Journal of Structural Geology, Vol. 16, No. 1, pp. 131 to 142, 1994
Printed in Great Britain

0191-8141/94 $06.00 + 0.00

Complete texture analysis of a deformed amphibolite: comparison between neutron diffraction and U-stage data

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(*Received* 13 *July* 1992; *accepted in revised form* 2 *February* 1993)

Abstract—This paper describes a new technique of analysing complex neutron diffraction patterns, allowing the quantitative texture analysis of each rock-forming mineral up to triclinic lattice symmetry in polymineralic rocks. The method is demonstrated using hornblende and plagioclase fabrics in Alzenau amphibolite from the Spessart Mountains (Mid-German Crystalline Rise). Hornblende and plagioclase exhibit a pronounced shape preferred orientation with respect to the macroscopic fabric elements. For control purposes, crystallographic preferred orientations were also determined independently by individual grain measurements using a U-stage. From the neutron texture analyses we obtain only superposed pole figures (hornblende and hornblende, hornblende and plagioclase, and plagioclase with plagioclase) of low-indexed lattice planes. Therefore, the critical crystallographic directions were recalculated by the orientation distribution function (ODF) which is given by texture components. The optical and neutron-derived pole figures are in a good agreement. All pole figures display strong preferred orientation, although the plagioclase texture is less pronounced. The hornblende texture consists of a [001] maximum parallel to the stretching lineation, with [010] showing a tendency to develop a girdle around the lineation. [100]-axes are distributed with a clearly split maximum representing the monoclinic angle between [100] and [001]. The plagioclase texture is a rare one with (001) subparallel within the foliation and [100] oriented subparallel to the lineation. [010] of plagioclase is concentrated normal to lineation within the foliation.

The technique outlined here is potentially the most useful one for texture analysis of polyphase rocks, independent of crystal symmetry.

INTRODUCTION

THE preferred orientation (texture) of crystallites in rocks contains valuable information on deformation history. The study of these textures in connection with structural analysis can be used for kinematic analyses. This is well established for rock-forming minerals like calcite (e.g. Schmid *et al.* 1981), quartz (e.g. Bouchez 1977) and olivine (Nicolas *et al.* 1972). Monomineralic rocks are often used to exclude the disturbing effects of other phases. In such a case texture development can be simulated using Sachs, Taylor or Self-consistent models (e.g. Wenk & Christie 1991) to describe the deformation path.

Simultaneous texture analyses of more than one mineral phase are scarce (e.g. Wenk 1936), in spite of the fact that most common rocks are polyphase in composition and all components exhibit different mechanical behaviour under deformation. Textures of minerals with low-lattice symmetry like plagioclase and hornblende which are some of the most abundant minerals in metamorphic and magmatic rocks at deeper crustal levels, have rarely been investigated. One reason is the extremely time-consuming work to determine hornblende and plagioclase preferred orientations using a conventional U-stage. This method also requires a lot of single-grain measurements to obtain a statistically relevant sample. Texture analysis by X-ray diffraction is a common and well-established technique in geosciences but is hampered by small grain size and the complexity of diffraction patterns of low symmetry minerals with many overlapping peaks. Presently, the application of neutron diffraction with position sensitive detector (Bunge *et al.* 1982, Wenk & Pannetier 1990) and time-of-flight (TOF) diffraction (Ananiev *et al.* 1984) allows texture analyses of coarse-grained rock samples. So far, no quantitative texture analysis of a polyphase rock material (e.g. Wenk & Pannetier 1990) composed of minerals with low-crystal symmetry (e.g. Wenk *et al.* 1986) was reported because the selection of relevant pole figures is difficult.

In this study we investigate the texture of hornblende and plagioclase in a deformed amphibolite. Comparison is made between texture analysis using TOF diffraction and the conventional U-stage technique for determination of the preferred orientation. This paper introduces and demonstrates a new approach for texture analyses of polyphase rock samples (Helming & Eschner 1991) allowing quantitative texture analysis of each rock-forming mineral up to triclinic lattice symmetry.

THE SPECIMEN

A specimen of fine-grained amphibolite was collected at Alzenau in the Spessart Mountains, which forms part of the Mid-German Crystalline Rise (northern part of the Saxothuringian Zone). According to major and trace element data the protolith of the metabasite is a subalkaline tholeiite (Okrusch *et al.* 1985) suggesting an island-arc or interarc-basin environment. The rock contains 58% hornblende, 40% plagioclase (An_{28-45}) and 2% other minerals (quartz, titanite, ilmenite, hematite, chlorite, sericite).

An estimate of the peak pressure–temperature (P–T) conditions in the amphibolite can be derived from intercalated calc-silicate gneisses which yield 620–650°C and 450 MPa. This indicates typical Barrovian, medium-pressure-type amphibolite-facies metamorphism (Okrusch *et al.* 1985). K–Ar hornblende mineral dates provide a minimum age for the metamorphism between 318 and 324 Ma (Nasir *et al.* 1991).

Optical microstructure

The amphibolite exhibits a well-developed compositional layering (<1 mm) defined by hornblende- and plagioclase-rich layers (Figs. 1a–c). Hornblende crystals define a macroscopically visible lineation, which causes the formation of a rod-shape fabric (Weber & Juckenack 1990). The green hornblende shows intracrystalline deformation structures like undulose extinction (Figs. 1a–c), kinking (Fig. 2c) and subgrains (Fig. 2e). The angle of misorientation between adjacent subgrains is less than 5°. Sometimes microfractures at a high angle to the *c*-axis cause slightly higher misorientations. (100) twinning could also be observed (Fig. 2b), either growth twins or deformation-induced twins (Biermann 1981). There is no indication of dynamic recrystallization of hornblende.

Plagioclase also displays optical evidence of plastic deformation (Figs. 2d & f), such as undulose extinction. In plagioclase-rich domains (Fig. 2f) incipient subgrain formation can be observed. In all thin sections deformation twins according to the albite- and pericline-laws or cleavage planes parallel to (010) and (001) are developed. The shape of plagioclase grain boundaries (Figs. 1a and 2a) is commonly controlled by hypidiomorphic hornblende crystals, especially in sections normal to the lineation.

METHODS

The complete texture of polyphase geological samples composed of minerals with low-crystal symmetry is difficult to determine. Traditionally, the universal stage on a optical microscope can be used, but for optical uniaxial minerals limited crystallographic directions can be directly measured. In the case of monoclinic or triclinic crystal symmetry a lot of individual measurements (optical indicatrix axes, cleavage planes, twin planes, etc.) must be performed (see Fig. 3). Based on these data the complete orientation may be found by construction.

Shape fabrics

A quantitative microstructural analysis was carried out using a semi-automated image analysis system designed by Duyster (1991). Hand drawn images of grain boundaries of representative cross-sections parallel to the XZ- and YZ-plane were scanned, vectorized and smoothed. Digitized grain-boundary outlines are shown in Figs. 4(a) and 5(a). The program then calculates for each phase in the separate sections: (i) the length and orientation of the included polygons; (ii) the surface and characteristic shape evaluation; (iii) shortest (D_{min}) and longest diameter (D_{max}) and their angle to the foliation. The quantified shape fabric parameters are given as the characteristic (average) shape of the grains of each phase (Figs. 4a and 5a), as surface rose diagrams (Figs. 4b and 5b), rose diagrams of long grain diameter (Figs. 4c and 5c) and the relation between D_{min}/D_{max} and the angle of D_{max} to the foliation (Figs. 4d and 5d).

U-stage method

Texture analysis of hornblende and plagioclase was carried out with a conventional universal-stage in three orthogonal thin sections oriented parallel to macroscopic fabric elements (foliation, lineation). In the case of (triclinic) plagioclases the crystallographic axes are not parallel to the optical indicatrices but with additional information from cleavage and twin planes the complete orientation could be determined with the stereogram reported by Burri *et al.* (1967). Plagioclase orientation was calculated with the computer program of Kruhl (1987a). However, since the program cannot determine unequivocally all crystallographic planes of plagioclase grains within certain An-contents (An_{25-35}), this provides only limited information. For these compositions the (010)- and (001)-planes in the Burri diagram provide more than one of the four possible orientations. In addition, the accuracy of the U-stage data is only up to 3°.

Neutron diffraction

Measurements were performed on the 100 m-flight channel at the IBR-2 pulsed reactor in Dubna, Russia. Because wavelength is proportional to the time of flight of neutrons, a complete diffraction pattern may be acquired by each of seven simultaneously used time-of-flight-detectors (TOF method, see Ananiev *et al.* 1984). Figure 6 shows such a spectrum for the amphibolite

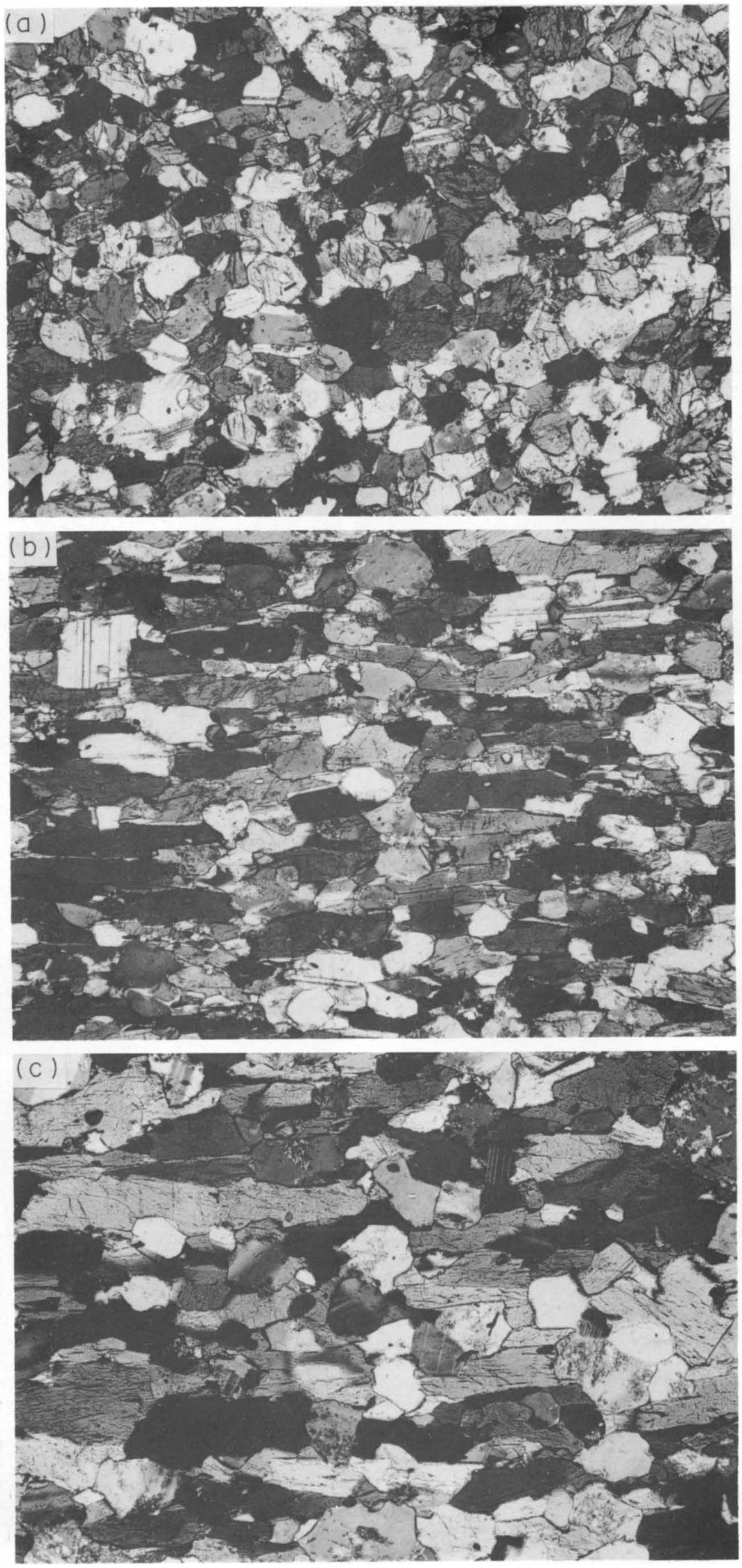

Fig. 1. Thin section photographs illustrating the microfabrics of the Alzenau amphibolite parallel to the (a) *YZ*-, (b) *XZ*- and (c) *XY*-plane. In section normal to the lineation (a) hornblende and plagioclase are hypidiomorphic. In (b) hornblende crystals are oriented with their long axes parallel to the foliation. Plagioclase displays alignments of (010) at a high angle and (001) parallel to the foliation. In the section normal to foliation (c) the dominant stretching lineation is defined by hornblende grains.

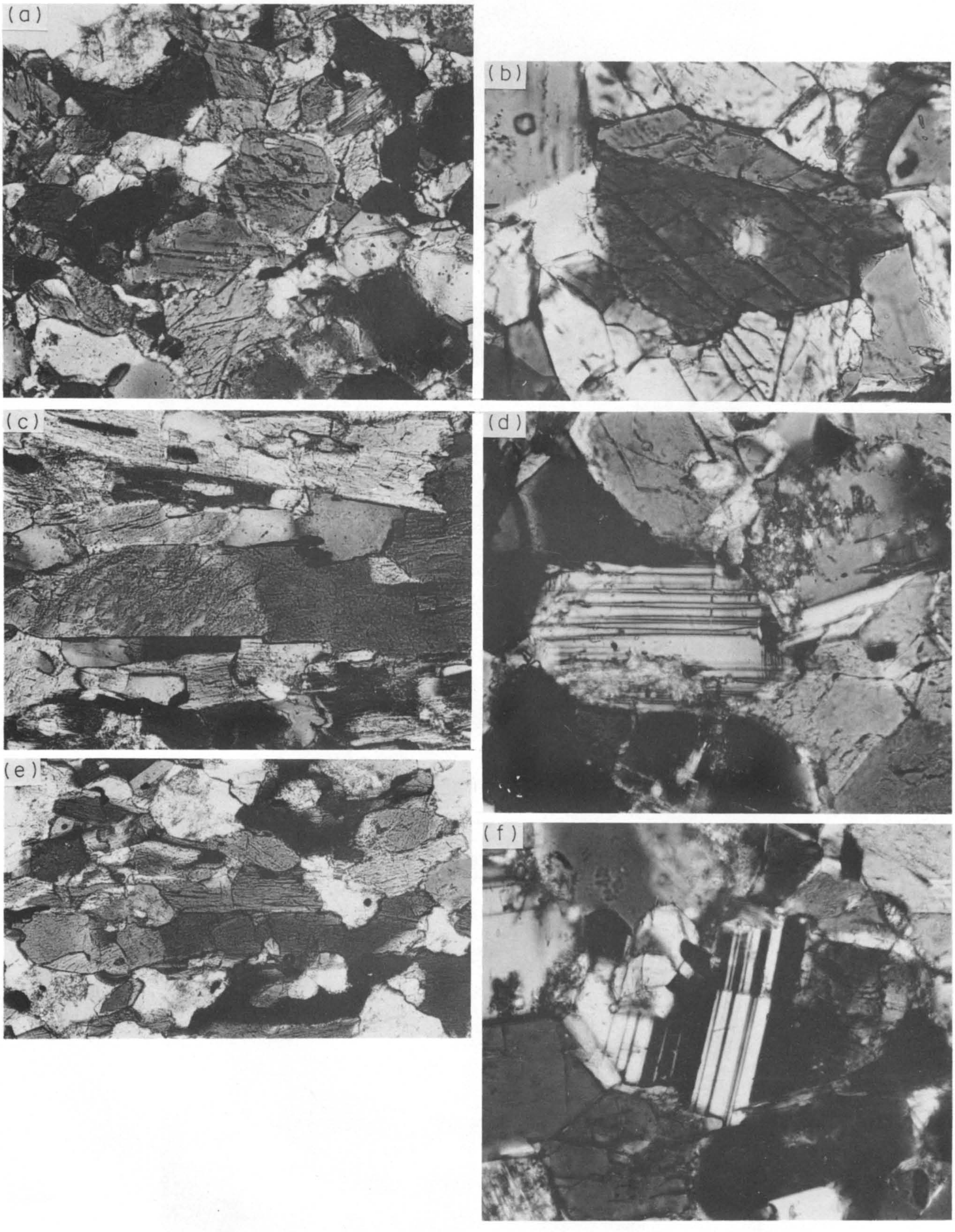

Fig. 2. Typical microstructures of the Alzenau amphibolite. (a) Preferred orientation of one hornblende cleavage plane parallel to the foliation. (b) (100) twins in hornblende. (c) Undulose extinction in hornblende. (e) Kinking and subgrain formation in hornblende. (d) & (f) Undulose extinction, deformation twins and microfracturing in plagioclase.

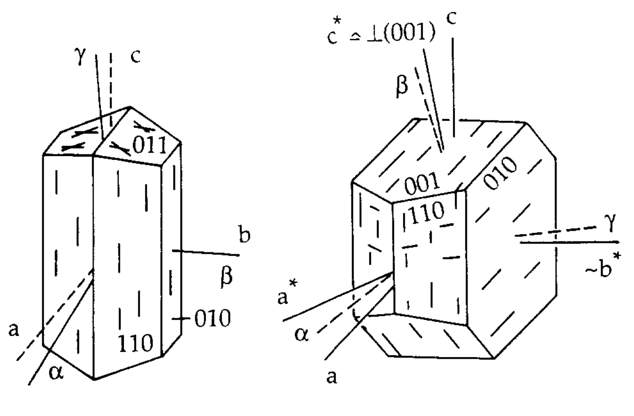

Fig. 3. Relationship between indicatrix axes and crystallographic directions of hornblende and oligoclase (after Kruhl 1987b and Deer *et al.* 1963).

sample. The presence of at least two crystalline phases with low crystal symmetry leads to a large amount of superposed Bragg reflections. Since crystal structure, phase fractions and diffraction conditions are not completely known, position and intensity of Bragg reflections may only be estimated. For the most important reflections of feldspar (o) and hornblende (h) one gets the results given in Fig. 6 and Table 1.

Spectra like those in Fig. 6 were measured for 650 sample directions describing a regular 7.2°-grid on the pole sphere around the sample. The total time of measurement was about 30 h. Starting from these spectra 21 pole figures were obtained, integrating in each of them the corresponding peak 1–21 (Table 2). Six of these pole figures are shown in Figs. 7(a_{exp})–(f_{exp}).

Unfortunately, a direct comparison with optically measured pole figures is not possible because neutronographic and optic measurements are based on different effects, leading to different pole figures. Furthermore the orientation of the sample was not the same in both cases. To make data comparable, the texture should be determined. From the texture all interesting pole figures may be recalculated and rotated.

QUANTITATIVE TEXTURE ANALYSIS FROM DIFFRACTION DATA

The increasing interest for quantitative texture analysis (QTA) in geosciences is caused by the fact that the texture in a rock may contain a lot of information on different processes like deformation, recrystallization and phase transitions. In a multi-phase system, different phases may interact. To determine the conditions of the past process it is therefore necessary to know the textures of all important minerals in a rock sample. Here we present a first QTA for a rock with monoclinic and triclinic minerals. Whereas pole figures are always given as two-dimensional distribution functions of special crystal directions like normals of net planes or lattice vectors, the more common textures of a crystalline phase p in a sample will be characterized by the three-dimensional Orientation Distribution Function (ODF):

$$f^{p}(g) = \frac{8\pi^2}{V^{p}} \cdot \frac{dV^{p}(g)}{dg}, \qquad (1)$$

were $f^{p}(g)$ describes the volume fraction of all crystallites of a phase possessing an orientation g in dg. To determine the required ODFs of a multi-phase system

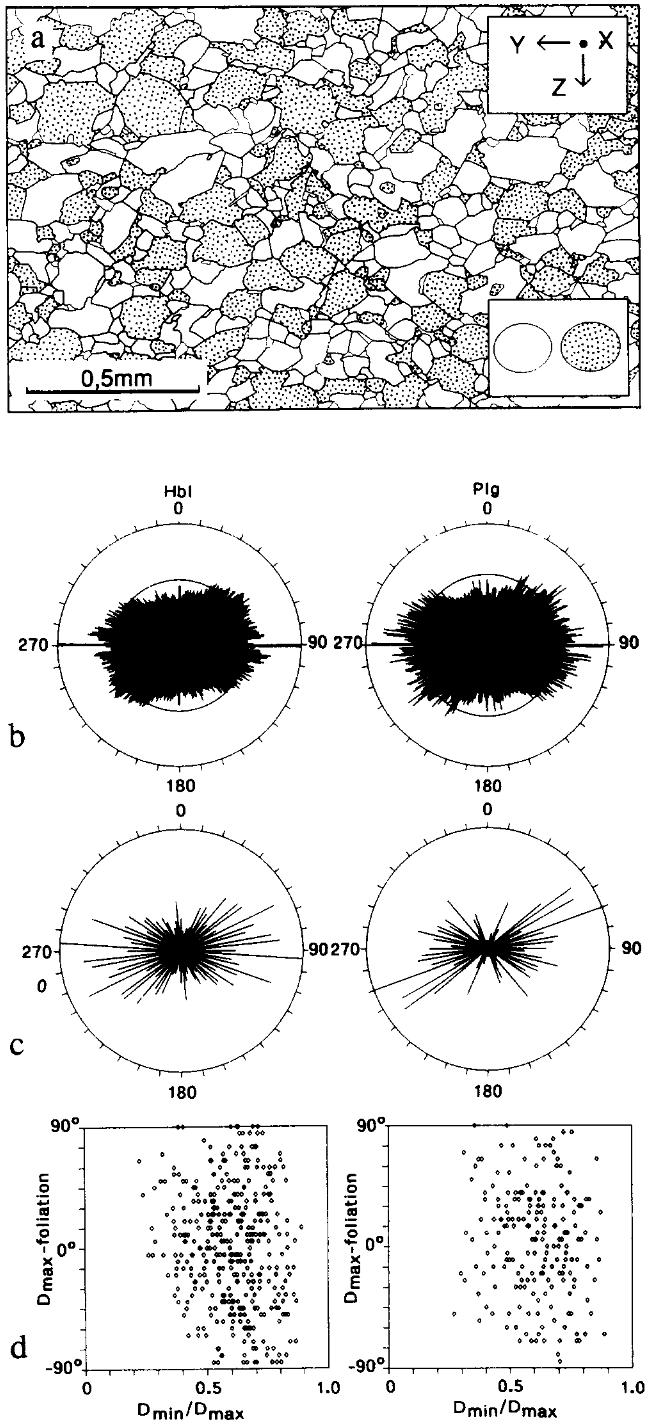

Fig. 4. Results of shape fabric analyses parallel to the *YZ*-plane. (a) Digitized grain-boundary outlines of hornblende (white) and plagioclase phases (shaded); the ellipses represent the average grainshape for the two minerals. (b) Grain-boundary orientation for hornblende and plagioclase plotted in a rose diagram. (c) Rose diagram for long axes of grains. (d) D_{min}/D_{max} ratio against the angle D_{max}/foliation. See text for further explanation.

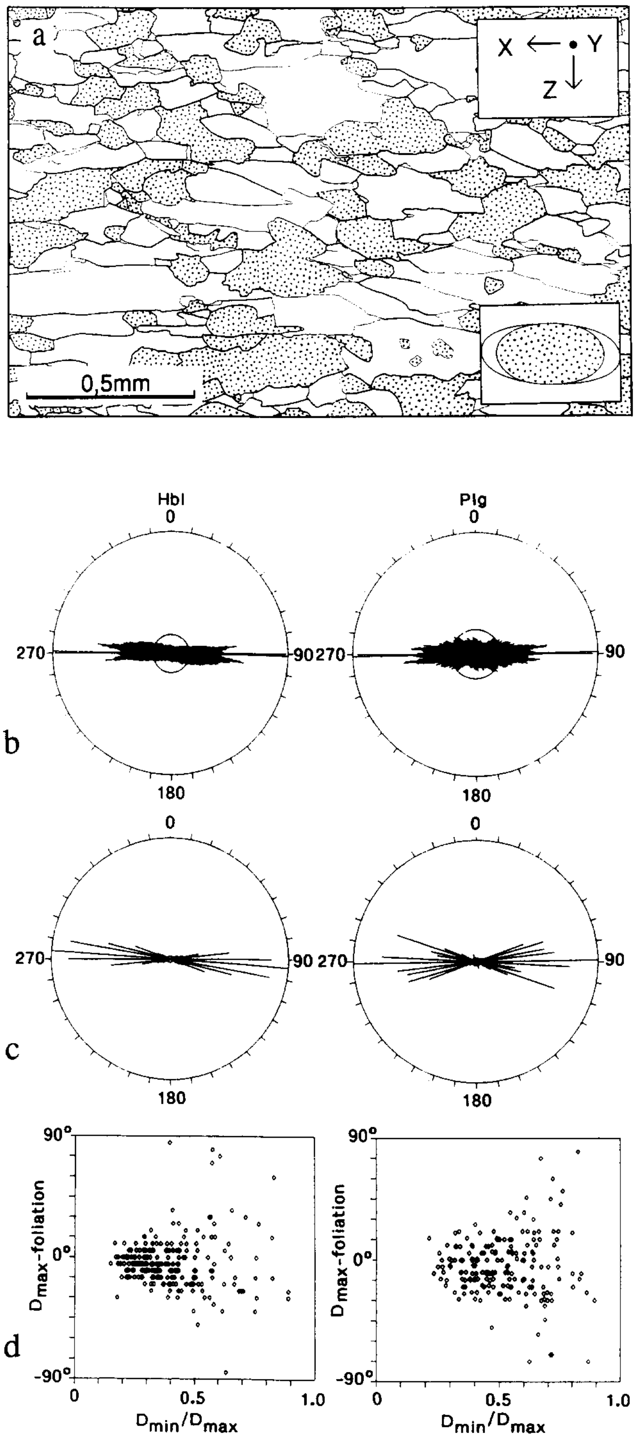

Fig. 5. Results of shape fabric analysis for the XZ-section. Rose diagrams are as described in the caption of Fig. 4.

we have to solve the projection relationship between the functions $f^{\mathrm{p}}(g)$ and the measured pole figures $D^{\lambda}(\mathrm{y})$ which depend on the sample direction y:

$$D^{\lambda}(\mathrm{y}) = \hat{P}(\mathrm{y}, \lambda, g)(f^{1}(g), f^{2}(g), \ldots) \qquad (2)$$

(Helming & Eschner 1990). As a solution for $f^{\mathrm{p}}(g)$ we get a superposition of C Gauss-shaped texture components $f(g_c, b_c, g)$ and a textureless background F:

$$f^{\mathrm{p}}(g) = F^{\mathrm{p}} + \sum_{c=1}^{C} I_c^{\mathrm{p}} f(g_c, b_c, g). \qquad (3)$$

g_c describes the preferred orientation, i.e. by the Eulerian angles $\{\alpha_c, \beta_c, \gamma_c\}$; b_c (the half-width) and I_c (the intensity of a component c) (Matthies *et al.* 1985). The method may be generally applicated to all multi-phase systems. The included separation of overlapped Bragg reflections depends on the sharpness of the investigated textures. For random textures a separation is impossible. If the texture distributions are very complicated, more spherical components are necessary for their mathematical representation.

RESULTS

Shape fabrics

A representative number of grains from thin sections parallel to the XZ- (Fig. 4) and YZ- (Fig. 5) planes have been investigated. The following results could be obtained. The orientation distribution of grain boundaries of hornblende and plagioclase (Fig. 4b) shows a very weak elongation. The angle between the foliation and the direction of elongation is less then 20°. The grain shape is based on the evaluated grain-boundary segments as convex ones only illustrates the averaged grain shape of each phase as nearly isometric (see Fig. 4a). The ratio of shortest to longest diameter covers the range from 0.4 to 0.8 without any distinct relationship to the angle between $D_{\max}$ and the foliation (Fig. 4d). In the XZ-plane (Fig. 5a) the grain-boundaries and long axes of hornblende and plagioclase exhibit a strong preferred orientation, parallel, or at a low-angle, to the foliation (Figs. 5b & c). The rose diagram illustrates the distribution of the long dimensions of notably the highly anisometric hornblende minerals parallel to the foliation. The obliquity between the foliation and plagioclase long axes is more pronounced (Fig. 5c). The $D_{\min}/D_{\max}$ ratio (Fig. 5d) varies for hornblende within a broad range from 0.2 to 0.5 and for plagioclase from 0.3 to 0.7, respectively. The angle of the longest diameter to the foliation increases with an increasing $D_{\min}/D_{\max}$ ratio. The most surprising result is that in both sections the shape fabric for hornblende and plagioclase show similar patterns.

Texture determination

Pole figures derived from U-stage data are shown for hornblende in Figs. 8(a)–(e), and for plagioclase in Figs. 8(f)–(j) (Kruse 1992). All plots are lower-hemisphere, equal-area projections where the vertical plane represents the foliation plane and the lineation is in the E–W position. For each pole figure the maxima are indicated by multiples of a random distribution (m.r.d.). The c-axes of hornblende exhibit a strong maximum parallel to the lineation (Fig. 8c). The optical indicatrix axes $n\alpha$—which are close to [100]—are concentrated in two maxima (Fig. 8a) elongated along two incomplete small-circle girdles with a opening angle around L of ~105° representing the monoclinic angle β. The con-

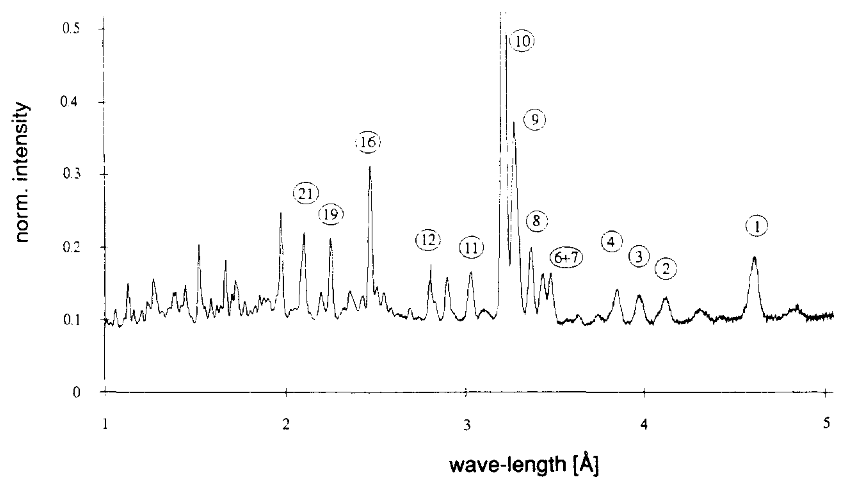

Fig. 6. Neutron diffraction spectrum of the amphibolite. The indicated peaks are used in the texture analyses. The numbers refer to the peaks given in Table 1.

Table 1. Description of 14 diffraction pole figures indicated in Fig. 6. Miller indices and overlapping factors Σ = 100% are given for hornblende (h) and oligoclase (o)

Superposed peak	Phase: Miller indices = relative intensity		
1	h: (040) = 100;		
2	h: (−201) = 19;	o: (20-1) = 81;	
3	h: (031) = 55;	h: (−131) = 36;	o: (−211) = 9;
4	o: (−130) = 74;	o: (111) = 26;	
6	h: (131) = 86;	h: (−231) = 14;	
7	h: (150) = 15;	o: (−202) = 51;	o: (−112) = 34;
8	h: (240) = 100;		
9	o: (002) = 52;	o: (040) = 48;	
10	h: (310) = 100;		
11	h: (221) = 77;	o: (−140) = 23;	
12	h: (151) = 100;		
16	h: (400) = 75;	o: (150) = 25;	
19	h: (261) = 100;		
21	h: (351) = 51;	h: (−201) = 49	

Table 2. Preferred orientations, intensities (volume fractions) and half-widths of determined texture components for hornblende and oligoclase

Component No.	Hornblende $F^1 = 48\%$					Oligoclase $F^2 = 42\%$				
	$g_c(°)$					$g_c(°)$				
C	α_c	β_c	γ_c	$I_c(\%)$	$b_c(°)$	α_c	β_c	γ_c	$I_c(\%)$	$b_c(°)$
1	264	107	88	6.5	22.0	144	48	222	9.4	45.8
2	265	57	93	5.6	22.2	182	135	14	7.9	52.3
3	93	85	91	5.1	18.7	3	53	329	6.2	37.4
4	268	80	90	4.8	17.8	74	63	134	5.4	40.0
5	96	115	91	4.4	18.4	27	73	205	4.6	40.0
6	97	59	90	4.2	21.3	216	160	332	4.2	37.3
7	111	22	73	3.8	23.5	118	138	356	3.8	34.4
8	69	94	89	3.2	24.8	116	153	271	3.1	45.9
9	262	139	84	3.0	20.7	100	68	211	2.9	31.8
10	96	139	92	2.5	18.5	15	21	120	1.9	25.5
11	260	24	99	2.4	19.6	70	155	351	1.9	27.6
12	351	186	167	2.3	23.2	6	36	98	1.2	22.5
13	110	98	91	1.1	14.7	31	130	266	1.1	28.2
14	296	68	85	1.0	16.6	104	102	200	1.1	23.4
15	213	11	94	0.9	22.5	122	165	17	0.9	19.1
16	89	105	90	0.6	9.0	266	94	7	0.6	18.5
17	277	125	90	0.3	12.8	246	45	114	0.5	16.5

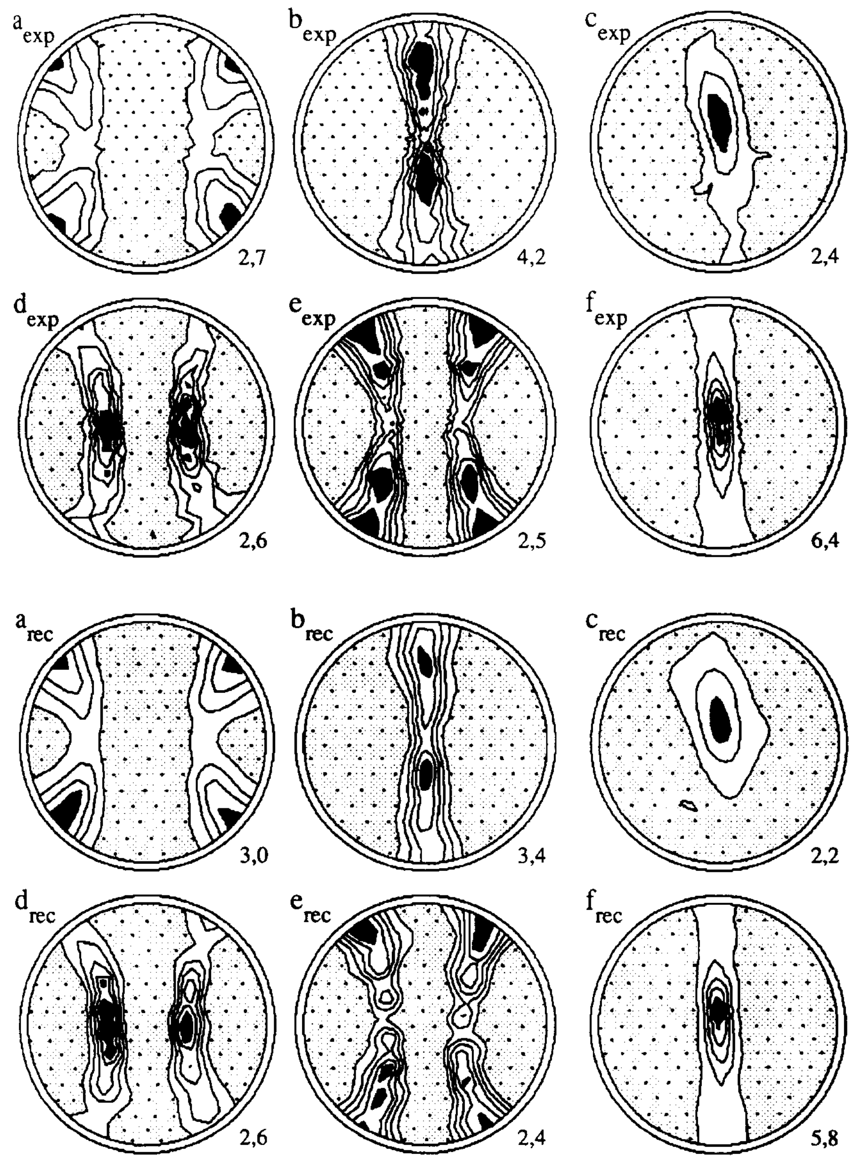

Fig. 7. TOF derived pole figures a_{exp}–f_{exp} [a: (3); b: (8); c: (9), d: (11), e: (12), f: (16)]. The numbers in parenthesis refer to Table 1 and Fig. 6. For example, a_{exp} :(3) is the superposed pole figure of hornblende (031),(−131) and oligoclase (−211); a_{rec}–f_{rec} are the corresponding recalculated pole figures via the ODF. Equal-area projection onto the foliation plane with the lineation in N–S position.

stituent plagioclase preferred orientation is less pronounced than that of hornblende. The (001)-poles form a strong maximum perpendicular to the foliation with a weak tendency to form a girdle around the lineation (Fig. 8f). The (010)-poles (Fig. 8g) are concentrated within a broad great circle parallel to the foliation with two weak submaxima; one is parallel to the lineation whereas the second is perpendicular to the lineation. The *a*-axes, calculated as an intersection lineation of (010)- and (001)-planes, are preferentially oriented parallel to *L* and linked by a weakly developed girdle within the foliation plane (Fig. 8h). In accordance with the crystallographic relationship the *c*-axes are arranged around the maximum distribution of the (001)-poles normal to the foliation, corresponding to an angle of 16° between (001)-poles and [001]-axis (Fig. 8j). The [010]-direction shows only a diffuse orientation pattern with some similarities to that observed in Fig. 8(g) for the (010)-poles (Fig. 8i). The plagioclase texture is only weakly developed. The background of pole figures is sometimes more than one-third of the absolute intensity. Therefore scatter diagrams are also given. The calculation of the [010]- and [001]-directions could only be performed for those plagioclase grains with more than 36% An content. Consequently, the U-stage derived plagioclase texture reflects only a partial texture.

Starting from 21 neutron diffraction pole figures (Fig. 7a) textures of both phases were determined, given in each case by 17 components (Table 2). Figure 10 shows the corresponding preferred orientations to the sample coordinate system by the directions of the lattice axis *a*, *b* and *c*, respectively. The higher-ordered texture of hornblende is characterized by small half-widths (15–25°) and parallel aligned *c*-axes of nearly all components. The texture of plagioclase shows low-ordered components with large half-widths (25–50°).

As a measure for the accuracy of the QTA method, the measured pole figures $D^{\lambda}(\mathbf{y})$ were recalculated (see

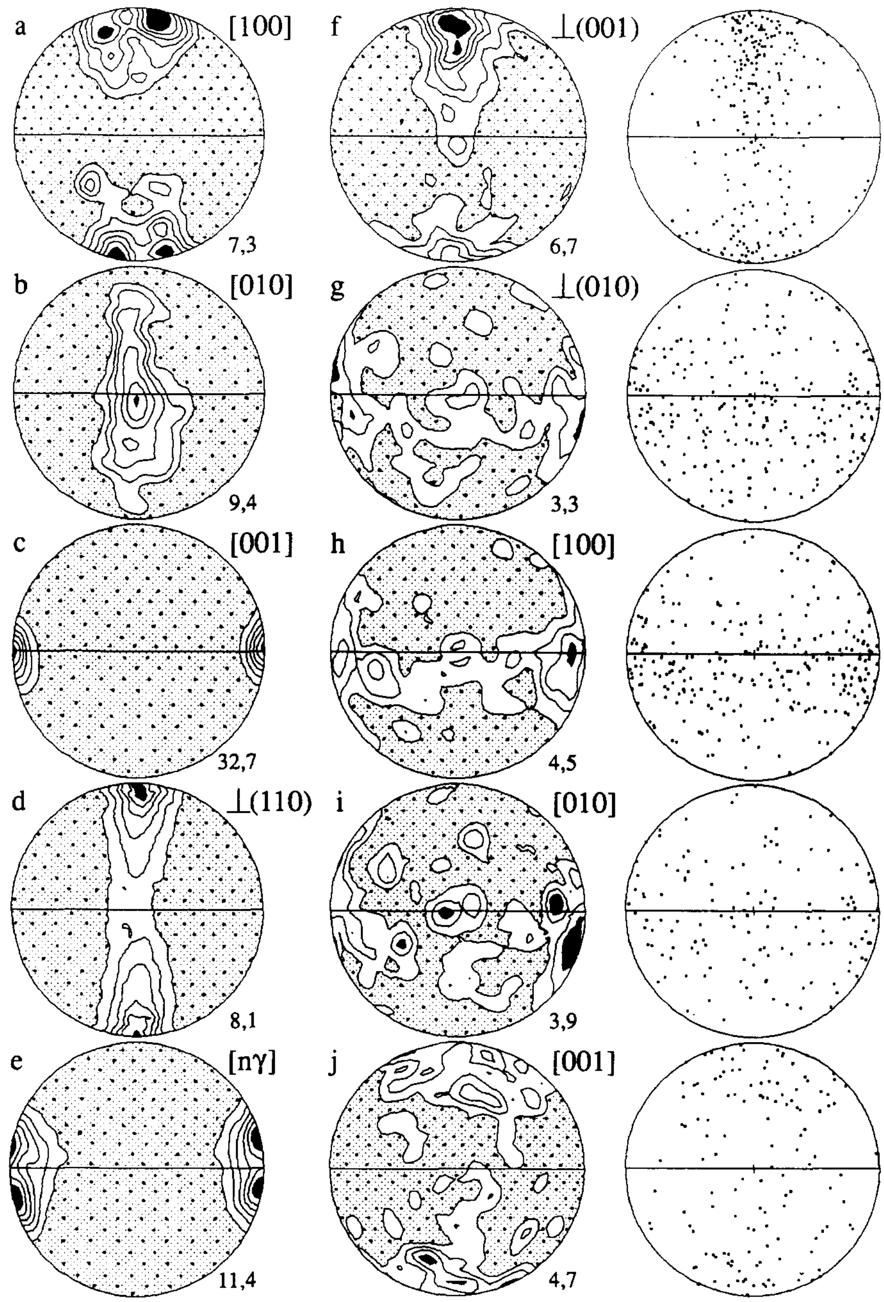

Fig. 8. Preferred orientations of hornblende (a–e) and plagioclase (f–j) measured by U-stage. For plagioclase scatter diagrams (U-stage) are also given (equal-area, lower-hemisphere projections). The trace of the foliation is horizontal and the lineation is in E–W position.

Figs. $7a_{rec}$–f_{rec}) from the calculated ODFs and compared with the original ones (Figs. $7a_{exp}$–f_{exp}). For comparison the pole figures for the same lattice directions as measured on U-stage were recalculated from diffraction data and rotated by $g = \{270°, 90°, 270°\}$ (Fig. 9).

DISCUSSION

Complete texture analysis of only one sample obviously does not provide a conclusive picture of texture development in amphibolites. The aim of this paper is to demonstrate that neutron diffraction combined with a new method of texture analysis for polyphase materials is a fruitful new approach for geological texture studies. The selected amphibolite which is composed of monoclinic hornblende and triclinic plagioclase with a large number of overlapping peaks is an excellent testing material. For comparison, the preferred orientation of selected crystallographic directions and lattice planes was evaluated with the U-stage.

The U-stage-derived hornblende pole figures (Figs. 8a–e) and the recalculated pole figures via the ODF for [100] (Fig. 9a), [010] (Fig. 9b), [001] (Fig. 9c), (110) (Fig. 9d) and the indicatrix axes $n\gamma$ (Fig. 9e) are clearly identical. Plagioclase U-stage (Figs. 8a–e) and ODF pole figures (Figs. 9a–e) are identical except for some directions. However, the (010)-poles and the [010]-direction exhibit a girdle pattern subparallel to the foliation with the maximum around the lineation pole

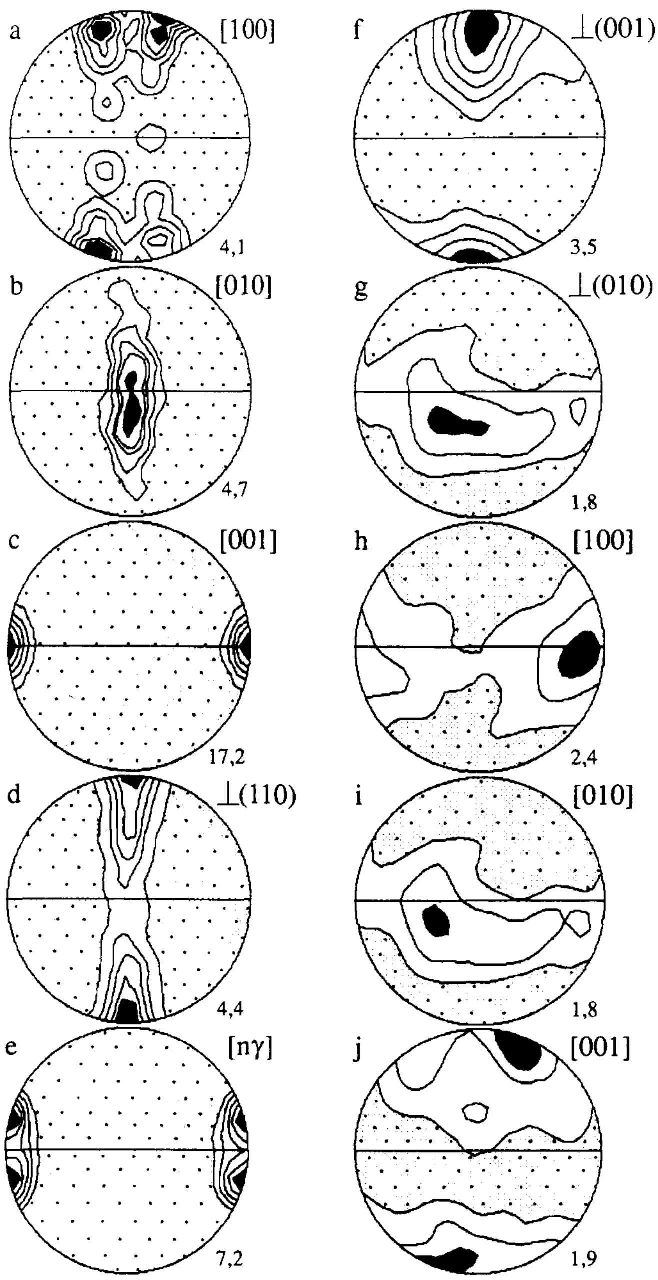

Fig. 9. Recalculated pole figures of hornblende (a–e) and plagioclase (f–j) obtained from ODF calculation.

within the foliation. The mean reason for the different results is the small number (around 300) of the measured grains using U-stage method. With a lower crystal symmetry the error of the measurement increases. If the crystallites would be randomly distributed in the orientation space, we would get for triclinic crystal symmetry a mean distance of orientations of nearly $42° = (360° \times 360° \times 180°/300)^{1/3}$ illustrating the significant weakness in resolution power of the measurement. For 300 measured crystallites the mean distance becomes about $34° = (180° \times 180° \times 360°/300)^{1/3}$ for the monoclinic and 10° for the cubic case. This effect is especially evident for weak textures like the plagioclase texture in our sample.

Hornblende textures commonly have a maximum concentration of [001]-directions parallel to the stretching lineation and (001)- or (110)-planes oriented nearly parallel to the foliation (e.g. Wenk 1936, Schwerdtner 1964, Gapais & Brun 1981, Kruhl & Huntemann 1991). An interesting phenomena is the distinctly split maximum of [100]. The angle between the two [100]-maxima and [001] correspond to the acute and obtuse monoclinic angle (Figs. 3 and 9a & c), respectively. The development of a complete girdle of the *b*-axes, *a*-axes and (110)-cleavage planes is suppressed by the tendency of one cleavage plane to be preferentially oriented subparallel to the foliation (see Figs. 8a–d and 9a–d).

It is well established that intracrystalline slip is the most important texture-forming mechanism (Wenk & Christie 1991). In low symmetry crystals a dominant slip system is aligned with slip planes parallel to the foliation and the slip direction parallel to the lineation (Mainprice & Nicolas 1989) in simple shear deformation. Amphiboles have very restricted slip and twinning systems (see review in Hacker & Christie 1990). In the present case the observed texture may be the result of rigid-body rotation of hornblendes during simple shear deformation, resulting in alignment of the long [001] dimensions of the crystals in the shear direction. Preferential orientation of (*hk*0) planes within the foliation may also play a role. On the other hand, single crystal tests of hornblende by Burnley & Kirby (1981) compressed

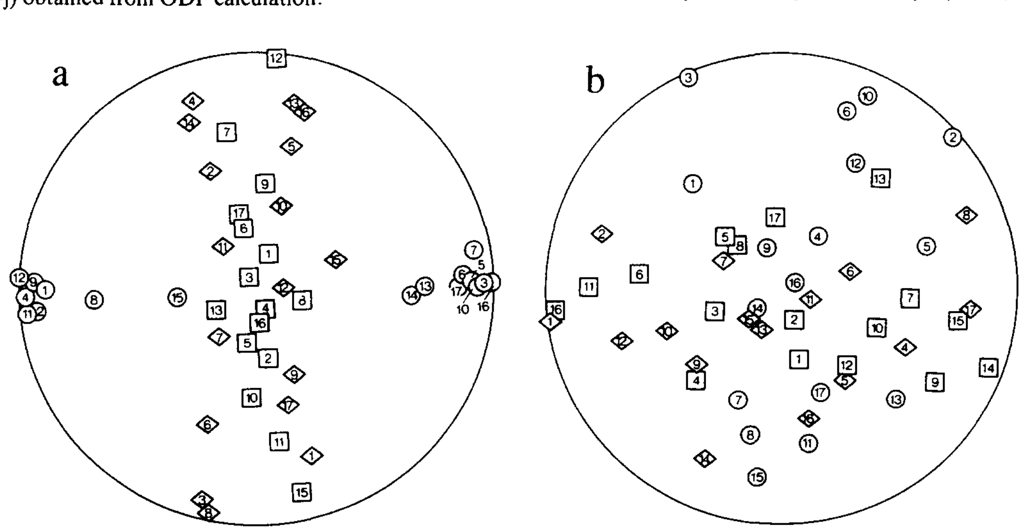

Fig. 10. Representation of the preferred orientation of evaluated texture components (as given in Table 2) for (a) hornblende and (b) plagioclase; symbols correspond to the following crystallographic directions; circles: [001], squares: [010] and rhombohedra: [100].

parallel to (010) at 45° to [001] with the acute angle between [100] and [001] exhibit very thin polysynthetic mechanical twins parallel to (100). Crystals compressed in the obtuse angle between [100] and [001] form no twins and show significantly lower strength.

These experimental results suggests that the split [100]-maxima in Figs. 8(a) and 9(a) are the product of (1) slip and (2) twinning as a result of different grain orientations with respect to the shear direction. However, contributions of grain growth under non-hydrostatic stress and anisotropic grain growth by diffusional flow could not be excluded. Texture development of hornblende could also be explained by preferred crystal growth under non-hydrostatic stress (e.g. Schwerdtner 1964) according to the thermodynamic theory given by Kamb (1959). From experimental and/or microstructural observations dislocation slip and recrystallization processes have been favoured by some authors (Rooney *et al.* 1974, Biermann & van Roermund 1983, Cumbest *et al.* 1989, Skrotzki 1990). Brodie & Rutter (1985), or more recently Hacker & Christie (1990) and Skrotzki (1992), refer to the importance of anisotropic grain growth by diffusional flow.

Little is known about the mechanisms of texture development of plagioclase in metamorphic rocks. The prediction of slip on (010) in the *a*- and *c*-directions was reported by Olsen & Kohlstedt (1985), Kruhl (1987b) and Ji & Mainprice (1988). Ji & Mainprice (1988) found that, independent from the An-content (An_{0-80}), dislocation glide of primary (010)[001] with secondary (010)[100] accommodated by recrystallization is the dominant orientation mechanism. Kruhl (1987b) observed a plagioclase texture with (001) subparallel to the foliation, whereas (010)-poles were arranged with the maximum parallel to the lineation. These orientation patterns should develop because plagioclase is completely recrystallized at high-grade metamorphic conditions. Recently, these orientation patterns were also obtained in metapelites from Calabria (Kruhl & Huntemann 1991). In contrast to most reported texture patterns, we find a strong alignment of (001)-planes subparallel to the foliation. The [100]-direction is concentrated at a maximum nearly subparallel to the foliation and lineation. The observed texture (Figs. 9a & c) can be considered to result from dominant slip of (001)[100] and secondary slip parallel to *b*. Such an orientation mechanism has not been reported in published TEM observations on naturally deformed plagioclase. The development of such plagioclase textures has also been interpreted as passive reorientation of anisometric plagioclase grains (Shelley 1979).

The plagioclase texture (Figs. 9f–j) is weak compared to that of hornblende (Figs. 9a–e). The question arises whether the fact that plagioclase occupies a smaller volume percentage (around 40%) than hornblende has some implications for the mechanical behaviour. There are no experimental data on the mechanical behaviour of such lithologies as a function of model composition. From microstructural observations it seems to us that plagioclase is the 'softer' phase and can accommodate strain incompatibilities at the interphase boundaries. This is in accordance with observations on amphibolites where plagioclase is completely recrystallized and wrapped around hornblende and clinopyroxene porphyroclasts (Siegesmund *et al.* 1989). In addition, the shape fabrics (Figs. 4 and 5) of hornblende and plagioclase are comparable suggesting that the mechanical behaviour of the 'softer' plagioclase was controlled by hornblende. Recently some authors (e.g. Kruhl 1987b, Ji *et al.* 1988) used asymmetric plagioclase textures to deduce the sense of shear. Macroscopic observations (Weber & Juckenack 1990) on boudins on a dm-scale indicate stretching parallel to the lineation, which is probably due to sinistral strike-slip movements along the near-by Michelbach fault. In our samples, it is impossible to use the observed textures for a shear-sense estimation. According to Weber (1992), deformation of the Alzenau amphibolite could have taken place in a transpressive regime where the reorientation of fabrics like the hornblende lineations are probably highly resistant to overprints by different phases of deformation.

Acknowledgements—We are appreciative for access to the facilities at JINR Dubna (Russia) especially to K. Ullemeyer, J. Heinitz, K. Walther and W. Voitus. We are grateful to H.-J. Bunge and K. Weber for their support in our collaboration. The paper benefited from the suggestions made by C. Biermann and C. W. Passchier. Technical help was provided by B. Mackewic. S. Siegesmund is grateful to the Deutsche Forschungsgemeinschaft for a travel grant.

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