THE OPTICAL ORIENTATION OF THE PLAGIOCLASES

By

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Introduction

Much interest attaches to a knowledge of the connections between chemical composition and optical orientation of the plagioclases. In the first place the plagioclases are one of the very few isomorphic series of triclinic symmetry about which accurate data are available. Secondly, the relations between An-content and optical orientation constitute an essential foundation for the microscopic determination of plagioclases in rocks. It is, therefore, not surprising that much attention has been devoted to this topic over the past hundred years and that it is at the present still subject of active research. It is impossible to review in this paper the interesting historical development of the insight gained into this topic or to mention the contributions made by individual scientists. Reference must be made, however, to the achievements of F. Becke and his numerous pupils. Their accurate determinations constituted for many years practically the only reliable foundation on which to construct the diagrams for plagioclase determinations. In the twenties of the present century work on the subject seemed to be more or less concluded, the results achieved being contained in the well-known stereograms for plagioclase determinations by L. Duparc and M. Reinhard (1924) or M. Reinhard (1931). As in all previous work the plagioclases were assumed by these authors to constitute a binary system albite-anorthite. Accessory small amounts of a potash feldspar component (usually called "Or") were neglected as was a suspected content in carnegeite, efforts to detect their influence having remained unsuccessful. In this respect the situation remains practically unchanged even today.

The authors referred to had comparatively few fixed points provided by plagioclases examined both optically and chemically. Thus Reinhard's migration curves were based on the following members: An_0, An_4, An_{13}, An_{20}, An_{25}, An_{29}, An_{52}, An_{64}, An_{97}, An_{100}, of which the two extreme ones were Wuelfing's extrapolations. Discrepancies which became evident when attempts were made to improve the course of the curves in the region of the andesines (e.g. by Becke (1922); Ernst and Nieland (1934)) lead to a distinction being made between high- and low-temperature optics. This most important conclusion is due to Köhler (1942) after Wenk (1933) and Larsen (1941) had reached rather similar results. The discovery of intermediate optical conditions (lying between high- and low-temperature optics) lead to the interpretation of the phenomena as being due, not to the existence of two modifications, but rather to the degree of order in the Si and Al distributions and in the case of anorthite also to that of Ca (Barth, 1928; Laves, 1950). New stereograms of the optical orientations were given by Tertsch (1942) and van der Kaaden (1951).

The stereograms hitherto published have the following shortcomings:

1) They are based on fixed points, too few in number and too irregular in distribution. Thus, for instance, as already stressed by Becke, a gap exists between labradorite An_{52} and anorthite An_{97} which hitherto has only been filled by two members of altered, i.e. uncertain composition, namely An_{64}(?) labradorite from Pillau and An_{72}(?) bytownite from Narödael. Additional data were, therefore, most necessary, at least at the basic end, but were difficult to obtain owing to lack of suitable material.

2) The irrugular distribution of the data along the curves and the very variable intervals between successive points rendered impossible the interpolation of values at regular intervals, e.g. such of 10% An. Interpolations of this kind have indeed been attempted from time to time and are in fact essential for plagioclase determinations. It must be stressed, however, that all such attempts are to a large extent arbitrary and can, therefore, make no claim to accuracy.

New work

In view of these facts the present authors decided to cooperate to form a study group for the total revision of existing data and in efforts to increase as far as possible the amount of data available. As regards point 1) discussed above, the action taken consisted in systematically collecting and critically examining all the material contained in the literature. Where gaps were found these were as far as possible filled by new determinations. The latter were not restricted to well-developed occurrences of freely-grown plagioclases or large individual crystals (e.g. from pegmatites) as had hitherto usually been done. In order to obtain urgently-needed members it was necessary, especially at the basic end, to separate plagioclases from rocks, among which gabbros, norites, and anorthosites provided much excellent, unzoned, and perfectly fresh material [1]. The chemical compositions were generally calculated from the determined amounts of CaO, Na_2O, K_2O, this procedure requiring much less time and material than complete analyses. The optical orientations were determined by various universal stage methods including such not involving the measurement of any morphological directions [2].

Work along these lines provided a series of 145 fixed points for plotting new migration curves which seems to constitute a considerable advance on previous constructions (Glauser (1959, 1961), Glauser and Wenk (1957, 1960), Wenk (1960), Wenk, Gruetter and Schwander (1961); another series of new determinations yet not having been published).

To avoid the lack of precision in interpolation mentioned under (2), use was made of a new method of formulating the optical orientation of plagioclases proposed by Burri in 1956. The method adopted by Becke consisted in fixing the positions of the optic axes on the sphere of reference by means of spherical co-ordinates corresponding to geographical latitude and longitude. When the optic character is given, the positions of the chief directions of vibration and accordingly the complete orientation of the indicatrix can easily be derived. This method is especially useful when sections of defined orientation are

[1] The present writers are greatly indebted to a number of colleagues and especially the following for kindly supplying suitable material: Messrs. R. C. Emmons (Madison), H. H. Hess (Princeton), N. Kolderup (Bergen), H. Kuno (Tokyo), P. Michot (Liége), W. E. Tröger (Freiburg i.Br.), L. R. Wager (Oxford), J. Willemse (Pretoria).

[2] Our thanks are due to Dr. Glauser in Basel and Dr. Bambauer in Zürich for help kindly given in carrying out the optical investigations. We have also to thank Dr. Schwander in Basel and Dr. Weibel in Zürich for carrying out chemical determinations.

being examined and the position of the optic axes can be determined with great accuracy. This can be achieved either by Becke's microconoscopic method or with Wuelfing's axial-angle apparatus, it being assumed that suitable material is available. The method is less well adapted to the universal stage on which the positions of the chief vibration directions (which are also the normals to optical planes of symmetry) can be more easily and accurately determined than those of the optic axes, which, indeed, are sometimes inaccessible.

The new method is based on the fact that the three chief vibration directions n_α, n_β, n_γ constitute a right-angled cartesian system X' Y', Z', which for a given orientation possesses a definable orientation in respect of a second right-angled system X, Y, Z, of fixed position as regards the crystal. In the latter system X, Y, Z were chosen as follows: Z parallel to the c-axis [001] of the crystal which is at the same time twin axis of the Carlsbad law; Y parallel to the normal of (010) which is also twin axis of the albite law; X perpendicular to the two other directions and hence parallel to a direction usually symbolized as

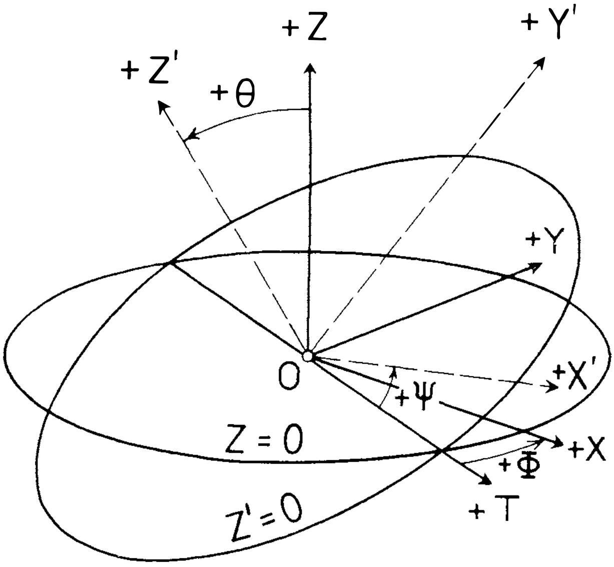

Figure 1. Definition of Euler angles Φ, Ψ and Θ.

$\frac{\perp [001]}{(010)}$. It is the twin axis in the complex twin law albite-Carlsbad (Roc Tourné). For characterizing the mutual positions of the two systems use is made of the so-called Euler angles Φ, Ψ, Θ as used in analytical geometry and mechanics. The optical orientation of the plagioclase is thereby uniquely determined. The definition of Φ, Ψ, Θ for the purposes under consideration is as follows (Figure 1).

Θ is the angle of inclination of Z' against Z. The two planes $Z=0$ and $Z'=0$ intersect in a straight line, the so-called line of nodes T to which a sense can arbitrarily be given. Within the plane $Z=0$ Φ represents the angle $(+T, +X)$ and within the plane $Z'=0$ Ψ represents the angle $(+T, +X')$. The dertermination of the sense of rotation follows the usual rules.

If for reasons of convenience it be assumed that $X'=n_\beta$, $Y'=n_\gamma$, $Z'=n_\alpha$, the positions and values of the Euler angles can be derived from a stereographic projection of normal orientation as shown in Figure 2 for high-temperature labradorite An_{50}. Thus the Euler angles

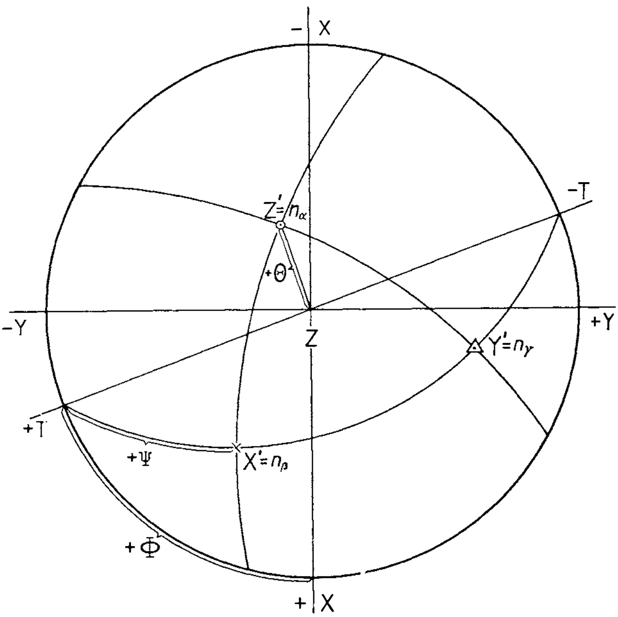

Figure 2. Euler angles, Φ, Ψ and Θ, derived from a stereographic projection of high-labradorite An_{50}. Plane of projection normal to c axis.

can be immediately read with the aid of a stereographic net or alternatively calculated from appropriate data by the methods of sperical trigonometry or vector analysis. Inversely the stereographic plot can easily be constructed from given values of the Euler angles (Burri, 1956). In a modification of the method suggested by Parker (1960) n_β is assigned to Z', n_α to X' and n_γ to Y' and additional angles are provided to define the positions of the optic axes. A combination of the original and the extended method can be used to detect and smooth out internal contradictions in the conventional data provided for any plagioclase. Tables are planned and already nearing completion in which the very heterogeneous data available from the literature will (perhaps for the first time) be presented in a quite uniform manner. The Euler angles and migration curves deduced from these values have been calculated for 5% An intervals.

When the Euler angles of all available optically and chemically analysed plagioclases are plotted against the An-content, variation curves are obtained on which Φ, Ψ, Θ can be accurately interpolated for any desired An-content and e.g. for intervals of 5% to 5% An. Proceeding from these values, calibrated migration curves can be drawn in stereographic projection which are quite free from the arbitrary features previously mentioned. As the variation curves of the Euler angles differ as between high- and low-temperature plagioclases, separate migration curves can be constructed for each of these. Plagioclases of intermediate composition which are found in nature or produced artificially by short tempering, have Euler angles lying between those of the high- and low-temperature varieties. A fact of importance is that where the migration curves of the high- and low-temperature plagioclases run close to one another or even coincide, as is the case with the n_α curves, for instance, considerable differences exist in the An-content of the two regions. In such cases the greater accuracy attainable by the new method is particularly valuable.

Because the Euler angles as originally conceived are calculated without reference to the optic angles, migration curves have to be specially constructed for these. With this in mind the $2V$ angles for all analysed plagioclases were collected and included in the above-mentioned tables. After plotting curves for both the high- and low-temperature series, averages were struck for 5% An intervals and the migration curves included in the stereograms.

As the work on the stereograms which include such showing the migration of morphological elements (crystal faces, cleavages, twin planes etc.) is not yet completed, these cannot at present be demonstrated. It seems likely, however, that the new migration curves while providing improved calibration will confirm the general trends of those of previous authors and especially of M. Reinhard (1931) for the low-temperature series and of C. Burri (1956) for the high-temperature members.

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