Optical, chemical and structural determinations of volcanic, acid icelandic plagioclase feldspars

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Objekttyp: **Article**

Zeitschrift: **Schweizerische mineralogische und petrographische Mitteilungen = Bulletin suisse de minéralogie et pétrographie**

Band (Jahr): **51 (1971)**

Heft 2-3

PDF erstellt am: **19.09.2024**

Persistenter Link: https://doi.org/10.5169/seals-39832

Optical, Chemical, and Structural Determinations of Volcanic, Acid Icelandic Plagioclase Feldspars

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With 18 figures, 3 tables and 2 plates

Abstract

In this work, the results of numerous optical, chemical, and structural measurements on acid, volcanic plagioclase feldspars from Iceland are given. These determinations were carried out on each feldspar twin-pair measured. The Euler- and Köhler-Angle curves of BURRI, PARKER and WENK (1967) were slightly modified in the compositional field An_{25-40}. An attempt at a finer subdivision into grades of ordering, using classical tables (e. g. 2 V) failed. On the other hand, two nomograms were constructed, each with four variables (three Euler Angles versus chemistry), with which the degree of ordering can be obtained with reasonable accuracy.

In the range An_{28-40}, no breaks or *sharp* bends in the optical and chemical curves are found, and a relatively constant transition is noted here. Below 28% An, a large scattering was discovered. As the specimens show a very variable Or-content here, it is doubtful whether all of the crystals under 28% An are plagioclases, as many of these fall into the field of "potassian oligoclase" described in BARTH (1969), and often show anomalous optical behaviour.

It is the opinion of the author, that the remaining problems in the study of the plagioclase feldspars, can most probably only be solved by refined structural work, coordinated with chemical and optical determinations.

The usefulness of the Köhler-, and especially the Euler-Angles in optical determinations has been verified.

Zusammenfassung

In dieser Arbeit werden die Resultate von zahlreichen optischen, chemischen und strukturellen Bestimmungen an sauren vulkanischen Plagioklasen aus Island gegeben. Diese Bestimmungen wurden jeweils an Feldspat-Zwillingspaaren durchgeführt. Die Kurven der Euler- und Köhler-Winkel von BURRI, PARKER, WENK (1967) wurden leicht modifiziert im Gebiet An_{25-40}. Der Versuch, eine feinere Unterteilung nach dem Grad der Ordnung, durch Benützung klassischer Tabellen (z. B. 2 V), zu erhalten, ist miss-

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lungen. Andererseits wurden zwei Nomogramme mit je vier Variabeln (drei Euler-Winkel gegen Chemismus) konstruiert, mit welchen man den Ordnungsgrad relativ genau bestimmen kann.

Im Gebiet An_{28-40} wurden keine Diskontinuitäten oder *scharfe* Krümmungen in den optischen oder chemischen Kurven festgestellt, vielmehr war ein relativ konstanter Übergang zu beobachten. Unterhalb 28% An ist eine grosse Streuung vorhanden; weil die Proben mit An < 28% einen sehr veränderlichen Gehalt an Or besitzen, ist es fraglich ob es sich in allen Fällen um Plagioklase handelt, da viele von ihnen im Feld "potassian oligoclase" (Barth, 1969) liegen und oft anomale optische Eigenschaften zeigen.

Es ist die Meinung des Autors, dass die übrigbleibenden Probleme im Falle der Plagioklase nur durch verfeinerte Strukturstudien zu lösen sind, und zwar koordiniert mit chemischen und optischen Bestimmungen.

Die Nützlichkeit der Köhler- und vor allem der Euler-Winkel bei optischen Bestimmungen wird bestätigt.

Contents

Preface

The present work was carried out under the guidance of Professor Ed. Wenk, whom I sincerely wish to thank, firstly for the valuable help and assistance he has always offered, and secondly for making it possible for me to travel twice to Iceland for the collection of the samples used in this work.

My gratitude is also due to Professor H. Schwander, and to Dr. W. Stern; the former for the chemical analyses of the samples, without which this work would have been impossible, and the latter for valuable suggestions and criticism.

I also extend my thanks to Professor P. Bearth for his lectures on volcanism, which served as a good introduction into "things volcanic".

H. Hänni and T. Fischer made good thin-sections for this work, and I am indebted to them for this, as well as to Dr. A. Steck and J. Arnoth who helped in the setting-up of the X-ray equipment.

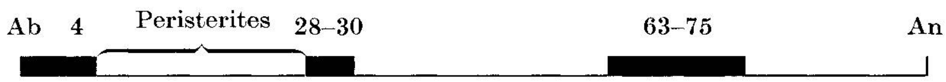
My colleagues, too numerous to name individually although all the more remembered, will not be forgotten for the discussions, not always scientific.

Lastly, I wish to express my thanks to the "Werenfels-Fonds", of the „Freiwillige Akademische Gesellschaft der Stadt Basel", and to the „Theodor Engelmann-Stiftung" in Basel, whose financial help for the journey to Iceland, made this work possible.

INTRODUCTION

Using X-ray apparatus, it has been shown that low-temperature plagioclase feldspars, instead of exhibiting a pure isomorphous series between the end-members albite and anorthite, show unmixing on a sub-microscopic scale, into intergrowths of, for example in the peristerites, An_4 and An_{28}. This unmixing probably relieves internal stresses created by the Si-Al substitution in the crystal-framework (RIBBE, 1960).

COLE, SÖRUM and TAYLOR (1951) have shown that low-temperature plagioclase feldspars ranging from about An_{30} to An_{70} may be made up of submicroscopic intergrowths with plagioclases of An_{30} and An_{70}. It would thus appear that plagioclases in the range 30–70% An are unstable at low temperatures. This has been supported by the work of other researchers, and generally the following isomorphous series can be set up (the exact An-values are still not accurately known):



Later work, shortly summarized in SMITH and RIBBE (1968) shows discontinuities at:

1. An_{33} and An_{50} for $2\,\theta_{131}$–$2\,\theta_{1\bar{3}1}$ (physical properties and unit cell parameter), observed by SMITH and YODER (1956).
2. An_{31-35} in the wave-length of the infra-red absorption band (THOMSON and WADSWOTTH, 1957).
3. An_{25-40}, and An_{52} in microhardness (MOOKHERJEE and SAHU, 1960).

All these data from widely differing properties can hardly be expected to coincide exactly at similar chemical compositions, but the nature of the discontinuities is either a break in plots, or bends (versus chemical composition). The results of the optical investigations, and the chemical plots, show only more or less sharp bends at certain compositions.

Work on the structure of the low-temperature plagioclase feldspars has also been partly confirmed by optical measurements – e. g. Euler-, Köhler-Angles etc., for low-temperature plagioclases – instead of forming curves with a constant progress, form ones with more or less sharp bends, and generally show anything but a constant course or pattern.

In general, if one examines optical curves by different authors (Köhler-, Euler-, optic axial angles etc.), it will be noticed that none of these graphs and curves have a constant course, which would naturally be expected for a pure isomorphous series. This is optically impossible to explain unless we accept an isomorphous series between certain intermediate (in composition, that is to say) plagioclases, and not between the extreme, pure members of the series, i. e. albite and anorthite.

This work, therefore, attempts to determine whether this is also the case for the high-temperature and intermediate plagioclases, by coordinating accurate optical and chemical analyses (in part, also with structural measurements).

Secondly, investigations of plagioclases showing intermediate optics were required. MARFUNIN (1958) drew curves for plagioclases with high- and low optics, and simply joined the two curves with straight lines for isochemical plagioclases of the high- and low-form, whereby the intermediate crystals would be expected (by him, that is) to fall on these lines. On the other hand, measurements of the Euler Angles have shown that this cannot be done. The three Euler Angles (from Euler II, for example) were plotted on a nomogram (containing four variables: three Euler Angles against chemistry), which had been constructed after the system used by GOTTARDI (1961) using the values of BURRI, PARKER and WENK (1967), and connecting the two curves (high- and low-temperature) at similar chemical compositions, with straight lines for e. g. R, from Euler II. The results measured on the universal stage produced a large triangle of error on the nomogram, which can only be due to the former false assumption of Marfunin (i. e. optical linear transition of low- to high-temperature forms).

Lastly, more data was desired for the curves of the Euler Angles, to see if they were formed with adequate data, i. e. to check the reliability of the curves.

A good historical background to the work carried out is given in the thesis of VAN DER KAADEN (1951), and the latter work should be consulted for further research, as well as BURRI, PARKER, WENK (1967).

The plagioclase feldspars determined and used in this work are mainly acidic types, ranging from about 0–50% An. The reason for this lies in the fact that the optical values (Euler-, Köhler-Angles, optic axial angles etc.) for the high- and for the low-temperature plagioclases of the same chemical composition, differ much more in the acid regions, and it is thus in this composition area that investigations will reveal the most information.

Samples: It is not the intention of the present author to go into the geology of Iceland, from where the samples originate, as this is amply covered by a number of writers. The two volumes by Thoroddsen, written in the years 1905 and 1906 respectively, are highly recommended, although slightly out-dated.

The rocks whose phenocrysts were determined and analysed in this work, all come from Iceland. They were collected during field-work in the summers of 1966 and 1968, over a period of about four months. The specimens were basically chosen on the merits of the size of the phenocrysts (ease of optical and structural determinations), their freshness, and acidity. An exact systematic search was therefore found to be unnecessary, and generally, samples of rhyolites (liparites), obsidians, pitchstones, ignimbrites, and consolidated volcanic ash were collected whenever found. An exacter description of the samples will follow later in this work, under *thin sections.*

All rock-samples, chemical, optical, and structural (film negatives) data, are deposited at the Mineralogisch-Petrographisches Institut der Universität, Basel, Switzerland.

METHOD AND PROCEDURE

In this section, the determination procedure is fully described from the microscopic study of the specimens, with some of the problems involved, to the tabulation of the results.

The specimens used were, as already mentioned, sampled in the summers of 1966 and 1968. As these were sampled at random, they may be considered to be a good general selection of acid Icelandic rocks. Thin sections were made of all the specimens collected, and approximately a third of these were found useful for optical study. The rest of the specimens contained plagioclases either too basic chemically, or were unsuitable for optical determinations (zoned, filled with inclusions etc.). As polishing of the specimens decreases the thickness by approximately 0.01 mm, the thin sections were made thicker than normal – about 0.04 mm. The polishing of the slides after the optical study was necessary for the chemical analysis, using the Electron Microprobe.

For the optical determination, a Leitz 4-axis universal stage and a microscope from the same firm were used. In each slide, the morphology and optics of all suitable plagioclases were measured, as far as possible. In the case of acid specimens (An_{0-50}), this was often found to be difficult, as the crystals are usually small, zoned, and filled with inclusions. The greatest problem in these acid rocks, on the other hand, was in finding plagioclases suitably twinned (Carlsbad-Roc Tourné), as opposed to the basic varieties where the latter twin-laws are the most common, and not an exception. Only plagioclases twinned according to these laws were used, for reasons described in sections *twin laws* and *errors*. It can therefore be understood why, in some cases, only one pair of twins in a slide filled with plagioclase crystals, could be determined with accuracy.

Each individual of the twin-pair was measured in the normal way on the universal stage using glass hemispheres with an index of refraction of 1.554 (REINHARD, 1931). Although this index of refraction corresponds to plagioclases in the range 40–50% An, and therefore more basic than most of those measured in this work, a correction of the measurements was not made. This was found to be unnecessary as the maximum possible error caused by the different refractive indices of glass and of the plagioclases used here, is approximately 1° in the measurements – a value which is probably never reached here. Even so, an error as high as 1° is permissible as the other errors in measurement (subjective and objective) certainly attain this value.

A stereographic projection of the morphology and optics of the individuals was then made, by plotting the values obtained on a stereographic net with a radius of 10 cm. The twin-axis (axes) was constructed on the net, and, according to the accuracy of the former, the plot of the composition plane corrected so that the latter was directly at right-angles to the twin-axis (axes), as the composition plane is often difficult to determine accurately. The Miller indices of the twin-axis and compodition plane were then determined using Tables IX and X from BURRI, PARKER, WENK (1967), and the measurements then accurately plotted on a stereographic net with a radius of 20 cm. The third morphological point on the projection, if not already constructed, was then constructed at right-angles to the other two. At this point, we have the [n_α], [n_β], and [n_γ] directions of the individuals, and (010), [001], and $\perp$ [001]/(010) (i. e. two independent right-angled coordinate systems).

The relationship between the optics and the morphology can therefore be directly determined, using the Euler Angles for example.

The twins determined in the thin sections were then sketched, ringed for identification purposes, and lastly, chemically analysed.

Chemical Analysis

The chemical analysis of the optically investigated crystals was carried out using a Jeol Electron Microprobe. This was found to be the most convenient and accurate method, as slide-specimens can be directly used if uncovered and suitably treated (polished, and coated with a 250 Angström layer of carbon for conductivity purposes). As the width of the microprobe-beam is approximately 1 μ, crystals of ½ mm length are ideally suited for a chemical investigation in many points of the crystal. No other methods of analysis can give such accurate results using such small amounts of material.

It should again be emphasised that as the optical and chemical measurements were carried out on the same crystal, a much higher degree of accuracy was attained.

It is not intended here to go into the description of the methods, as this is amply dealt with in the literature (SCHWANDER, 1966; WENK and SCHWANDER, 1966; WENK and SCHWANDER, 1967). It suffices to mention that calcium, potassium, and in many cases also sodium and aluminium were determined, transformed into values for their oxydes, and from the latter, the anorthite-, albite-, and orthoclase-contents were individually calculated. The sum of these three often gave a total differing from 100% by up to 10%. If this was the case, the albite value was discarded, the sodium measurement being the cause of this inaccuracy (due to its volatility during the chemical investigation of the specimen). The final accuracy (in % An) of the determination is a variable, depending on the composition of the plagioclase, but in the ranges measured, this lies within 0.5% An, which is an acceptable margin of error, considering the subjective error due to optical measurements.

TWIN-LAWS

As far as the twin-laws of the measured crystals are concerned, only certain ones and certain combinations of these can be used for the accurate determination of the Euler Angles. As has been mentioned elsewhere in the text, the following planes and axes must be reproducible in the stereographic projection:

1. cleavage plane (010) (composition plane, albite twins)
2. c-axis [001] (twin-axis for Carlsbad twins)
3. direction ⊥ [001]/(010) (twin-axis for Roc Tourné twins)

As 1, 2, and 3 all stand at right-angles to each other, only two of these need be measured. In most cases, where each twin is composed of two individuals, these three planes and axes can be constructed by measuring composition plane (010), and then constructing the twin-axis, if the twins are twinned according to either the Carlsbad, or the Roc Tourné law.

It will be shown later in this paper, why only two twin-types and combinations of these can be used for accurate calibration purposes (Carlsbad and Roc Tourné). With the latter two twin-laws, the twin-axis can be constructed in only one construction and is directly used in the determination of the Euler Angles. The only objective error here lies in this construction. This assumes an identical chemical composition for both individuals, whereas an An-difference of up to 5% can often be observed (Microprobe). With other twin-laws, at least three constructions are necessary before the axes needed for the determination of the Euler Angles are plotted, thereby introducing a large source of error.

Normal Twins

Albite and Manebach twins

The Euler Angles of a pair of individuals twinned according to either of the above laws, can only be determined if the normals to both the planes (010) and (001) can be measured. If this is possible, then the following constructions can be carried out on the stereographic net, step by step for each individual:

1. edge [100] (a-axis)
2. plane (100)
3. edge [001] (c-axis)
4. ⊥ [001]/(010) (twin-axis, Roc Tourné)

As will be shown under the section *Errors*, four constructions, each one based on the last construction, produces an objective and subjective error too large for accurate determinations; therefore, crystals twinned according to the albite and Manebach laws have not been used here.

Parallel Twins

1. *Acline:* With the acline twin-law, the measured and constructed morphological directions are composition plane (010), and twin-axis [010]. As the relationship between [001], (001) and [010], is approximately known, it is possible to construct four positions where [001] can lie. On the other hand, it is not possible to determine in which of these four positions [001] really lies, unless (001) of each individual can be measured. Even if this (001)-measurement is possible, the subjective error produced by the construction renders the acline twin-law unsuitable for accurate determinations of the Euler Angles.

2. *Ala-A (Estérel):* The measured composition plane here is (001), with a constructed twin-axis [100]. (010) can therefore lie in one of two positions. To decide which of these two is the correct one is impossible, as this depends on whether (001) is really (001), and not (00$\bar{1}$). Another difficulty with this law is that it is virtually impossible to differentiate it definitely from the Manebach-acline twin-law.

3. *Ala-B:* As for Ala-A twins, and differing only in the composition plane and twin-axis.

4. *Carlsbad:* Plagioclases twinned according to the Carlsbad twin-law are the only ones among the parallel twins which can be used here. Composition plane is (010), and the twin-axis [001]. At right-angles to these two axes lies ⊥ [001]/(010), by construction. We have therefore the three morphological axes necessary for the evaluation of the Euler Angles.

Complex Twins

With the exception of the Roc Tourné law, all the complex twins are such, that, with their respective composition planes and twin-axes, the morphological directions (planes and edges), 1. must be constructed (subjective and objective errors), and 2. give at least two possibilities for the required morphological axis.

Therefore, the most favourable plagioclases for the accurate determination of the Euler Angles, are those twinned according to the Carlsbad and Roc Tourné laws, especially if an albite-twinned individual is added to this combination. The latter is useful for accurately measuring the composition plane.

The existence of three individuals twinned one with another according to the Roc Tourné, Carlsbad, and albite twin-laws is unfortunately rather rare in acid rocks, and one must usually be content to construct the composition plane, knowing it to be at right-angles to the twin-axis.

In this paper therefore, only Roc Tourné and Carlsbad twins have been determined, as these give the most accurate positions of the morphological axes needed for the determination of the Euler Angles.

ERRORS

Subjective Errors

a) It is difficult to say how much error in the measurement may be attributed to the inexact adjustment of the microscope and the universal stage. If this is done with patience and care before the actual measurements are taken, this instrument-error can be eliminated, or at least diminished to a value which falls well within the total error permitted.

b) The adjustment of maximum extinction in a crystal varies from observer to observer. The only method of correction involves measuring extinction a number of times, each time narrowing down the "area of extinction" until the maximum has been determined. Approximately four determinations were undertaken by the author for each extinction, and the values averaged. To determine the individual bias from investigator to investigator, a typical twin-pair (in RS 80 E) was also measured by two other workers. The results show, that in accurate measurements from three investigators, an error of $\pm 1^\circ$ must be reckoned with in optical determinations.

Objective Errors

a) The assumption that two individuals of a twin-pair possess the same chemical composition is used in the construction of the twin-axes of twins other than normal twins (in the case where the twin-axis is measured, and not constructed), i. e. for parallel and complex twins. This assumption is often erroneous and can produce incorrect values for the Euler Angles. On the other hand however, this error is largely eliminated if the average Euler Angles of both individuals are determined.

A point which the reader may note, is the omission of any reference to the so-called "triangle of error" under the heading "Subjective Errors". This has purposely been omitted, as the expression "triangle of error" is a misnomer. To recapitulate, in projecting a twin-pair on the stereographic net, the twin-axis is constructed by drawing planes through like vibration directions of the two individuals. These three planes bisect one another in a line *only* if one condition is satisfied – namely, if both individuals have the same chemical composition, and not as in URUNO (1963) who considers the existence of a "triangle of error" to be purely a function of error in measurement. On the stereographic net, this line represents the twin-axis. If, as can be seen by a test-projection, the An-% of each individual varies by a small amount, the three planes through each pair of vibration directions do not meet in a point, but form the so-called "triangle of error".

Practical example: A Roc Tourné twin – one individual 25% An and the other 26% An (high optics) yields a "triangle of error" with sides of ca. 4°, 4°, 2° and an area of ca. 4° square, instead of bisecting one another in a single point.

Summing up, therefore, the so-called "triangle of error" need have no relationship to any measurement error, but results from each twin-pair whose individuals differ in chemical composition one from another. Conversely, if the twin-axis of two individuals twinned with each other is constructed as a point, when the two are of different chemical composition, it can be definitely said that a subjective (measurement) error exists in the determination. Therefore, the size of the "triangle of error" of the constructed twin-axis is by no means a yardstick for the accuracy of measurement *when* the two individuals making up a twin possess different An-contents. It should also be mentioned that in these cases (i. e. where the twin-axis is constructed as a triangle and not as a point), the two individuals are not joined together by a strict, accurate twin-law.

To avoid confusion, therefore, the term "triangle of error" should be abandoned in favour of a more accurate one, such as, for example, "constructed twin-axis triangle". With very accurate measurements and constructions, the size of this triangle is a function of the difference in the chemistry of the two individuals.

RESULTS

The results obtained from the optical and chemical investigations consisted of:

1. The three Angles of Euler I, II, and III.
2. The Köhler Angles for the twin law(s) determined in the measured individuals.
3. The optic axial angles of the plagioclases.
4. The chemical composition in weight-% of the crystals (oxydes of calcium, potassium, in part also sodium, and aluminium).

The individual graphs constructed with this data will now be examined in detail.

1. Euler Angles I, II, III (Figs. 1, 2, 3, 4)

In the determination of the Euler Angles for a twin-pair, the construction most commonly used was that for Euler III (D, N, 180-K_α). This was not done without reason. For the plagioclases mentioned (volcanic, mainly in the range An_{0-50}), the angle of intersection between the plane ⊥ [001] (c-axis), and the plane containing two of the main indicatrix axes ([n_α], [n_β], [n_γ]), must be as near to 90° as possible, for reasons of measurement accuracy. For the type of plagioclases mentioned this is best fulfilled using Euler III, where the plane containing [n_α] and [n_β] cuts the plane ⊥ [001] at nearly 90°.

The Euler Angle determined (Euler III) was then transformed mathematically into Euler I and Euler II using the formulae in Burri, Parker and Wenk (1967, p. 124).

The nine curves for the three types of Euler Angles in the above work were then used as a basis for plotting and comparing the new values, with the results shown in Figs. 1, 2, and 3. As can be seen, a rather large scattering (up to 10°) is thereby produced. As all the plagioclases come from rocks of volcanic origin, the average course of the plots produces a modification of the original curves in the range measured, i. e. from 25–40% An, as is to be expected. In the range mentioned, the former authors possessed only nine plots, as compared with the 54 plots of the present author, which is naturally of better statistical value.

The scattering of the plots proves that it is impossible to investigate a single plagioclase in a thin section, and to speculate (from a single measurement!) with the aid of the Euler Angles, as to the chemical composition of the feldspar, not to mention the structural state! This can only be accomplished when one possesses several determinations, say, for example, at least 20 twin-

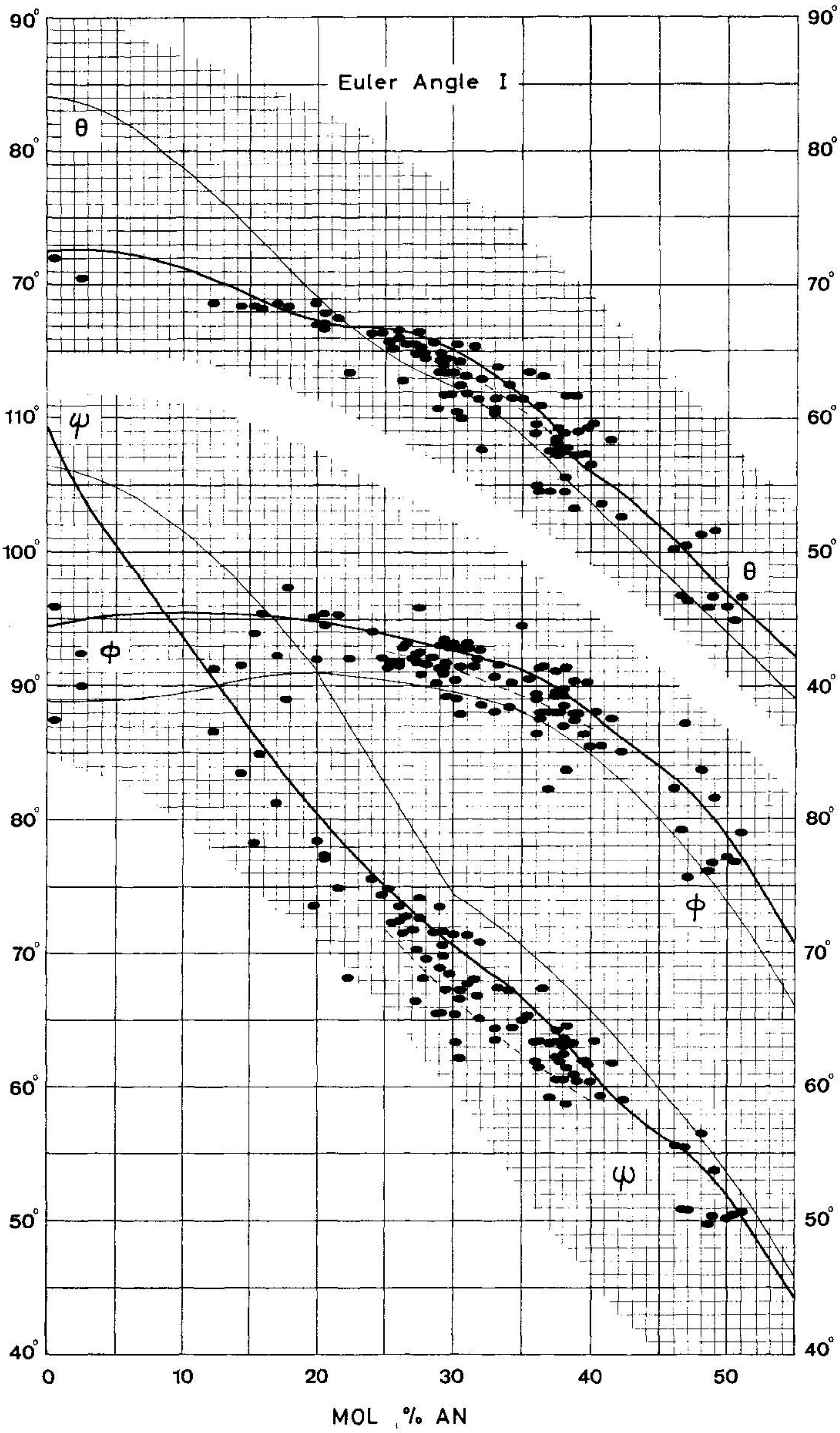


Fig. 1. Euler Angles I, with modified curve (dashed) for high-temperature plagioclases (thick curves), showing values obtained.

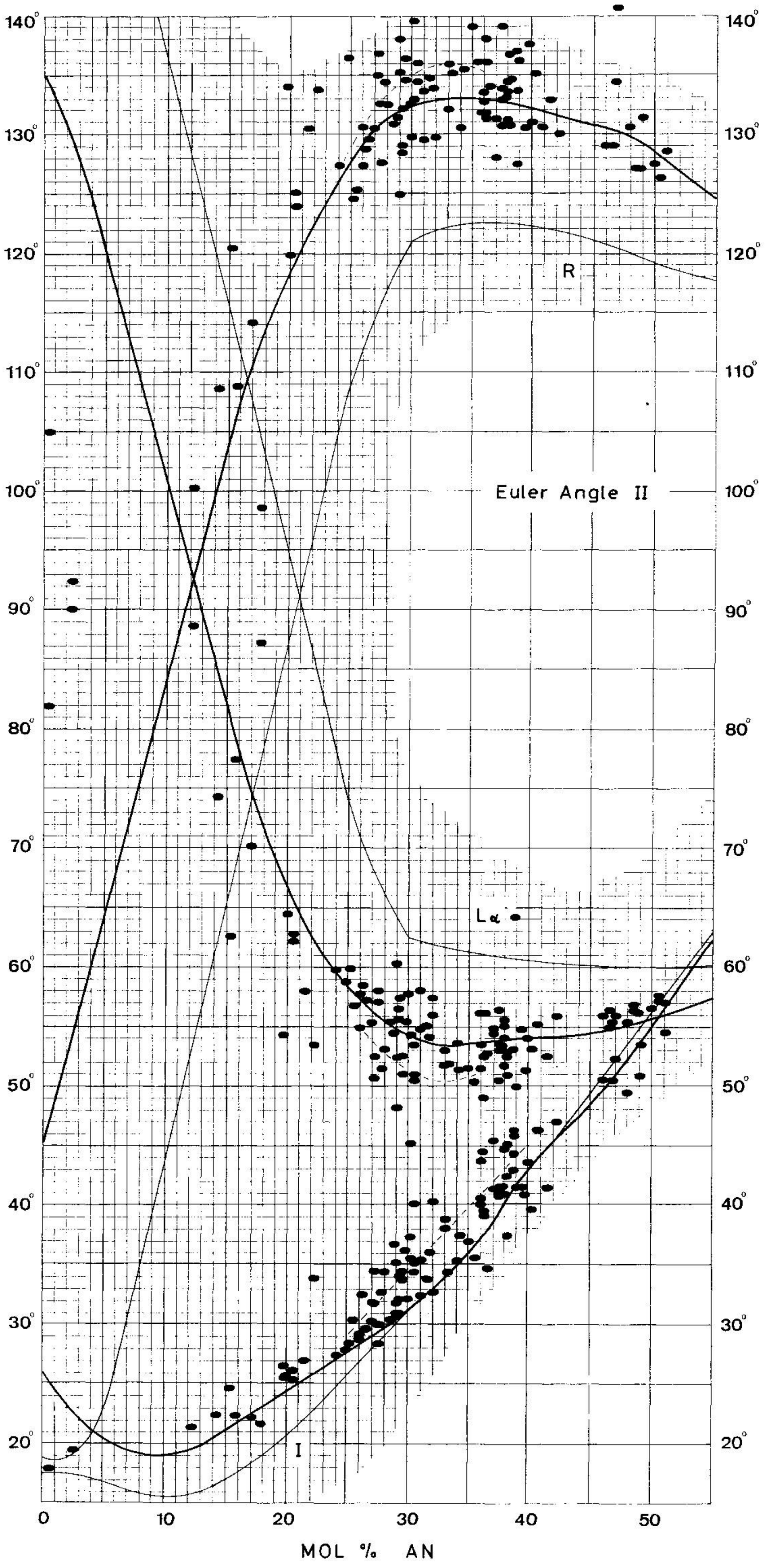


Fig. 2. Euler Angles II, with modified curve (dashed) for high-temperature plagioclases (thick curves), showing values obtained.

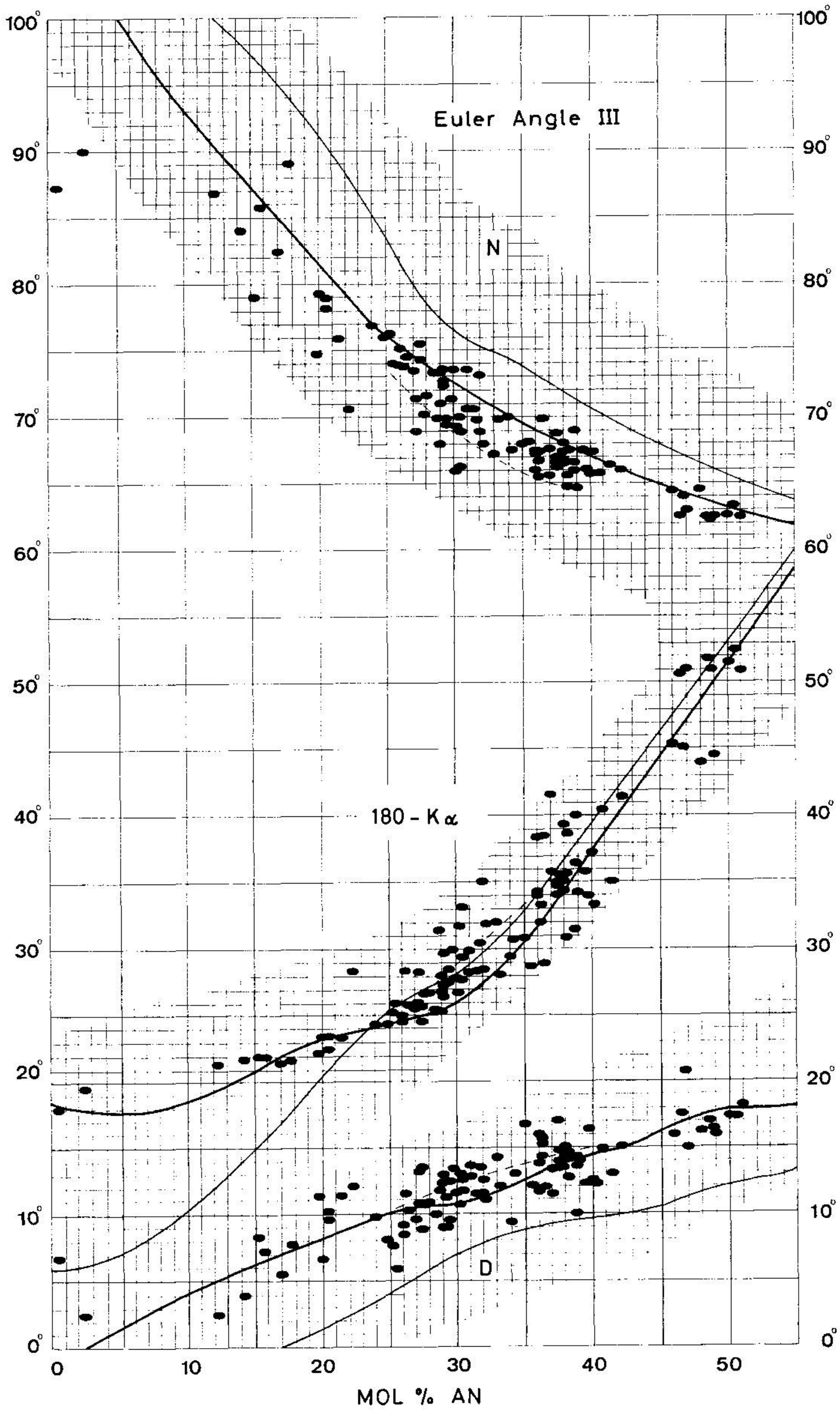


Fig. 3. Euler Angles III, with modified curve (dashed) for high-temperature plagioclases (thick curves), showing values obtained.

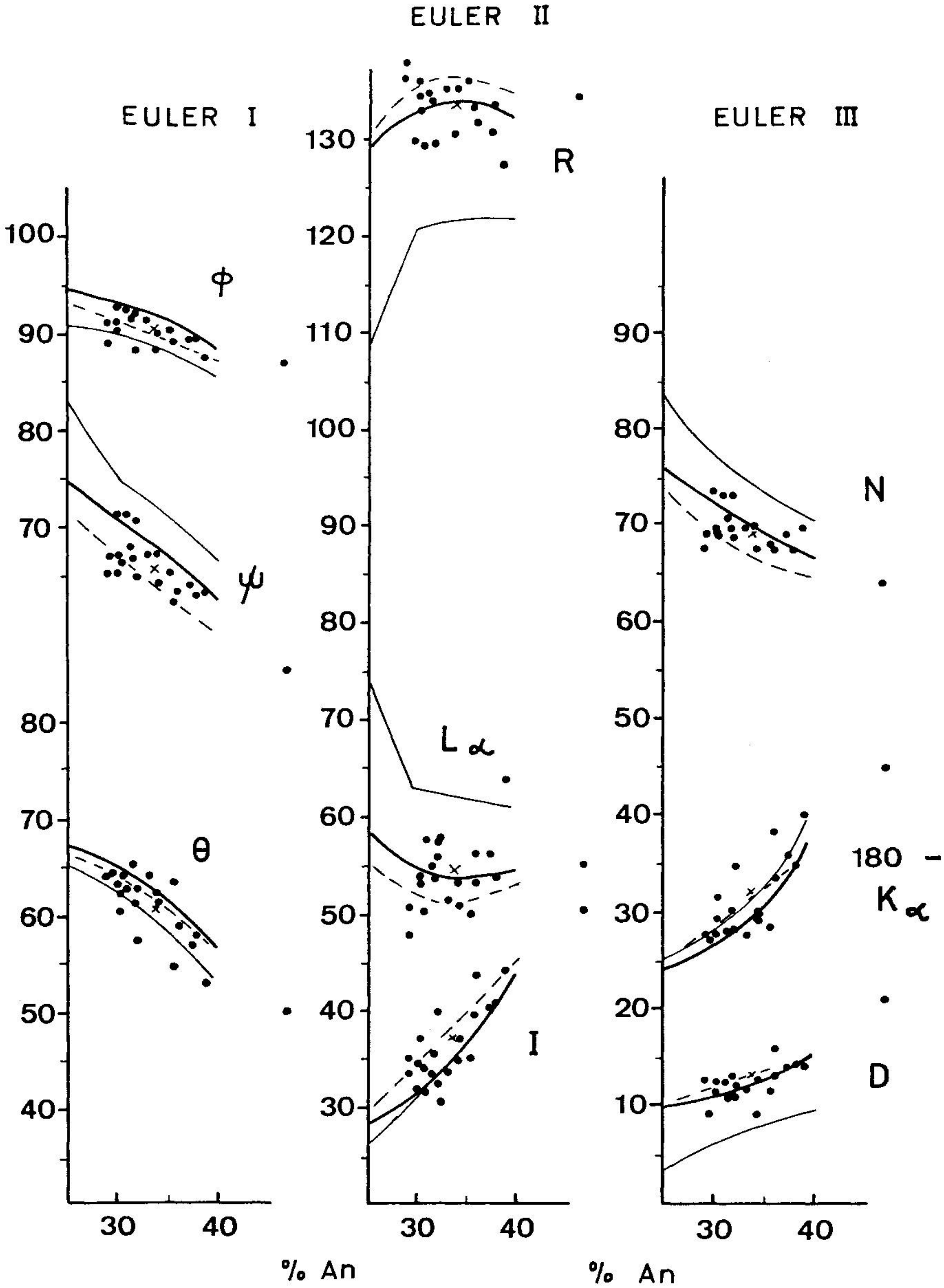


Fig. 4. Euler Angles for twins determined from the same rock-specimen (RS 87, RS 213A).

pair measurements. This can well be seen in Fig. 4 where, only after 21 measurements of different twins in the same slide do we see a *rough* statistical trend in the plots.

It is fruitless to speculate on the origin of the scattering in the Euler Angles – whether due to measurement error (very unlikely), or to the fact that crystals only millimetres distant may have formed under different conditions. This also seems unlikely, but what else can explain the fact that the scattering in the curves of BURRI, PARKER, WENK (1967), covers the same area as that of the present author although the latter plotted six times the number of plagioclases in the curves? This latter argumentation settles any accusations of insufficient optical data. The latter is more than adequate – the problem lies in its interpretation, and one can only speculate on this when sufficient, accurate optical data are coordinated with *accurate* structural determinations on the *same* crystal, and not on a general selection of plagioclases from the same rock, as was done here (the problem here was due to the fact that the optically determined crystals were not permitted to be destroyed for collection reasons).

The modified curves for the Euler Angles II and III were calculated from the new Euler I curves. These calculated modifications are seen to harmonise excellently with the plots on the former curves, that is to say, they form a curve which is a good average for the plots. This strengthens the case for the necessity of modification through a (laborious!) statistical optical determination of plagioclases of different compositions.

Fig. 4 is also important as it shows the large scattering of the Euler Angles which exists, although all the crystals here come from the same rock-specimen. At first, it was difficult to determine whether the scattering on the curves (Figs. 1, 2, 3) was due to the fact that the different specimens were not equally tempered. The scattering in Fig. 4 is similar to that in the curves of Figs. 1, 2, and 3, and therefore removes, or seems to remove this suspicion.

So far, the three types of Euler Angles only define the relationship between the optical indicatrix and the morphology, omitting that of the axial angle. PARKER (1961) resolved this by introducing the function L_A, which may be defined mathematically as: $L_A = L_\alpha + V_\gamma - 90$. The values for L_A, therefore, were calculated (Fig. 5) wherever possible from L_α and V_γ. Before this curve was plotted, it was thought that the values for 2 V_γ were to be accepted with much greater caution than the curves show is necessary (the scattering is no greater than in Figs. 1–4) – the calculated high-temperature curve is a good average for the measured plots. This suspicion was due to the fact that whenever both optic axes were measured, they would often give (2 V_γ) values differing one from another by as much as 5–10°. The reason for this must lie elsewhere; possibly it is due to a summation of the measurement errors for n_β, and both the axes, whereas the actual error produced is only a third of this.

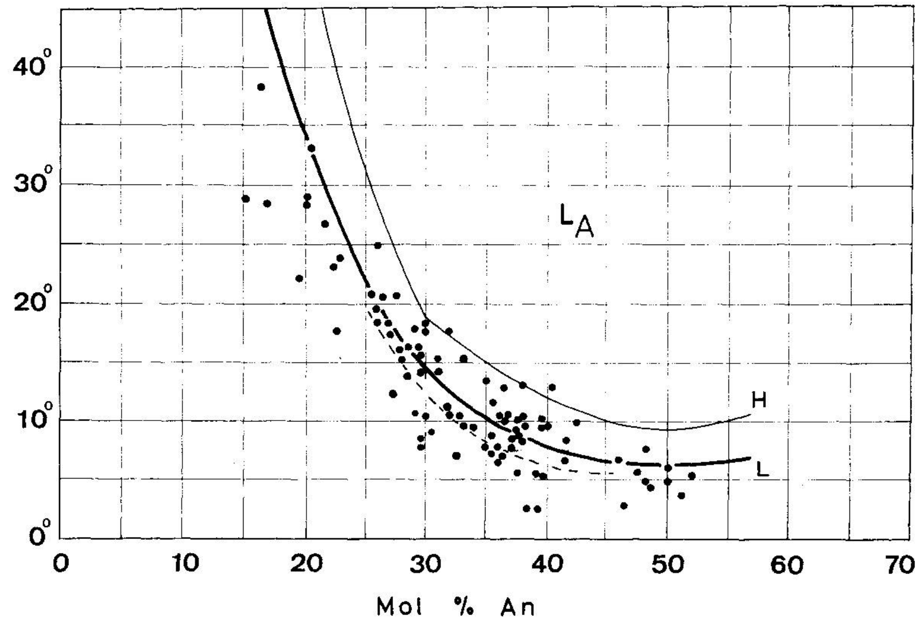


Fig. 5. Diagram of the values for L_A (Euler II) from the curves of Burri, Parker, Wenk (1967), with the modifications (dotted) mathematically calculated from the known values for V_γ and L_α (the latter from the corrected curves).

2. Axial Angle (Fig. 6)

Fig. 6 shows the values for the axial angle of the various individuals measured. As can well be seen, no modification of the original curves of Burri, Parker, Wenk (1967) was deemed necessary, the average of the values determined by the author coinciding well with the former. Also, it should be mentioned that the accuracy in the measurements of the axial angle using the

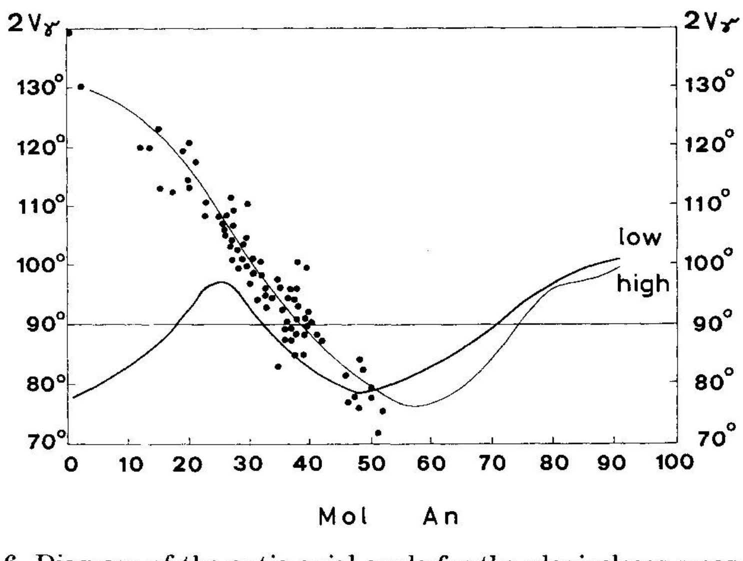


Fig. 6. Diagram of the optic axial angle for the plagioclases measured.

universal stage is much lower than for the other measurements, since the area of extinction covers a larger area and it is often difficult to find the maximum. Moreover, we have a doubling of the error as usually only one optic axis can be measured. We thus have 2 V/2, and only by doubling this do we get 2 V, thereby also doubling the error.

Fig. 7 shows the plot of the composition plane (010) superimposed on Table IX of Burri, Parker, Wenk (1967). These plots are the average for each twin-pair, and were determined by measurement and construction. In the range An_{25-40}, it can be seen that no modification at right-angles to the curve is necessary. By mathematical transformation of the modified Euler- and Köhler-Angles, the modified high-temperature (010)-curve still falls on that of Burri, Parker and Wenk, but with different values for the An-content. These new An-values do not appear in Fig. 7, due to problems of scattering, which make an exact plotting of their positions difficult. It suffices to mention that the compositional area An_{30-40} (B.P.W.), corresponds to An_{25-35} of the present author.

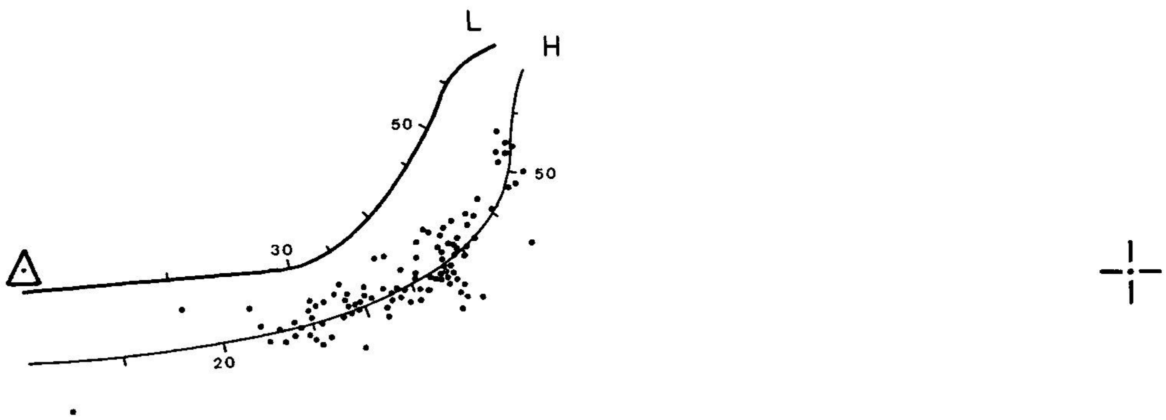


Fig. 7. Average plot of the normal to plane (010) for each twin-pair measured.

3. Köhler Angles (Figs. 8, 9, 10)

These three diagrams show where the plots of the Köhler Angles fall on the curves of Burri, Parker, Wenk. The modification of the volcanic curves was carried out, not directly by drawing the average curve through the measured plots, but purely by mathematical conversion of the new Euler Angle curves. That these modifications (on the Köhler Angle curves) happen to coincide very well with the visible average is another factor in favour of the necessary modifications of the Euler Angle curves.

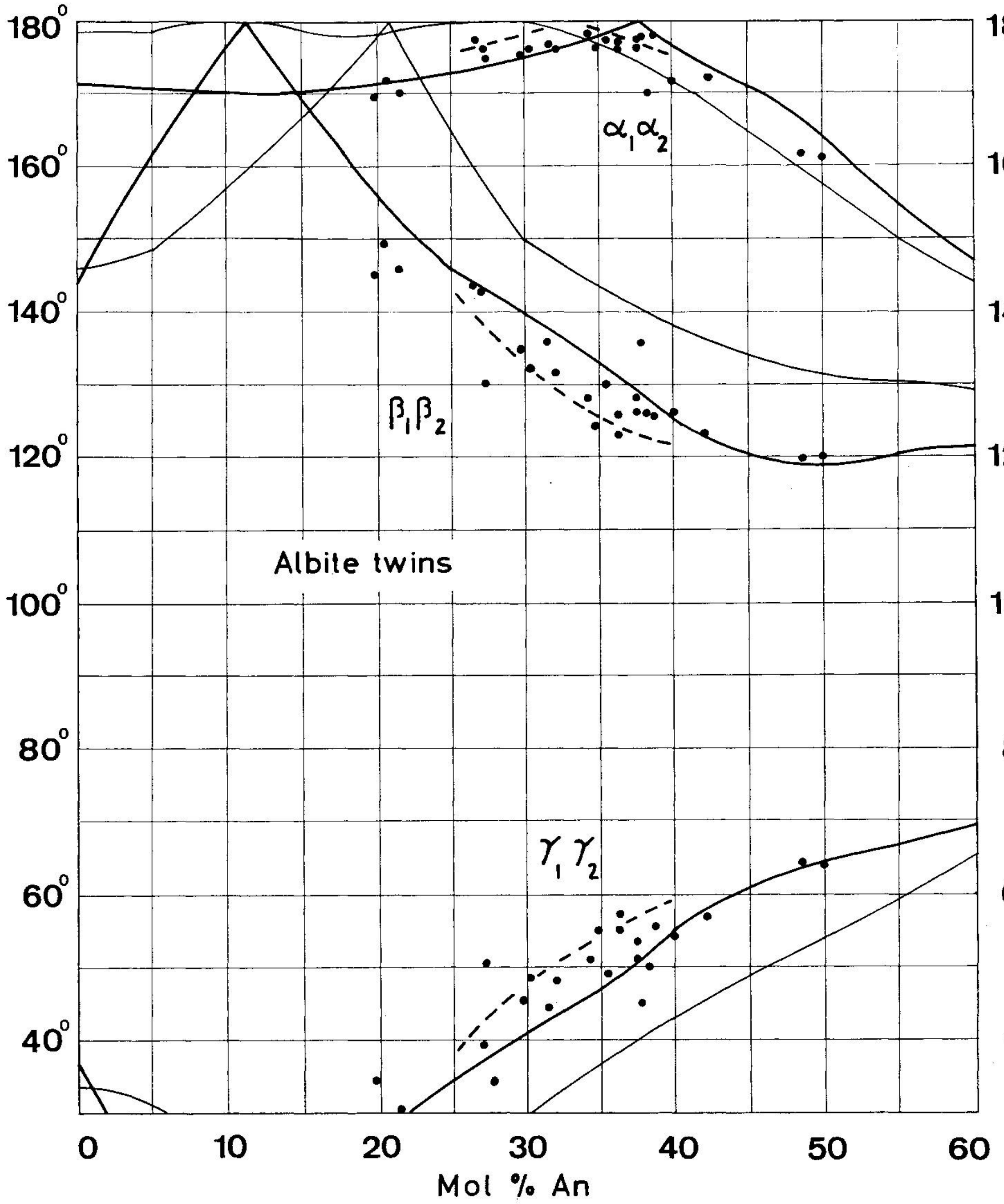


Fig. 8. Diagram of the Köhler Angles for albite twins, with the values for the plagioclases measured.

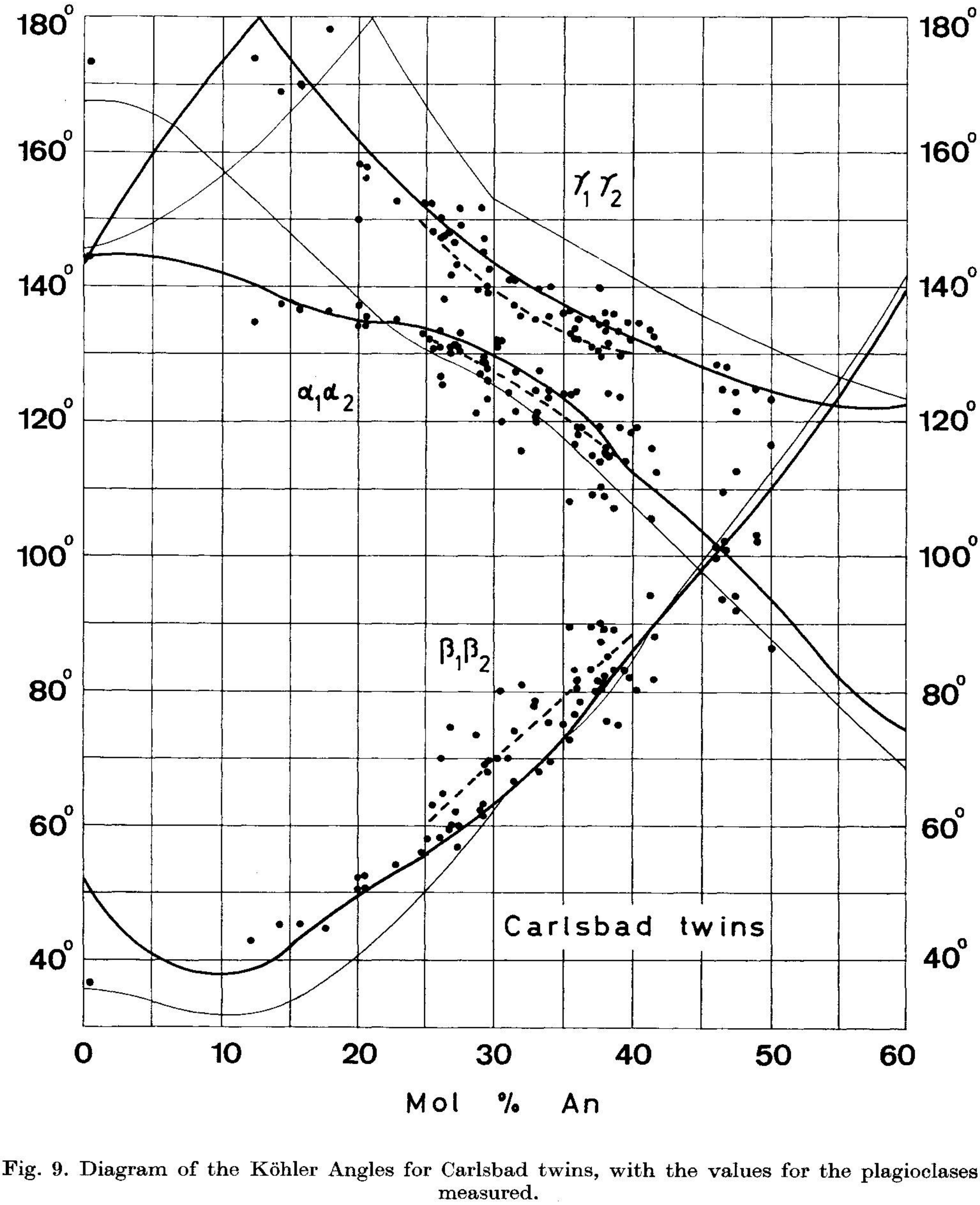


Fig. 9. Diagram of the Köhler Angles for Carlsbad twins, with the values for the plagioclases measured.

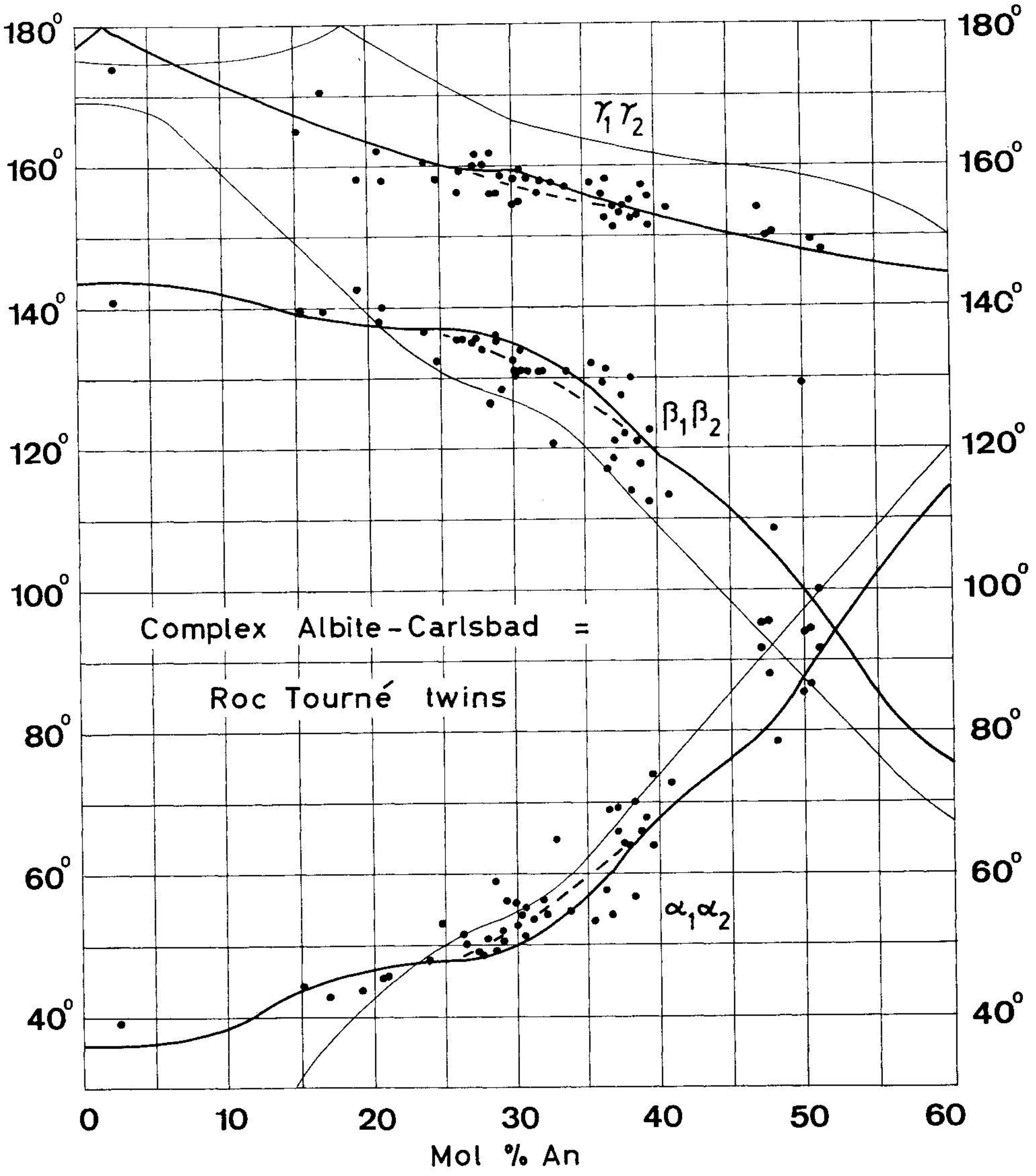


Fig. 10. Diagram of the Köhler Angles for Roc Tourné twins, with the values for the plagioclases measured.

4. Graphical Evaluation of Chemistry and Mineralogy (Figs. 11–15)

a) Ternary Feldspar Diagram

Fig. 11 shows the relationship between albite, anorthite, and orthoclase in the measured crystals (potassium component described as orthoclase). As can be seen, the progress of the band An_{50-28} is normal, as is to be expected. With an average of about 3% Or at An_{50}, the former (Or) increases linearly to about 5% Or at An_{28}. Below this, there is a very variable Or-content. It is still difficult to understand why this occurs, but in general, it is most likely to be solved by structural considerations beyond the scope of this work. It is also interesting to note that a Sr-maximum can also be found at about An_{30} (personal communication from H. Schwander). That these two phenomena are in any way connected is very likely, but this cannot at present be regarded as anything but pure speculation. Also of interest is the relative chemical homogeneity of the specimens above 30% An, whereby the Or-content at a certain % An varies over a range of only approximately 3%.

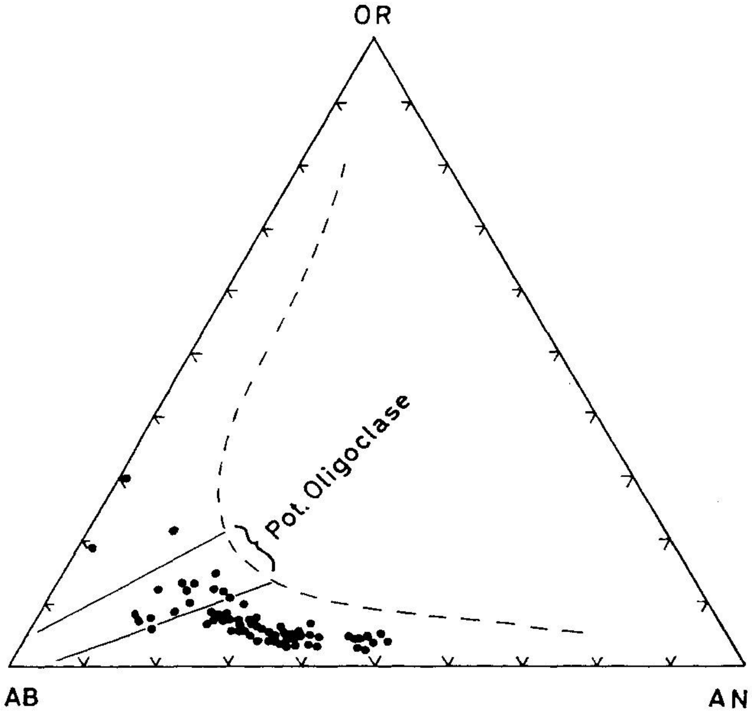


Fig. 11. Or-Ab-An diagram for the feldspars measured, showing the field of "potassian oligoclase" of BARTH, 1969.

b) Figs. 12–15

These graphs show indirectly the same pattern as in Fig. 11. If one compares the three graphs in Figs. 13, 14, and 15, we see that above 6.0% CaO in Fig. 15, the calcium oxydes are roughly proportional to their respective sodium oxydes

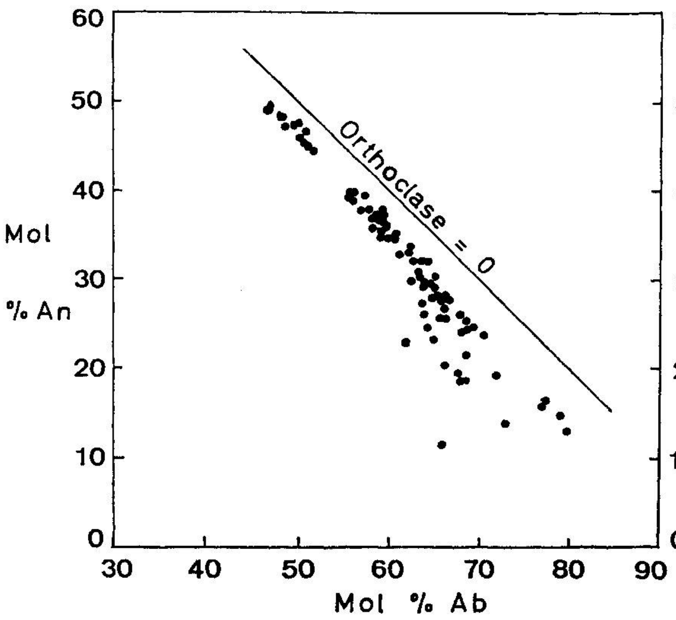


Fig. 12. Graph of Ab-An, showing the line which represents Or = 0 %.

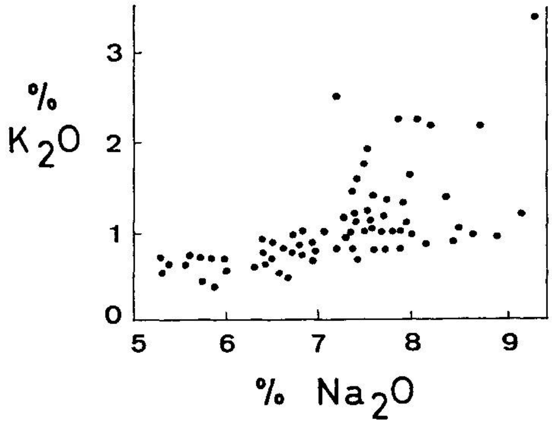


Fig. 13. Graph of the relations between K_2O and Na_2O of the plagioclases measured.

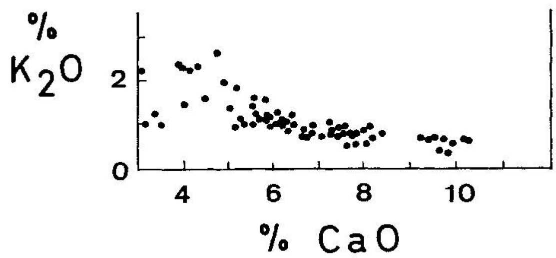


Fig. 14. Graph of the relations between K_2O and CaO of the plagioclases measured.

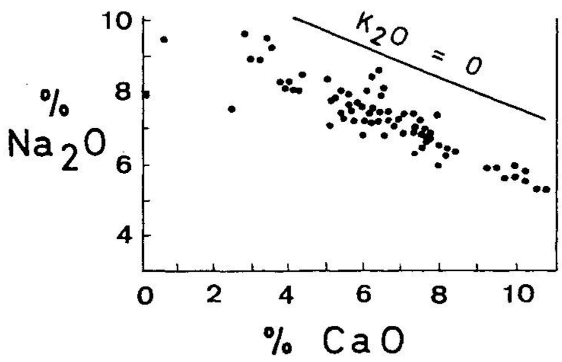


Fig. 15. Graph of the relations between Na_2O and CaO of the plagioclases measured, showing the line representing K_2O = 0 %.

with K_2O corresponding to about 4% Or. Analysis of the graphs at An_{0-30} shows that CaO is roughly proportional to K_2O, with Na_2O remaining approximately constant. This means that below 30% An, the Ab-content remains more or less unchanged, the An-content only decreasing because of the increase in Or. How this is to be explained is still unknown. This occurrence is possibly best seen in Fig. 11, where under 30% An, the plots no longer approach the Ab corner, but proceed parallel to it until the Or-content exceeds 20%, when the Ab-content decreases.

STRUCTURAL MEASUREMENTS

As stated by different researchers, the optics of volcanic plagioclases show an intermediate position between low-temperature plagioclases from plutonic rocks, and high-temperature synthetic crystals. This is usually the case although many feldspars showing purely high optics are often found in volcanic tuffs etc. This is best explained by the assumption that the rate of cooling in volcanic feldspars is slower than in the case of synthetic samples.

As the rocks sampled are mainly glasses and rhyolites with relatively large crystals, it was decided that a rough determination of their structural state was a minimum necessity.

Method: In the X-ray diffraction analysis, the Debye-Scherrer method was used. Although the resulting resolution is relatively small compared with other methods, the quantity of powder needed is minimum using this method.

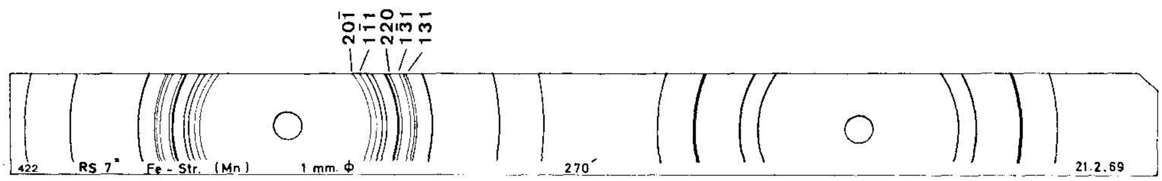


Fig. 16. Debye-Scherrer negative, showing the four reflections needed for the analysis.

Preciser results could have been obtained by the X-ray analysis of the chemically and optically measured crystals themselves. This procedure would have meant the destruction of the optically and chemically analysed grains, and no test material would have been left for later checks. The structural variation of the feldspars in a relatively homogeneous handspecimen was assumed to be within the margin of error of measurement. On the other hand, a rather more serious problem arises in the second assumption. If a powder-sample is taken from a number of feldspar crystals in the hand-specimens, an *average* structural state is obtained. To correlate this with the optical and chemical data, from, in some cases, one or two crystals per slide, assuming an average chemistry for the rocks from so few determinations, is incautious. This problem was (had to be!) taken into account in the X-ray results, in that variation limits of the average An% are given. As previously stated, the X-ray determinations here are only to be used as a rough guide to the structural state of the optical and chemical data as a whole.

Still too little is known on the influence of the Or-content on the line-differences, especially considering $2\,\theta_{131}-2\,\theta_{1\bar{3}1}$, where an Or-content of 1–2% can disturb the results, as stated by BAMBAUER et al. (1967b). In the same article (p. 348), BAMBAUER is even more cautious when he states:

"A quantitatively restrictive subdivision into grades of order (e.g. "intermediacy index", SLEMMONS, 1962) is to be avoided,

a) because absolutely no quantitative relation between the "Δ (θ)" values and the actual Al-Si distribution is known, and
b) because of the difficulties mentioned in the introduction of distinguishing between stable and unstable Al-Si distributions."

The results are often questionable, as the measured angle "2 θ" for different reflections was often determined with great difficulty, the lines seldom being sharp and thin. This may be due to contamination of the samples with groundmass (although in the case of the glasses, *apparently* non-crystalline). The

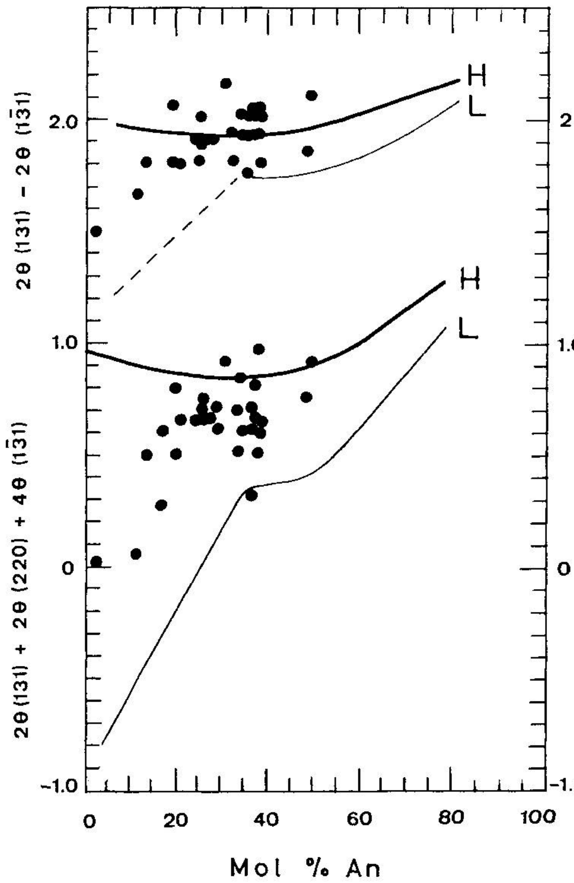


Fig. 17. Structural values for $2\,\theta(131)-2\theta(1\bar{3}1)$, after SMITH and YODER, 1956, and for $2\,\theta(131)+2\,\theta(220)-4\,\theta(1\bar{3}1)$, after SMITH and GAY, 1958, for the Icelandic plagioclases measured.

Table 1. *Structural Measurements*

Sample	Film No.	ca. An %	220	$1\bar{3}1$	131	$131-1\bar{3}1$	$131+220-2\,(1\bar{3}1)$	Structure
RS 228A	400	2.5	28.3	29.7	31.25	1.55	0.15	3
RS 228A	442		28.5	30.0	31 4	1.4	–0.1	
						1.48	0.02	
RS 110D	429	12	28.5	30.1	31.75	1 65	0.05	3
RS 218A	425	14	28.5	29.8	31.6	1.8	0.5	3
RS 217B	407	17	28.75	30.1	31.7	1.6	0.25	3
RS 217B	438		28.8	30.1	31.7	1.6	0.3	
						0.6	0.27	
Isl 191a	419	20	28.7	29.95	32.0	2.05	0.8	1
RS 5A	427	20	28.7	30.0	31.8	1.8	0.5	3
RS 223D	398	21	28.7	29.85	31.65	1.8	0.65	3
Isl 220	417	24.5	28.45	29.7	31.6	1.9	0.65	2
RS 28B	421	25.5	28.6	29.7	31.5	1.8	0.7	2
RS 93E	430	25.5	28.4	29.75	31.75	2.0	0.65	2
RS 30A	410	25.5	28.5	29.55	31.6	2.05	1.0	2
Isl 1	439	26	28.8	29.95	31.85	1.9	0.75	2
RS 93B	431	27	28.7	29.95	31.85	1.9	0.65	2
RS 93	412	27	28.65	29.9	31.8	1.9	0.65	2
RS 93A	432	28	28.7	29.9	31.8	1.9	0.7	3
RS 94B	441	28	28.6	29.9	31.8	1.9	0.6	3
Isl 27	415	31	28.5	29.75	31.9	2.15	0.9	1
RS 87	436	33	28.55	29.95	31.85	1.9	0.5	3
RS 87	413		28.7	29.85	31.85	2.0	0.85	
RS 213A	402		28.75	29.9	31.75	1.85	0.7	
						1.92	0.68	
RS 89	423	33	28.5	29.8	31.6	1.8	0.5	3
RS 88A	440	34	28.6	29.75	31.75	2.0	0.85	1
RS 213F	406	34.5	28.7	30.0	31.9	1.9	0.6	3
RS 80D	411	36	28.4	29.6	31.5	1.9	0.7	2
RS 80C	408	36	28.55	30.0	31.75	1.75	0.3	5
RS 213D	426	36.5	28.6	30.0	32.0	2.0	0.6	2
RS 80E	435	37	28.45	29.85	31.9	2.05	0.65	2
RS 88B	437	37.5	28.4	29.8	31.7	1.9	0.5	3
RS 213B	404	37.5	28.65	29.85	31.85	2.0	0.8	1
RS 83	434	38	28.6	29.9	31.8	1.9	0.6	2
RS 80F	414	38	28.65	29.75	31.8	2.05	0.95	1
Isl 194c	418	38.5	28.4	29.8	31.8	2.0	0.6	2
RS 80B	433	39	28.6	29.75	31.55	1.8	0.65	3
RS 7*	422	49	28.6	29.7	31.55	1.85	0.75	3
Isl 225	420	50	28.5	29.7	31.8	2.1	0.9	1

Numbers 1–5 under structure, denote *approximate* structural state:
1 = high; 2 = high-intermediate; 3 = intermediate;
4 = intermediate-low; 5 = low, structural states.

feldspars in the hand-specimens were bored out of the mother-rock using a dentists' drill. As the diameter of the drill-bit (0.3 mm) was often similar in size to the size of the crystals, it would be very surprising if no contamination had taken place.

The powder so obtained was then crushed between two specimen slides for about one minute, mixed with a minimum of rubber cement, and rolled into a ball of ca. 0.5 mm diameter. The ratio of the amount of rubber cement to that of specimen powder was kept as low as possible so that reflections of maximum intensity and sharpness were obtained. The results for different rock-specimens are shown in Table 1, and Fig. 17, where they are superimposed on the curves of SMITH and YODER (1956), and those of SMITH and GAY (1958), (also in BAMBAUER, 1967a). The reflections measured were identified from BAMBAUER (1967c, p. 354–355). Some of the specimens were exposed to X-ray radiation using a copper- (Ni-filter), others using an iron- (Mn-filter) tube, but all results were mathematically reduced to Cu-radiation as normal practice for comparison with results from publications.

DISCUSSION OF RESULTS

The results of this work have been fruitful, not only in producing better statistics for the refinement of the optical curves, but also in serving as a guide for future investigations into this problem. From now on, it is the belief of the author that future research should deal mainly with structural work on the plagioclases, as now ample optical, combined with chemical data exist. It will have been noted that problems arise, especially at the acid end of the plagioclase series in the case of the anorthoclases (?). Whether the scattering produced below ca. An_{30} (where a sharp bend is apparent in the curves of the chemistry), is due to structural changes, can only be solved by structural investigations.

Another conclusion of the author is that it is fruitless to attempt a fine division of the grades between the high- and low-temperature plagioclases. The reason for this is that the measurements of the author, as well as the data compiled in BURRI, PARKER and WENK (1967), produce a scattering of the results (e. g. Euler-, Köhler-Angles etc.) of at least 5° (often 10°). The maximum angular difference between high- and low-temperature plagioclases attained in the feldspars measured here is approximately 15° in angle "R" (Euler II). Only in the more acid members is an angular difference of up to 40° present. SLEMMONS (1962, p. 535) mentions that the degree of ordering in plagioclases with 0–40% An is best optically determined by measuring "2 V". This has been shown to be a rather optimistic view, firstly because extinction of the optic axes on the universal stage is seldom sharp, and secondly, the graphical results show a scattering between and *outside* the curves.

The relatively large scattering on the curves (ca. 5°), was found to be due neither to measurement error, nor to random sampling (containing, for example, high- and low-temperature types), and the scattering therefore cannot be corrected (by more exact determinations, for example). The three slides RS 87, RS 87_α, and RS 213A all come from the same rock, and the plagioclases contained therein must have all been formed under similar conditions (Fig. 4).

For reasons of caution, it was decided to regard all feldspars with a higher Or-content than 8% with suspicion, although no direct influence of Or on the optics could be ascertained. CHUDOBA (1938), mentions that he noticed strong optical anomalies with a sample approximating $Or_{20}(Ab+An)_{80}$. This may be due to the fact that the specimen was not a plagioclase but a structurally different feldspar. It is reasonable to expect an optical deviation in a plagioclase rich in potassium, but the amount of deviation cannot be determined, although it could lie well within the measurement error, and therefore remain unnoticed.

The reason why feldspars with more than 8% Or were questioned by the author, becomes convincing when the optical results are studied – they show optics incompatible with those of plagioclases, although morphologically determined as such. The author also considered this ommission permissible considering the disputed transitional boundary between anorthoclase- and oligoclase feldspars (BAMBAUER, 1967a). The three individuals measured in RS 228A, RS 228C, and in RS 110D should be left out of consideration as they fall well outside the transitional boundary, and in the anorthoclase field. The fact that plagioclases with more than 8% Or were regarded with suspicion, results in a regular transition (Or-Ab-An diagram, Fig. 11) from An_{50} to at least ca. An_{28}. Here the regularity ceases, as can be seen on the diagram. Of particular interest is the fact that the "irregular" feldspars here (An $>27\%$), fall into the exact area where the anorthoclase-oligoclase transition takes place (BAMBAUER, 1967a) although Bambauer has as yet been unable to fix the boundary. The feldspar-types in this area cannot be determined in a work where exact structural measurements were not carried out on the same crystals („Zudem ist ein wesentlicher Teil der für Plagioklase charakteristischen Baueigentümlichkeiten auf lichtoptischem Wege nicht nachweisbar" BAMBAUER (1967a, p. 715)). The structural difficulties encountered with the feldspars led to a random nomenclature based on their chemical composition, whereby each field in the Or-Ab-An diagram was given a definite name. BARTH (1969, p. 44) shows such an Or-Ab-An diagram whereby he defines potassian oligoclase as a field lying more or less between oligoclase and anorthoclase. This definition helps a little as it points to a transition between the latter two, if only chemically. The determinations of the author, on the other hand, question the border potassian oligoclase/oligoclase if only because the optical data show a continuity cutting across this purely chemical boundary. In future, the decision should be made to name these feldspars by defining either their chemistry or their structure, as recent structural developments have shown that arbitrary borders should no longer exist if confusion is to be avoided.

The big problem with feldspars formed under high temperature and low pressure conditions (i. e. volcanic conditions), is that they show a complete chemical transition from anorthoclase to oligoclase, as opposed to low-temperature feldspars where immiscibility gaps exist. This results in an easy, undisputed (more or less!) nomenclature for the latter compared to that of the high-temperature forms.

Until the nomenclature problems have been solved, presumably by advanced structural work, the optically measured feldspars of this work whose chemistry falls into the "no-mans-land" in the Or-Ab-An diagram, must await suitable definition.

It is interesting to note that if the potassium-content of these feldspars had not been determined, their chemical deviation would naturally not have been evident. This would have led to an erroneous explanation of their anomalous optics, blindly accepting the crystals as plagioclases. Those feldspars lying in the transitional field anorthoclase/oligoclase (BAMBAUER, 1967a) must be accepted with caution. Their optical properties often suggest plagioclases, although their position in the Or-Ab-An diagram is suspicious. The optics of these problematic feldspars, permit one to concur with LAVES (1960, p. 293) when he says in his discussion of the term "anorthoclase":

„Es hat sich unter Mineralogen und Petrographen eingebürgert, dass praktisch jeder seine eigene Vorstellung von einem ‚Anorthoklas‘ hat. Alle sind sich aber darin einig, dass ‚Anorthoklas‘ ein *relativ* Na-reicher Alkali-Feldspat ist, und dass er *meistens irgendwelche* Hinweise dafür erkennen lässt, dass er *nicht richtig* monoklin ist, und dass sich seine optischen Eigenschaften *nicht eindeutig* als Funktion seiner chemischen Zusammensetzung darstellen lassen."

From this rather frustrating definition, one can paraphrase H. H. READ in his meditations ("The Granite Controversy": "Granites and Granites"), by acknowledging that there are also "Feldspars and Feldspars".

CONCLUSION

1. The specimens studied in this work (feldspars from acid volcanics) have been shown to be high-temperature plagioclases, when the optical results are averaged together. The finer subdivision into grades of ordering, which was hoped to be achieved, was found to be impossible by normal optical means, which is seen especially well in Fig. 4. Measurements of the optic axial angle give bad results and cannot be used for accurate determinations of the "intermediacy index" (SLEMMONS, 1962). This is also the case for structural measurements using the Debye-Scherrer method, when the optically measured crystal is not used. The best method for optically determining the degree of ordering, are the two nomograms (Plates I and II) constructed after the system of

Gottardi, but using the new Euler values of 1. R, I, L_α and 2. R, L_α, L_A against chemical composition. These two nomograms should be used with reservation, as the measured values often bisect one another in a small "triangle of error".

2. In the range An_{28-40} for high-temperature plagioclases, no breaks or *sharp* bends (apart from R and L_α; Euler II) have been found. On the other hand, one would expect graphs with constant courses for a purely isomorphous series. This is seldom the case (only in D; Euler III). The chemical determinations (Fig. 11) have shown a constant transition chemically, from An_{40-28}, where a sharp bend accompanied by scattering takes place, only to be explained by coordination with full, exact structural research.

3. It is the first time that numerous optical determinations have been systematically coordinated with chemical analyses using an Electron Microprobe, whereby the actual specimens investigated under the microscope were used. The results obtained using synthetically tempered feldspars (Gay, 1956) from very homogeneous material, coordinated with a microprobe analysis would be highly interesting for further research, although possible rather difficult (tempering of acid feldspars).

4. For an experienced operator, it is relatively easy to recognise twin-laws and then to derive the Euler- and Köhler-Angles quickly and accurately from optical and crystallographical data. A further advantage of the Euler Angles (as opposed to the Köhler Angles) is that it is possible to construct the stereographic projection using published Euler values, with considerable accuracy. This is not the case with the Köhler Angles; a reconstruction of the stereographic projection is laborious and inaccurate. On the other hand, Euler Angles can only be measured on certain twin-types. Köhler Angles can be measured for any twins, and determination curves formed.

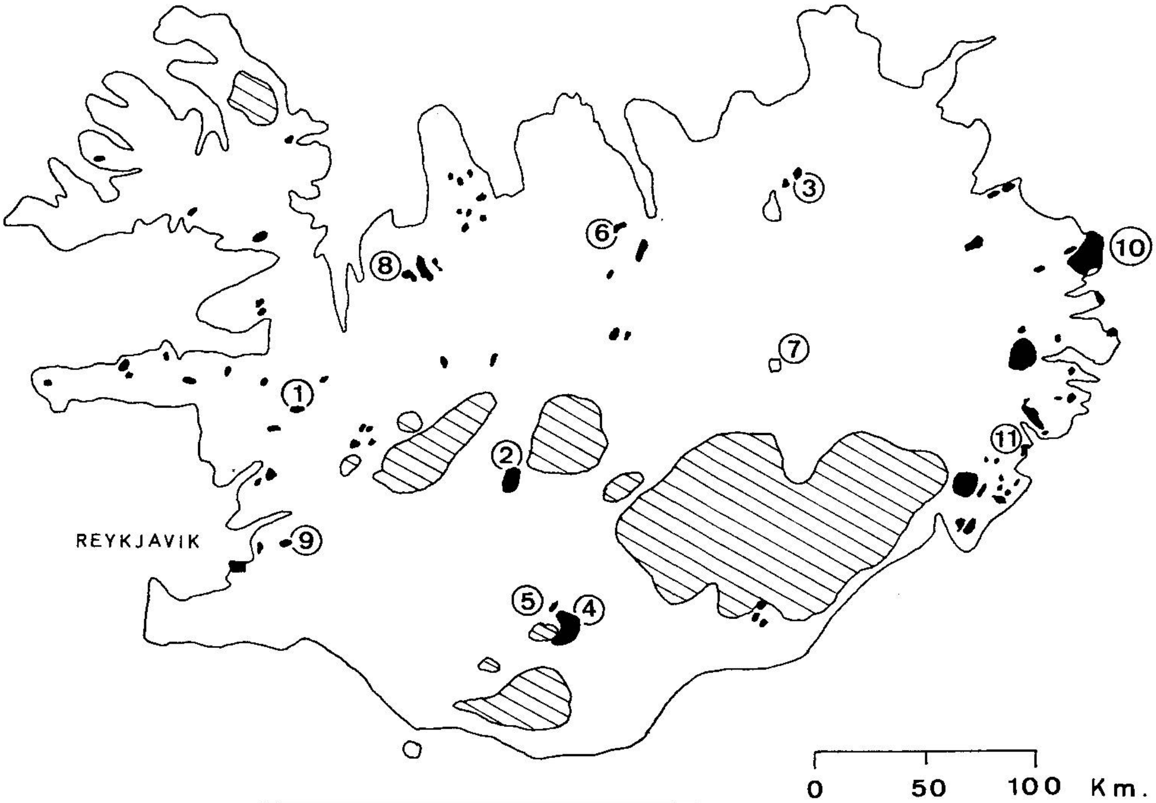
THIN SECTIONS (Description)

Remarks

1. Nomenclature: a) The term "Pheno-rhyolite" is used for the nomenclature here, as opposed to "Rhyolite", as the latter expresses an exact chemical composition of the rock. As no total rock analyses were carried out in this work, the former definition is more suitable here (Streckeisen, 1967, p. 178). The term "Liparite" has been omitted, as it is seldom used nowadays, although still often mentioned in Icelandic literature.

b) The terms "Obsidian" and "Pitchstone" were given to rocks, after the definitions of Holmes, 1920. If numerous perlitic cracks were present, the term "Perlite" was used.

2. The discussion of an exact genetical origin of the rocks has been omitted, as several of the specimens were collected loose (from scree, boulders, riverbeds etc.).



No.	RS.	ISL.
1	93, 94	
2	5	
3	80, 83	194c
4	223 D	
5	110 D, 228	
6	87–89, 213	
7	7	225, 234, 235
8		1
9		191a
10	28, 30, 217, 218	219, 220
11		27

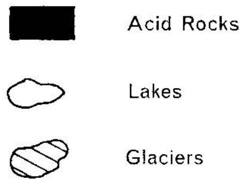


Fig. 18. Map of Iceland, showing the localities sampled.

1. Baula (934 m), W Iceland (ca. 21° 28′ W/64° 51′ N)

Baula is a steep-sided (over 30°) mountain rising 600 m above the surrounding Plateau Basalts, slightly resembling a strato-volcano in appearance. It is a liparitic intrusion into the Tertiary Plateau Basalts. As this imposing mountain shows signs of glacial erosion, the date of intrusion can be established between Young Tertiary and Late Quaternary.

The contact of the liparitic intrusion with the surrounding Plateau series, is a chilled centimeter to meter margin of obsidian and pitchstone (RS 93_B), often difficult to find as it is usually covered with scree. The Baula liparites sampled here are in part massive (RS 93_A, RS 94_B), and in part show flow-textures (RS 93, RS 93_E), but are all light greyish-white in colour, contrasting sharply with the surrounding Plateau Basalts. In all the specimens, two generations of plagioclase can be seen; 1. small laths, and 2. large, in part euhedral phenocrysts. With the exception of RS 93_B, the microcryptocrystalline groundmass was determined by PEACOCK (1927) as potash feldspar with as much as 32% quartz.

RS 93_A: Oligoclase-, andesine-bearing pheno-rhyolite column: Light grey-brown, fine-grained, vesicular (seldom amygdaloidal), six-sided column with sides of ca. 2 cm length, composed of ca. 2% angular pores of ca. 1–3 mm size. Thin sections were taken at right-angles to the c-axis of the column. Microcryptocrystalline porphyritic. Minute patches of brown glass, otherwise groundmass consisting of crystals of ca. 0.1 and 0.01 mm size, in equal proportions. Small amount of chloritic substance. Plagioclase phenocrysts of 1–2 mm size making up 5% of the slide, often euhedral, twinned, zoned. Plagioclase determined (avge. of two): $An_{29.5}Ab_{64.5}Or_6$.

RS 94_B: Vesicular oligoclase-bearing pheno-rhyolite: Very similar to RS 93_A, but fewer plagioclase phenocrysts. Rock greyish-white, massive. Plagioclase determined (avge. of three): $An_{29}Ab_{64.5}Or_{6.5}$.

RS 93_E: Vesicular oligoclase-bearing pheno-rhyolite: Light pinkish-grey rock, exhibiting a fine wavy flow-texture only seen macroscopically. Microscopically massive and similar to RS 93_A; numerous fine ore particles. 30–40% angular pores 0.5–1 mm in size. Groundmass microcryptocrystalline as above, with 5% twinned, zoned oligoclase phenocrysts. Plagioclase determined: $An_{26.5}Ab_{67}Or_{6.5}$.

RS 93: Vitrophyric oligoclase-andesine-bearing pheno-rhyolite: Light grey-pink, dense rock with a marked flow-texture due to the differing properties of glass in different bands (light- and dark brown). Microscopically hypocrystalline (ca. 70% glass), mainly microcryptocrystalline crystals, otherwise 5% mainly lathed or euhedral, twinned, zoned plagioclases of 0.1 mm size, with a tendency to parallel orientation. Under 2% of very fine grains (ca. 0.02 mm) of ore, densely distributed. This rock cooled faster than the other specimens from Baula, and lies genetically between the pitchstone RS 93_B and the deeper liparites. Oligoclase-andesine phenocrysts typical for the Baula specimens (often euhedral, twinned, zoned etc.). Plagioclase determined (avge. of four): $An_{28.5}Ab_{65.5}Or_6$.

RS 93_B: Biotite-, olivine-, oligoclase-bearing perlitic Pitchstone: Compact, dull black glass with big (up to 4 mm long) plagioclase phenocrysts. Microscopically: 70% more or less homogeneous (colourless to yellow-brown) glass with wavy fluidal-texture containing unoriented plagioclases 0.1–0.2 mm in size, and filled with 0.05 mm long microlites. Perlitic fractures weakly present.

Oligoclase: 5% 0.5–2 mm long phenocrysts in part euhedral. Oscillatory zoning occasionally present.

Ore: Less than 2%. Fine grains of ca. 0.05 mm diameter. Biotite: Less than 1%; pleochroic light-brown to light-green, often in lamellar aggregates most probably containing zircon inclusions, and occasionally surrounded by euhedral magnetite. Olivine: Less than 1%. Single crystals, polygonal in form, ca. 0.5 mm in size, often partly surrounded by 0.1 mm magnetite grains, the latter also being finely distributed in fractures in the olivine. Plagioclase determined: $An_{25.5}Ab_{69}Or_{5.5}$.

2. *Kerlingarfjöll, Central Iceland* (19° 13′ W / 64° 39′ N)

Mountain of Lodmundur (1432 m), a steep-sloped, truncated pyramid contrasting sharply in colour from its surroundings. Possibly formed due to the agency of volatiles, resulting in an upheaval of liparitic magma through the basaltic plateau sheets. Weathering has split the liparites of the mountain into thin plates. Lodmundur is covered with platy and angular scree consisting of liparite (RS 5_C), and in part, fragments of obsidian (RS 5_A) and pumice.

RS 5_C: Oligoclase pheno-rhyolite: Light-coloured, platy to columnar. Hypocrystalline microcryptocrystalline, containing ca. 50% light yellow-brown, in part devitrified glass. Twinned oligoclase phenocrysts (<2%) ca. 0.5 mm long, occasionally zoned. No flow-textures in the groundmass. Oligoclase determined: $An_{15}Ab_{72}Or_{13}$.

RS 5_A: Augite-bearing oligoclase obsidian: Compact, black, shiny glass with conchoidal fracture on centimeter scale. Flow-texture shown by microlites and crystallites (in part feldspar). Oligoclase: Phenocrysts 5–10% of rock, ca. 0.5 mm long. Less than 1% of rock, rounded octagonal cross-sections of augite. Oligoclase determined: $An_{20}Ab_{66.5}Or_{13.5}$.

3. *Hlidarfjall (771 m), Myvatn* (16° 52′ 48″ W / 65° 40′ 42″ N)

This steep rhyolitic extrusion, rising 300 m above the surrounding area is cone-shaped, and covered with scree up to an altitude of 650 m. The highest point lies on the southernmost end of a gently-sloping ridge, about one kilometer in length. According to VAN BEMMELEN and RUTTEN (1955), this mountain is the result of subglacial volcanism. Large amounts of obsidian are found on and around the summit ridge (RS 80_{B-F}, RS 83), and the rhyolites can contain as much as 95% glass, all of which denotes very quick cooling. Strictly, the rhyolites should most probably be termed "Hyalo-andesites", as they contain andesine, apart from small quantities of ferromagnesian material (pigeonite!).

RS $80_{B,C,D,E}$: (Spherulitic) Pyroxene-, andesine-bearing obsidians: Black, lustrous, in part columnar glasses with conchoidal fracture on mm. scale. In part, fluidal textures; weakly oriented plagioclases up to 3 mm in length. Microscopically: No perlitic-, and only seldom flow-textures, the latter shown by crystallites. In thin sections, colour of glass varies from light- to dark brown; the latter in RS 80_B which is the most inhomogeneous, containing very fine streaks of very dark glass, due to the reaction of water along fine fractures in the rock.

RS 80_B: Spherulitic augite-, pigeonite-, andesine-bearing obsidian: Hypocrystalline, containing ca. 90% glass, and often dark spherulites. Phenocrysts: ca. 5% plagioclase, 0.5–2 mm, often oscillatory zoned, and twinned. Occasionally, octagonal, euhedral, in part rounded crystals of augite and pigeonite (ca. 1%, 0.5–1 mm in diameter). Very rare olivine.

RS 83, RS 80_{C-F}: (Spherulitic) Pigeonite-, augite-, andesine-bearing obsidians: Light brown glassy groundmass, containing ca. 10% phenocrysts randomly arranged. No fluidal-textures. Ca. 1% dark brown spherulites of 0.2–0.5 mm diameter in RS 80_D, containing relatively big, inhomogeneous crystals (plagioclase?) in centre. Fractures in the glass pass through the spherulites in part, in part not. In both specimens, 10% phenocrysts of lath-like andesine feldspars, zoned, twinned, and often with ore inclusions. Less than 2% augite and pigeonite, often difficult to differentiate one from another (optic sign, axial angle, colour). The latter two are often more or less octagonal in form (both cleavages visible), but are seldom more than 0.5 mm in diameter. RS 83: Dark, columnar glassy rock. Very porous. Microscopically: Hypocrystalline, microcryptocrystalline, with ca. 50% nearly colourless glass, 35% matrix, and 15% angular pores of mm size. Matrix made up of spherulitic clusters (1 mm diameter) of microcryptocrystalline matter.

Approximately 5% andesine phenocrysts of rounded to lath-like forms, often with inclusions of ore and glass. Often oscillatory and sharp zoning.

Hlidarfjall plagioclase determined (avge. of 16): $An_{38}Ab_{57}Or_5$, and all lying between $An_{35-40}Ab_{55-65}Or_{4-6}$.

4. Landmannalaugar, S Iceland (19° 4′ W / 63° 59′ N)

The specimen described here comes from an acid obsidian lava-flow ("Laugahraun"), approximately one kilometer in length, and an average of 200 meters in breadth, lying more or less in the centre of a liparite landscape. As the obsidians and pitchstones here contain plagioclase lathes up to 5 mm long, and 1 mm wide, samples (RS 223_D) were taken, and the feldspars determinded.

RS $223_{D}2$: Augite-, oligoclase-bearing pitchstone: Dull black rock with up to 5 mm long oriented plagioclase laths. Microscopically: Hypocrystalline, microcryptocrystalline, containing ca. 5–10% light-grey to yellow-brown glass surrounded by a groundmass of crystallites so fine, as to make it difficult to judge the glass-content. 1% of matrix consists of plagioclase laths, ca. 0.2 mm in length (twinned).

Plagioclase: 5–10% lath-like and euhedral (0.5–2 mm) containing inclusions of ore and glass. Often polysynthetic twinning. Undulatory extinction. Augite: Less than 1%; grains 0.01–0.3 mm in diameter, usually in rounded octagonal cross-sections. Ore: Less than 1%, often as euhedral grains.

Plagioclase determined (avge. of three): $An_{20.5}Ab_{66}Or_{13.5}$.

5. Raudfoss, S Iceland: 20 km NW of Torfajökull (19° 19.5′ W/64° 2′ N)

The samples here are all loose river samples from the same *geological* area as in 4., and 13 km to the WNW of Landmannalaugar. The three specimens were taken from the bottom and the top of the waterfall Raudfossar, which lies about 1 kilometer south of the road to Landmannalaugar, on the river Helliskvisl. This Foss falls over a vertical profile of pretty liparites, described by THORODDSEN, p. 281.

RS 228_A: Olivine-, aegirine-augite-bearing anorthoclase-obsidian: Compact, melanocratic glass made up of clusters of dark green, olive-green, and colourless clusters of glass, each with a diameter of 3–5 mm (resembling a gabbro). These different-coloured areas cannot be resolved under the microscope. Also, clusters of basaltic, originally holocrystalline matter which has been penetrated by the obsidian: in part microcryptocrystalline, otherwise 50% originally octagonal augite (+ olivine?), and 40% twinned, zoned labradorite lathes (65–70% An). Grains of ore. Phenocrysts: *Feldspar:* 30% big (up to 2 mm) idiomorphic crystals, twinned and zoned. Often polysynthetic twinning. *Pyroxene:* 2% dark green, weakly pleochroic aegirine-augite, often with inclusions of ore grains. Seldom augite. *Olivine:* 2% idiomorphic, typical cross-sections. 2 A + (Forsterite).

Plagioclase determined: $An_{2.5}Ab_{77.5}Or_{20}$.

RS 110_D: Aegirine-augite-, augite-, potassian oligoclase-bearing pitchstone: Massive, dull black glassy rock with 5–10% fresh feldspar phenocrysts, up to 5 mm in length. Microscopically: Hypocrystalline (50% light-brown glass), microcryptocrystalline groundmass, containing up to 0.2 mm crystallite needles. No fluidal-textures, or perlitic structures. Phenocrysts: *Feldspars:* 5–10% euhedral, polygonal crystals of albite ($An_{2.5}$), usually twinned. Also fine normally-twinned cross-twinning. *Pyroxene:* Fine grains of less than 2% augite, 0.2–0.5 mm in size, occasionally twinned with (100) as twin-plane. Also single crystals of aegirine-augite, with ore inclusions. Plagioclase determined: $An_{12}Ab_{64}Or_{24}$.

RS 228$_C$: Spherulitic anorthoclase-pheno-rhyolite: Pinkish-red, massive, fine-grained porphyritic rock with phenocrysts as large as 4 mm. Microscopically: Groundmass hypocrystalline, microcryptocrystalline (possibly quartz and feldspar grains – undulatory extinction). Spherulites with a diameter of ca. 0.2 mm, and with no distinct borders. By staining the slide, one finds that the latter are made up of plagioclase. The spherulites make up about 50% of the matrix, grains of ore ca. 25%. No fluidal-texture, and the phenocrysts are randomly arranged. Minute quantities of ferromagnesian material (interference colour: green II) are also found in the groundmass. Phenocrysts: *Feldspar:* ca. 20%, large, in part twinned, in part euhedral, often fractured, seldom zoned. *Quartz:* about 3% (phenocrysts!) ca. 1 mm in diameter, fresh.

Plagioclase determined: $An_{0.5}Ab_{66.5}Or_{33}$.

6. Bakkahals, Oxnadalur, N Iceland (prominent pinnacle west of Bakki, ca. 18° 30′ W/ 65° 39′ N)

When travelling down the Oxnadalur towards Akureyri, the plateau basalt mountain-chain which borders the western side of the valley can be seen as a long ridge. At Bakki, this ridge is called "Bakkahals", and the most prominent small peak is a very sharp pinnacle, strongly resembling the "Aiguilles" of the Western Alps, although much smaller. A mighty vertical liparite dyke can be seen from the road (2 km away!), about 200 m to the north of this pinnacle, and from this 5–20 m wide dyke, a number of samples were taken. The intruded dyke eroded the basalts around it up to a distance of about 10 m. Between many of the basalt flows, concordant layers of red tuff material can be found, also cut by the acid dykes. One half of this dyke is here schematically represented:

	←	5 m		→	
	RS 89 RS 213$_F$	RS 88$_A$ RS 88$_B$ RS 213$_D$	RS 213$_B$	RS 87 RS 213$_A$	Basalt
avge. An%	34 (28–40)	36 (33–38)	38.5	33.5 (29–47)	

RS 88$_{A-B}$, 89, 213$_D$, 213$_F$: (Vesicular) augite-bearing pheno-rhyolites: More or less compact (slightly fluidal-textured), leucocratic, vesicular, porphyritic rocks. Microscopically: Hypocrystalline (10–20% glass), microcryptocrystalline groundmass, with very slightly oriented crystallites. 5–10% long drawn-out pores (up to 2 by 5 mm). Phenocrysts: *Feldspars:* ca. 15% large (up to 2 mm), more or less euhedral acid plagioclases. Twinning usually albite, Carlsbad, Roc Tourné twin laws (very good specimens for Euler-angle measurements). Strong normal zoning, often oscillatory. *Augite:* less than 1%, small (less than 0.5 mm diameter) octagonal cross-sections. Also grains of ore. Plagioclase determined (avge. of 12): $An_{35.5}Ab_{60}Or_{4.5}$. ($An_{28-42}Ab_{56-65}Or_{3-7}$.)

RS 213$_B$: Augite-bearing pheno-rhyolite: Light-coloured, inhomogeneous rock with uneven fluidal-texture, and containing up to 3 mm long phenocrysts. Microscopically: Hypocrystalline (approximately 50% pinkish-brown structurally inhomogeneous glass, filled with crystallites randomly oriented). No fluidal-textures visible, no pores. Phenocrysts: *Plagioclase:* 10–15% usually elongated andesine crystals, nearly always twinned (seldom normal twin laws). Often oscillatory, and occasionally inverse zoning. *Augite:* Less than 2%, small, in part octagonal cross-sections, in part parallel to (010). Rounded grains of ore (diameter less than 0.3 mm).

Plagioclase determined (avge. of three): $An_{38.5}Ab_{58.5}Or_3$.

RS 87, 87_α, 213_A: Palagonitic calcite-, olivine-, augite-bearing andesine-pitchstone: Dull black, compact pitchstone with randomly arranged, fresh feldspars, ca. 2 mm in size. Microscopically: Hypocrystalline (approximately 60% yellow-brown glass with crystallites). Patches of tuffic and more or less holocrystalline (originally) basaltic material within the glass, occasionally still showing intersertal texture. These patches have in part been completely converted to palagonite, thereby making an exact optical determination very difficult, apart from the plagioclase, and the occasional traces of calcite. Phenocrysts: *Plagioclase:* 15% oligoclase-andesine crystals of 0.2–2 mm size, often as sharp and jagged fragments (in part, very good for Euler-angle determinations). *Augite:* ca. 1%, and up to 2 mm in size. In part strong palagonitisation along fractures; often filled with rounded to euhedral grains of ore. *Olivine:* Less than 1%. Relicts. *Calcite:* Traces in the tuff and basaltic xenolites.

Plagioclase determined (avge. of 21): $An_{33.5}Ab_{61}Or_{5.5}$. ($An_{29-47}Ab_{49-66}Or_{4-.7}$)

7. *Askja, Central Iceland* (16° 45′ W / 65° 3′ N)

Askja is the name given to a large caldera which lies in the centre of the Dyngjufjöll mountains, in Central Iceland. These mountains cover an area of about 600 km², and rise out of the vast Odadahraun lava-fields. To the southeast, lies lake Óskjuvatn (still a part of the caldera), roughly square in form with sides of approximately three km. These mountains are mainly built up of volcanic breccia and tuff, formed by subaqueous eruptions. These eruptions could, for a long time, not take place (during the Ice Age), because of the overlying ice and water. The magma therefore absorbed water and solidified relatively quickly. When the mountains rose, the lake receded, and volcanic eruptions took place, throwing out the breccia material, as well as ash and pumice (forming ignimbrites – Isl 225, 234–5). During later eruptions, a mantle of lava formed on top of the scoriaceous matter. The specimens described below all came from the shore of Óskjuvatn (the second lake formed in the caldera), south-east of the crater Viti, as:

1. RS 7*, a glassy component of a tuff, and
2. Isl 225, 234–5, "welded tuffs", or ignimbrites.

RS 7: Augite-, andesine-labradorite-bearing obsidian:* Compact, shiny black glass with small feldspar phenocrysts (rare). Microscopically: Hypocrystalline (over 90% homogeneous light brown glass). In part microcryptocrystalline elongated clusters of stumpy to lath-like feldspars (60–65% An), also pyroxene (augite), randomly distributed, with a tendency to an ophitic texture (basaltic xenolites), often along fractures. No perlitic structures. The phenocrysts and clusters tend to form a fluidal-texture.

Isl 234–5, 225: Palagonitic diopside-, augite-, andesine-labradorite-bearing ignimbrite: Rust-brown to black consolidated molten ash with fluidal-textures, containing oriented basaltic xenoliths. Few feldspar phenocrysts. Very porous. Isl 225: Dark, "welded", rock more or less interstratified with lenses of black compact glass. Microscopically: resolved into inhomogeneous areas of palagonitisation, in various stages of hydration. In both specimens, 25–30% pores, on the one hand small, sharp, and angular (Isl 235), on the other, more rounded, elongated (Isl 234), and with the major-axis parallel to the lamination. "Bogenstruktur", or "ash-texture" typical of the ignimbrites, in Isl 235 and Isl 225, mainly in the unhydrated areas. Both slides contain eroded clusters of basaltic material still showing an intersertal texture (plagioclase laths and augite, randomly oriented). Phenocrysts: *Plagioclase:* Less than 5%, twinned, zoned (normal, inverse, seldom oscillatory). Often oriented parallel to the lamination of the matrix. *Augite:* small prismatic crystals with octagonal cross-sections, as well as *Diopside* (2 A+).

Plagioclase phenocrysts determined (avge. of three): $An_{48}Ab_{48}Or_4$. ($An_{45-51}Ab_{45-51}Or_{3-4}$).

8. Vatnsdalsfjall, Hunafjördur, N Iceland (20° 22′ 13″ W / 65° 29′ 36″ N)

The specimen described here, comes from a moraine in the north of Iceland, and has been described by Glauser (1966); therefore, as the author himself has not visited this locality, only a short description is given.

Isl 1: Pyroxene-, oligoclase-bearing pheno-rhyolite: Banded, pinkish-red liparite with alternating bands of hypocrystalline, microcryptocrystalline material (pink), and dark brown glass (ca. 50%), flowing around the few oligoclase phenocrysts (less than 2%). Minute crystals of pyroxene (augite, possibly).

Plagioclase determined (avge. of three): $An_{27}Ab_{67}Or_6$. ($An_{26-28}Ab_{66-68}Or_6$.)

9. Moskardshnukar, Esja, Reykjavik (21° 32′ 52″ W / 64° 14′ 11″ N)

The first mountain to be seen from Reykjavik to the north-east, is the Esja, about five km away and 909 m in height. It is in fact a ridge running from west to east. The summit lies at the eastern end, below which, around Moskardshnukar, the main mass of liparite is found, although many dykes of the latter material can be found scattered around the mountain. The specimen described here came from the main mass at Moskardshnukar.

Isl 191a: Spherulitic oligoclase-bearing pheno-rhyolite: Finely-banded, rust-brown to purple rock with few phenocrysts (1 mm in size). Microscopically: Hypocrystalline to holohyaline, microcryptocrystalline. Parallel bands containing oriented crystallites, separated one from another by material without lamination. Circular spherulites, in part hydrated, fill the matrix up to 50% (diameter 0.3 mm). Oligoclase phenocrysts 1–2 mm long), randomly oriented, mainly albite-twinned, make up less than 5% of the rock.

Plagioclase determined: $An_{20.5}Ab_{71}Or_{8.5}$.

10. Lambadalur, E Iceland (13° 54′ W / 65° 26′ N)

The remote valley of Lambadalur lies 13 km SSW of Bakkagerdi, and 10 km NW of Husavik, and is enclosed by the mountains Midfjall (769 m), and Nonfjall (634 m). The entrance to this valley can be easily reached by jeep, when the rivers are not in flood. From there, the way is four km by foot along the river Lamba, at times treacherous due to the steep-sided, scree-covered walls of the valley. Needless to say, Lambadalur has not been visited by many geologists – unfortunately, as, especially in the case of the two mountains mentioned, a very clear profile of the area is exposed: i. e. of two basalt series, one above and one below a layer of "welded tuffs", the latter being as thick as 100 m. According to Dearnley, 1954, the geological history can be divided into three acts:

1. Period of outpouring of plateau basalts.
2. Period of purely explosive activity (formation of ignimbrites).
3. Renewal of 1.

And from 2. onwards, the slow intrusion of a rhyolitic laccolite, which now makes up an exposure of over 100 km². Glass samples from the contact of the rhyolite with the basalt series were collected, and are described below.

RS 28_B: Pyroxene-, oligoclase-bearing perlitic obsidian: Specimen taken one meter from the plateau basalt contact, about 400 m inside the valley, by the river. Compact black glass with conchoidal fracture on the centimeter scale. Microscopically: Over 95% more or less homogeneous yellow-brown glass, interstratified with more or less parallel streaks of colourless glassy and crystallitic material. Traces of perlitic texture. Phenocrysts: *Oligoclase:* 1–2%, up to 1 mm in size; usually twinned and zoned (normal and oscillatory). Often as clusters (intersertal xenoliths?). Unòriented. Microcryptocrystalline pyroxene-lath with parallel extinction and high birefringence (yellow II – aegirine?), as well as a rather corroded augite with ore inclusions. Rare small ore grains.

Plagioclase determined (avge. of two): $An_{25}Ab_{65}Or_{10}$. ($An_{22-27.5}Ab_{62.5-72}Or_{6-13.5}$.)

RS 30_A: Aegirine-augite-, augite-, oligoclace-bearing perlitic pitchstone: Specimen taken from river-bed ca. 150 m upstream of RS 28_B. Compact black rock, with dull, pitch-like lustre, and containing plagioclases up to 3 mm in size. Microscopically: Over 90% glass, containing minute crystallites. Fluidal-texture. Very strong perlitic texture (diameter ca. 1 mm), whereby the cracks are slightly elongated parallel to the direction of the flow. Phenocrysts formed before consolidation (flow-textures mould the crystals). Phenocrysts: *Plagioclase:* ca. 5% (less than 1 mm in size), unoriented and often grouped together in clusters. Normally- and often osciliatory zoned. A few small laths and octagonal cross-sections of augite and aegirine-augite (less than 0.5 mm in size).

Plagioclase determined (avge. of four): $An_{25.5}Ab_{63}Or_{11.5}$. ($An_{23-29}Ab_{56.5-66}Or_{9-15}$.)

RS 217_B: Albite-oligoclase-bearing pitchstone: Specimen taken from scree on the mountain of Gatfjall (621 m), 4 km south of Bakkagerdi, at a height of ca. 500 m. White to black banded glass with all colour transitions present. A few, up to 3 mm long, plagioclase crystals generally oriented parallel to the banding. Microscopically: colourless to yellow-brown glass bands containing crystallites, the latter so oriented, that each band extinguishes as a separate unit. Fluidal-texture around the few albite-oligoclase phenocrysts, the latter occasionally arranged in clusters, and containing ore in the interstices.

Plagioclase determined (avge. of three): $An_{17}Ab_{77}Or_{6}$. ($An_{15.5-18}Ab_{76-78}Or_{5.5-7.5}$.)

RS 218_A: Quartz-, albite-oligoclase-bearing perlitic obsidian: Specimen taken at a height of ca. 700 m, from the ridge between Kaekju mountain (879 m), and P. 739. Black, compact glass with shiny to dull lustre, containing phenocrysts up to 4 mm in size. Also, a few spherulites present. Microscopically: More than 95% colourless glass containing minute crystallites. Perlitic texture nearly absent. No fluidal-texture. Occasionally, spherulites with a diameter of about 3 mm, with twinned plagioclase in the centre (plagioclase determined). These spherulites have well-defined boundaries, and are surrounded by slight flow-texture. Phenocrysts: *Plagioclase:* Ca. 2%, up to 3 mm long, randomly arranged, occasionally in clusters. Very fractured. *Quartz:* Less than 2%, as clusters of irregular grains of ca. 0.5 mm diameter, òccasionally in rounded cavities.

Plagioclase determined: $An_{14}Ab_{78}Or_{7}$.

Isl 219: Aegirine-augite-, augite-, oligoclase-bearing spherulitic obsidian:* Loose specimen taken from river-bed in valley. Shiny to dull, grey to black obsidian. Microscopically: resolved into a groundmass of inhomogeneous colourless to dark brown glass, containing 20% of fractured, otherwise fresh spherulites, up to 2 mm in diameter. No flow-texture apart from very thin, wavy, almost invisible bands of lighter glass. Phenocrysts occasionally lie parallel to this banding. No perlitic textures. Phenocrysts: *Plagioclase:* Less than 2%, laths often oriented parallel to the banding. Often highly zoned (25–55%, normal), occasionally oscillatory zoning. *Augite:* clusters (seldom), with grainsize under 0.2 mm. *Aegirine-autite:* Lathe determined.

Plagioclase determined (avge. of two): $An_{27}Ab_{65}Or_{7.5}$. ($An_{24.5-30}Ab_{63.5-68}Or_{6-8.5}$.)

Table 2. *Rock specimens, An-content, locality*

Slide No.	No. of Plags. measured	Range of: An %	Range of: Or %	Host-rock / % glass estimated. (O) = outcrop sample.	Locality and coordinates (exact to 100 m, i. e. longitude ±3", latitude ±8")
RS 228 C	1	0.5	33	Pheno-rhyolite 20%	Raudfoss (19° 20' 0" W / 64° 1' 5" N)
RS 228 A	1	2.5	20	Obsidian 65%	Raudfoss (19° 20' 0" W / 64° 1' 5" N)
RS 110 D	1	12	24	Pitchstone 50%	Raudfoss (19° 19' 6" W / 64° 1' 37" N)
RS 218 A	1	14	7	Obsidian 95%	Lambadalur (13° 51' 5" W / 65° 25' 8" N)
RS 5 C	1	15	13	Pheno-rhyolite 50%	Kerlingarfjöll (19° 12' 47" W / 64° 39' 3" N)
RS 217 B	3	16–18	5–7	Pitchstone ca. 40%	Lambadalur (13° 46' 27" W / 65° 28' 51" N)
Isl 191 a	1	20.5	9	Pheno-rhyolite 45%	Esja (21° 32' 52" W / 64° 14' 11" N)
RS 5 A	1	20	13.5	Obsidian 90%	Kerlingarfjöll (19° 12' 47" W / 64° 39' 3" N)
RS 223 D_2	3	19–23	11–15	Pitchstone 5–10%	Landmannalaugar (19° 3' 52" W / 63° 59' 11" N)
Isl 220	1	27	8.5	Obsidian 90%	Lambadalur (13° 54' 49" W / 65° 25' 43" N)
RS 30 A	4	23–29	8.5–20.5	(O) Pitchstone 90%	Lambadalur (13° 52' 16" W / 65° 26' 30" N)
RS 28 B	2	22–28	6–14	(O) Obsidian 95%	Lambadalur (13° 52' 16" W / 65° 26' 30" N)
RS 93 E	1	26	6.5	Pheno-rhyolite +	Baula (21° 27' 40" W / 64° 51' 12" N)
Isl 1	3	26–28	6	Pheno-rhyolite 50%	Vatnsdalsfjall (20° 22' 13" W / 65° 29' 36" N)
Isl 219*	2	24–30	6–9	Obsidian 75%	Lambadalur (13° 54' 8" W / 65° 26' 5" N)
RS 93 B	1	25–26	5–6	Pitchstone 70%	Baula (21° 27' 40" W / 64° 51' 12" N)
RS 93	4	27–30	6–7	Pheno-rhyolite 70%	Baula (21° 27' 40" W / 64° 51' 12" N)
RS 94 B	3	28–30	6–7	Pheno-rhyolite +	Baula (21° 29' 13" W / 64° 50' 48" N)
RS 93 A	2	29–30	6	Pheno-rhyolite +	Baula (21° 27' 40" W / 64° 51' 12" N)
Isl 27	2	24–31	5.5–12	Pitchstone 80%	Hamarsfjördur (14° 22' 54" W / 64° 39' 44" N)
RS 87/213 A	21	29–47	4–7	(O) Pitchstone 60%	Bakkahals (18° 30' 0" W / 65° 38' 48" N)
RS 89	2	27–37	4–7	(O) Pheno-rhyolite 10–20%	Bakkahals (18° 30' 0" W / 65° 38' 48" N)
RS 88 A	1	33	5–6	(O) Pheno-rhyolite 10–20%	Bakkahals (18° 30' 0" W / 65° 38' 48" N)
RS 213 F	4	30–40	3–6	(O) Pheno-rhyolite 10–20%	Bakkahals (18° 30' 0" W / 65° 38' 48" N)
RS 80 C	7	30–41	4–6	Obsidian 90%	Hlidarfjall (16° 52' 48" W / 65° 40' 42" N)
RS 80 D	3	36–38	5–7	Obsidian 95%	Hlidarfjall (16° 52' 48" W / 65° 40' 42" N)
RS 213 D	3	35–42	3–5	(O) Pheno-rhyolite 10–20%	Bakkahals (18° 30' W / 65° 38' 48" N)
RS 80 E	1	37	5–6	Obsidian 90%	Hlidarfjall (16° 52' 48" W / 65° 40' 42" N)
RS 88 B	2	37–38	4–5	(O) Pheno-rhyolite 10–20%	Bakkahals (18° 30' W / 65° 38' 48" N)
RS 213 B	3	37–40	3–4	(O) Pheno-rhyolite 50%	Bakkahals (18° 30' W / 65° 38' 48" N)
RS 80 B	1	37–39	5–6	Obsidian 90%	Hlidarfjall (16° 52' 48" W / 65° 40' 42" N)
RS 83	1	38–39	5	Obsidian 50%	Hlidarfjall (16° 52' 48" W / 65° 40' 42" N)
RS 80 F	3	36–42	4–6	Obsidian 90%	Hlidarfjall (16° 52' 48" W / 65° 40' 42" N)
Isl 194 c	2	39–41	4–6	Pheno-rhyolite 60%	
Isl 235	1	45–48	4	Ignimbrite 95%	Askja (16° 44' W / 65° 2' 33" N)
Isl 233	2	47–49	2–3	Ignimbrite 95%	Askja (16° 44' W / 65° 2' 33" N)
Isl 234	2	46–51	3–4	Ignimbrite 95%	Askja (16° 44' W / 65° 2' 33" N)
RS 7*	3	45–50	3–5	(O) Obsidian 90%	Askja (16° 44' W / 65° 2' 33" N)
Isl 225	2	45–52	3–5	Ignimbrite 95%	Askja (16° 44' W / 65° 2' 33" N)

Table 3. *Optical results of twins*

(Euler Angles in italics are those measured)

Specimen XX No.	Twin Law	Mol.-%		Köhler Angles			Euler I			Euler II				Euler III		
		An	Or	α α′	β β′	γ γ′	φ	θ	ψ	R	I	L_α	L_A	D	N	180–K_α
RS 228 C I	Karls	0.5	33.0	144	36.5	173	96.0	72.0	87.5	105.0	18.0	82.0	58.5	*6.8*	*87.3*	*18.0*
RS 228 A I	RT	2.5	20.2	39	141	174	92.5	70.5	90.0	92.5	19.5	90.0	67.5	*2.5*	*90.0*	*19.5*
RS 110 D I	Karls	12.25	24.0	137	42	173.5	91.2	68.7	86.7	100.2	21.6	88.7	58.5	*2.4*	*86.9*	*21.4*
RS 218 A I	Karls	14.2	7.0	137	45	169	91.6	68.4	83.6	108.7	22.5	74.2	—	*4.0*	*84.0*	*21.8*
RS 5 C I	RT	15.2	13.0	44	139.5	165	*93.9*	*68.4*	*78.2*	120.6	24.6	62.7	31.6	*8.3*	*79.0*	*22.0*
RS 217 B III	Karls	15.8	6.0	136.5	45	170	95.3	68.1	84.9	108.9	22.5	77.5	48.6	*7.3*	*85.8*	*22.0*
RS 217 B II	RT	17.0	7.0	43	139.5	170.5	92.3	68.7	81.3	114.1	22.2	70.1	40.0	*5.5*	*82.4*	*21.5*
RS 217 B I	Karls	17.8	5.7	136	44.5	178	97.4	68.3	89.0	98.6	21.8	87.3	55.8	*7.8*	*89.0*	*21.8*
RS 223 D_2 II	Karls RT Ab	19.8	13.5	137 44 169.5	52 142.5 145	150 158 37	95.2	68.7	73.7	134.0	26.7	54.3	22.0	*11.3*	*74.8*	*22.2*
RS 5 A I	Karls	20.0	13.5	134	50.5	158.5	92.0	67.1	78.4	*119.9*	*25.7*	*64.5*	*29.0*	6.7	79.3	23.4
RS 223 D_2 III	Karls Ab RT	20.5	12.8	134 171.5 46	52.5 149 138	156 31 162	94.6	67.0	77.1	123.9	26.2	62.1	28.7	*9.7*	*78.2*	*23.5*
Isl 191 a I	Karls	20.5	8.7	135.5	50.5	157.5	95.3	67.9	77.3	125.0	25.3	62.8	33.1	*10.2*	*79.0*	*22.6*
RS 223 D_2 I	Karls Ab RT	21.5	13.5	135 170 46	54 145.5 140	152.5 35.5 158	95.3	67.5	74.8	130.4	27.0	58.0	26.5	*11.3*	*76.0*	*23.3*
RS 28 B I	RT	22.2	9.7	53.5	132.5	158	92.0	63.4	68.2	133.7	33.9	53.5	17.5	*12.1*	*70.6*	*28.3*
RS 30 A/α I	RT	24.0	15.0	47.5	136.5	160.5	*94.0*	*66.5*	*75.6*	127.3	27.4	59.7	30.2	9.8	76.9	24.2
RS 30 A III	Karls	24.8	11.5	133	56	152	92.0	66.5	74.5	136.4	27.9	58.7	23.8	*8.1*	*76.0*	*24.3*
Isl 219* II	Karls	25.2	8.0	132	58	152.5	91.3	65.7	74.9	124.6	28.5	59.9	24.9	*7.6*	*76.3*	*25.1*
RS 93 B I	Karls	25.5	5.5	130.5	63	148	91.8	65.1	72.3	125.3	30.3	56.8	20.8	*5.9*	*74.0*	*26.0*
Isl 1 I	Karls	26.0	6.0	133	58.5	147	91.8	66.6	72.5	*130.6*	*29.2*	*54.9*	*18.5*	9.2	73.8	24.6
RS 30 A I	Karls	26.0	10.7	131	58	150	91.6	66.1	73.6	127.3	28.8	57.8	18.3	*8.4*	*75.1*	*24.9*
RS 93 E I	Karls	26.2	6.5	125.5	64.5	147.5	92.9	62.8	71.6	128.8	32.6	58.5	20.0	*11.5*	*73.8*	*28.5*
Isl 1 II	Karls Ab RT	26.5	6.0	131 177 50	59.5 143.5 135.5	148 37 159	93.1	65.4	72.8	*129.7*	*29.7*	*57.2*	*21.5*	10.2	74.5	25.9

Isl 220	I	RT Ab Karls	27.0	8.3	49 176 131.5	135.5 142.5 60	161.5 39 146.5	92.0	65.5	71.8	130.4	30.3	55.5	17.4	*9.7*	*73.5*	*25.7*
Isl 27	II	RT Karls Ab	27.2	8.3	51.5 126.5 174.5	135.5 70 130	156 138 50.5	92.2	64.9	66.4	136.8	34.5	50.7	11.0	*13.1*	*69.0*	*28.2*
RS 93	IIIB	Karls	27.2	6.0	131	62	143	91.8	65.5	70.2	135.0	31.9	52.4	12.6	*10.7*	*71.3*	*26.0*
Isl 1	III	Karls	27.5	6.0	130.5	60	149	95.9	65.3	72.7	*132.6*	*30.0*	*57.1*	*20.8*	13.4	74.3	25.8
RS 28B	II	Karls	27.5	9.8	133	56.5	151.5	92.4	66.4	74.1	127.7	28.4	58.0	23.0	*8.9*	*75.5*	*24.5*
RS 89	II	Karls Ab RT	27.8	7.0	130.5 177.5 49	74.5 135.5 135	141.5 45 160	90.9	64.9	68.1	134.4	32.8	51.5	16.0	*10.7*	*70.2*	*26.8*
RS 93	I	RT	28.0	6.5	51	134	160	91.6	64.6	69.6	132.5	34.4	53.1	14.9	*10.7*	*71.7*	*26.9*
RS 30A	II	RT	28.5	9.0	49	135.5	161.5	92.1	65.7	71.6	130.9	30.3	55.4	16.6	*9.9*	*73.3*	*25.5*
RS 94B	II	Karls	28.8	6.5	121.5	73.5	139.5	90.2	60.9	65.6	*131.4*	*36.8*	*54.5*	—	11.7	69.9	31.3
RS 213A	V	RT	29.0	5.5	52	135	156	91.3	64.2	65.5	138.0	35.1	48.2	9.2	*13.0*	*68.0*	*28.0*
RS 93	II	RT	29.0	6.0	50.5	136	156.5	93.0	64.9	68.9	135.2	31.9	52.5	15.9	*12.3*	*71.0*	*26.8*
RS 94B	I	Karls	29.0	7.0	127	62	151.5	91.2	63.5	73.4	*124.9*	*31.0*	*60.3*	—	9.0	75.2	25.3
RS 94B	III	Karls	29.2	6.7	129.5	61.5	147	90.9	64.6	71.7	128.5	31.0	56.6	15.7	*9.0*	*73.5*	*26.6*
Isl 219*	I	Karls	29.2	7.0	128.5	63	145	93.4	64.0	70.7	132.1	32.1	55.8	16.4	*12.2*	*72.6*	*27.3*
RS 93	IIIA	RT	29.2	6.2	56.5	128.5	158.5	91.3	61.9	69.9	129.1	34.1	57.3	17.7	*11.1*	*72.4*	*29.7*
RS 93A	II	Karls	29.5	6.0	126	68	140	91.7	63.4	67.4	134.6	34.4	52.5	14.2	*12.3*	*69.9*	*28.5*
RS 213A	VII	Karls	29.5	6.2	128	69	139	89.2	64.4	67.2	136.4	33.8	51.0	13.0	*9.5*	*69.5*	*27.5*
RS 93A	I	RT Ab Karls	29.8	6.0	56 175 123.5	131 134.5 69.5	154.5 45.5 142.5	92.8	61.9	68.6	132.4	36.2	55.0	18.3	*13.3*	*71.2*	*29.9*
RS 87	I	RT	30.0	6.0	53	132.5	158	93.1	63.4	71.5	129.8	32.2	57.8	17.4	*11.6*	*73.5*	*27.9*
RS 87 α	I	Karls Ab RT	30.2	7.1	121.5 176 59	74 132 126.5	137 48.5 156	90.5	60.5	65.5	132.9	37.4	54.2	14.2	*13.0*	*69.2*	*31.8*
RS 213F	I	Karls	30.2	5.5	131	70	132	89.0	65.0	63.5	139.5	35.5	45.5	12.0	*10.8*	*66.0*	*26.8*
RS 213A	II	RT	30.5	5.7	51.5	134	159	92.9	64.2	66.6	136.0	34.3	50.5	11.3	*11.0*	*69.0*	*27.8*
RS 87α	II	RT	30.5	6.5	55.5	131	155	91.4	62.5	67.2	134.5	35.1	53.4	13.8	*12.8*	*70.0*	*29.5*
RS 80C	II	Karls	30.5	6.0	120	80	132	87.9	60.0	62.2	134.5	40.0	51.0	7.0	*12.7*	*66.2*	*33.1*
RS 213A	III	RT	31.0	6.2	54	131	158	93.1	63.1	71.4	129.6	32.4	58.0	14.6	*12.8*	*73.5*	*28.3*
Isl 27	I	Karls	31.0	6.2	124	70	141	92.8	61.9	67.8	*133.7*	*35.3*	*54.8*	*14.3*	13.6	70.6	29.9
RS 87	VI	Karls Ab RT	31.5	4.7	127.5 176.5 54.5	66.5 135.5 130.5	141 44.5 158.5	91.4	65.3	68.1	134.8	33.8	55.1	14.0	*11.5*	*70.7*	*28.3*
RS 213A	I	RT	31.8	5.5	56.5	131	156	92.0	61.6	66.9	133.9	36.1	54.1	11.0	*13.5*	*69.8*	*30.5*

Specimen XX No.	Twin Law	Mol.-% An	Mol.-% Or	Köhler Angles $\alpha\,\alpha'$	Köhler Angles $\beta\,\beta'$	Köhler Angles $\gamma\,\gamma'$	Euler I ϕ	Euler I θ	Euler I ψ	Euler II R	Euler II I	Euler II L_α	Euler II L_A	Euler III D	Euler III N	Euler III 180– K_α
	Karls			115.5	81	135.5										
RS 87 α III	Ab	32.0	7.0	176	131.5	48	88.6	57.7	65.1	129.7	40.3	56.1	13.0	*12.5*	*68.9*	*35.0*
	RT			65	120.5	157.5										
RS 87 III	RT	32.0	5.7	54.5	131	158	92.7	62.9	70.9	129.8	32.9	57.5	17.2	*11.6*	*73.1*	*28.5*
RS 213F II	Karls	33.0	4.2	120	78.5	135	88.0	60.5	64.5	132.0	38.2	53.0	11.0	11.0	68.0	32.0
RS 88A I	Karls	33.0	5.5	121	78	124.5	90.7	60.7	63.7	135.9	38.8	51.8	9.4	*14.3*	*67.3*	*32.1*
RS 87 VII	Karls	32.2	4.0	127.5	68	139.5	91.6	63.9	67.3	135.1	34.2	51.8	9.2	*12.0*	*69.8*	*28.0*
RS 87 V	Karls	34.0	5.0	124.5	69.5	140	88.5	62.5	67.3	130.6	35.3	53.6	10.4	*9.4*	*70.0*	*29.5*
	Ab			178.5	128	51										
RS 87 α IV	RT	34.2	6.0	55	131	157	90.2	61.7	64.4	135.5	37.5	51.3	8.7	*13.0*	*67.7*	*30.8*
	Karls			123.5	75	135.5										
RS 213D I	Karls	35.0	4.0	124	75	136	94.5	61.5	65.0	139.0	37.0	51.5	11.0	*16.8*	*68.0*	*30.8*
RS 87 II	Karls	35.5	4.9	124	73	136.5	90.4	63.4	65.3	136.1	35.6	50.3	7.4	*12.1*	*68.2*	*28.8*
	Ab			176.3	124.3	55										
RS 213A IX	Karls	36.0	5.0	110.3	87.3	134.3	89.0	55.0	61.9	131.8	43.7	56.2	10.1	*16.0*	*67.3*	*38.4*
	RT			69.3	118.6	151.3										
RS 213A IV	Karls	36.0	4.5	118	80.5	135	89.3	58.9	63.4	133.4	40.0	53.5	13.4	*13.8*	*67.5*	*34.0*
RS 80D IA	Karls	36.0	6.0	119	81.5	132	86.5	59.4	62.0	*132.8*	*40.6*	*51.5*	*6.5*	11.7	66.0	34.2
	Ab			108	89.5	133										
RS 89 I	Karls	36.2	4.0	176	125.5	55	87.6	54.4	61.5	131.2	44.5	56.2	7.8	*15.7*	*66.7*	*38.5*
	RT			69	117	152.5										
	Ab			177	123	57										
RS 213D II	Karls	36.2	4.3	124.5	76.5	132	88.0	61.0	61.5	138.0	39.5	49.0	10.0	*14.3*	*65.5*	*32.0*
	RT			58	129	156										
RS 80F II	Karls	36.2	5.2	119	78.5	135	91.2	59.7	63.4	136.1	39.5	52.5	10.4	*15.4*	*67.4*	*33.2*
RS 80D II	RT	36.5	5.5	54.5	131	158	91.3	63.1	67.3	134.0	34.7	52.8	—	*12.0*	*69.9*	*28.9*
RS 88B II	Karls	37.0	4.7	115	83	135	88.0	57.4	63.2	131.2	41.4	54.8	14.6	*13.3*	*67.7*	*35.8*
RS 80E I	Karls	37.0	5.5	109	89.5	131	82.2	54.6	59.2	*128.0*	*45.5*	*54.5*	*8.0*	11.4	65.6	41.7
	Ab			177	128	51										
RS 213A VIII	Karls	37.5	4.8	114	81.5	140	89.5	57.1	64.2	130.7	40.8	56.4	11.5	*14.0*	*68.8*	*35.7*
	RT			66	121	154										
RS 213F III	Karls	37.5	3.5	119	80	130.5	91.0	59.2	60.5	139.0	41.5	50.5	1.5	*17.0*	*65.3*	*34.0*
RS 80C I	RT	37.5	4.0	64.5	127.5	153.5	89.3	58.0	63.5	133.8	41.2	53.6	—	*14.8*	*67.0*	*34.8*
	Ab			176	126	53.5										
RS 80C III	Karls	37.5	5.3	116.5	83	133.5	88.0	58.4	62.2	132.9	41.2	53.1	10.9	*13.4*	*66.7*	*35.0*
	RT			64	122.5	155.5										
RS 80D III	TR	37.8	5.5	64	122	154.5	88.0	57.8	62.0	133.0	41.6	53.4	8.3	*13.8*	*66.6*	*35.5*

RS 80 B	I	Karls	38.0	4.5	116	82	136	88.4	57.6	63.6	131.2	41.0	55.1	13.4	*13.4*	*68.0*	*35.4*
RS 87	IV	Karls	38.0	4.0	115.5	81.0	134.5	89.8	57.9	63.1	133.6	*40.9*	54.0	8.2	*14.8*	*67.4*	*35.0*
RS 213 B	I	Karls	38.0	3.0	109	89	133	87.0	54.5	60.7	131.0	44.8	55.6	14.6	*15.0*	*66.5*	*39.3*
RS 88 B	I	Karls	38.0	4.5	116	82	136	88.4	57.6	63.6	131.2	41.0	55.1	13.4	*13.4*	*68.0*	*35.4*
		Ab			170	123	50										
RS 213 B	II	RT	38.2	3.0	70	114	155	83.8	55.6	58.8	130.8	45.1	52.9	8.1	*12.7*	*64.7*	*38.7*
		Karls			110.5	90	129.5										
RS 80 C	VII	Karls	38.2	5.0	114.5	85	131.5	91.3	57.9	61.5	*134.6*	*42.3*	*52.3*	*12.3*	14.7	65.7	35.7
RS 83	I	Karls	38.2	5.0	124	75.5	134.5	91.3	61.8	64.6	136.8	37.4	50.9	8.7	*14.0*	*67.4*	*30.9*
RS 80 C	V	RT	38.8	4.0	66	121	153	88.0	57.1	61.0	*133.7*	*42.8*	*53.1*	*15.2*	10.0	66.0	36.5
RS 213 A	X	Karls	38.8	4.7	107	89	136	87.5	53.1	63.4	127.4	44.4	64.1	15.8	*14.2*	*69.0*	*40.0*
		Karls			123.5	75	133.5										
RS 213 B	III	Ab	38.8	3.0	178	125.5	55.5	90.3	61.8	63.3	137.0	46.0	46.3	4.2	*13.7*	*66.7*	*31.5*
		RT			57	130	152.5										
Isl 194 c	II	Karls	39.0	4.7	119	83	129.5	87.9	59.0	60.4	136.2	41.6	49.9	2.4	*14.0*	*64.7*	*34.2*
RS 80 C	VI	Karls	39.5	4.5	114	83	134.5	86.5	57.2	62.0	*130.6*	*41.5*	*54.8*	*8.5*	12.3	67.6	35.9
RS 80 F	I	Karls	39.8	5.2	118.5	82	132	91.2	59.3	61.8	137.6	40.9	51.4	3.0	*16.5*	*66.0*	*34.0*
		Karls			112.5	88	131										
RS 213 F	IV	Ab	40.0	3.5	171.5	126	54.5	85.5	56.5	60.5	131.0	43.5	54.0	9.5	*12.5*	*65.8*	*37.3*
		RT			68	118	157										
Isl 194 c	I	Karls	40.2	5.5	119	80	134.5	*88.0*	*59.6*	*63.4*	135.2	39.6	53.1	5.4	12.2	67.3	33.3
RS 80 C	IV	RT	40.8	4.5	73	113.5	154	85.6	53.7	59.3	130.7	46.3	55.2	9.8	*14.9*	*65.8*	*40.4*
RS 80 F	III	Karls	41.5	4.5	116	81.5	132.5	87.4	58.3	61.8	132.9	41.4	52.5	7.3	*13.0*	*66.3*	*35.0*
		Karls			105.5	94	133.5										
RS 213 D	III	Ab	42.2	3.3	172	123	57	85.0	52.5	59.0	130.0	47.0	56.0	10.0	*15.0*	*66.0*	*41.5*
		RT			74	112.7	151.5										
Isl 225	I	Karls	46.0	4.0	99.5	101.5	128.5	82.3	50.2	55.7	*128.0*	*50.6*	*56.0*	*6.7*	15.9	64.4	45.3
Isl 235	I	Karls	46.5	4.0	93.5	109.5	124.5	79.2	46.8	51.0	*129.0*	*54.9*	*56.4*	*5.8*	17.5	62.6	50.7
RS 213 A	VI	Karls	46.8	4.0	102	101	128	87.1	50.5	55.4	134.4	50.5	55.4	9.1	*20.8*	*64.0*	*45.0*
Isl 234	I	RT	47.0	4.0	91.5	95	154	75.7	46.2	50.9	140.8	55.9	52.2	−0.3	*15.0*	*63.0*	*51.0*
Isl 233	I	RT	48.0	2.5	78.5	108.5	150.5	*83.7*	*51.3*	*56.5*	130.6	49.5	55.3	2.9	16.2	64.5	43.9
		RT			88	95.5	150										
RS 7*/α	II	Ab	48.5	4.3	161.5	119.5	64	76.2	45.9	49.8	127.1	56.9	56.3	5.2	*17.0*	*62.4*	*51.8*
		Karls			92	113	121.5										
Isl 233	II	Karls	48.8	2.5	94	112.5	124.5	76.9	46.6	50.4	127.0	56.2	56.2	4.9	*16.5*	*62.3*	*51.0*
RS 7*/α	I	Karls	49.0	3.5	103	102	125	81.6	51.6	53.9	131.3	50.8	53.5	2.0	*16.0*	*62.5*	*44.5*
		RT			94	85.5	129										
RS 7*	I	Ab	50.0	4.2	161	120	64	77.2	45.9	50.2	127.4	56.5	56.5	5.0	*17.3*	*62.7*	*51.6*
		Karls			86.5	116.5	123.5										
Isl 225	IV	RT	50.5	3.7	86.5	94.5	149.5	76.9	44.9	50.4	126.3	57.1	57.6	5.4	*17.3*	*63.3*	*52.5*
Isl 234	II	RT	51.0	3.5	91.5	100	148	78.9	46.6	50.7	128.6	54.6	57.0	3.5	*18.2*	*62.5*	*50.9*

Isl 220: Pyroxene-, oligoclase-bearing perlitic obsidian: Specimen taken from outcrop in river-bed, about 2 km inside valley. Shiny black structurally inhomogeneous glass, with flaky conchoidal fracture on the centimeter scale. Up to 3 mm long phenocrysts. Microscopically: Colourless to light brown streaky glass with weak wavy fluidal texture, and containing few slightly-oriented crystallites. Strong perlitic texture. Phenocrysts unoriented, and often in clusters. Phenocrysts: *Plagioclase:* Less than 5%, often in groups, twinned and slightly zoned. *Pyroxene:* Occasionally clusters of nearly microcryptocrystalline crystals, with birefringence high (yellow I, and blue II) – most probably augite, and aegirine-augite. Also single augite crystals (seldom).

Plagioclase determined: $An_{27}Ab_{64.5}Or_{8.5}$.

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Manuscript received November 30, 1970.

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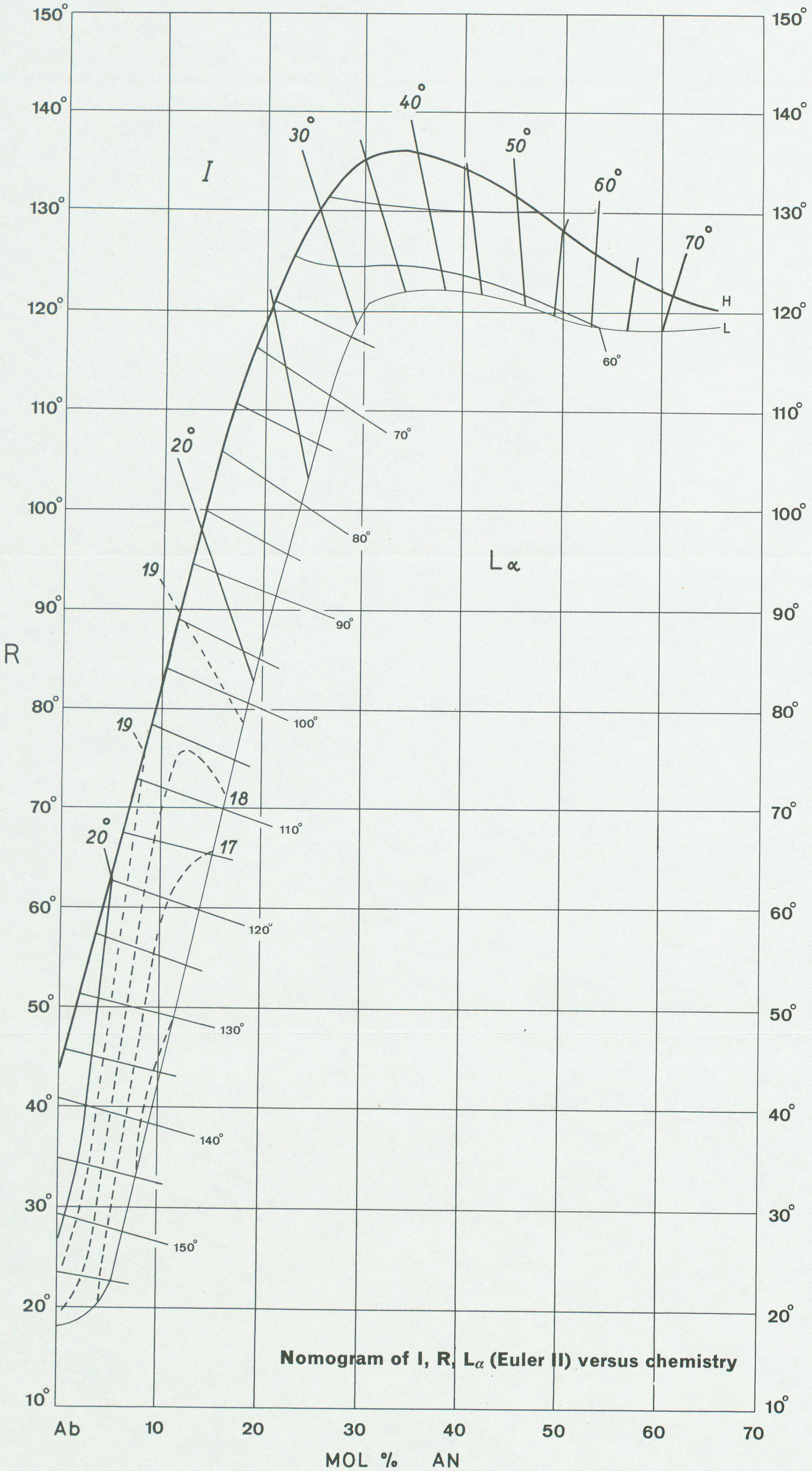
PLATE I

R. A. SCHEDLER: Optical, Chemical, and Structural Determinations of Volcanic, Acid Icelandic Plagioclase Feldspars



Nomogram of I, R, L_α (Euler II) versus chemistry

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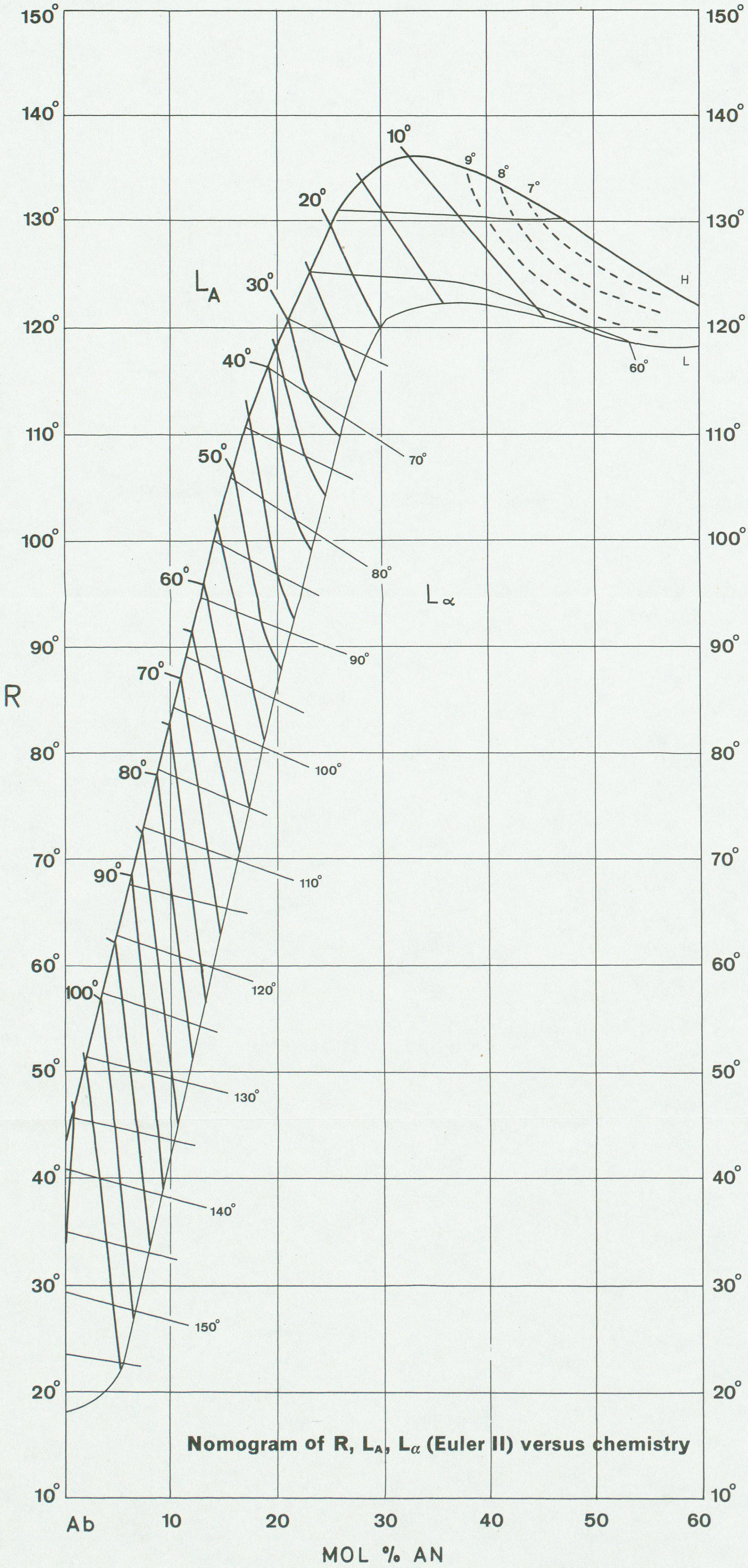

Nomogram of R, L_A, L_α (Euler II) versus chemistry