

The microcline/sanidine transformation isograd in metamorphic regions: Western Tauern Window and Merano–Mules–Anterselva complex (Eastern Alps)

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Abstract

Lattice parameters and optic axial angles of alkali feldspars from the Penninic augen gneisses of the western Tauern Window and from the Austroalpine Merano–Mules–Anterselva unit south of it have been determined along eight N–S profiles.

Parallel and somewhat below the 500°C isotherm of the syn- to post-kinematic metamorphism of Tertiary age the K feldspars show an abrupt change in their optic axial angle and their Al–Si order. This line separates a northern area showing exclusively low microclines ($2V_x \geq 76^\circ$ and $0.95 \leq (t_1O - t_1m) \leq 1.0$) from a southern area showing “high microclines” ($2V_x \leq 76^\circ$ and $0.0 \leq (t_1O - t_1m) \leq 0.55$). The border line represents the isotherm at which the diffusive phase transformation microcline/sanidine occurred during prograde Alpine metamorphism.

The Merano–Mules–Anterselva complex is characterized by low grade Hercynian metamorphism below 500°C. In spite of the fact that north of the Deferegggen–Anterselva–Valles line the Alpine metamorphism seems to have exceeded 500°C all investigated K feldspars of the complex are low microclines.

Introduction

The temperature of the diffusive phase transformation between microcline and sanidine (T_{diff}) has not been determined experimentally because of the very slow kinetics of Al–Si ordering. This temperature can be estimated from a careful study of the structural state of alkali feldspars and their relation to metamorphic temperatures estimated by independent methods. A discussion of the available information on the temperature of this transformation is given in a separate paper by Bambauer and Bernotat (1982).

A temperature-induced boundary between a low microcline area and an intermediate to high microcline area was found in the rocks of greenschist facies of the Central Swiss Alps (Bambauer and Bernotat, 1976; Bernotat and Bambauer, 1980). According to Frey *et al.* (1976) Alpine metamorphism reaches approximately 400°C in this area.

Raith (1971) and Raase and Morteani (1976) stud-

ied the optic axial angles of the K feldspars in the Penninic rocks of the central and western Tauern Window. They found that in a zone along the border of the Tauern Window, which shows a greenschist facies metamorphism, the K feldspars are low microclines, whereas in the highest-grade metamorphic central part of the Window, the K feldspars are intermediate microclines to “orthoclases”. By comparing $^{18}O/^{16}O$ data from Hoernes and Friedrichsen (1974) they deduced a temperature of 500°C for the microcline/sanidine phase transition.

The Penninic rocks of the Tauern Window belong to the deepest tectonic unit of the East Alpine tectonic pile. They consist of phyllites, schists, ortho- and paragneisses and represent the basement over which the Austroalpine nappes moved to the North. The Tauern Window is surrounded on the western, southern and eastern sides by rocks of the Austroalpine “Altkristallin”. The Penninic zone comprises two main lithological and tectonic units: the “Zentralgneis” and the “Schieferhülle”. The

"Zentralgneis" consists mostly of augen and flaser gneisses and metatonalites. In these well foliated gneisses, one to two cm K feldspar crystals or crystal aggregates or chessboard albites are sheathed by white mica and set in a finer ground-mass of quartz, plagioclase, K feldspar, biotite and light mica. The metatonalites range in their chemical composition between granitic and dioritic, with granodioritic composition most frequent. Although they have often maintained magmatic textures, their primary magmatic minerals underwent complete recrystallization in Alpine times. The "Schieferhülle" is a complicated sequence of gneisses, amphibolites, schists, marbles and phyllites generally overlying the "Zentralgneis" cores (for details see e.g., Morteani, 1974). The "Zentralgneis" is polymetamorphic with not only Alpine but also a Hercynian and perhaps a Caledonian metamorphic history; an intense pre-Alpine metamorphism is revealed by the migmatitic structures (Morteani, 1974). All Penninic rocks of the western Tauern Window were affected by a pervasive recrystallization during Alpine metamorphism. In some rocks of the amphibolite facies a relic mineral paragenesis of an earlier greenschist facies is found, indicating that the Alpine metamorphism was a two stage event, with the earlier one being lower in grade (Morteani, 1971; Morteani and Raase, 1974). A temperature difference of about 200°C between these two stages seems probable. The thermal climax of the Alpine metamorphism was reached in the second stage, to which radiometric mica cooling ages of 35–25 m.y. are related (Raith *et al.*, 1978; Satir, 1975). In the Alpine metamorphism the highest degree of metamorphism, corresponding to the lower amphibolite facies, was reached in the western Zillertal Alps. The gradual decrease of metamorphic grade from the center to the margin of the Tauern Window is marked by isograds of the anorthite content of plagioclase coexisting with epidote in mica schists, and by the biotite isograd (Morteani and Raase, 1974; Hoernes, 1973). $^{18}\text{O}/^{16}\text{O}$ data of Hoernes and Friedrichsen (1974) indicate temperatures of up to 600°C in the western Zillertal Alps and less than 500°C at the northern border of the Tauern Window.

The Austroalpine unit south of the Tauern Window is called the Merano–Mules–Anterselva complex (Baggio *et al.*, 1979). It consists of paragneisses, marbles, amphibolites and granitic gneisses, partly developed as augen gneisses. As shown in Figure 1, there are also granitic to granodi-

oritic bodies of Oligocene age (Borsi *et al.*, 1978a, 1978b) in the complex which is subdivided by some important west–east trending tectonic lines (Sassi *et al.*, 1976). The most important one is the Deferegen–Anterselva–Valles line (DAV line), as recently demonstrated by Borsi *et al.* (1978) and Sassi *et al.* (1978) (Fig. 1).

The pre-Alpine metamorphic history of this complex is characterized by a high grade Caledonian as well as a low grade Hercynian metamorphic event (Sassi and Zanferrari, 1972; Borsi *et al.*, 1978). The breakdown of kyanite and staurolite to sericite $\pm$ chlorite $\pm$ chloritoid (Sassi and Zanferrari, 1972; Sassi *et al.*, 1974) indicates temperatures lower than 550°C. North of the DAV line the Austroalpine rocks show not only a pre-Alpine but also an Alpine metamorphic history. According to Borsi *et al.* (1978) Rb–Sr ages of muscovites and biotites suggest that Alpine temperatures did not significantly exceed $500 \pm 50^\circ\text{C}$ north of the DAV line. Maximum temperatures were probably reached in the Upper Eocene–Lower Oligocene. They suggest that the Alpine temperatures probably never exceeded 300°C south of the DAV line.

Statement of problem

In the western Tauern Window, the line separating the low microcline area from the intermediate microcline and "orthoclase" area is found in a region without postmetamorphic Alpine faulting. It can be supposed, therefore, that the areal distribution of the different structural states of the K feldspar has remained unchanged since the Alpine metamorphism produced it. In the northern part of the western Tauern Window the transition can be observed in very homogeneous augen gneiss series of granitic composition. Because the gneisses have the same chemical and mineral composition and the same tectonic history, we must conclude that the adjacent areas with microclines of different structural state were caused by a thermal gradient. The region is therefore very suitable for a detailed X-ray study of the Al–Si ordering process in K feldspars. In this paper the structural state is studied in more detail than by Raase and Morteani (1976) and by Bernotat *et al.* (1977). In particular, the following questions are considered:

(1) Is the transition from low microcline to high microcline in the Tauern Window abrupt, and therefore caused by a well defined isotherm, or does it form a rather broad zone?

(2) Does the transition line really occur in the

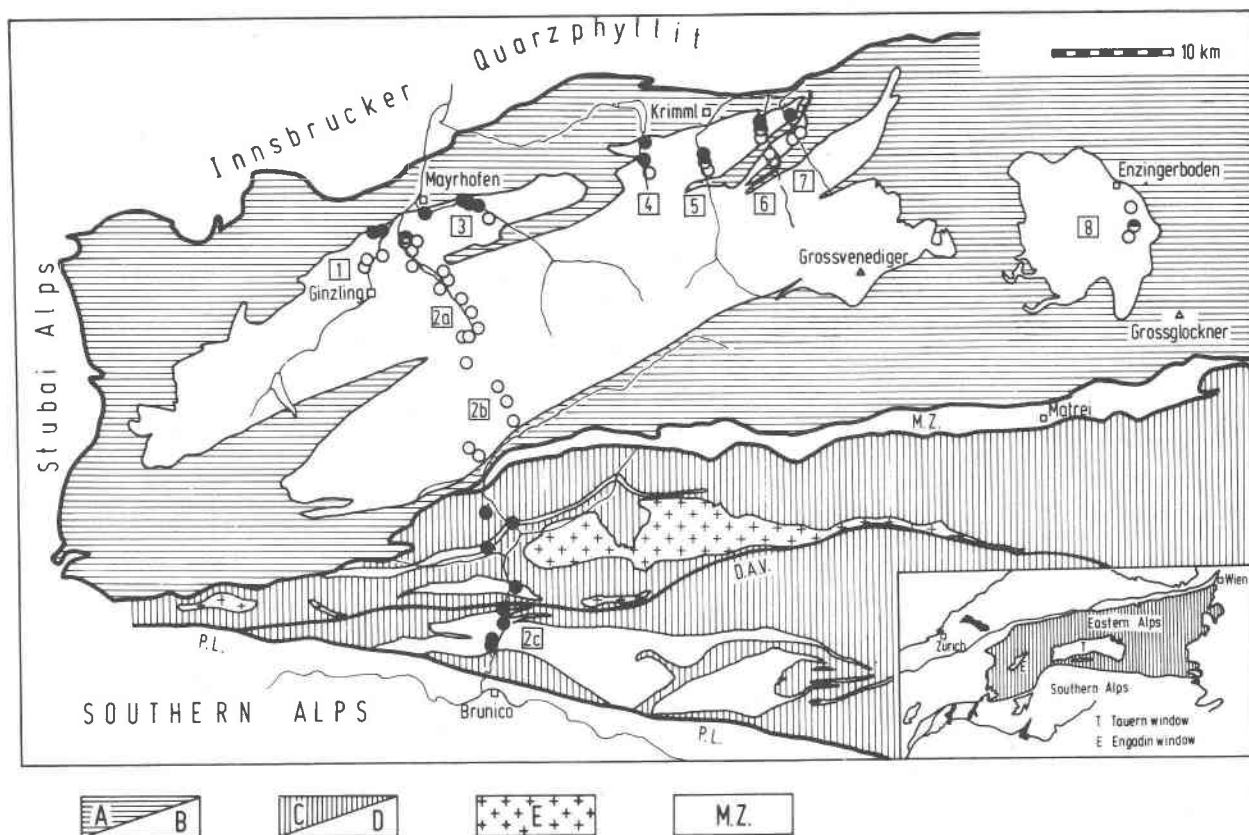


Fig. 1. Distribution of low microcline and of intermediate to high microcline along the profiles 1 to 8. Filled dots are low microclines, open dots are intermediate to high microclines. A and B are the Penninic units; A = upper and lower Schieferhülle, B = Zentralgneiss. C and D are rocks of the Merano-Müles-Anterselva complex; C = prevalently micaschists, D = Augengneisses. E = granites to granodiorites of Oligocene age. M.Z. is the Matrei Zone. D.A.V. is the Deferegggen-Anterselva line and P.L. the Periadriatic line.

southwestern part of the Zentralgneiss as Raase and Morteani (1976) supposed? From $^{18}\text{O}/^{16}\text{O}$ data a temperature higher than 500°C can be deduced.

(3) Was the influence of Alpine metamorphism in the Merano-Müles-Anterselva complex strong enough to change the structural state of the K feldspars?

(4) Do we find here the same frequency distribution of Al-Si order as in the Central Swiss Alps?

Sampling

Samples were taken along eight north-south profiles shown in Figure 1. These are: (1) Mayrhofen-Ginzling; (2) Mayrhofen-Stillupptal-Ahrntal (Valle Aurina)-Brunico (Bruneck); (3) Mayrhofen-Zillergrund; (4) Wilde Gerlos Tal; (5) Krimmler Achental; (6) Obersulzbachtal; (7) Untersulzbachtal; and (8) Enzingerboden-Weisse (Granatspitz). Rock samples with K feldspar "Augen" were chosen.

Two types of K feldspars are distinguishable.

Type (a) is the older, probably magmatically grown, deformed and recrystallized Hercynian K feldspar which is generally perthitic, and usually twinned according to the Carlsbad or Baveno law. This feldspar forms lenses up to 10 mm in the augen and flaser gneisses. Often the K feldspar is partially or completely replaced by chess-board albite. In the region of highest metamorphic grade the K feldspars are often replaced by chessboard oligoclase which contains amoeboidal quartz inclusions such as those described by Raith (1970).

Type (b) is the newly-formed Alpine K feldspar, which is generally fine-grained (up to 1 mm) and usually granoblastic, and formed at the expense of the older K feldspar. The newly-formed K feldspar is generally not perthitic and without simple growth twins.

Samples of the older K feldspars (type a) were obtained in the following way for X-ray studies. With the aid of thin sections the least altered parts

of big lens-shaped or subhedral K feldspars were marked on rock slabs. Drill cores of about 8 mm³ were then cut out from the marked area with an ultrasonic drill. From fine grained rocks, the K feldspar was separated by heavy liquid technique.

Optical data for the K feldspars

Measurements of the optic axial angle $2V$ were made on 59 samples. Three to ten determinations of the optic angle were made for each sample on different lens-shaped old K feldspar grains. A Zeiss four axial universal stage was used, usually employing the method of locating both optic axes. The error is about 1–2°. In the rare cases in which only one axis could be located, the optic angle was determined from a stereographic projection of the indicatrix.

The optic axial angle was determined for samples only along the profiles 1, 2a, 2b and 3. Optic and X-ray measurements were made from the same sample, but not on the same mineral grains (Table 1)¹. The results of the determination of the optic axial angle are given in Figure 2A. As can be shown from Figure 2A, the optic angle reflects the change of Al–Si order. For a detailed survey of the optic data of the K feldspars in the Penninic rocks of the area west of the Grossvenediger see Raase and Morteani (1976).

Lattice parameters and determination of Al–Si order

X-ray photographs from powdered samples were obtained by the Guinier method (camera according to Jagodzinski) with $\text{CuK}\alpha$ radiation and were calibrated with Si powder. The position of powder lines was determined with an accuracy of 0.01° for 2θ . Only powder data of K feldspars showing more than 18 unequivocally identifiable lines have been refined by a least squares program (Burnham, 1962). The calculated mean standard deviation of the parameters a , b , c is about 0.00015 nm and of the angles α , β , γ about 0.015°. The real error may even be twice as high in some cases. The refinement of lattice parameters is especially difficult for K feldspars because in most samples the extent of Al–Si ordering varies considerably in even the smallest grains. This shows up in powder diagrams as broadening of reflections. It must be stressed that lattice parameters given in Table 2¹ are averages of single

crystals with differing states of order, and that exact lattice parameters of single microcline crystals are unknown.

The Ab contents of these feldspars were calculated from the volume of the unit cell according to a formula given by Stewart and Wright (1974) and were from 1.6 to 8.4 mole % Ab, with most samples having about 3–5 mole % Ab.

The extent of ordering of an alkali feldspar can be calculated from the lattice parameters by comparing them with low albite (LA), analbite (AA, the so-called high albite HA), low microcline (LM) and high sanidine (HS) (data from Stewart and Wright, 1974, and I. V. Smith, 1974).

Figures 3 and 4 show correlations between lattice parameters from samples of the western Tauern Window and from the Granatspitz area as they are commonly used in feldspar literature. The state of order varies between completely ordered low microcline and pseudomonoclinic high microcline. On Figure 4 the b^* , c^* values plot in many cases outside the field defined by the end-members. This has been observed repeatedly by other authors as well. The samples form two clusters on each diagram, and clusters on both diagrams are formed by the same members. In the following, the population of intermediate to high microclines is called "high microcline". Most "high microclines" show only a slight deviation from monoclinic symmetry. This is a strong indication that they originate from low sanidine whose ordering process became too sluggish after its transformation into microcline to proceed further.

The Al–Si order of some K feldspars from the western Hohe Tauern was estimated by Raase and Morteani (1976) by the $2\theta(060)$, $2\theta(\bar{2}04)$ method from data obtained by diffractometry (Wright, 1968), but a prerequisite for reliable data is the precise determination of lattice parameters. The Al–Si order was calculated according to the $\text{tr}[110]$, $\text{tr}[1\bar{1}0]$ method (Kroll, 1980 and personal communication; for details see Bambauer and Bernotat, 1982). The $\Delta(b^*, c^*)$, $\Delta(\alpha^*, \beta^*)$ method (Stewart and Ribbe, 1969) gives almost identical results.

Stewart and Wright (1974) represent the course of the Al–Si ordering process in a triangular diagram with the coordinates $t_1\text{O}$, $t_1\text{m}$ and $(t_2\text{O} + t_2\text{m})$. We prefer a similar but modified $(2t_1 - 2t_2)$ versus $(t_1\text{O} - t_1\text{m})$ diagram. The value $(2t_1 - 2t_2)$ shows the extent of Al transition from T_2 to T_1 for sanidine and the difference of Al occupancy between T_2 and T_1 for alkali feldspars in general. The values $(t_1\text{O} - t_1\text{m})$ show the increasing "triclinicity" during the order-

¹To receive a copy of Table 1 and Table 2, order Document AM-82-189 from the Business Office, Mineralogical Society of America, 2000 Florida Avenue, N.W., Washington, D.C. 20009. Please remit \$1.00 in advance for the microfiche.

ing of microclines. Figure 5 is a plot of the Al-Si order for these samples using the $tr [110]$, $tr [1\bar{1}0]$ method. The $\Delta(b^*, c^*)$, $\delta(\alpha^*, \beta^*)$ method gives almost identical results. These methods are preferred to the (b, c) method, results shown on Figure 6, because the $tr [110]$, $tr [1\bar{1}0]$ method relies on those directions which are most affected by changes in Al-Si order. Furthermore a comparison of Figure 5 and 6 shows that in Figure 6 the scatter of points is high and sample K 235 as determined by crystal structure refinement does not lie within the "high microcline" cluster.

The transition from monoclinic to triclinic symmetry or vice versa took place below $2t_1 - 2t_2 \approx 0.50$, i.e., $t_1 \approx 0.37$. The pseudomonoclinic high microclines show only a small scatter. With increasing Al-Si order the frequency of high microclines decreases. All samples are found within a small strip extending from $t_1O = t_1m \approx 0.37$ to LM.

No K feldspar individuals have been found which are "high microcline" in only one state of order. It must be supposed therefore that domains of metastable "high microcline" have formed under disequilibrium conditions as the temperature fell sufficiently below T_{diff} (the temperature of diffusive phase transition from sanidine to microcline) during retrograde metamorphism. We conclude that the pre-Alpine alkali feldspars of the Hercynian gneisses and metagranites have been transformed into low sanidine during prograde Alpine metamorphism and became "high microcline" during uplift and cooling of the studied area.

Regional variation of the optic axial angle $2V_x$ and the Al-Si order of K feldspar

The X-ray investigations have shown that K feldspars from different localities of the studied area may differ considerably with respect to their Al-Si order. A large variation can also be found within single parts of a K feldspar crystal. It was observed that even a very small portion of a K feldspar may show two states. Accordingly the variation of the Al-Si order within some selected feldspar individuals was tested by taking several small drillcores from the same crystal. The low microcline perthites were found to be homogeneous with respect to their Al-Si order. The "high microcline" individuals vary between intermediate microcline and pseudomonoclinic "orthoclase", and sometimes even the presence of small amounts of low microcline is indicated by a few powder lines. From a single K feldspar from profile 2, six drill-cores gave ($t_1O - t_1m$) values between 0.07 and 0.55 (Fig. 2B).

Figure 2 shows the variation of the optic axial angle and of the calculated ($t_1O - t_1m$) values along the fairly complete profile 2. It must be mentioned that only some general conclusions can be drawn from a comparison of optical with X-ray data since the crystals investigated by optical and those investigated by X-ray methods are not the same. Considering the variation of the Al-Si order along this profile there is a clear-cut jump from low microclines to variable "high microclines" (Fig. 2B). With respect to $2V_x$, this change is visible, though less clearly, in Figure 2A. A similar discontinuous transition from microcline to "orthoclase" was observed in the contact aureole of an intruded quartz-monzonite by Steiger and Hart (1967).

The same discontinuity is found in all seven profiles (Table 2 and Fig. 1). This permits the definition of a low microcline and a "high microcline" area.

In the northernmost part of the Tauern Window only low microcline was found. The optic axial angle $2V_x$ is $\geq 76^\circ$. In the northeastern part near Krimml (profile 4 to 7) the microcline is completely ordered and has t_1O values of 1.0. The calculated Ab content of these microclines is 1.9 to 0.9 mole %. It is interesting to note that the low microcline is less ordered in the northwestern area near Mayrhofen and has calculated t_1O values between 0.95 and 0.98 (profile 1 to 3) and a calculated Ab content of 3.8 to 5.7 mole %. These data suggest that the Al-Si ordering process is accompanied by unmixing. The samples which appear to be the most fully exsolved are also the most ordered with respect to Al-Si.

Immediately south of the low microcline area there is a region with intermediate and high microcline. The optic angles are $\leq 76^\circ$ and the ($t_1O - t_1m$) values are ≤ 0.55 . This confirms the optical results of Raith (1971) and Raase and Morteani (1976). Although the Al-Si order of the "high microclines" varies considerably, the mean ($t_1O - t_1m$) value is the same in different parts of Zentralgneis. It should be noticed that even the "high microclines" of the Gamsbodengneis in the Gotthard "Massif" (Central Swiss Alps) have the same mean value as those of the Zentralgneis (Bambauer and Bernotat, 1976). This is an indication that in each area the different structural states of "high microclines" occur in almost equal proportions.

The zone between both regions is fairly sharp in all profiles. Within a transition zone, which is one to several hundred meters wide, we found coexisting low microcline and high microcline throughout. But intermediate microcline did not occur preferential-

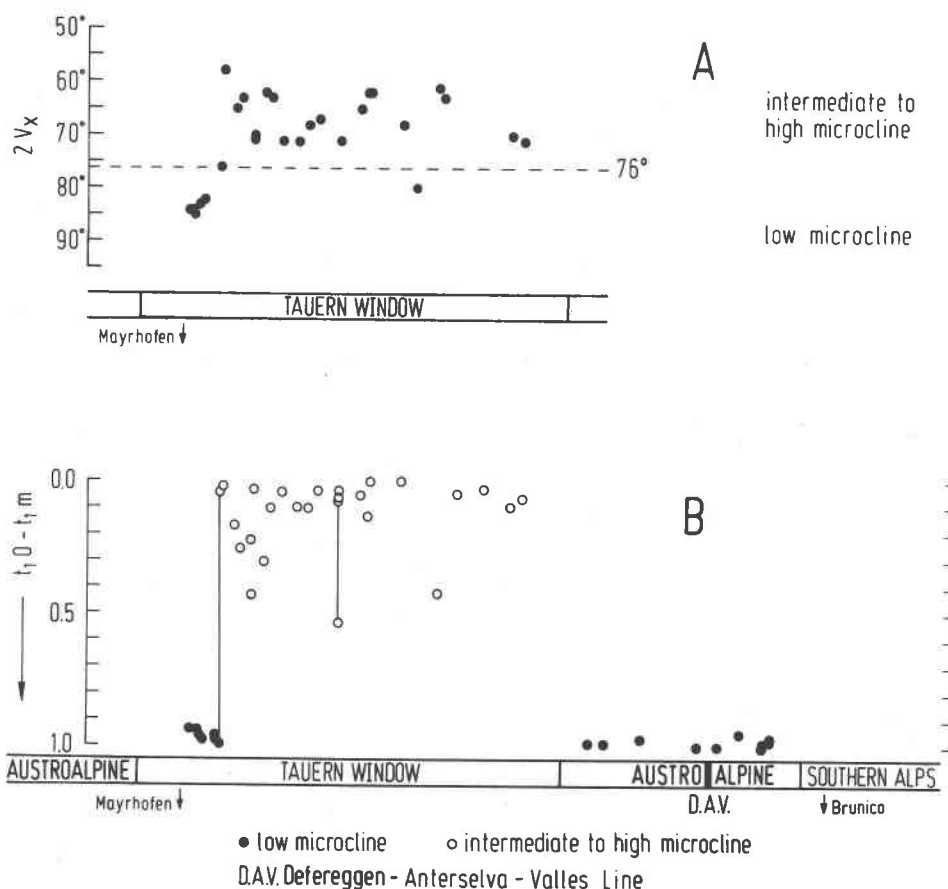


Fig. 2. Variation of the structural state of K feldspars along the north-south profile from Mayrhofen to Brunico. Optic and X-ray investigations were done on the same rock specimens but on different crystal grains. (A) variation of the optic axial angle $2V_x$ (B) variation of Al-Si order ($t_{1O} - t_{1m}$) as calculated from lattice parameters. Samples from the same K feldspar crystals are connected by a line.

ly. (Compare Table 1: samples 77-101 and 77-102, 77-115/1 and /2, 77-128(1) and (2), 77-163(1) and (2), 77-178(1) and (2), 77-138(1) and (2), 77-146(1) and (2)). A small K feldspar fragment from one sample showed clearly distinguishable powder lines of low microcline with $\alpha = 90.71^\circ$ and high microcline with $\alpha = 90.03^\circ$. In many other samples from the transition zone it has been possible to identify a number of powder lines from low and high microclines but in general the number of lines was not sufficient to calculate reliable lattice parameters. We assume that along this narrow zone the low microcline/low sanidine phase transition took place during prograde alpine metamorphism. We cannot determine from the petrologic criteria if this was a transformation of first or second order. If the K feldspar transformation is of second order we must assume that the temperature interval of stable intermediate microcline is only about 10 degrees. Our data thus

confirm the supposition of Stewart and Wright (1974, p. 373) "that the range of temperature under which intermediate microcline is stable is so narrow that only fortuitously would a rock be held in the stability field of intermediate microcline, when quenched".

The K feldspars of the Granatspitz gneisses (Fig. 1 profile 8) differ from those of the Zentralgneis with respect to their structural state. In all the samples from this unit we found high microcline associated with low microcline. It seems that the ordering process of the sanidine in the Granatspitz gneisses proceeded further than in the Zentralgneis during retrograde metamorphism.

The lattice parameters give more detailed information on the structural state of K feldspar domains than the optical axial angle. The optical data did not show clearly the conspicuous gap between the structural states of low and "high" microcline,

although a limiting value of $2V_x = 76^\circ$ divides these structural states.

Our observations fit well with that of Mergoïl-Daniel (1970) on the alkali feldspars from the Montagne Noire. She could define an area characterized by low microcline, showing an optic angle $2V \geq 75^\circ$, and an area with less ordered microcline having an optic angle $2V \leq 75^\circ$.

Metamorphism and Al-Si order of K feldspars

1. Tauern window

The boundary between the low and high microcline areas does not correspond to any known tectonic line (Fig. 1). It runs parallel to the general E-W tracking limit of the gneiss series but is not the border of a rock unit. Parallel to it and close by lies the 500°C isotherm of Hoernes and Friedrichsen (1974) which is deduced from $^{18}\text{O}/^{16}\text{O}$ data. Only a few oxygen isotope measurements were made close to this line. Therefore a detailed oxygen isotope study along this line is in preparation in order to attempt to determine the temperature more accurately.

As described above the rocks of the studied area show a Hercynian migmatization. Therefore sanidine must have been formed during the Hercynian metamorphism. The Alpine metamorphism is characterized by one (or two) precursory (eo-Alpine) low temperature events later followed by a (late-Alpine) high temperature event, the Tauern metamorphism. We have no knowledge about the structural state of the K feldspars during eo-Alpine phases. Low microcline may well have been formed from the Hercynian sanidines. Not later than during the late-Alpine metamorphism all K feldspars were annealed long enough at low temperatures to form low microcline throughout the Tauern Window. Low microcline remained stable in the augen gneisses of the border zone of the Tauern Window.

According to mineral equilibria and $^{18}\text{O}/^{16}\text{O}$ data, the metamorphic temperatures in the border zone remained below 500°C ; however, metamorphic temperatures up to 630°C have been estimated for the central part of the western Tauern Window, which led to the transformation of low microcline into the high temperature phase sanidine. This is indicated by the sudden increase of disorder, e.g., in profile 2 of Figure 1.

During the cooling period which followed, the temperature in the central part of the window also

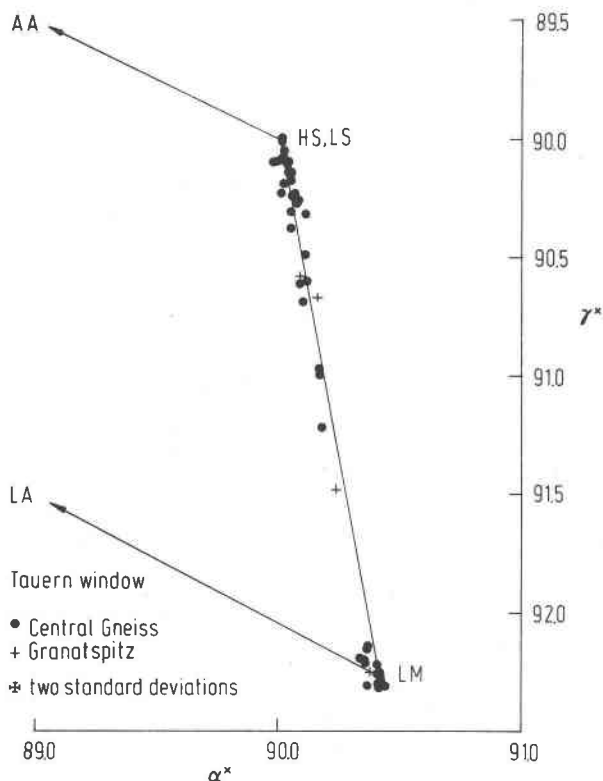


Fig. 3. Correlation between α^* and β^* for alkali feldspars. The quadrilateral joins the reference points for high sanidine (HS), low sanidine (LS), low microcline (LM), analbite (AA) and low albite (LA).

dropped below the temperature of the phase transformation. Either because of a rapid cooling rate or due to other conditions which slowed diffusion, the K feldspar remained intermediate to high microcline and only very small amounts of low microcline were formed. In Figure 2 the former sanidine zone is clearly indicated by the presence of many almost monoclinic microclines.

Sanidine was also formed in the gneisses of the Granatspitz during late-Alpine metamorphism. During cooling after this metamorphic event sanidine was also transformed into intermediate and high microcline. According to Luckscheiter and Morteani (1980) fluid inclusions from Alpine veins contain up to 80% CO_2 in the western Zillertal area and no CO_2 in the eastern Grossvenediger area. We therefore assume that a high water content in the gneisses of the Granatspitz area favored the diffusive Al-Si ordering in the K feldspars during cooling. A considerable portion of the K feldspar crystals of the augen gneisses of the Granatspitz area in fact transformed into low microcline.

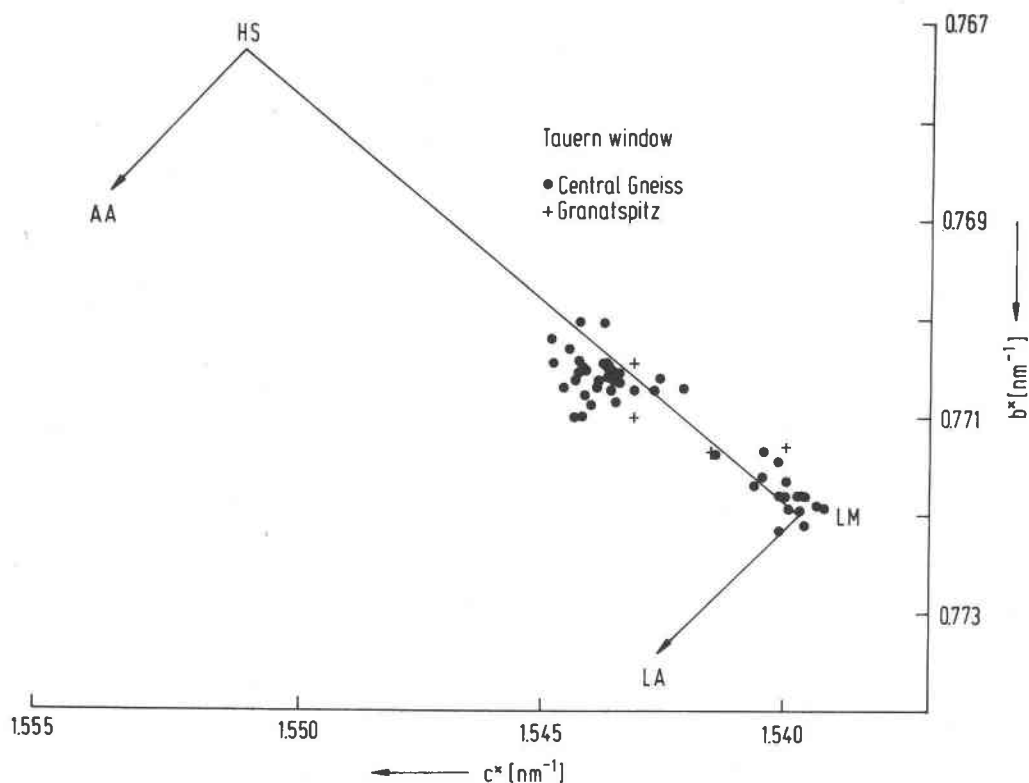


Fig. 4. Correlation between b^* and c^* for alkali feldspars. The quadrilateral joins the reference points for high sanidine (HS), low microcline (LM), analbite (AA) and low albite (LA).

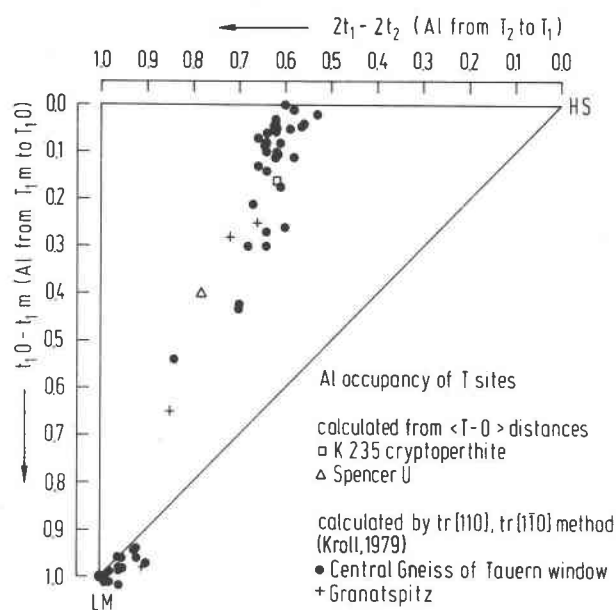


Fig. 5. Al-Si order of the K feldspar phase of perthites from gneisses of the Tauern Window (Eastern Alps) as calculated from lattice parameters according to the method of Kroll (1980).

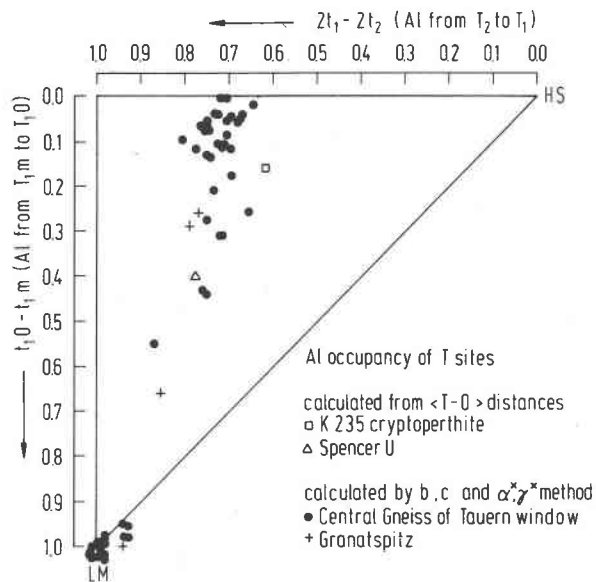


Fig. 6. Al-Si order of the K feldspar phase of perthites from gneisses of the Tauern Window (Eastern Alps) as calculated from lattice parameters according to the method of Stewart and Ribbe (1969).

2. Merano–Mules–Anterselva complex

North of the Deferegggen–Anterselva–Valles line (DAV for short) the rocks of the Merano–Mules–Anterselva complex show effects of the eo- as well as of the late-Alpine metamorphism. In fact, in most cases the muscovites of the pre-Alpine orthogneisses show a Rb–Sr Alpine age of about 60 to 65 m.y. On this basis it is possible to suppose that the eo-Alpine metamorphic event is widespread in the Austridic “Altkristallin” of the Eastern Alps (Lambert, 1970; Borsi *et al.*, 1978). However, the above quoted muscovite ages could also represent mixed ages, *i.e.*, partially rejuvenated Hercynian ages. If this is the case the Hercynian Rb/Sr biotite ages have completely disappeared while the muscovite ages were only partially rejuvenated. This suggests that during the eo-Alpine phase the augen gneisses north of the DAV line experienced a temperature very close to 500°C (Borsi *et al.*, 1978). Such a temperature is in good agreement with the temperature estimated for the nearby metamorphic dikes which locally cross the Penninic–Austridic limit.

Figure 1 (profile 2c) shows that not only the K feldspars north of the DAV-line but all the K feldspars of the Merano–Mules–Anterselva complex are low microclines. No intermediate or high microcline was found. It can be assumed that the Hercynian metamorphic grade north and south of the DAV line was the same. The K feldspars south of the line are low microcline and this area was almost not affected by the Alpine metamorphism. The temperature remained below 300°C since the Hercynian Rb/Sr and K/Ar biotite ages are not rejuvenated (Borsi *et al.*, 1978). Therefore it must be assumed that low microcline north of the DAV line was formed at Hercynian times.

Yund and Tullis (1980) have shown that a trace amount of water has a very large effect on the kinetics of Al–Si ordering. But there is no evidence that the partial pressure of H₂O north and south of the line were different.

Given the uncertainties of the temperature of phase transitions and of the maximum temperature reached in the area north of the DAV line, we assume that the late-Alpine event has not been high enough in grade or did not last long enough to transform the K feldspars to sanidine.

Conclusions

It has been possible to distinguish in the western Tauern Window areas bearing only low microcline

and areas with prevalently intermediate to high microcline. Optic axial angles $2V_x$ and X-ray data give the same pattern.

The low microcline area and the high microcline area are separated by a narrow transition zone in which both low and high microcline occur. This zone is close to and below the 500°C isotherm with the intermediate to high microcline on the high temperature side. This intermediate to high microcline was formed from sanidine during the cooling period at the end of the Alpine metamorphism. Low microcline of the border zone of the Tauern Window was formed during the cooling period after the Hercynian metamorphic event. In the Merano–Mules–Anterselva complex only low microcline is present. It can be supposed that it was formed at the end of the Hercynian metamorphism. The important isograd of microcline/sanidine phase transition cannot be found in metamorphic areas if one distinguishes only between triclinic and “monoclinic” K feldspars (as has often been tried).

The optic axial angle $2V_x = 76^\circ$ discriminates between low microcline and intermediate to high microcline. Microclines from the Tauern Window and from the Gotthard massiv (Central Swiss Alps) have the same frequency distribution of Al–Si order. This argues in favor of similar metamorphic conditions in these two areas.

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