Origin of ternary film and string perthites from a Uruguayan Migmatite

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Origin of Ternary Film and String Perthites from a Uruguayan Migmatite

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With 5 figures in the text

Abstract

The crystallographic distribution of oligoclase and microcline in the ternary microperthites from Valentines (Florida, Uruguay) is explained by exsolution. From a rather homogeneous ternary feldspar $Or_{42}(Ab_{76}, An_{24})_{58}$ formed by microclinization of oligoclase, oligoclase unmixes in a triclinic submicroscopically twinned microcline-host. Exsolution mainly occurs along [106] producing strings and along ($\bar{6}$01) forming films. Differences between the primary and the secondary oligoclase, confirm that strings and films cannot possibly be remnants of the ancient oligoclase.

Zusammenfassung

Die Oligoklas-Verteilung in den ternären Mikroperthiten aus dem Migmatit von Valentines (Florida, Uruguay) ist durch Entmischung erklärt. Ein ternärer Feldspat $Or_{42}(Ab_{76}, An_{24})_{58}$ wurde durch Mikroklinisierung von Olikoklas gebildet. Ein ähnlicher Oligoklas sondert sich später in einem submikroskopisch verzwillingten Mikroklin-Wirt ab. Die Entmischung schreitet hauptsächlich in der [106]-Richtung und auf den ($\bar{6}$01)-Flächen fort, so dass Fäden und Filme gebildet werden. Unterschiede zwischen dem primären und sekundären Oligoklas beweisen weiterhin, dass die Plagioklas-Filme und -Fäden nicht als Reste des ursprünglichen Oligoklases anzusehen sind.

INTRODUCTION

Numerous examples of metamorphic perthites and antiperthites in albitized microcline or orthoclase are found in the literature. Examples

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of perthites in microclinized plagioclase were given more recently, in descriptions of granulites and charnokites or related migmatites. TERMIER and TERMIER (1956) revised the older literature on this subject. It is usually admitted that these metamorphic perthites are formed by replacement in the solid state. The perthitic inclusions (microalbite or plagioclase) are considered to be remnants of the primary plagioclase and are not related to exsolution. ROBERTSON (1959) makes a detailed study of string-perthites occurring in the microclinized plagioclases of metamorphic rocks. He also admits that the plagioclase strings are remnants. HEIER (1961) suggests that ternary perthites from the granulite-amphibolite facies may have been originally one homogeneous phase, formed metasomatically and actually unmixed as "mesoperthites".

ALLING (1932) taking into account Andersen's and other previous papers believes that film-perthites, as well as string-perthites are produced by exsolution. The subject was widely discussed in the literature. Different explanations were given for the crystallographic orientation of the plagioclase films in the perthites. MÄKINEN (1917) already suggests that perthitic unmixing can be simultaneous with the transformation of the originally monoclinic $KAlSi_3O_8$ into microcline. He also notes that the Murchisonitic parting, along ($\bar{8}01$) may be the initial "unmixing surface", that is the plane where unmixing starts. LAVES (1952) studied the perthite-problem and the mutual orientation of albite and microcline, demonstrating that in the [106] and [301] directions the arrangement of albite and microcline lattices approximately coincide. By X-ray studies MÄKINEN's idea is verified: Murchisonitic feldspars are in fact crypto- or microperthites, the exsolution-planes are the schiller-planes which lie between ($\bar{6}01$) and ($\bar{8}01$) forming with (001) an angle of 106—109°. LAVES and SOLDATOS (1963) point out that the (h0l) planes called "rhombic section", which are the contact planes of pericline twinning, are "active" planes compared with the rest of the lattice, as they belong to the interphase of two crystals with different orientation. Unmixing will therefore start on these planes in the triclinic feldspar with cross-grating twinning. In microperthites a mean inclination of 107° was determined for the microalbite-films with (001).

The mechanism of film and string-perthite formation was studied by LAVES and SOLDATOS (1963); these microperthites are considered to be formed by unmixing from triclinic, twinned $KAlSi_3O_8$. The evolution of unmixing and ordering in a zoned ternary feldspar $Or_{26}(Ab_{60}$-$An_{14})$ was studied by LAVES (1956). The relation between composition and the displacive monoclinic-triclinic transformation temperature in these feldspars, was discussed by LAVES (1952, 1960a, 1960b), MACKENZIE (1952), SMITH and MACKENZIE (1958) and BROWN (1960). WYART and SABATIER (1958, 1961) prepared artificial ternary feldspars $Or_{28}Ab_{13}An_{29}$ which unmixed in presence of water-vapour into a regular aggregate of K-feldspar and plagioclase. Reordering was found to occur under these conditions at rather low temperatures.

DESCRIPTION OF THE SAMPLES

The ternary string and film perthites were found by Prof. J. Bossi in Valentines (Florida, Uruguay) in a migmatite of granitic texture originated by microclinization of an ancient gneiss, without fusion. The petrographic and geological study of the area will be published elsewhere by Prof. Bossi.

The perthitic crystals are regularly distributed in the migmatitic rock of granitic, panxenomorphic, heteroblastic texture. They are about 1 mm large and together with quartz are the main components of the rock. Hornblende and biotite occur in minor amounts. The perthite is an oligoclase-microcline perthite grading from the string- into the film-type. The (Ab, An)/Or relation varies somewhat from one sample to an other and is also usually higher in the centre of the perthitic grain than at its border. Some remnants of ancient oligoclase are found. They are usually altered and present multiple twinning according to the albite law. In sample 27 the amount of oligoclase remnants is specially low. The microcline is twinned according to the albite and pericline law. Sometimes the cross-grating twinning can be observed, but frequently the twinning is submicroscopic, so that the crystal behaves as pseudomonoclinic. Even in these crystals the optic-axial angle is large and the X-ray study confirms that $KAlSi_3O_8$ is of high triclinicity. No twinning could be detected in the unmixed oligoclase by optical means. (The term "microplagioclase" will be used in the same sense as "microalbite" for the unmixed albite according to LAVES (1960a). According to the optical and X-ray data the microplagioclase contains 18—20% An. It is found in the perthite as films and strings. As in most crystals films grade into strings, observed on (010) the microplagioclase has a spindle-like aspect (fig. 1). The films lie on $(\bar{h}01)$ faces inclined 104—108° to (001); an average of 106° was determined on 30 crystals. Locally the films sometimes diverge somewhat from this direction specially in the sodium-rich perthites. The strings lie along [10h] contained in the $(\bar{h}01)$ plane. These

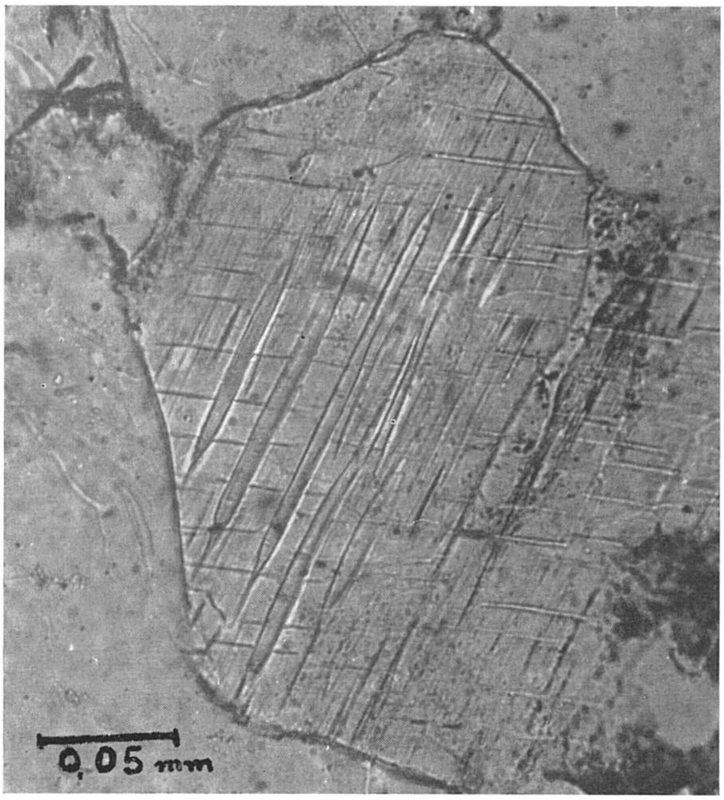

Fig. 1. Section // (010) of the microperthite. The plagioclase strings grade into films and cut the (001) cleavage at 106°.

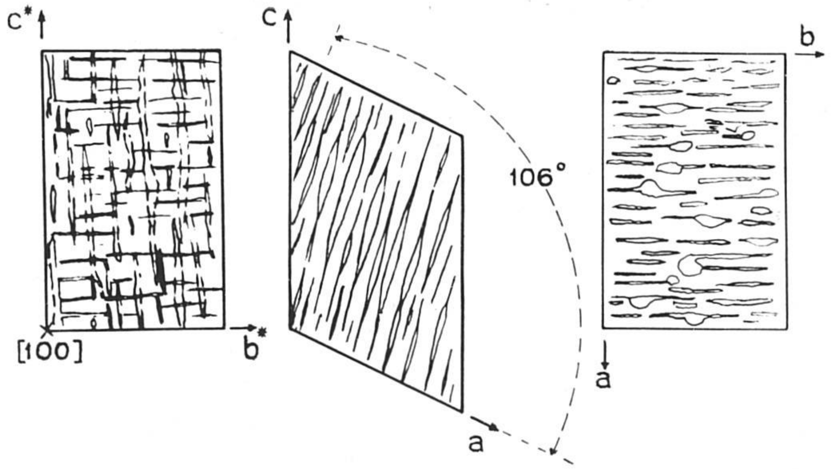

Fig. 2. Aspect of the microperthite in different directions. Compare fig. 1.

directions coincide approximately with ($\bar{6}01$) and [106]. The aspect of the perthite observed in different directions is represented in fig. 2 for a microperthite grading from the string- into the film-type. On (001) the strings appear as spots and the films as thin straight lines parallel to the b-axis. On (010), the spindle-like aspect also seen in fig. 1, is observed. In a section perpendicular to [100] strings appear rather irregular due to their varying thickness. Some relation is observed between the development of the cross-grating twinning and the thickness of the microplagioclase strings. In fact, when microcline twinning is submicroscopical mostly thin films are found, but in crystals with distinct microcline twinning, separate spots, corresponding to the plagioclase strings, can be observed on (001).

The optical properties of the microcline, the ancient oligoclase and the microperthite were determined with the universal stage. Exact optical measurements of the ancient oligoclase could be accomplished only in a few fresher remnants. According to these data the compositions of the oligoclase remnants and the microplagioclase are very similar: the latter has a somewhat lower Ca-content. For ancient oligoclase $2V_\alpha = 83{,}5° \pm 0{,}5$; X measured against (001) ⊥ Z = 6°; according to the values given by VAN DER KAADEN and by KÖHLER (TRÖGER, 1956, p. 99 and 101) these data correspond to the composition: $Ab_{77}An_{23}$ for low-temperature feldspars. In fig. 3 the values corresponding to one

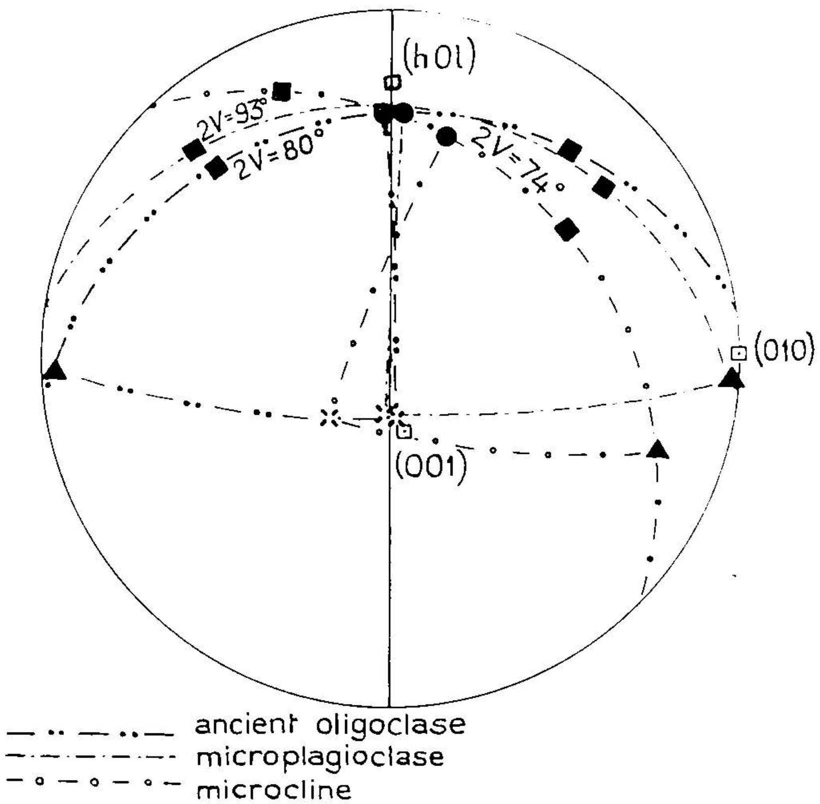

Fig. 3. Stereographic projection corresponding to the three phases found in the same perthitic grain. Compare fig. 4.

slide where the three phases could be measured are represented. The optics of these feldspars are not very uniform, rather large variations are found from one point to another of the same grain. From separate measurements of $KAlSi_3O_8$ and microplagioclase similar results were obtained:

Ancient oligoclase: $2V_\alpha = 80° \pm 5$ (3 cryst.)
Microplagioclase: $2V_\alpha = 93° \pm 3$ (5 cryst.)
Microcline: $2V_\alpha = 75° \pm 5$ (9 cryst.)

The approximate composition of both plagioclases according to these values and the optical orientation would be: $Ab_{80}An_{20}$—$Ab_{75}An_{25}$ for the oligoclase remnants and $Ab_{83}An_{17}$ approx. for the microplagioclase.

X-ray powder diagrams were taken from three samples containing both plagioclases. $d_{(131)}$—$d_{(1\bar{3}1)}$ for $KAlSi_3O_8$ corresponds to maximum microcline although a very slight diffuse area exists between the two lines, proving that some intermediate microcline may exist. Two distinct $(20\bar{1})$ lines appear at d = 4,03 and 4,22 corresponding to a sodium-rich plagioclase and microcline. Intermediate "anorthoclase" values are not found proving that the ternary feldspar is completely unmixed. The spacings of the other lines coincide with those given by Brown (1960) for plagioclase with $\gamma^* = 89°$. Low-temperature plagioclases $Ab_{80}An_{20}$ have this γ^* value. This is a somewhat rough confirmation as unmixed plagioclase is known to have lattice angles which differ from the normal ones, if there is cryptoperthitically unmixed material due to the influence of the lattice of the $KAlSi_3O_8$ host (Laves, 1952, and Laves and Soldatos, 1963).

Another approximate confirmation results from the chemical analysis of the rock (Analyst M. Umpierre). Following the CIPW norm the feldspar composition was calculated: $Or_{42}(Ab_{76}An_{24})_{58}$ for sample 27. As the rock also contains some oligoclase remnants which are calcium-richer, the plagioclase content of the ternary feldspar determined by chemical analysis must be somewhat high as well as the anorthite content of the plagioclase. In sample 27 ancient oligoclase is scarce so that the error is not too considerable; in sample 32 the plagioclase remnants are more abundant. (Compare fig. 5.)

In fig. 4 ancient oligoclase can be seen together with microplagioclase. Fingerlike appendices of the former reach into the perthite and small long remnants are also found. This may possibly lead to confusion as the shape and size of the remnants is in some samples very similar to that of the microplagioclase strings. Careful examination shows, however,

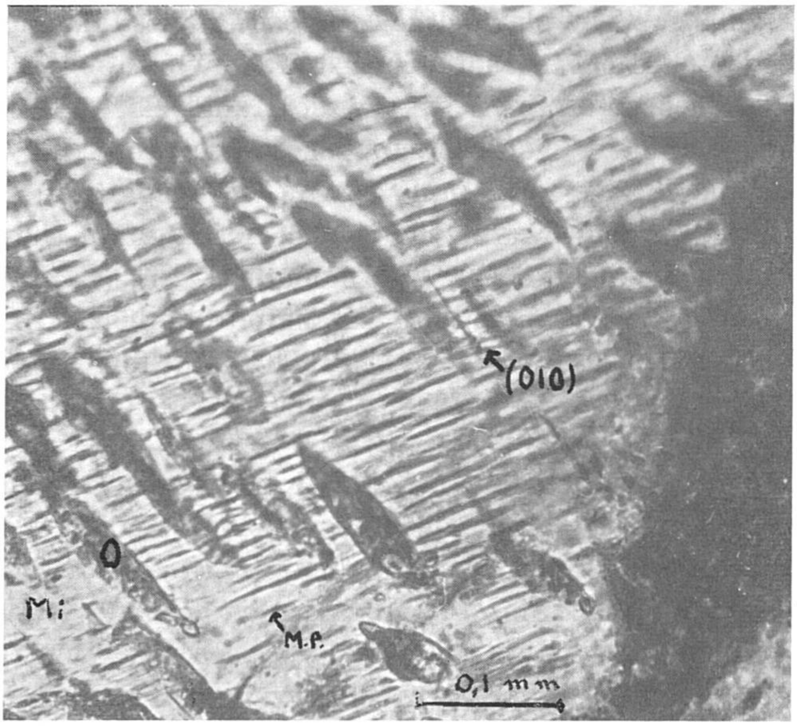

Fig. 4. Ancient oligoclase remnants (0) in the microperthite. Section ⊥ ($\bar{6}01$); (010) is somewhat inclined. Constant inclination of the microplagioclase (M.P.) to the cleavage was determined. The distribution of the remnants is rather irregular. Due to the difference of the refractive indices the relief of the unmixed oligoclase against microcline (Mi) is visible (sample 55).

that both plagioclases are different. The old plagioclase is rather altered, the d'stribution of the plagioclase-inclusions follows no definite crystallographic orientation, they cut the (001) cleavage and the microplagioclase at varying angles; their optical orientation is analogous to that of the microperthite. The measurements represented in fig. 3 correspond to a slide, very similar to the one represented in fig. 4; they show that the different orientation corresponds to differences in the composition of both plagioclases. It is further noted that the outlines of the oligoclase remnants are rather diffuse. In fresher remnants distinct albite twinning is observed.

CONCLUSIONS

The plagioclase content of these perthites is higher than 50%, but the plagioclase is found as guest in the microcline-host. Therefore the samples are called perthites and not antiperthites. In fig. 5 the ternary feldspar is located in the phase diagram given by Laves (1952, 1960) and Smith and Mackenzie (1958). The nomenclature proposed by

Laves (1960) is used. The plagioclase composition was taken as $Ab_{80}An_{20}$ as determined by optical measurements and X-rays. For the total composition the values determined by chemical analysis were used; these should be very similar to the real composition in sample 27 and somewhat high in plagioclase for sample 32. As the plagioclase content increases from the border towards the centre of the grain, the main portion falls into the monoclinic K, (Ca)-monalbite, Na, (Ca)-sanidine one phase field, near to the K-monalbite, K-analbite limit (B-D). This limit was established for $Or_{33}Ab_{67}$ by Laves (1960b) and for $Or_{37}Ab_{63}$ in previous papers.

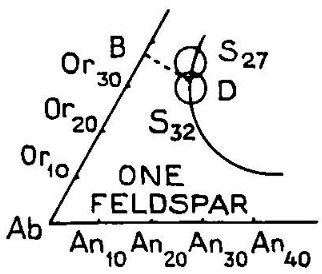

Fig. 5. Sample 27 and 32 located in the triangular diagram given by Laves (1952). B-D separates the K-Ca analbite from the K-Ca monalbite, Na-Ca sanidine zone. The upper curve divides the one-phase from the two-phase field.

Excepting perhaps some specially sodium-rich parts of the grains, the ternary feldspar must suffer diffusive transformation to pass from monoclinic to triclinic symmetry. Those parts that may lie in the K-analbite field have a high K-content and the displacive transformation temperature is therefore very low. They will remain monoclinic until the latest stages of cooling of the rock. Almost immediately as unmixing progresses under these conditions, the displacive transformation can no longer occur, as for Na-rich K-analbites the transformation-temperature is high (Laves, 1952b, 1956, 1960a and b; Mackenzie, 1952; Smith and Mackenzie, 1958; Brown, 1960).

The location of the ternary feldspar on the Or-Ab solubility curve, shows that a temperature of about 600° C will be sufficient to obtain a single-phase feldspar $Or_{42}(Ab, An)_{58}$. As the microclinization must have occurred in the presence of water vapour, re-ordering will occur at rather low temperature and the ternary feldspar will be monoclinic. The presence of biotite in the rock agrees with this estimate of the microclinization-temperature.

The following genetic sequence is proposed for these perthites:

1. A more or less homogeneous ternary feldspar is produced by a

diffussive Na-K exchange process from an ancient oligoclase at about 600° C. At the same time changes of the Si-Al distribution take place and a monoclinic ternary feldspar is obtained. As the process occurs without fusion the original orientation of oligoclase is maintained; the oligoclase remnants are in "optical continuity" with the perthite. The plagioclase concentration is somewhat higher in the centre than at the border of the grains as substitution must have proceeded inwards from the interphase.

2. As the feldspar cools, ordering and unmixing progress. Monoclinic-triclinic transformation starts mainly as a diffusive process (see above). Unmixing mostly occurs in a cross-hatched intermediate triclinic feldspar. Locally some unmixing might occur from the monoclinic phase in the more Ab-rich parts of some grains where the inclination of the plagioclase films is rather irregular. Unmixing progresses mainly along the rhombic section ($\bar{h}0l$) planes of intermediate microcline and the [l0h] directions which belong to four different crystal-orientations (A_1, A_2, P_1 and P_2); these are the most active sites of the lattice (see discussion above). Certainly unmixing did not occur in cross-hatched twinned analbite formed in the monalbite-analbite displacive transformation, as the rhombic section of K, Ca analbites lies nearly parallel to (001) (see MACKENZIE, 1956, and SMITH, 1958). Antiperthites unmixed from such a host would have a completely different orientation. LAVES and SOLDATOS (1962) also found that in a perthite with a high albite content ($Or_{43,3}Ab_{50,7}An_{4,2}$) microcline, with a somewhat distorted cross-grating twinning is the host.

3. Finally by recrystallization the single-crystal areas of the twinned microcline grow and simultaneously the strings thicken at the expense of the plagioclase films. This does not mean that the strings are actually a later stage in the perthite evolution than the film-perthites. LAVES and SOLDATOS (1963) found the inverse sequence. In our samples unmixing probably also started more intensely along the [l0h] directions then on the ($\bar{h}0l$) planes, but both are thought to have occurred simultaneously. As strings grade continuously into films by recrystallization the interphase diminishes if the films disappear and the strings grow thicker. The strings of our samples have a smaller inclination to (001) than those described by these authors; [l0h] $\wedge$ (001) is 106° in our samples and 114—118° in theirs. Probably their string perthites unmixed from a feldspar with lower triclinicity than ours and therefore represent an earlier stage of perthite evolution than ours; certainly they represent an earlier stage than pure film-perthites.

The distribution of plagioclase in microcline of these string- and film-perthites, is taken as a proof that these perthites have been formed by unmixing from a homogeneous ternary phase and that the plagioclase strings and films cannot be considered as remnants. It would not seem probable that K-replacement occurred in the ancient oligoclase over all the lattice, but not in the $(\bar{h}0l)$ planes and [l0h] directions, which are non-equilibrium sites of the cross-hatched twinned microcline. Either a distribution related to the twinning of oligoclase, or more or less randomly orientated plagioclase inclusions can be expected in that case. In fact, in our case it was observed that the plagioclase remnants are more or less irregularly distributed among the perthite. The difference in freshness and in optical properties and twinning observed in our samples, between the primary and the secondary oligoclase, confirms this idea. The fact that both oligoclases have a very similar composition, cannot be taken as evidence that one is a remnant of the other. If a homogeneous phase is obtained by ion exchange with a potash phase, no considerable Ca-amounts being removed, later unmixing will again produce the nearly pure $KAlSi_3O_8$ phase and a very similar oligoclase when it is complete.

Note: The present study was carried out on request of Prof. J. Bossi who also supplied the samples.

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