.38	5.10	2.37	14.6	41.9	43.4	50.8
Hu 1170a_3	6.29	2.39	1.71	0.68	0.86	1.17	0.06	2.12	1.94	0.32	0.21	0.10	—	1.58	4.99	2.46	32.9	24.6	42.5	50.4
Bni 258	7.65	0.57	0.35	0.23	1.17	0.93	0.13	2.24	0.18	2.19	0.14	0.06	—	2.58	4.77	2.52	30.6	22.4	47.0	50.0
Mera 34	6.10	2.22	1.90	0.32	0.78	1.57	0.06	2.36	1.95	0.26	0.17	0.11	—	1.81	5.21	2.39	23.3	31.4	45.2	49.4
GdT S 580	6.04	2.90	1.96	0.95	0.68	1.50	0.05	1.59	1.55	0.40	—	0.11	—	2.84	4.88	1.95	35.7	31.7	32.7	41.5
Hu 1202a	6.14	2.29	1.86	0.43	0.73	1.80	0.05	1.52	1.83	0.35	0.17	0.24	—	2.50	4.77	2.35	29.4	38.8	31.8	37.1
FK 644	6.39	2.37	1.61	0.76	0.63	2.60	0.03	0.66	1.89	0.24	0.12	0.03	—	2.64	4.70	2.24	30.2	55.8	14.0	16.9

Table 6. *Microprobe analyses of calcic amphiboles, structural formulae* (basis 23 O)

	Ad 36e			AS 907			AS 907II		
SiO_2	47.5	49.7	51.0	47.5	51.5	49.8	51.5	45.7	46.8
Al_2O_3	11.9	11.5	11.3	12.0	9.1	8.8	6.3	13.1	13.8
FeO	8.9	8.9	7.4	13.8	12.5	12.5	13.9	15.0	14.2
MgO	14.6	15.2	16.7	12.0	11.1	13.9	10.2	9.8	9.8
CaO	11.0	8.6	9.4	12.9	12.7	12.6	12.5	12.8	12.5
Na_2O	1.6	2.5	1.8	0.9	1.5	1.5	1.2	0.8	1.3
K_2O	0.4	0.4	0.4	0.4	0.4	0.4	0.9	0.7	0.8
TiO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.6
	95.9	96.8	98.0	99.7	99.0	100.1	97.0	98.4	99.8
Si	6.88	7.07	7.10	6.79	7.33	7.05	7.55	6.68	6.71
Al^{IV}	1.12	0.93	0.90	1.21	0.67	0.95	0.45	1.32	1.29
Al^{VI}	0.91	1.00	0.96	0.81	0.85	0.52	0.64	0.93	1.04
Fe^{+2}	1.08	1.06	0.86	1.65	1.49	1.48	1.70	1.83	1.70
Mg	3.15	3.22	3.47	2.56	2.35	2.93	2.23	2.13	2.09
Ca	1.70	1.31	1.40	1.98	1.94	1.91	1.96	2.00	1.92
Na	0.45	0.69	0.49	0.25	0.41	0.41	0.34	0.23	0.36
K	0.07	0.07	0.07	0.07	0.07	0.07	0.17	0.13	0.15
Ti	0.0	0.0	0.0	0.02	0.02	0.06	0.06	0.05	0.06
Okt.	5.14	5.28	5.29	5.04	4.71	5.00	4.63	4.96	4.89
Alk.	2.23	2.07	1.96	2.30	2.42	2.39	2.47	2.36	2.43
R^{+3}	17.7	18.9	18.1	16.6	18.5	11.7	15.1	20.0	22.5
Fe^{+2}	21.0	20.1	16.3	32.7	31.6	29.6	36.8	37.0	34.8
Mg	61.3	61.0	65.6	50.7	49.9	58.7	48.1	43.0	42.7

	Bi 22			Cal 21			Frod. 1		
SiO_2	48.5	47.9	54.0	45.5	45.1	44.0	43.3	43.5	43.3
Al_2O_3	13.0	13.0	5.5	13.6	13.2	14.4	18.1	18.4	18.0
FeO	12.4	12.4	9.7	12.9	13.9	14.7	15.5	15.8	14.8
MgO	12.5	11.8	16.8	11.2	11.2	10.6	8.8	8.5	9.3
CaO	11.6	11.9	13.1	12.7	12.7	12.7	10.4	10.5	11.2
Na_2O	1.2	1.0	0.9	1.1	1.2	1.1	1.4	1.4	1.4
K_2O	0.3	0.3	0.3	0.4	0.4	0.4	0.0	0.0	0.0
TiO_2	0.2	0.2	0.2	0.6	0.3	0.3	0.4	0.4	0.4
	99.7	98.5	100.2	98.0	98.0	98.2	98.0	98.6	98.5
Si	6.84	6.85	7.48	6.51	6.59	6.45	6.31	6.31	6.28
Al^{IV}	1.16	1.15	0.52	1.49	1.41	1.55	1.69	1.69	1.72
Al^{VI}	1.00	1.04	0.38	0.86	0.87	0.94	1.42	1.45	1.35
Fe^{2+}	1.46	1.48	1.12	1.70	1.70	1.80	1.89	1.91	1.79
Mg	2.63	2.51	3.47	2.44	2.44	2.31	1.91	1.83	2.01
Ca	1.75	1.82	1.94	1.99	1.99	1.99	1.69	1.63	1.74
Na	0.33	0.28	0.24	0.31	0.34	0.31	0.40	0.39	0.39
K	0.05	0.05	0.0	0.07	0.07	0.07	0.0	0.0	0.0
Ti	0.02	0.02	0.02	0.07	0.03	0.03	0.04	0.04	0.04
Okt.	5.11	5.05	4.99	5.07	5.04	5.09	5.27	5.25	5.21
Alk.	2.13	2.15	2.18	2.38	2.40	2.38	2.02	2.02	2.13
R^{+3}	20.0	20.9	8.0	18.2	17.8	19.1	27.7	28.4	26.8
Fe^{+2}	28.6	29.3	22.5	33.6	33.7	35.4	36.1	36.7	34.7
Mg	51.4	49.7	69.5	48.2	48.4	45.5	36.2	34.9	38.6

	Frod. 2		Jo 545			Sci 123			Spl 104b		
SiO_2	43.2	41.7	50.0	51.8	48.8	47.1	46.7	46.7	55.5	54.7	51.9
Al_2O_3	18.8	18.1	9.8	7.6	11.0	8.9	9.4	8.9	4.0	5.2	6.2
FeO	15.1	18.4	6.5	6.5	7.5	14.3	15.4	15.4	10.1	10.1	10.7
MgO	7.9	6.3	18.7	17.0	17.0	11.9	11.9	11.2	14.9	14.9	14.8
CaO	10.9	10.1	12.6	12.2	12.7	11.8	12.3	11.7	11.3	10.3	10.5
Na_2O	1.4	1.2	0.8	1.2	1.0	1.0	0.8	1.3	1.4	1.2	1.4
K_2O	0.0	0.0	0.4	0.4	0.4	0.1	0.1	0.1	0.3	0.3	0.3
TiO_2	0.0	0.0	0.3	0.3	0.3	0.3	0.3	0.6	0.0	0.0	0.0
	96.3	95.7	99.1	97.0	98.7	95.4	96.9	95.9	97.5	96.7	95.8
Si	6.27	6.30	6.95	7.32	6.85	7.05	6.93	7.00	7.86	7.78	7.53
Al^{IV}	1.73	1.70	1.05	0.68	1.15	0.95	1.07	1.00	0.14	0.22	0.47
Al^{VI}	1.54	1.53	0.55	0.59	0.67	0.62	0.57	0.57	0.53	0.66	0.59
Fe^{+2}	1.87	2.33	0.75	0.77	0.88	1.79	1.91	1.93	1.20	1.20	1.30
Mg	1.74	1.42	3.87	3.58	3.55	2.65	2.63	2.50	3.14	3.16	3.20
Ca	1.73	1.64	1.87	1.85	1.91	1.89	1.95	1.88	1.71	1.57	1.63
Na	0.4	0.35	0.22	0.33	0.27	0.29	0.23	0.38	0.38	0.33	0.39
K	0.0	0.0	0.07	0.07	0.07	0.02	0.02	0.02	0.05	0.05	0.06
Ti	0.0	0.0	0.03	0.03	0.03	0.03	0.03	0.07	0.0	0.0	0.0
Okt.	5.17	5.27	5.20	4.97	5.13	5.09	5.14	5.07	4.87	5.02	5.09
Alk.	2.13	1.99	2.16	2.25	2.25	2.20	2.20	2.27	2.15	1.96	2.08
R^{+3}	29.8	29.0	11.2	12.5	13.6	12.8	11.7	12.6	10.9	13.1	11.6
Fe^{+2}	36.4	44.1	14.5	15.5	17.2	35.1	37.1	38.1	24.6	23.9	25.5
Mg	33.8	26.9	74.3	72.0	69.2	52.1	51.1	49.3	64.5	62.9	62.9

	Spl 119			Toce 82a			Trem. 4			
SiO_2	43.3	45.0	42.5	42.7	42.7	44.8	42.3	43.8	43.9	44.6
Al_2O_3	12.3	12.5	12.7	11.6	12.8	11.5	17.2	17.5	17.7	17.2
FeO	17.4	17.4	17.6	18.0	18.0	18.2	18.2	18.0	18.7	18.6
MgO	9.5	9.8	9.6	9.2	9.2	9.3	7.1	6.6	6.8	7.0
CaO	12.5	12.5	12.0	12.8	12.4	12.8	10.6	10.6	10.4	10.7
Na_2O	1.2	1.1	1.4	1.2	1.0	1.0	1.6	1.9	1.8	1.4
K_2O	0.8	0.8	0.9	1.1	1.1	1.0	n.d.	n.d.	n.d.	n.d.
TiO_2	0.5	0.5	0.5	0.6	0.5	0.5	0.4	0.4	0.4	0.4
	97.5	99.6	97.2	97.2	97.7	99.1	97.4	98.8	99.7	99.9
Si	6.52	6.59	6.43	6.50	6.44	6.65	6.30	6.40	6.37	6.45
Al^{IV}	1.48	1.41	1.57	1.50	1.56	1.35	1.70	1.60	1.63	1.55
Al^{VI}	0.70	0.75	0.70	0.58	0.72	0.66	1.32	1.41	1.40	1.38
Fe^{+2}	2.19	2.13	2.23	2.29	2.27	2.26	2.27	2.20	2.27	2.25
Mg	2.13	2.14	2.16	2.09	2.07	2.05	1.58	1.44	1.47	1.51
Ca	2.01	1.96	1.94	2.09	2.00	2.03	1.69	1.66	1.62	1.66
Na	0.35	0.31	0.41	0.35	0.29	0.29	0.46	0.54	0.51	0.39
K	0.15	0.15	0.17	0.21	0.21	0.19	0.0	0.0	0.0	0.0
Ti	0.06	0.06	0.06	0.07	0.06	0.06	0.04	0.04	0.04	0.04
Okt.	5.07	5.08	5.14	5.02	5.11	5.02	5.22	5.12	5.20	5.19
Alk	2.52	2.42	2.53	2.65	2.51	2.51	2.15	2.20	2.12	2.05
R^{+3}	14.8	15.9	14.6	12.9	15.1	14.2	26.2	28.5	27.7	27.4
Fe^{+2}	43.2	42.0	43.3	45.6	44.4	44.9	43.7	43.4	44.1	43.6
Mg	42.0	42.1	42.1	41.5	40.5	40.9	30.1	28.1	28.2	29.0

	Trem. 6		Trem. 8			Trem. 9			Wurz 121e		
SiO_2	41.4	41.0	43.6	43.3	44.0	43.8	43.4	43.2	42.8	40.9	42.1
Al_2O_3	17.8	18.0	15.7	15.8	16.7	17.3	17.2	17.2	13.0	13.1	13.3
FeO	24.6	24.3	16.2	17.8	17.7	20.3	20.5	21.1	15.1	16.1	15.7
MgO	3.6	3.7	8.0	8.0	8.0	6.1	6.5	5.6	9.6	10.0	9.9
CaO	10.0	10.0	10.2	10.5	11.3	10.0	10.2	9.9	12.3	11.8	11.9
Na_2O	1.4	1.4	1.8	1.9	1.7	1.9	1.8	1.9	1.7	1.7	1.5
K_2O	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.4	1.5	1.4
TiO_2	0.3	0.3	0.5	0.5	0.4	0.3	0.3	0.4	1.2	1.4	1.3
	99.1	98.7	96.0	97.8	99.8	99.7	99.9	99.3	97.1	96.5	97.1
Si	6.23	6.19	6.51	6.41	6.37	6.40	6.35	6.37	6.43	6.24	6.34
Al^{IV}	1.77	1.81	1.49	1.59	1.63	1.60	1.65	1.63	1.57	1.76	1.66
Al^{VI}	1.38	1.40	1.27	1.17	1.23	1.38	1.31	1.36	0.74	0.60	0.71
Fe^{+2}	3.09	3.10	2.02	2.20	2.14	2.48	2.51	2.60	1.90	2.05	1.98
Mg	0.81	0.83	1.78	1.76	1.73	1.33	1.42	1.23	2.15	2.27	2.22
Ca	1.61	1.62	1.63	1.67	1.75	1.57	1.60	1.56	1.98	1.93	1.92
Na	0.41	0.41	0.52	0.55	0.48	0.54	0.51	0.54	0.50	0.50	0.44
K	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.29	0.27
Ti	0.03	0.03	0.06	0.06	0.04	0.03	0.03	0.04	0.14	0.16	0.15
Okt.	5.34	5.35	5.16	5.22	5.16	5.24	5.28	5.25	4.92	5.09	5.05
Alk.	2.02	2.03	2.15	2.21	2.23	2.10	2.11	2.11	2.74	2.72	2.63
R^{+3}	26.5	26.8	25.8	23.5	24.6	27.0	25.5	26.8	17.7	15.0	16.9
Fe^{+2}	58.4	57.6	39.7	42.7	42.0	47.6	47.7	49.8	38.6	40.4	39.1
Mg	15.1	15.6	34.5	33.8	33.4	25.4	26.8	23.4	43.7	44.6	44.0

Table 7. *Trace elements*

Sample	Ba	Be	B	Pb	V	Cu	Y	Zr	Ni	Co	Sr	Mn	Cr
AS 912	ca. 100	<3	19		300			105	380	<50	14		500
AS 941	100	<2	25		350			100	100				200
Blen 48b	<100	5	20		250			ca. 50	60	<50	30		360
Bni 176	<100	17	29		140			88	1	14	40		<10
Brg 2	<100	3	<10	120	400	<10	<10	<50	<10	10	60	300	<20
Cal 25	100	<2	250		250			180	300	120	20		170
Cal 29	<100	1	28		360			140	96	65	18		280
Cal 30	< 30	<2	18		350			100	80	30	25		400
Ct 19 «L»	<100	25	40	100	>1000	15	20	<50	15	<10	35	<200	130
Ct 19 «S»	<100	30	25	60	>1000	14	15	<50	20	<10	35	<200	130
FK 644	120	6	60		50			ca. 60	650		20		25
HoVo	30	<1	<10	10	245	29	15	65	240	45	245	950	875
Hu 1015	1200	1	0		50			60	500	40	10		500
Hu 1026 I	0	1	2		110			100	500	52	13.5		500
Hu 1026e I	0	1	20		150			140	500	40	22		500
Hu 1026 II	0		2		45			80	500	50	15.5		500
Hu 1026e II	0	2	10		120			150	500	48	18.5		500
Hu 1164d	0	0	10		300			150	170	50	28		500
Hu 1170	110	1	2		170			145	500	48	16.5		500
Hu 1170a_3	125	1	20		315			105	26	41	21		80
Hu 1202a	195	2	30		360			325	22	42	305		80
Luk 24	<100	<2	230		370			110	90	200	20		270
Mas 9z	ca. 100	<3	19		350			100	70	<50	15		380
Mas 19	350	3	30		450			80	55	<50	25		70
Mera 33a	<30	3	20		350			170	145	100	20		550
Mera 34	100	4	50		360			80	2	25	24		34
Mera 40	<90	1	<80	110	40	6	<10	<50	10	10	25	340	15
Mto 798a	<100	3	26		350			200	60	70	22		70
Mto 798b	<30	3	20		450			140	<80	50	20		90
Mto 823	140	<3	280		500			130	55	30	21		70
Pior 9	<100	<3	450		400			230	300	>200	24		80
PK 834	<100	<3	230		350			140	230	75	12		120
Riv 17	100	<2	18		250			<100	140		<10		450
ShLz A 22a	150	<3	10		250			80	250	<50	500		350
Spl 125	140	<3	450		330			130	160	140	360		200
TV 116e	< 90	<1	≪80	<10	30	8	<10	<50	10	<10	35	150	15
Varzo 6	<100	2	2		70			170	480	35	280		880
Varzo 7	<100	1	1.5		58			48	13	11	23		16
Vz 194	< 30	<2	2		100			110	250	25	15		650
Vz 394	<100	5	11		160			78	250	80	13		850
Vz 428	def.	<2	4		110			<100	190	25	19		700
Vz 631	120	<1	>500		250			50	130	200	11		300
Vz 673	<100	<3	250		250			220	450	200	11		500
Wurz 138	<100	<3	19		>500			ca. 45	130	<50	400		160
Wurz 150		<3	14		150			ca. 50	40	<50			170
Wurz 175	90			8	250	58		170	430	55	50	3200	600
Wurz 176	<90	4		65	300	21	50	110	165	50	130	2400	900
Wurz 177b	<90				250	54	17	170	200	58	190	2800	680
20.7.69.01	<90			<8	250	48	15	240	135	58	40	3400	1000
22.7.69.02	<90	<1	≪80	25	360	15	20	120	30	70	30	2000	500

Table 8a. *Optical data of calcic amphiboles*

Sample	n_α				n_β				n_γ				$2V_x$
AS 912	1.653	1.651	1.654		1.663	1.661	1.665		1.673	1.669	1.673		76½–78
AS 941	1.663	1.664	1.664		1.675	1.675	1.675		1.683	1.684	1.684	1.604	72 –75
Blen 48b	1.655	1.655	1.651		1.665	1.665	1.659		1.675	1.675	1.669		83 –86
Brg 75	1.656	1.656	1.628		1.665	1.666	1.667	1.641	1.673	1.674		1.651	78 –83
Cal 25	1.655	1.655	1.655		1.665	1.667	1.667		1.672	1.673	1.675		72½–74½
Cal 29	1.665	1.663	1.663		1.667	1.667	1.667		1.683	1.685	1.683		67 –69½
Cal 30	1.645	1.637	1.651		1.657	1.653	1.665		1.672	1.659	1.675		80 –81½
FK 644	1.683		1.681		1.706	1.707	1.699		1.7115		1.706		46½–48
Frod 1	1.656	1.652	1.653	1.652	1.669	1.664	1.664		1.681	1.673	1.674	1.673	80 –87
Hovo	1.638	1.640	1.640		1.646	1.646			1.660	1.660			102
Hu 1164d	1.638	1.645	1.645	1.639	1.650	1.657	1.656	1.651	1.660	1.667	1.667	1.662	82 –83½
Hu 1170		1.645	1.639	1.643		1.655	1.651	1.653	1.660	1.665	1.661	1.661	79 –81
Hu 1170a_3		1.665	1.667	1.666		1.678	1.679	1.679	1.680	1.686	1.689	1.687	60 –65
Hu 1202a		1.678	1.676			1.690	1.671	1.691		1.696	1.697	1.697	53 –56
Luk 24	1.635				1.647	1.651			1.657				81 –82½
Mas 9z	1.664	1.658	1.660	1.644	1.674	1.672	1.672	1.677	1.672	1.680	1.680	1.683	64
Mas 19	1.671	1.665	1.665		1.685	1.681	1.681		1.691	1.685	1.685		58½–60½
Mera 33a	1.655	1.647	1.653		1.667	1.663	1.663		1.673	1.671	1.675		72½–80
Mera 34	1.667	1.673	1.680	1.671	1.685	1.683	1.689		1.687	1.691	1.693		60 –63
Mis 52c	1.624	1.622	1.624	1.628	1.635	1.642	1.634	1.642	1.642	1.652	1.642	1.651	77 –79
Mto 798a	1.657	1.657	1.655		1.669	1.669	1.667		1.677	1.679	1.677		74½–76
Mto 798b	1.657	1.657	1.655		1.670	1.669	1.667		1.679	1.677	1.675		74 –74½
Mto 823	1.658	1.653	1.653	1.652	1.669	1.667	1.667	1.663	1.679	1.675	1.673	1.673	71
Pior 9	1.657	1.651	1.655		1.667	1.663	1.667		1.679	1.675	1.677		82 –85
PK 834	1.645	1.643	1.645		1.659	1.657	1.658		1.667	1.667	1.667		79½
Riv 17	1.655	1.657	1.658		1.669	1.667	1.668		1.677	1.673	1.677		75½–77
Splug 11d	1.653	1.653			1.666	1.663			1.674	1.676			71 –72
Trem 4	1.664	1.662	1.666	1.666	1.674	1.677	1.678	1.678	1.682	1.684	1.684	1.685	75 –79
Trem 6	1.667	1.668	1.672	1.668	1.676	1.678	1.686	1.681	1.687	1.689	1.694	1.689	72 –76
Trem 8	1.659	1.658	1.658	1.659	1.667	1.668	1.670	1.671	1.679	1.680	1.680	1.681	77 –78
Trem 9	1.663	1.664	1.663	1.665	1.673	1.674	1.675	1.673	1.682	1.683	1.684	1.683	69 –76
Vz 631	1.639	1.638	1.639		1.653	1.651	1.649		1.663	1.661	1.659		82½–84½
Vz 673	1.623				1.645				1.659				84 –87
Wurz 138	1.643	1.649	1.647	1.649	1.655	1.659	1.656	1.657	1.667	1.671	1.656	1.667	81½–83
Wurz 150	1.655	1.643			1.662	1.663?			1.676	1.671			73½–76½

Table 8b. *Optical data of tremolitic/actinolitic hornblendes*

Sample	n_α				n_β				n_γ				$2V_x$
CT 19 «L»	1.607				1.616				1.630				
CT 19 «S»	1.605				1.616				1.627				
Hu 1015	1.622	1.617	1.616	1.623	1.634	1.633	1.632	1.639	1.648	1.643	1.641	1.649	82 –84½
Hu 1026 I	1.630				1.641				1.653				
Hu 1026e I		1.617	1.617			1.630	1.631			1.643	1.643		80 –81
Hu 1026 II	1.620	1.616	1.617		1.632	1.633	1.628		1.644	1.642	1.644		80 –82
Hu 1026e II	1.626	1.628	1.619	1.640	1.637	1.642	1.638	1.651	1.650	1.653	1.647	1.659	80 –85
Mera 40	1.601	1.602			1.616	1.616			1.629	1.628			
Varzo 6	1.615	1.615	1.616		1.631	1.631	1.631		1.641	1.643	1.641		81½–83
Varzo 7	1.6125	1.612	1.612		1.629	1.627	1.627		1.639	1.639	1.639		80½–81
Vz 194	1.611	1.611	1.611		1.627	1.627	1.627		1.638	1.639	1.639		82
Vz 394	1.627	1.630	1.628		1.639	1.641	1.640		1.652	1.653	1.651		84½–88½
Vz 428	1.617	1.621	1.619		1.623	1.635	1.631		1.642	1.647	1.643		79 –82

Table 9a. *List of analysed samples* (Tables 2–4)

Sample	Rock	Location	Coordinates	Biotite	Rock	Hornblende
AS 912	Oligoclase-amphibolite	Giessen, Binntal	658.6/135.6		+	+
AS 941	Oligoclase-amphibolite	Simplon, Alte Kaserne	650.2/115.1		+	+
Blen 48b	Epidote-andesine-amphibolite	Loderio	717.7/157.3			+
Bni 258	Albite-crossite-schist	ESE Grevasalvas	775.4/143.9			+
Brg 73	Andesine-amphibolite	Muretto	776.2/136.3		+	
Brg 75	Chlorite-oligoclase-amphibolite	Muretto	776.2/135.7		+	+
Cadonigo	Green tremolite in dolomite-marble	A. Cadonigo	701.3/146.6			+
Cal 25	Biotite-albite/oligoclase-amphibolite	A. Alögna	729.8/143.5	+	+	+
Cal 29	Epidote-oligoclase-amphibolite	W Sta. Domenica	729.3/134.8			+
Cal 30	Biotite-oligoclase-andesine-amphibolite	New Calanca-road	730.7/123.7	+		+
CT 19	Light-green tremolite in dolomite-marble	A. Campolungo	698.8/147.4			+
FK 644	Quartz-calcite-magnetite-hornblende-rock	W P. Mascarpino	691.0/142.7			+
GdT S 580	Chlorite-biotite-garnet-amphibolite	Gotthard roadtunnel 580 m S		+	+	+
HoVo	Hornblendite	R. del Motto				+
Hu 1015	Inclusion in dolomite-marble	A. Bosa, V. di Campo	675.2/123.4	+		+
Hu 1026	Inclusion in hornblende-plagioclase-gneiss	N Cma. di Tramolino, V. di Campo	678.7/125.2			+
Hu 1164d	Epidote-oligoclase-amphibolite	S Motta del Termine, V. di Campo	678.1/124.9			+
Hu 1170	Inclusion in oligoclase-amphibolite	SE Mattignello, V. di Campo	678.8/125.8			+
Hu 1202a	Oligoclase-amphibolite	SE A. Bosa, V. di Campo	674.7/123.4		+	+
KAW 657	Prasinite	Pfulwe	631.4/ 96.2			+
KAW 658	Hornblende-albite vein	Pfulwe	631.4/ 96.2			+
Luk 24	Biotite-oligoclase/andesine-amphibolite	NNW Aquila	714.9/151.5	+		+
Mas 9z	Pyroxene-andesine/labradorite-amphibolite	Corte Vecchia, Bagni del Masino	766.1/124.2			+
Mas 19	Biotite-hornblende-andesine/labradorite-gneiss	Quarry E Bagni del Masino	767.2/123.5	+		+
Mera 33a	Andesine/labradorite-amphibolite	Berzo S Prato/Chiavenna	750.6/129.1		+	+
Mera 34	Epidote-biotite-hornblende-andesine-gneiss	S Motta dei Cecchi	754.9/116.6	+	+	+
Mera 40	Tremolite-diopside-marble	Mte. Peschiera	753.2/120.1			+
Mis 52	Calcite-clinozoisite-biotite-chlorite-amphibolite	S Bernardino	734.6/145.1		+	
Mis 52b	Garnet-biotite-chlorite-amphibolite	S Bernardino	734.6/145.1		+	+
Mis 52c	Garnet-muscovite-amphibolite	S Bernardino	734.6/145.1		+	+
Mto 798a	Oligoclase-amphibolite	Campo la Torba	687.3/147.6			+
Mto 798b	Biotite-oligoclase-amphibolite	Campo la Torba	687.3/147.6	+		+
Mto 823	Oligoclase-amphibolite	W Colla near Fusio	694.8/145.4			+
Pior 9	Epidote-oligoclase-amphibolite	W Staz. Piora	694. /153.5			+

PK 834	Hornblende-andesine-gneiss	S Cma. del Sassone, Centovalli	683.1/113.5			+
Riv 17	Epidote-diopside-andesine-amphibolite	NNW Gorduno, Riviera	722.7/119.9		+	+
Sci 171	Andesine/labradorite-amphibolite	Denc dal Luf	762.7/131.3		+	
Sci 186	Hornblendite	Bondasca, SW Gerp	764.0/132.3		+	
Sci 244	Epidote-biotite-hornblende-andesine-gneiss	Preda Rossa	774.2/121.9		+	
Sh Lz A 22a	Bytownite-amphibolite, inclusion in gneiss	Lavertezzo	707.8/124.1		+	+
Spl 125	Oligoclase-amphibolite	Quarry Vogelsang	646.4/124.1			+
Spluga 11d	Clinozoisite-andesine-biotite-hornblende-schist	Liro W Chiavenna	749.4/132.2		+	+
TV 116e	Tremolite in white dolomite-marble	Campolungo	697.3/146.8			+
Varzo 6	Actinolite-phlogopite-calcite-oligoclase-gneiss	E Ciöina di dentro	660.2/119.9	+		+
Varzo 7	Actinolite-phlogopite-calcite-oligoclase-gneiss	E Ciöina di dentro	660.2/119.9	+		+
Vz 194	Biotite-schist	Mte. Sambuco	709.4/125.2	+		+
Vz 394	Biotite-actinolite-schist	NW A Tencio, V. Verzasca	702.6/129.9	+		+
Vz 428	Actinolite-biotite-schist	Fontöbbia	709.7/118.6	+	+	+
Vz 631	Labradorite/bytownite-amphibolite	Cargello near Corippo	707.1/122.3		+	+
Vz 673	Hornblendic inclusion in oligoclase/andesine amphibolite	A. Mugaglia, V. Redorta	699.8/133.8			+
Vz 703	Andesine-amphibolite	Madone Grosso	707.4/135.6		+	
Wurz 138	Biotite-andesine/labradorite-amphibolite	Aurigeno-Dunzio	700.1/119.5	+		+
Wurz 150	Pyroxen-andesine-amphibolite	Brè-Monteggia (Locarno)	703.3/116.9			+
Wurz 166	Epidote-andesine-amphibolite	Riei, Verscio	699.4/116.9		+	
Wurz 175	Titanite-quartz-andesine-amphibolite	W Sementina	718.3/116.1		+	+
Wurz 176	Andesine-amphibolite	San Defendente	717.5/115.7		+	+
Wurz 177b	Andesine/labradorite-amphibolite	N S. Defendente	717.7/116.4		+	+
Wurz 179	Pyroxene-bytownite-amphibolite	Mti di Ditto	712.26/115.72		+	
19.7.69.01	Andesine/labradorite-amphibolite	Mti. Laura	729.9/117.6		+	
20.7.69.01	Andesine/labradorite-amphibolite	Mti. Laura	729.9/119.9		+	+
20.7.69.02	Andesine-amphibolite	V. Traversagna	731.1/120.4		+	
20.7.69.03	Oligoclase-quartz-chlorite-amphibolite	Quarry Cama	734.0/125.5		+	
22.7.69.01	Biotite-quartz-andesine-amphibolite	A. Scimetta, V. Mesocco	736.9/130.3		+	
22.7.69.02	Biotite-andesine-amphibolite	A. Scimetta, V. Mesocco	736.9/130.3		+	+
29.9.69.01	Calcite-chlorite-epidote-albite-schist	Valserberg	735.1/157.4		+	

Table 9b. *Amphiboles, analyzed by microprobe* (Table 6)

Sample	Rock type	Locality	Coordinates
Ad 36e	albite amphibolite, chlor. biot. musc. rut. ore bearing	Hinterrhein	728.2 /151.1
AS 907	clinoz. oligocl. amphibolite, tit. biot. bearing	Merezenbachtal	666.4 /145.8
Bi 22	biot. epid. oligocl. amphibolite, rut. bearing	Alp Freiche	662.7 /136.45
Cal 21	andesine, amphibolite, epid. tit. bearing	W Santa Domenica	728.7 /134.8
Frod 1	kyanite biotite garnet hornblende-schist	Frodalera	706.7 /154.2
Frod 2	hornblende garnet biot. schist	Frodalera	706.7 /154.2
Jo 545	biot. andes./labrad. amphibolite, tit. rut. epid. bearing	N Lago Devero	671.27/134.75
Sci 123	andesine amphibolite, ore bearing	Forno	774.45/136.65
Spl 104b	chlor. epid. albite/oligocl. amphibolite, tit. bearing	S Alpe Straciugo	652.6 /108.0
Spl 119	albite/oligocl. epid. amphibolite, biot. tit. bearing	below Lago di Paione	658.0 /113.2
Toce 82a	oligocl. amphibolite, tit. bearing	quarry SE Croppo	667.8 /106.8
Trem 4	garnet biotite chlor. hornblende-schist	Motto Bartola	687.9 /154.4
Trem 6	biot. chlor. garnet hornblende-schist, staurolite bearing	Motto Bartola	687.9 /154.4
Trem 8	chlor. hornblende plagiocl. gneiss epid. bearing	Motto Bartola	687.9 /154.4
Trem 9	garnet hornblende schist, carbonate bearing	Lago Ritom	695.5 /155.3

Table 10. *Grouping according to metamorphic grade*

Group	Type	An content	Analyses Rock	Analyses Mineral
0	greenstones (diabase a. o.)		29	—
I	hornblende-bearing greenschists, prasinites		10	6
II	albite-amphibolites	0–5	9	8
IV	albite-plus oligoclase-, or oligoclase-amphibolites	(0–5)+(10–25) or 17–30	17/37	18
V	andesine-amphibolites	30–50	25	18
VI	labradorite/bytownite-amphibolites	>50	8	6
III	Garbenschiefer and oligoclase-amphibolites (Gotthard, Frodalera)	20–30	8	30

Table 11a. *Statistical values of calcic amphiboles. Grouping according to petrographical criteria and increasing metamorphic grade. Weight percentages*

Group	Rock type		SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	H_2O^+
I	Greenschists	N_x	6	6	6	6		6	6	6	6	6	6
	(prasinites)	$\bar{x}$	48.18	8.20	3.83	8.88		15.10	10.82	1.95	0.15	0.42	2.38
		S_x	2.05	2.26	1.14	1.50		2.87	1.10	0.50	0.14	0.41	0.58
		V_x	4.3	27.6	29.7	16.9		19.0	10.2	25.9	91.9	97.7	24.2
II	Albite-amphibolites	N_x	8	8				8	8	8			
		$\bar{x}$	45.65	11.34				9.98	11.58	2.24			
		S_x	4.03	3.62				2.72	0.52	0.80			
		V_x	8.8	32.0				27.3	4.49	35.8			
III	Hornblende rocks	N_x	30	30	13	13	30	30	30	30	13	28	13
	of the zone	$\bar{x}$	42.85	17.09	4.09	12.85	0.18	7.60	10.27	1.64	0.36	0.45	2.22
	Tremola-Frodalera	S_x	1.02	0.99	1.08	1.44	0.11	1.60	0.43	0.28	0.03	0.16	0.09
		V_x	2.4	5.8	26.3	11.2	63.4	21.1	4.2	16.9	21.2	35.4	4.0
IV	Oligoclase-amphi-	N_x	18	18	18	18	18	18	18	18	18	18	18
	bolites ± albite	$\bar{x}$	43.79	12.52	4.82	11.46	0.26	10.66	10.90	1.59	0.53	0.96	2.41
		S_x	2.38	1.18	1.56	2.62	0.13	2.06	0.99	0.73	0.26	0.38	1.12
		V_x	5.4	9.4	32.4	22.9	50.9	19.4	9.1	45.8	49.0	39.7	46.5
V	Andesine-	N_x	18	18	18	18	18	18	18	18	18	18	18
	amphibolite	$\bar{x}$	44.77	11.72	3.98	11.10	0.32	11.63	11.91	1.19	0.50	0.88	1.97
		S_x	2.19	1.16	1.43	2.77	0.14	2.46	0.52	0.37	0.25	0.40	0.29
		V_x	4.9	9.8	35.8	24.9	44.8	21.2	4.3	31.0	50.9	45.5	14.8
VI	Labradorite/	N_x	6	6	6	6	6	6	6	6	6	6	6
	bytownite-	$\bar{x}$	44.75	11.63	3.62	11.27	0.27	11.98	12.05	1.10	0.53	0.93	1.98
	amphibolite	S_x	1.93	1.02	2.25	3.03	0.08	1.61	0.65	0.50	0.35	0.45	0.32
		V_x	4.3	8.8	62.1	26.9	30.5	13.4	5.4	45.3	65.6	48.2	16.1

Table 11b. *Statistical values of amphibolites and hornblende bearing rocks. Grouping according to petrographical criteria and increasing metamorphic grade. Base: Weight percentages*

Group	Rock type		SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	H_2O^+
0	Greenstones (diabase)	N_x	29	29	29	29	29	29	29	29	29	29	29
		$\bar{x}$	46.47	17.02	3.67	5.54	0.17	6.66	8.21	3.99	0.51	1.73	4.72
		S_x	5.22	1.48	1.84	2.27	0.06	2.33	4.27	1.94	0.52	0.59	1.81
		V_x	11.2	8.7	50.1	40.9	36.9	35.0	52.0	48.8	102.5	34.2	38.4
I	Greenschists (prasinites)	N_x	10	10	10	10	10	10	10	10	10	10	10
		$\bar{x}$	47.45	16.61	3.25	6.80	0.16	7.60	9.01	3.10	0.46	2.04	3.08
		S_x	3.09	2.20	1.45	2.11	0.06	2.18	2.66	1.10	0.45	0.80	1.26
		V_x	6.5	13.2	13.2	30.9	37.5	28.7	29.5	35.5	98.3	39.5	40.9
II	Albite-amphibolites	N_x	9	9	9	9	9	9	9	9	9	9	9
		$\bar{x}$	46.85	15.18	3.10	6.85	0.16	8.11	10.12	2.68	1.01	1.51	1.91
		S_x	6.21	4.11	1.77	2.31	0.09	3.17	3.13	0.72	0.97	1.06	0.37
		V_x	13.3	27.1	56.9	33.7	57.1	39.0	30.9	26.9	95.9	70.2	19.5
III	Hornblende rocks of the zone Tremola-Frodalera	N_x	8	8	8	8	8	8	8	8	8	8	8
		$\bar{x}$	53.15	18.49	4.21	6.77	0.11	5.74	6.23	1.80	1.65	1.42	1.86
		S_x	3.58	3.19	2.52	2.69	0.12	1.48	2.33	0.58	0.84	0.87	0.87
		V_x	6.7	17.2	59.8	39.8	114.1	25.8	37.5	32.4	51.0	61.1	46.5
IV	Oligoclase-amphibolites ± albite	N_x	17	17	17	17	16	37	37	37	37	17	17
		$\bar{x}$	49.01	15.30	2.86	8.62	0.20	7.43	9.20	2.82	0.84	1.76	2.40
		S_x	2.94	1.24	1.16	3.12	0.12	2.40	1.71	1.12	0.82	0.70	0.71
		V_x	6.0	8.1	40.7	36.2	59.3	32.4	18.6	39.6	97.2	39.4	29.6
V	Andesine-amphibolite	N_x	25	25	25	25	25	25	25	25	25	25	25
		$\bar{x}$	50.93	15.37	2.60	6.46	0.16	7.97	10.06	2.58	0.84	1.17	1.62
		S_x	4.02	2.74	1.39	1.60	0.06	3.11	1.91	0.72	0.74	0.48	0.55
		V_x	7.9	17.9	53.6	24.8	37.6	39.0	19.0	27.9	87.7	40.6	33.9
VI	Labradorite/bytownite-amphibolite	N_x	8	8	8	8	8	8	8	8	8	8	8
		$\bar{x}$	48.69	16.26	2.38	6.65	0.12	8.50	12.12	1.89	0.53	1.47	1.27
		S_x	1.77	1.46	1.07	1.43	0.06	2.46	1.41	0.72	0.55	0.57	0.37
		V_x	3.6	9.0	45.0	21.5	52.4	28.9	11.6	37.9	103.2	38.6	29.2

Table 12. *Average modes of plagioclase-amphibolites with changing An-content, deduced from the modes of 85 amphibolites from the Central Alps*

An %	0	10	20	25	30	35	40	45	50	55	60	65	70	75	80	90
Vol-%												data less reliable				
Plagioclase	17	18	23	31	32	33	34	35	36.5	38	38	34	30	30.5	29	28.5
Hornblende	60	60	60.5	60	60	59.5	58.5	55.5	53.5	50	50	55	57	57	56	56.5
Clinopyroxene	—	—	—	—	—	0.5	1.5	4	6	7.5	8	7.5	7	6	8.5	5
Chlorite, Biotite	7	6	5	4	3.5	3	2	1	1	0.5	—	—	—	—	—	—
Klinozoisit/ Epidote	13	11	7	3.5	2.5	1	1	1	0.5	0.5	0.5	0.5	1.5	3.5	2.5	3
Quartz	1	2	2.5	0.5	—	1	1	1	0.5	1	1	1	1.5	1	1.5	4
Accessories	2	3	2	1	2	2	2	2.5	2	2.5	2.5	2	3	2	2.5	3

Table 13. *Approximate modal variation with rising metamorphic grade, calculated in cation % for 3 different amphibolites*

1. Si 45.8, Al 15.7, Fe^{III} 1.6, Fe^{II} 7.4, Mg 13.6, Ca 10.2, Na 4.6, K 0.2, Ti 0.9 (approximate composition of average albite-amphibolite in Table 12).

	Metamorphic grade		
An Plag.	0	33	50
% Plag.	17.5	26.5	35
Ho	60	61	38
Chlor.	7	—	—
Biot.	—	3.5	—
Clzt	12.5	2	—
Clpx	—	—	5
Opx	—	—	19
Ru	1	—	—
Tit	—	1	2
Ore	1	2	1
Qz	1	4	—

2. Si 45.3, Al 19.0, Fe^{III} 1.6, Fe^{II} 6.1, Mg 10.8, Ca 12.4, Na 3.1, K 0.5, Ti 1.2 (sample Wurz. 177b)

An Plag.	0	26	50	60	68
% Plag.	9.5	13.5	19	30	56.5
Ho	66.5	66.5	66.5	55	—
Clzt	18.5	14	9	—	—
Clpx	—	—	—	9	20
Opx	—	—	—	—	18.5
Ru	1	1	1	1	1
Ore	0.5	0.5	0.5	1	4
Qz	4	4.5	4	4	—

3. Si 45.0, Al 19.0, Fe^{III} 3.0, Fe^{II} 4.9, Mg 9.8, Ca 14.1, Na 3.0, K 0.2, Ti 1.0 (sample Wurz. 179)

An Plag.	0	50	67	71
% Plag.	11.5	23	36.5	55.5
Ho	60.5	60	56	—
Clzt	21.5	13	—	—
Clpx	—	—	4	21
Opx	—	—	—	16
Tit	2.5	2.5	2.5	3
Ore	1	0.5	1	4.5
Qz	3	1	—	—

Table 14. *Quantitative variation of plagioclase with constant Na content, but changing anorthite proportion. Calculations in cation percentages. Na = 2 cation %*

Si	Al	Ca	Na	∑ cat. %	An %
6	2	—	2	10	0
1	1	0.5	—		
6	2	—	2	12.5	20
1.33	1.33	0.67	—		
6	2	—	2	13.3	25
2.67	2.67	1.33	—		
6	2	—	2	16.7	40
4	4	2	—		
6	2	—	2	20	50
6	6	3	—		
6	2	—	2	25	60
12	12	6	—		
6	2	—	2	40	75
16	16	8	—		
6	2	—	2	50	80
36	36	18	—		
6	2	—	2	100	90

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