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On fourlings of plagioclase twinned according to the laws albite, Ala, and albite–Ala

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Abstract

New evidence is presented for the realization of the twin laws Ala, albite, and albite–Ala in fourlings of plagioclase from different rocks: authigenic albite in foraminiferal limestone, andesine in granite, labradorite in norite, and bytownite in anorthosite. Fourlings and chain-forming repeated fourlings of labradorite, with transitional to high-temperature optics, are common in Sudbury quartz norite, similar to conditions reported by Gay and Muir (1962) from the Skaergaard intrusion in East Greenland and recently observed also in the Stillwater layered intrusion.

Introduction

In his review of twinning in feldspar minerals Smith (1974, p. 314, 324) concluded that the Ala twin law has not been established satisfactorily, that the albite–Ala edge-normal twin is either rare or absent, and that the case requires a thorough reexamination. I agree with the last conclusion and admit that several doubtful reports exist, but I do not believe that these outweigh the solid old evidence published by experts like Duparc and Reinhard (1924, p. 102–105), Reinhard (1931, p. 100–102), or Nikitin (1936, p. 81–82). Recently excellent test-cases were found in rocks of contrasting geological origin, and this paper presents new U-stage data of Ala and albite–Ala twins in plagioclases of different composition. The discussion concentrates upon fourlings because these are representative examples and allow the reliable construction of three rectangular twin axes.

Observations

Authigenic albite from foraminiferal oolitic limestone intercalated in a Carboniferous graywacke–shale series of the Vosges, France, is the first test-case. This sedimentary sequence displays remarkable graded and convolute bedding and occurs in the base of the andesitic lavas (labradorite–porphyrite) of the Rossberg. The locality is Source St. Jean near Belacker, sample V.699d.

In a thin section of this limestone two fourlings (Fig. 1) have been examined. They are cut nearly perpendicular to the crystallographic X-axis, which is common to all individuals. The albite crystals contain tiny inclusions of calcite which affect the extinction of the feldspar and render the U-stage work rather tiresome. The composition planes 1–2 and 3–4, common to all subindividuals, were determined as (010), the slightly diverging composition planes 1–4 and 2–3 as (001). The twin axes of the fourling have been constructed as centers of symmetry between corresponding axes of the four indicatrices. They are perpendicular to each other and could be interpreted as pole (010), [100] and ⊥ [100] in (010). The original U-stage data were rotated in order to bring the axis [100] into the center of the projection, as shown in Figure 1. Individuals 1–2 and 3–4 are albite twins, repeated in narrow lamellae. Individuals 1–4 and 2–3 are twinned according to the Ala law with composition plane (001). Individuals 1–3 and 2–4 are in twin relation according to the complex albite–Ala law, but in the thin section are in contact with each other only along the edge [100]. The pole to (001) deviates several degrees from the direction ⊥ [100] in (010), which facilitates the interpretation. For the determination of the optic and crystallographic data of Ala twin-complexes the stereographic projection perpendicular to [100], *e.g.* Plate VI of Burri *et al.* (1967), is well suited. Our fourlings are analogous to Figure 31 in Nikitin (1936), and to Plate I in van der Kaaden (1951). A test with wooden plagioclase models shows that four individuals twinned this way fit perfectly.

Fourlings of authigenic albite have been described

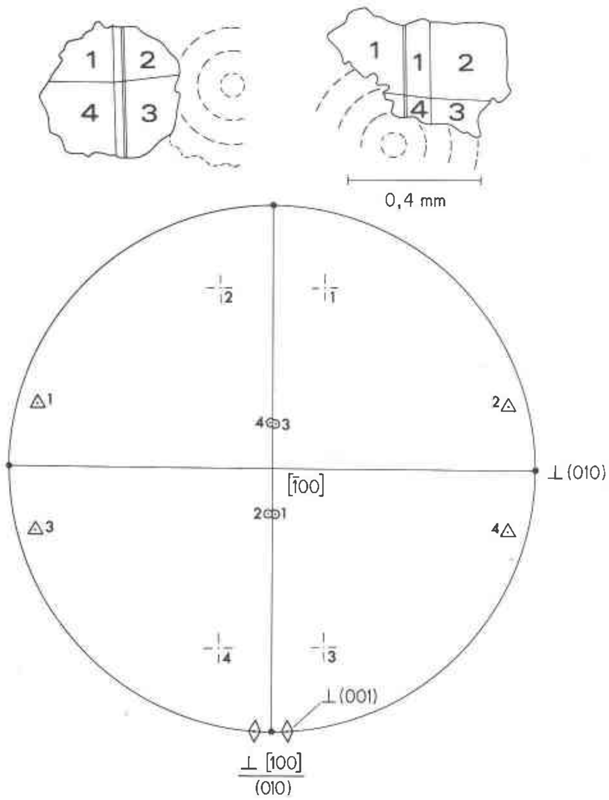

Fig. 1. Sketch and stereographic projection of fourlings of authigenic albite from Carboniferous foraminiferal oolitic limestone, Rossberg, Vosges, France. (010) vertical, (001) subhorizontal. Twin laws: albite 1–2 and 3–4, Ala 1–4 and 2–3, albite–Ala 1–3 and 2–4. Stereographic projection perpendicular to [100], with pole (010) as abscissa (y axis), showing the symmetry relations of the main vibration directions ($n\alpha$ = circles, $n\beta$ = crosses, $n\gamma$ = triangles) of the four individuals.

by many authors during the past 115 years (for a review see Smith, 1974), but as Smith (p. 262) correctly states, "the literature is bedevilled with confusion concerning the type of twinning," and we recommend a re-study of authigenic albite from classical localities.

Andesine An 35–40 (all An determinations by U-stage methods) occurs in biotite–hornblende–monzogranite ("granite du Ballon d'Alsace") at Isenbach, NW Lac d'Alfred, Vosges, France, sample V.783. A euhedral twin-complex of square shape, measuring 2 mm across, showing fine oscillatory zoning, and enclosed in a large perthitic alkali feldspar, consists of four subindividuals twinned like the above-described albite according to the laws albite, Ala, and albite–Ala. Due to a slight offset of the albite-twinned lamellae 1–2 in relation to the polysynthetic albite-twinned lamellae 3–4, subindividuals twinned by the albite–Ala law are in contact on (001). This example is important for the later discussion, because it proves that also in this An-range the four indicatrices are clearly separated.

In the above mentioned rocks combinations of the laws albite, Ala and albite–Ala are of casual occurrence. They are very common in *labradorite* An 57–66 from biotite-bearing quartz norite, Murray Mine, Sudbury, Canada, sample G.4. The plagioclases of this rock are very fresh, euhedral to subhedral, and twinned throughout; they are well suited for U-stage study. The anorthite content indicated refers to the large, fairly homogeneous cores. Quartz fills interstices between feldspar crystals, and at the contact the labradorite is distinctly zoned to more sodic (An 50) at the margin.

In each of the four thin sections studied, 8 to 13 albite–Ala fourlings and 2 to 5 zig-zag chains composed of repeated albite and Ala twins of the type shown in Figure 2 are found. They are less common than twin combinations after the albite, Carlsbad, and complex albite–Carlsbad laws. The laws acline and Manebach occur subordinately; pericline is absent. An astonishing feature is the square shape of many crystals, composed of albite twins 1–2, 3–4 and Ala twins 1–4, 2–3, in contact along the edge [100] and producing the crosswise arrangement of the edge-normal law albite–Ala. This law is only locally developed with face contact (001).

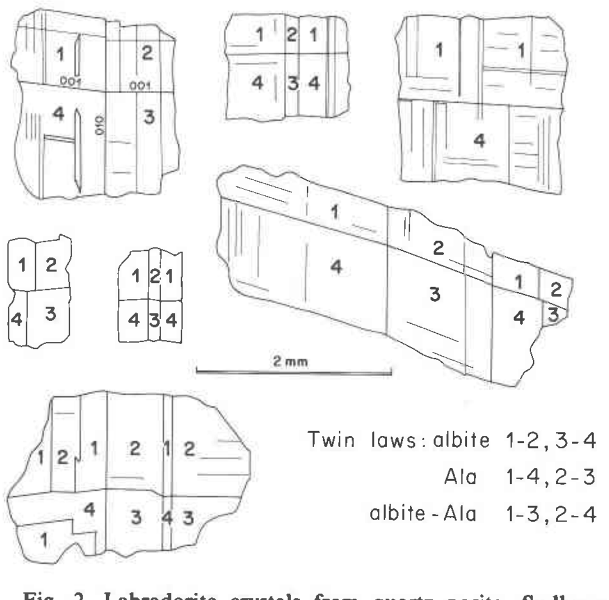

Fig. 2. Labradorite crystals from quartz norite, Sudbury, twinned after the laws albite, Ala and albite–Ala. (010) is vertical throughout and (001) subhorizontal.

Figure 3 shows in its upper part the sketch of a labradorite twinned repeatedly after the albite and Ala laws, and elongated perpendicular to (010), with characteristic zig-zag chain of (001). The lower part displays a stereographic projection of this poly-fourling. Plane of projection is the slide, cut nearly perpendicular to [100] of the crystal. The observed universal-stage data are entered as well as the constructed planes and axes of symmetry of the fourling. Using a large scale stereo-net (d = 40 cm) these were derived in two ways: by constructing the planes of symmetry between all twinned pairs, and by finding the centers of symmetry between corresponding axes of the four indicatrices. This cross-check established the existence of a rectangular system of twin axes. In master diagrams (Burri *et al.*, 1967) showing the migration of the crystallographic directions referred to a fixed setting of the chief vibration directions, the twin axes could be identified as pole (010), [100] and ⊥ [100] in (010).

The pole (010) differs from the zone [010], and also the equal illumination (éclairement commun) of the twinned individuals proves that the albite, not the acline, law is present. By optic methods the axis [100] = Ala cannot be separated from the direction ⊥ [010] in (001) = Manebach–acline; we preferred the first solution because neither Manebach nor acline twins are combined. This interpretation is supported also by the third twin axis ⊥ [100] in (010), which is clearly distinguished from the poles of the observed cleavage and often irregular composition plane (001), arranged symmetrically to this twin axis. The combination albite + Ala + albite–Ala is well borne out.

Referred to the classic rectangular coordinate system [001] = Z, pole (010) = Y and ⊥ [001] in (010) = X, introduced by Fedorow, the following Eulerian angles are deduced for this repeated fourling:

	ϕ	θ	ψ	$2V\gamma$
	65.5°	38°	41°	80°
	64.5°	40.5°	44°	80°
	64.5°	38°	39°	77°
	67°	40°	40.5°	82°
$\bar{X}$	65.5°	39°	41°	80°

The mean values correspond to An 57–58 on the Burri *et al.* (1967) migration curves, with distinct transitional optics, close to the high curves. This supports unpublished earlier observations of A. Glauser on the same material, which showed that 30 poles of composition planes (010) and (001) scatter between the low and high curves, with a maximum near the high curve.

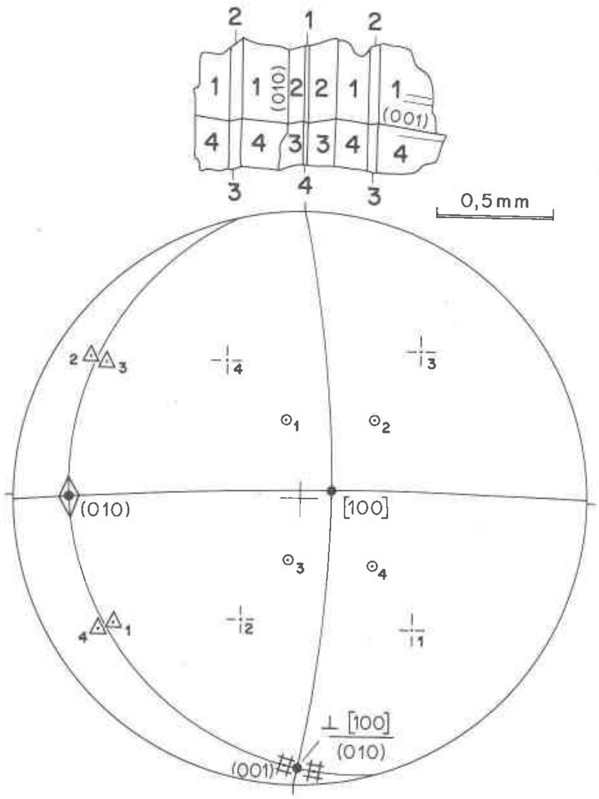

Fig. 3. Sketch and stereographic projection of a labradorite crystal (Sudbury), twinned repeatedly after the laws albite 1–2 and 3–4, Ala 1–4 and 2–3, albite–Ala 1–3 and 2–4.

Five additional fourlings, examined by the same procedure, gave mean values:

ϕ	θ	ψ	$2V\gamma$
51°	35.5°	25.5°	79°
56.5°	36°	31.5°	83°
62°	38.5°	37°	80°
63.5°	39°	38.5°	-
68.5°	38°	43.5°	-

Figure 4 shows the position of the twin axes (010), [100] and ⊥ [100] in (010) of the six fourlings in the projection perpendicular to [$n\beta$]. The average composition of different crystals varies; large crystals (up to 6 mm) tend to be more calcic than small ones. Throughout, the optical structural states are either transitional or approach the high form. To find high optical forms in plutonic plagioclase which shows a well developed e-superstructure (H. R. Wenk, unpublished) is an interesting by-product of our study,

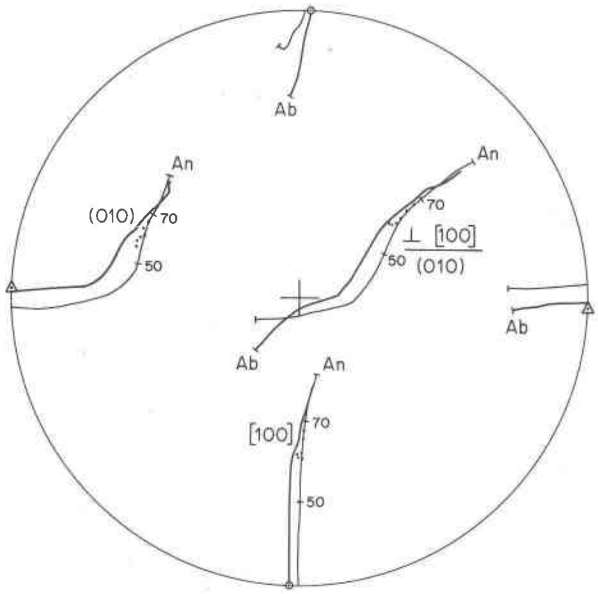

Fig. 4. Stereographic projection perpendicular to [$n\beta$], showing position of the twin axes (010), [100], and ⊥ [100] in (010) of six fourlings of labradorite, Sudbury. The structural states are either transitional or approach the high optic curves of Burri *et al.* (1967).

significant for the still debated history of Sudbury quartz norite.

Gay and Muir (1962) described albite–Ala fourlings of andesine An 34–40, with transitional to high-temperature optics, from the upper sequences of the layered series and the top of the ferro-gabbros of the Skaergaard intrusion in East Greenland. Plate 1 of these authors (reproduced also in Smith, 1974, Fig. 18-25) fits perfectly the Sudbury twins described above, and shows a chain formed by repeated combination of the albite, Ala, and albite–Ala laws. Gay and Muir proposed that the gradual deviation from the low structural state resulted from conditions in the chilled upper margin of the intrusion. This may be the case also in the Sudbury example.

A rapid check of some thin sections from the Stillwater layered intrusion disclosed the presence of Ala twins in these rocks also. Though the seemingly homogeneous plagioclases show dusky optical extinction and may be structurally inhomogeneous, a fourling like those described from Sudbury could be proven by U-stage methods in bytownite An 82 from the upper anorthosite series at Nye, Anaconda chromite mine, Montana.

Discussion

The information brought forward demonstrates that the Ala twin law exists, in concord with old evidence. It shows also that rational intergrowth of four individuals, twinned according to the laws albite, Ala, and albite–Ala, occasionally reported by earlier investigators, is present in rocks of different origin and in different An-ranges of plagioclase. The rocks discussed in this paper have one thing in common: their plagioclases are subidiomorphic and they tend to form square aggregates with a well-developed zone [100].

The fourlings are easily overlooked in thin section, because the subindividuals may show pairwise similar extinction angles, but on the U-stage the four indicatrices are usually clearly distinguished. Another circumstance that hampers the recognition is the "Schnitteffekt": The fourling is readily recognized in sections perpendicular to [100]. In sections parallel to (010) only a simple Ala twin is seen, and in those perpendicular to (010) and subparallel to (001) only the albite twin. A simple albite–Ala twin would be seen in a (0*kl*) section cut right through the center of the fourling. The complex albite–Ala twin An 75 with irregular composition face, reported by Reinhard (1931, p. 100), represents possibly a (0*kl*) section across a fourling.

There could be some argument about the realization of the albite–Ala edge-normal law. The four individuals of identical composition, but with their own proper orientation, are intergrown, and they are related by symmetry operations not present in the single individual. All of them have the plane (010) and the direction [100] in common; however, the crosswise arranged albite–Ala twins in most cases contact each other only along the edge [100]. All the individuals of the fourling are in twin relation, and the three twin axes form a rectangular system. They are non-accidental intergrowths of identical crystals, having only part of the crystallographic directions in common, at least two directions. The twin laws fulfil even the requirement of repeated occurrence in a given population—a condition not included in the old definition of a twin, but mentioned in some recent textbooks. In consideration of composite and penetration twinning the original definitions do not make statements about composition planes. Rational intergrowth and the mentioned conditions of symmetry between two or more identical crystals are essential. Though we found only occasionally albite–Ala twins intergrown along plane (001) (see Fig. 2, left bottom), it would be highly sophistic to deny the realization of this law in the fourlings discussed.

In stereographic projections and X-ray photographs the fourlings have orthorhombic symmetry, a remarkable deviation from the triclinic symmetry of the single crystal. A simple twin can easily be accommodated by a twin plane, and in albite twins (010) is generally well defined, also on submicroscopic scale. Albite–Ala twins are more difficult to accommodate in the structure and—while the strict geometric relationship holds—the composition planes are poorly defined and rather irrational boundaries on submicroscopic scale.

Finally the special case of low-temperature oligoclase An 27–28 must be considered. In a low plagioclase, An 27–28, the vibration direction [$n\alpha$] coincides with [100], and the other two main vibration directions lie in the symmetry plane of the Ala law (see plates VI and VIII in Burri *et al.,* 1967). Therefore, the optic orientation of the two subindividuals of an Ala twin is identical. Universal-stage methods fail to recognize the twin; they do allow, however, the determination of the orientation of a visible contact plane (001), and only in the case that (*hk*0) or (*hkl*) planes were developed in both subindividuals could the twin be proven. X-ray methods, of course, do recognize the Ala twin in this composition range. In an albite-twinned, An 27–28, low plagioclase both indicatrices can be measured, and their plane of symmetry and of composition is (010). Thus albite and Ala laws are clearly optically distinguishable, but the albite–Ala twin cannot be separated by universal-stage methods from the albite twin in this An range, even if (010) as well as (001) are present. So far we agree with the discussion of Tobi (1965). Experience shows that this difficulty is present in low plagioclase in the range An 25–30, but that already at An 20–25 and 30–35 low the twin laws can be discerned, and that there is no difficulty at all in high-temperature plagioclases. The conclusion of Tobi (1965, p. 717) that almost all the reported albite–Ala twins are in reality ordinary albite twins, is therefore incorrect.

This study shows that combined albite and Ala twins are common (> 10 percent of all twins) in certain rocks. Their occurrence in several layered intrusions (Skaergaard, Sudbury, Stillwater), mainly in layers containing plagioclase with transitional to high-temperature optics, is conspicuous and requires further investigation. There is a great need for combined X-ray, TEM, and light optic studies. Especially the structure along the composition planes of these twins should be investigated.

Acknowledgments

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References

Burri, C., R. L. Parker and E. Wenk (1967) *Die optische Orientierung der Plagioklase.* Birkhäuser, Basel.

Duparc, L. and M. Reinhard (1924) La détermination des plagioclases dans les coupes minces. *Mém. Soc. Phys. Hist. Nat. Genève 40,* Fasc. 1.

Gay, P. and I. D. Muir (1962) Investigation of the feldspars of the Skaergaard intrusion, Eastern Greenland. *J. Geol., 70,* 565–581.

Nikitin, W. (1936) *Die Fedorow-Methode.* Bornträger, Berlin.

Reinhard, M. (1931) *Universal Drehtischmethoden.* Wepf, Basel.

Smith, J. V. (1974) *Feldspar Minerals,* Vol. II. Springer, New York.

Tobi, A. C. (1965) On the cause of internal optical scatter in plagioclase, and the occurrence of lamellar albite–Ala B twinning. *Am. J. Sci., 263,* 712–718.

van der Kaaden, G. (1951) *Optical Studies on Natural Plagioclase Feldspars with High- and Low-Temperature Optics.* Dissertation, University of Utrecht.

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